

DESCRIPTION

HOT-ROLLED STEEL SHEET AND METHOD FOR PRODUCING SAME

Technical Field

[0001]

The present invention relates to a hot-rolled steel sheet having excellent scale adhesion, and a method for producing the hot-rolled steel sheet, the hot-rolled steel sheet being used for construction machinery, automobiles, home appliances, building materials, and other applications. More particularly, the present invention relates to a hot-rolled steel sheet that exhibits excellent scale adhesion suitable as a material for construction machinery parts subjected to laser cutting processing and that has a small variation in scale adhesion in the width direction of the steel sheet, and a method for producing the hot-rolled steel sheet.

Background Art

[0002]

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

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

[0003]

Scale on hot-rolled steel sheets tends to peel off more easily as the thickness of the hot-rolled steel sheets increases, because strain generated in the scale during deformation increases with increasing thickness. As a result, scale is more likely to peel off during forming involving a high degree of processing, such as bending and press forming. In recent years, however, demand for mill scale hot-rolled steel sheets having a large thickness has been increasing. For example, there is a strong demand for improved scale adhesion for hot-rolled steel sheets having a thickness exceeding 5.0 mm.

[0004]

Furthermore, variation in scale adhesion in the width direction of steel sheets and the presence of portions with poor scale adhesion lead to processing troubles. This is because, for example, the amount of thermal energy of laser

light absorbed at the surface of the steel sheet becomes unstable during laser cutting processing. It is thus necessary to remove portions having poor scale adhesion before use. Therefore, there has been a strong demand for hot-rolled steel sheets having uniform scale thickness in the width direction and excellent scale adhesion in order to improve yield, workability, and appearance quality.

[0005]

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

magnetite layer, wherein an average grain size of the magnetite grains and/or an average block size of the eutectoid transformation microstructure is 3 μm or more and 8 μm or less, and a mass fraction of wustite contained in the scale layer is 10% or less.

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

In formula (1),

T_1 : the temperature ($^\circ\text{C}$) of the steel sheet at a central portion in the width direction at a position 30 m from a leading end in the longitudinal direction after finish rolling,

T_2 : the temperature ($^\circ\text{C}$) of the steel sheet at a central portion in the width direction at the center in the longitudinal direction after finish rolling, and

T_3 : the temperature ($^\circ\text{C}$) of the steel sheet at a central portion in the width direction at a position 30 m from a trailing end in the longitudinal direction after finish rolling.

[0006]

Patent Literature 2 discloses a method in which a slab containing, in mass%, C: 0.02% to 0.20%, Mn: 0.1% to 2.0%, Si: 0.3% or less, P: 0.03% or less, S: 0.03% or less, Ni: 0.03% to 0.3%, Cu: 0.04% to 0.5%, and Cr: 0.03% to 0.3%, with the balance being Fe and unavoidable impurities, is heated to 1100 $^\circ\text{C}$ or higher, then hot-rolled in a temperature

range of 800°C to 950°C, and coiled at 400°C to 650°C. This method provides a hot-rolled steel sheet having excellent tight scale adhesion, wherein the number of unevenness heights of 0.5 μm or more per inch of length is 300 or more as an index of surface roughness at the interface between the scale on the steel sheet surface and the steel substrate of the steel sheet.

[0007]

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

less.

Citation List

Patent Literature

[0008]

PTL 1: Japanese Unexamined Patent Application

Publication No. 2019-183267

PTL 2: Japanese Unexamined Patent Application

Publication No. 2004-027312

PTL 3: Japanese Unexamined Patent Application

Publication No. 2012-148286

Summary of Invention

Technical Problem

[0009]

In the technique described in Patent Literature 1, a steel material having a predetermined chemical composition is used, and the finish rolling delivery temperature during hot rolling, the cooling rate after rolling, and the coiling temperature are controlled. Accordingly, the average grain size of magnetite grains and/or the average block size of the eutectoid transformation microstructure containing iron and magnetite on the magnetite layer on the steel substrate side in the scale layer is optimized. Furthermore, the temperature of the steel sheet in the longitudinal direction immediately after finish rolling is controlled to improve uniform scale adhesion in the longitudinal direction.

However, no method for uniformly improving scale adhesion in the width direction is mentioned.

[0010]

In the technique described in Patent Literature 2, a hot-rolled steel sheet having excellent tight scale adhesion is produced by hot-rolling a steel containing predetermined amounts of Ni, Cu, and Cr and controlling the surface roughness at the interface between the scale on the steel sheet surface and the steel substrate of the steel sheet within a predetermined range. Although adhesion at the interface between the scale layer and the steel substrate is improved, there is a concern that scale adhesion becomes insufficient when the hot-rolled steel sheet has a larger thickness. Furthermore, no method for uniformly improving scale adhesion in the width direction is mentioned.

[0011]

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

to 480°C or lower within 5 minutes from start of coiling. Thereafter, the temperature at the end surfaces is maintained at 480°C or lower, and the steel sheet is subsequently gradually cooled, while being maintained in a coil shape, from a time point at which the temperature at the end surfaces is 400°C to 480°C. This process yields a hot-rolled steel sheet having excellent scale adhesion at the edge portions of the hot-rolled coil. However, a scale microstructure suitable for improving adhesion at a central portion in the width direction of the steel sheet is not specified. As a result, there is a concern that scale adhesion becomes insufficient when the hot-rolled steel sheet has a larger thickness. Although the adhesion at the outermost edge portions is improved, there is a concern that the adhesion in portions within 200 mm from the edges is not sufficiently improved.

[0012]

An object of the present invention is to solve the above-described problems and to provide a hot-rolled steel sheet that, even when having a larger sheet thickness, exhibits excellent scale adhesion, particularly a small variation in scale adhesion in the width direction of the steel sheet, and improved laser cuttability, and a method for producing the hot-rolled steel sheet.

Solution to Problem

[0013]

The inventors of the present invention have first investigated the causes of the failure to obtain excellent uniformity in scale adhesion in the width direction in conventional hot-rolled steel sheets. During hot rolling, scale is formed in the order of hematite (Fe_2O_3), magnetite (Fe_3O_4), and wustite (FeO) from the scale surface side at high temperatures. Among these oxides, wustite undergoes eutectoid transformation during cooling after coiling to form a eutectoid transformation microstructure containing magnetite and precipitated Fe ($4\text{FeO} \rightarrow \text{Fe}_3\text{O}_4 + \text{Fe}$). The eutectoid transformation microstructure containing magnetite and precipitated Fe contributes to improvement in scale adhesion because the eutectoid transformation microstructure has particularly high coherency with the surrounding magnetite grains and the surrounding steel substrate. In the related art, scale adhesion has tended to deteriorate, particularly in regions within 200 mm from the edges in the width direction. This is because scale reoxidation caused by air penetrating from the edges after coiling excessively increases the amount of hematite on the scale surface and the amount of a magnetite layer containing columnar magnetite grains near the scale surface. This decreases the proportion of the eutectoid transformation microstructure, which contributes to improvement in scale adhesion, and

increases the scale thickness at the edge portions, as has been found. It has been further found that, in the regions within 200 mm from the edges in the width direction, the adhesion at the edges and at portions 200 mm from the edges deteriorates via different mechanisms. At the edges, the cooling rate is the highest, wustite remains in the final scale microstructure, and scale adhesion is more likely to further deteriorate. At the portions 200 mm from the edges, the steel sheet is exposed to air penetrating from the edges, and recuperation from a central portion in the width direction decreases the cooling rate. For this reason, the amount of hematite formed and the amount of the magnetite layer formed near the scale surface become the largest in the width direction, and the adhesion significantly decreases. In other words, it has been found that it is necessary to improve scale adhesion at the edges and at the portions 200 mm from the edges in order to obtain excellent uniformity in scale adhesion in the width direction.

[0014]

Furthermore, under ordinary production conditions, particularly in a case of a large sheet thickness, transformation expansion after coiling occurs non-uniformly in the longitudinal direction of the coil. This induces loosening of the hot-rolled coil and causes air to penetrate even into a central portion in the width direction,

resulting in deterioration of scale adhesion in some cases, as has been found.

[0015]

Accordingly, the inventors of the present invention have inventively studied means for solving the above-described problems to obtain a hot-rolled steel sheet that, even when having a larger sheet thickness, exhibits excellent scale adhesion, particularly a small variation in scale adhesion in the width direction of the coil. As a result, the following findings have been obtained.

- (i) A steel material having a predetermined chemical composition is descaled after hot rough rolling, performed finish-rolling at a finish rolling delivery temperature of 800°C to 950°C, and then cooled to a coiling temperature at a predetermined cooling rate. This process appropriately controls scale thickness and suppresses formation of cracks in the scale that cause a decrease in scale adhesion.
- (ii) After start of coiling, the entire coil is cooled such that the temperature of edge portions of the coil decreases at an average cooling rate of 0.5 °C/s or higher and 6.0 °C/s or lower from the coiling temperature to a cooling stop temperature of 300°C or higher and 450°C or lower. The edge portions of the coil refer to regions within 200 mm from the edges of the coil in the width direction. This process increases coil rigidity and prevents coil loosening.

As a result, at the center in the width direction, shielding from an oxidizing atmosphere can suppress reoxidation, and a eutectoid transformation microstructure suitable for improving scale adhesion can be sufficiently obtained. At the edge portions of the coil in the width direction, complete shielding from an oxidizing atmosphere is difficult; however, cooling of the edge portions suppresses reoxidation, and recuperation from the central portion in the width direction promotes eutectoid transformation, thereby ensuring excellent scale adhesion. This mechanism can reduce a variation in scale thickness in the width direction and can uniformly improve scale adhesion in the width direction to improve laser cuttability.

[0016]

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

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

microstructure containing iron and magnetite: 30% or more, wherein magnetite includes the magnetite grains and the magnetite contained in the eutectoid transformation microstructure, and wustite: 15% or less, and, in terms of mass fraction, hematite: 5% or less, an average thickness of the scale in the width direction of the steel sheet is 5 μm or more and 20 μm or less, and a variation in a thickness of the scale in the width direction of the steel sheet is 4 μm or less.

[2] The hot-rolled steel sheet according to [1], wherein the chemical composition further contains, in mass%, at least one selected from Cu: 1.0% or less, Ni: 0.50% or less, and Cr: 2.0% or less.

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

[4] A method for producing a hot-rolled steel sheet, the method including: subjecting a steel material having the chemical composition according to any one of [1] to [3] to: descaling after hot rough rolling; finish rolling at a finish rolling delivery temperature of 800°C or higher and 950°C or lower; cooling at an average cooling rate of 5 °C/s or higher in a temperature range from the finish rolling

delivery temperature to 750°C; then cooling at an average cooling rate of 1 °C/s or higher and 30 °C/s or lower in a range from 750°C to a temperature at start of coiling; coiling at a coiling temperature of 500°C or higher and 650°C or lower; and after start of coiling, cooling such that an entire coil is cooled so that a temperature of an edge portion of the coil decreases at an average cooling rate of 0.5 °C/s or higher and 6.0 °C/s or lower from the coiling temperature to a cooling stop temperature of 300°C or higher and 450°C or lower.

Advantageous Effects of Invention

[0017]

According to the present invention, a hot-rolled steel sheet having excellent scale adhesion can be easily and inexpensively produced, yielding remarkable industrial advantages. According to the present invention, the variation in scale adhesion in the width direction of the steel sheet can be reduced, which also produces advantageous effects that greatly contribute to improvement in the surface quality of products, improvement in the laser cuttability of products, and improvement in the working environment. It is also possible to solve the problem of a decrease in scale adhesion associated with an increase in the thickness of the hot-rolled steel sheet.

[0018]

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

Description of Embodiments

[0019]

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

[0020]

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

[0021]

C: 0.01% to 0.30%

Carbon C is an element useful for ensuring strength. When the C content is less than 0.01%, the effect of ensuring strength is small; therefore, the C content is set to 0.01% or more. When the C content exceeds 0.30%, CO gas is generated at the interface between the scale and the steel substrate to cause peeling at the interface between

the scale and the steel substrate during rolling, resulting in scale defects; therefore, the C content is set to 0.30% or less. From the viewpoint of scale adhesion, the C content is preferably 0.20% or less.

[0022]

Si: 0.50% or Less

Si is an element that functions as a deoxidizing agent. Although Si is not necessarily required to be contained, the Si content is preferably 0.01% or more in order to obtain such a deoxidizing effect. When the Si content exceeds 0.50%, however, Si enriches at the interface between the scale and the steel substrate to form a Si oxide layer. As a result, the scale easily peels off at the interface between the Si oxide layer and the scale layer formed on the Si oxide layer. For this reason, the Si content is set to 0.50% or less. The Si content is preferably 0.20% or less.

[0023]

Mn: 0.01% to 2.0%

Mn is an element that has the effect of neutralizing dissolved S, which causes embrittlement during hot working, by converting S into MnS, and also has the effect of improving strength. In particular, Mn has the effect of ensuring the strength of thick steel sheets whose strength tends to decrease after hot rolling. When the Mn content is less than 0.01%, such effects are small. When the Mn

content exceeds 2.0%, the toughness is reduced, and Mn-based oxides are formed at the interface between the scale and the steel substrate, causing a decrease in scale adhesion. In addition, transformation after finish rolling is delayed, transformation is not completed until coiling, and transformation proceeds partially and non-uniformly in the longitudinal direction after coiling. This induces loosening of the hot-rolled coil after coiling, and even at a central portion in the width direction of the coil, reoxidation occurs due to contact between the steel sheet surface and an oxidizing atmosphere, that is, the amount of hematite and magnetite grains increases, and the amount of the eutectoid transformation microstructure decreases, resulting in deterioration of scale adhesion. For these reasons, the Mn content is set to 0.01% to 2.0%. The lower limit is preferably 0.05% or more. The upper limit is preferably 1.5% or less.

[0024]

P: 0.10% or Less

P is an element that is preferably reduced as much as possible because P adversely affects grain boundary embrittlement. In addition, P forms a very brittle oxide layer at the interface between the scale and the steel substrate and lowers scale adhesion. When the P content exceeds 0.10%, these adverse effects increase; therefore,

the P content is set to 0.10% or less. The P content is preferably 0.05% or less. P may be absent; however, from the viewpoint of production cost, the lower limit is preferably 0.001% or more.

[0025]

S: 0.10% or Less

S is an element that significantly degrades hot workability and toughness. In addition, S enriches at the interface between the scale and the steel substrate and lowers scale adhesion. When the S content exceeds 0.10%, these adverse effects increase; therefore, the S content is set to 0.10% or less. The S content is preferably 0.05% or less. S may be absent; however, from the viewpoint of production cost, the lower limit is preferably 0.0001% or more.

[0026]

Sol. Al: 0.10% or Less

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

[0027]

N: 0.015% or Less

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

[0028]

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

[0029]

Cu: 1.0% or Less

Cu is an element that enriches at the interface between the scale and the steel substrate to promote grain boundary oxidation and also to promote unevenness of the interface between the scale and the steel substrate, thereby enhancing adhesion at the interface between the scale and the steel

substrate. To obtain these effects, the Cu content is preferably 0.01% or more. When the Cu content exceeds 1.0%, however, there is a concern that molten Cu penetrates into austenite grain boundaries of the steel substrate during heating, resulting in deterioration in surface properties due to hot embrittlement. Therefore, when copper is contained, the Cu content is set to 1.0% or less. The Cu content is preferably 0.8% or less.

[0030]

Ni: 0.50% or Less

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

[0031]

Cr: 2.0% or Less

Cr has the effect of enhancing strength, hardenability, and corrosion resistance. Cr enriches at the interface

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

[0032]

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

[0033]

Mo: 1.0% or Less

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

[0034]

Nb: 0.1% or Less

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

[0035]

V: 0.1% or Less

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

[0036]

Ti: 0.03% or Less

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

[0037]

B: 0.01% or Less

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

[0038]

Sb: 0.03% or Less

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

[0039]

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

amounts less than the preferable lower limits, these elements are regarded as unavoidable impurities.

[0040]

Next, the scale microstructure in the width direction of the steel sheet of the present invention will be described. The scale microstructure in the width direction of the steel sheet means the scale microstructure at a central portion in the width direction of the steel sheet and in a region within 200 mm from an edge in the width direction. In fact, the scale microstructure is measured at a central portion in the width direction of the steel sheet, at a position 5 mm from an edge in the width direction, and at a position 200 mm from the edge, and it is sufficient that the microstructure at each position falls within the ranges described below. When the microstructure at each measurement position falls within the ranges described below, the microstructure is considered to be uniform in the width direction.

[0041]

Area Fraction of Magnetite Grains: 20% or More and 60% or Less

Magnetite of the present invention includes magnetite grains and magnetite contained in the eutectoid transformation microstructure. These are microstructures that can be distinguished from each other as described

below. The magnetite grains in the present invention include a magnetite layer located near a scale surface and containing columnar magnetite grains, and massive pre-eutectoid magnetite grains formed inside or adjacent to the eutectoid transformation microstructure prior to progress of eutectoid transformation. The magnetite grains further include a so-called magnetite seam, which is a thin layer of fine magnetite grains formed at the interface between the scale and the steel substrate. The magnetite seam is distinguished from magnetite contained in the eutectoid transformation microstructure containing iron and magnetite. The magnetite grains have higher ductility at room temperature than wustite and hematite and contribute to improvement in scale adhesion. In particular, the magnetite seam has high coherency with the steel substrate, and thus contributes to improvement in scale adhesion by suppressing peeling of scale from the interface between the scale and the steel substrate. When the area fraction of the magnetite grains is less than 20%, this effect cannot be sufficiently obtained; therefore, the area fraction of the magnetite grains is set to 20% or more. The area fraction of the magnetite grains is preferably 30% or more. When the area fraction of the magnetite grains exceeds 60%, cracks occur in magnetite, and scale adhesion deteriorates. Therefore, the area fraction of the magnetite grains is set

to 60% or less, preferably 50% or less.

[0042]

Area Fraction of Eutectoid Transformation

Microstructure Containing Iron and Magnetite: 30% or More

The eutectoid transformation microstructure containing iron and magnetite contributes to improvement in scale adhesion because magnetite and precipitated Fe have high coherency with the steel substrate. When the area fraction of the eutectoid transformation microstructure is less than 30%, this effect cannot be sufficiently obtained; therefore, the area fraction of the eutectoid transformation microstructure containing iron and magnetite is set to 30% or more. The area fraction of the eutectoid transformation microstructure is preferably 35% or more, more preferably 40% or more. The upper limit is not particularly specified; however, in order to obtain a synergetic effect with the effect of improving scale adhesion by the magnetite grains, the area fraction of the eutectoid transformation microstructure containing iron and magnetite is preferably 80% or less, more preferably 70% or less.

[0043]

Area Fraction of Wustite: 15% or Less

Wustite is a phase that is stable at high temperatures, and most of the wustite disappears by undergoing eutectoid transformation during cooling after coiling. When the

cooling rate is high, however, wustite may remain at room temperature in an untransformed state. In particular, near the edge portions in the width direction of the coil, the cooling rate is relatively high, and wustite tends to remain at room temperature. Wustite is more brittle than magnetite at room temperature, and cracks in the scale impair scale adhesion. Therefore, the area fraction of wustite is set to 15% or less. The upper limit of the area fraction of wustite is preferably 10% or less, more preferably 7% or less. The area fraction of wustite may be 0%.

[0044]

Mass Fraction of Hematite: 5% or Less

Hematite may be formed in a layered form on the surface of the scale, in addition to the magnetite grains, the eutectoid transformation microstructure containing iron and magnetite, and wustite. In particular, at the edge portions in the width direction of the coil, scale reoxidation caused by air penetrating from the edges after coiling tends to form hematite. Hematite leads to deterioration in scale adhesion and also causes surface defects, such as red scale. Therefore, the mass fraction of hematite is set to 5% or less.

[0045]

Average Thickness of Scale in Width Direction of Steel Sheet Is 5 μm or More and 20 μm or Less, and Variation in

Scale Thickness in Width Direction of Steel Sheet Is 4 μm or Less

When the average thickness of the scale is less than 5 μm , processing troubles may occur. This is because the amount of thermal energy of laser light absorbed at the surface of the steel sheet becomes insufficient during laser cutting processing. When the average thickness of the scale exceeds 20 μm , particularly when the hot-rolled steel sheet has a large thickness, the strain applied to the scale surface during processing of the steel sheet increases, and the occurrence of cracks in the scale reduces scale adhesion. Therefore, the average thickness of the scale is set to 20 μm or less. The average thickness of the scale is preferably 18 μm or less, more preferably 15 μm or less. To uniformly enhance scale adhesion in the width direction and obtain excellent laser cuttability, the average thickness of the scale in the width direction of the steel sheet is controlled to be 5 μm or more and 20 μm or less, and the variation in the scale thickness in the width direction of the steel sheet is set to 4 μm or less. The variation in the scale thickness in the width direction of the steel sheet is preferably 3 μm or less. The variation in the scale thickness means the maximum difference among the average thicknesses of the scale measured at a plurality of measurement positions. The plurality of measurement

positions, the average thickness of the scale, and the method for measuring the variation in the scale thickness will be described below.

[0046]

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

[0047]

The area fractions of the magnetite grains, the eutectoid transformation microstructure containing iron and magnetite, and the wustite can be determined as follows. Cross-sections in the sheet thickness direction that are perpendicular to the steel sheet surface and parallel to the rolling direction are cut out, mirror-polished, and then observed using a scanning electron microscope (SEM). With respect to the field of view of the SEM, the entire scale thickness from the scale surface to the interface between the scale and the steel sheet is targeted for observation. Accordingly, the area fractions can be measured by observing the backscattered electron image of each scale cross-section at an observation magnification at which the entire scale thickness fits within the field of view. In the backscattered electron image obtained using the SEM, the magnetite grains appear as the darkest region, the steel substrate appears as the brightest region, and wustite

appears as a region having intermediate contrast.

Furthermore, the eutectoid transformation microstructure containing iron and magnetite is a region containing magnetite and iron in a layered form.

[0048]

Hematite is formed as an extremely thin layer on the scale surface and easily detaches during mirror polishing; therefore, it is difficult to quantitatively evaluate the area fraction of hematite using the SEM. Accordingly, the integrated intensities of diffraction peaks of respective phases in the scale are measured using an X-ray diffractometer with a Co K α radiation source, and from the ratios of the integrated intensities of the respective phases between a standard sample and a test sample, the mass fraction can be obtained using the following formula (2). The standard sample is a mixture of Fe, FeO (wustite), Fe₂O₃ (hematite), and Fe₃O₄ (magnetite) at equal weights. The mass fraction of hematite can be regarded as an area fraction.

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

(2)

In formula (2),

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

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

A: Fe, FeO, Fe₂O₃, or Fe₃O₄.

[0049]

The average thickness of the scale is measured in accordance with the following procedure. For example, cross-sections in the sheet thickness direction that are perpendicular to the steel sheet surface and parallel to the rolling direction are cut out from a central portion in the width direction of the hot-rolled steel sheet, from a portion 200 mm from an edge in the width direction of the hot-rolled steel sheet, and from a portion 5 mm from the edge in the width direction of the hot-rolled steel sheet, and the cross-sections are mirror-polished. Subsequently, the scale thickness is measured at three locations for each cross-section using an SEM, and the measured values are averaged to obtain the scale thickness at each position in the width direction. The average thickness of the scale in the width direction in the present invention means that the average thickness of the scale at each position in the width direction is 5 μm or more and 20 μm or less.

The variation in the scale thickness in the width direction can be determined by subtracting the minimum value from the maximum value among the respective average thicknesses of the scale at the central portion in the width direction of the hot-rolled steel sheet, the portion 5 mm from the edge in the width direction, and the portion 200 mm

from the edge in the width direction.

[0050]

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

[0051]

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

[0052]

In the present invention, a method for producing a steel material having the chemical composition described above is not limited, and any commonly used method can be employed. For example, a molten steel having the chemical composition described above is preferably melted in a converter, an electric arc furnace, or the like and formed into a steel material, such as a slab, by a casting method, such as continuous casting. An ingot casting-blooming rolling method can be employed without any problem. In general, a steel material is hot-rolled after heating. This heating needs only to be sufficient to achieve adequate solid-solution treatment, and the steel material is

preferably heated to an A_{c3} point or higher. Specifically, the heating temperature is preferably in a range of 1060°C to 1300°C , which is a normal slab heating temperature range. For a slab produced by continuous casting, hot direct rolling may be employed in which rolling is performed without further treatment or after holding the slab to suppress a decrease in temperature.

[0053]

The hot rolling step includes rough rolling and finish rolling. Rough rolling involves forming a sheet bar having predetermined dimensions, and it is not necessary to limit the rough rolling conditions. Before rough rolling, scale formed by slab heating is preferably removed by descaling. The material to be rolled may be heated during rolling by using a heating means, such as a sheet bar heater, in order to perform finish rolling at a predetermined temperature. Before finish rolling after rough rolling, the scale formed on the surface of the sheet bar is removed by descaling using high pressure water or the like on the inlet side of a rolling mill.

[0054]

Next, finish rolling is performed. When the finish rolling inlet temperature exceeds 1100°C , the thickness of the scale may increase, and scale adhesion may decrease. When the finish rolling inlet temperature is lower than

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

[0055]

Finish Rolling delivery Temperature: 800°C or Higher
and 950°C or Lower

When the finish rolling delivery temperature is lower than 800°C, a decrease in scale ductility causes cracks. These cracks promote scale reoxidation to form hematite, which causes a decrease in scale adhesion. Furthermore, the scale microstructure becomes finer, and an increase in hardness of the scale itself causes a decrease in scale adhesion. Meanwhile, when the finish rolling delivery temperature exceeds 950°C, excessive scale growth increases scale thickness, resulting in a decrease in scale adhesion. In addition, an increase in grain size of each phase in the scale microstructure causes a decrease in scale adhesion. Therefore, the finish rolling delivery temperature is set to

800°C or higher and 950°C or lower. The lower limit is preferably 820°C or higher. The upper limit is preferably 930°C or lower.

[0056]

Cooling at Average Cooling Rate of 5 °C/s or Higher in Temperature Range from Finish Rolling Delivery Temperature to 750°C

Since scale grows more rapidly in a high-temperature region, it is necessary to perform rapid cooling in a high-temperature region immediately after finish rolling in order to suppress a decrease in scale adhesion caused by excessive scale growth. When the average cooling rate in a temperature range from the finish rolling delivery temperature to 750°C is lower than 5 °C/s, scale excessively grows, which causes a decrease in scale adhesion. For this reason, the average cooling rate in the temperature range from the finish rolling delivery temperature to 750°C is set to 5 °C/s or higher. The average cooling rate is preferably 7 °C/s or higher. When the average cooling rate in the temperature range from the finish rolling delivery temperature to 750°C exceeds 80 °C/s, the scale microstructure may become finer, and scale adhesion may decrease. In addition, a decrease in scale ductility causes cracks, and these cracks promote scale reoxidation to form hematite, which may cause a decrease in scale adhesion. For

this reason, the average cooling rate in the temperature range from the finish rolling delivery temperature to 750°C is preferably 80 °C/s or lower. The average cooling rate is more preferably 50 °C/s or lower.

[0057]

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

In a range from 750°C to a temperature at start of coiling, scale growth is relatively slower than in a high-temperature region immediately after finish rolling; however, it is necessary to suppress a decrease in scale adhesion caused by excessive scale growth. When the average cooling rate in the range from 750°C to the temperature at start of coiling is lower than 1 °C/s, scale excessively grows, which causes a decrease in scale adhesion. For this reason, the average cooling rate in the range from 750°C to the temperature at start of coiling is set to 1 °C/s or higher. The average cooling rate is preferably 3 °C/s or higher. When the average cooling rate in the range from 750°C to the temperature at start of coiling exceeds 30 °C/s, cracks occur in the scale due to refinement of the scale microstructure and an increase in the stress difference between the scale and the steel substrate. These cracks promote scale reoxidation to form hematite, resulting

in a decrease in scale adhesion. For this reason, the average cooling rate in the range from 750°C to the temperature at start of coiling is set to 30 °C/s or lower. The average cooling rate is preferably 20 °C/s or lower.

[0058]

Coiling Temperature: 500°C or Higher and 650°C or Lower

After the cooling described above, the steel sheet is coiled at a coiling temperature of 500°C or higher and 650°C or lower. When the coiling temperature is lower than 500°C, eutectoid transformation from wustite does not sufficiently proceed after coiling, and an excessive amount of wustite remains at room temperature. As a result, scale adhesion decreases since wustite is brittle at room temperature. When the coiling temperature exceeds 650°C, scale adhesion decreases due to excessive scale growth. In addition, at a central portion in the width direction that is shielded from an oxidizing atmosphere after coiling, hematite and magnetite on the scale surface are reduced to wustite, and an adequate amount of magnetite grains is not obtained. Accordingly, the coiling temperature is set to 500°C or higher and 650°C or lower. The lower limit is preferably 530°C or higher. The upper limit is preferably 630°C or lower.

[0059]

After Start of Coiling, Entire Coil Is Cooled Such That

Temperature of Edge Portions of Coil Decreases at Average Cooling Rate of 0.5 °C/s or Higher and 6.0 °C/s or Lower from Coiling Temperature to Cooling Stop Temperature of 300°C or Higher and 450°C or Lower

After start of coiling, the entire coil is cooled such that the temperature of edge portions of the coil decreases at an average cooling rate of 0.5 °C/s or higher and 6.0 °C/s or lower from the coiling temperature to a cooling stop temperature of 300°C or higher and 450°C or lower. This process decreases the temperature of the edge portions of the coil, increases coil rigidity, and prevents coil loosening. The entire coil refers to both edge portions and sheet surface of the coil. The edge portions of the coil refer to regions within 200 mm in the width direction of the coil from both edges in the width direction of the coil. The sheet surface of the coil refers to the surface of the coil in a region other than both end portions. As a result, at the central portion in the width direction of the coil, shielding from an oxidizing atmosphere can suppress reoxidation, and a eutectoid transformation microstructure suitable for improving adhesion can be sufficiently obtained. At the edge portions of the coil in the width direction, complete shielding from an oxidizing atmosphere is difficult; however, cooling of the edge portions suppresses reoxidation, and recuperation from the central

portion in the width direction promotes eutectoid transformation, thereby ensuring excellent adhesion. This mechanism can reduce a variation in scale thickness in the width direction and can uniformly improve scale adhesion in the width direction to improve laser cuttability. The temperature of the edge portions can be measured, for example, by using a radiation thermometer. The temperature of the sheet surface is not specified because the temperature of the sheet surface at a specific longitudinal position cannot be measured during coiling; however, the above effects can be obtained by cooling the entire coil by the same cooling method as that for the edge portions. When the cooling stop temperature at the edge portions of the coil exceeds 450 °C, the above effects cannot be sufficiently obtained. When the cooling stop temperature at the edge portions of the coil is lower than 300 °C, the edge portions undergo overcooling, and a large amount of wustite remains in the scale at the edge portions, which leads to a decrease in adhesion. Therefore, the cooling stop temperature at the edge portions of the coil is set to 300 °C or higher and 450 °C or lower. The cooling stop temperature is preferably 320°C or higher and 430°C or lower. When the average cooling rate at the edge portions is lower than 0.5 °C/s, the above effects cannot be sufficiently obtained. When the average cooling rate at the

edge portions exceeds 6.0 °C/s, cracks occur in the scale due to refinement of the scale microstructure and an increase in stress difference between the scale and the steel substrate. These cracks promote scale reoxidation to form hematite, resulting in a decrease in scale adhesion. Therefore, the average cooling rate at the edge portions is set to 0.5 °C/s or higher and 6.0 °C/s or lower. The average cooling rate is preferably 1.0 °C/s or higher and 5.0 °C/s or lower. A method for cooling the coil is not particularly specified; however, for example, the coil is preferably cooled, during coiling in a coiler, using a cooling device that applies water spray cooling to the sheet surface and both edge portions of the coil.

[0060]

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

[0061]

Furthermore, the hot-rolled steel sheet coiled into a coil shape may be subjected to shape correction by deforming the steel sheet using a roller leveler, a tension leveler, or the like. For example, a hot-rolled steel sheet with a thickness of 12 mm is subjected to shape correction using an arrangement of two upper rolls and three lower rolls, each

φ250 mm, with an indentation depth of 2 mm.

EXAMPLES

[0062]

Examples of the present invention will be described below.

[0063]

Steels having the compositions shown in Table 1 were melted and cast into steel materials. These steel materials were hot-rolled under the conditions shown in Table 2 to obtain hot-rolled coils having a sheet thickness of 3 to 23 mm. The obtained hot-rolled coils were subjected to shape correction by leveler processing and then cut to a predetermined length to obtain hot-rolled sheets. Test specimens were taken from central portions and edge portions in the width direction of the obtained hot-rolled sheets, and the scale microstructure, scale thickness, scale adhesion, and laser cuttability were evaluated by the methods described below. The evaluation results are shown in Table 3.

[0064]

[Table 1]

Steel No.	Chemical Composition (mass%)											Note
	C	Si	Mn	P	S	sol. Al	N	Cu	Ni	Cr	others	
A	0.063	0.13	0.91	0.016	0.0028	0.038	0.0038	-	-	-	-	Inventive Steel
B	0.072	0.01	1.46	0.011	0.0049	0.043	0.0060	-	-	-	-	Inventive Steel
C	0.164	0.05	0.81	0.013	0.0044	0.041	0.0060	-	-	-	-	Inventive Steel
D	0.024	0.17	1.92	0.011	0.0033	0.025	0.0028	0.05	0.04	-	-	Inventive Steel
E	0.123	0.47	0.42	0.018	0.0027	0.043	0.0021	-	-	0.30	-	Inventive Steel
F	0.142	0.03	0.64	0.018	0.0030	0.038	0.0024	0.25	0.15	0.63	-	Inventive Steel
G	0.198	0.13	0.85	0.011	0.0030	0.043	0.0030	0.42	0.21	0.13	-	Inventive Steel
H	0.133	0.33	1.51	0.015	0.0043	0.031	0.0029	-	-	-	Mo:0.32, Nb:0.02, V:0.03	Inventive Steel
I	0.292	0.15	0.33	0.020	0.0022	0.046	0.0026	0.15	0.07	0.25	Ti:0.022, B:0.011, Sb:0.01	Inventive Steel
J	<u>0.315</u>	0.19	0.55	0.017	0.0030	0.046	0.0052	-	-	-	-	Comparative Steel
K	0.164	<u>0.65</u>	1.50	0.020	0.0026	0.024	0.0027	-	-	-	-	Comparative Steel
L	0.255	0.15	<u>2.08</u>	0.017	0.0056	0.050	0.0035	-	-	-	-	Comparative Steel

Underlined entries are outside the scope of the present invention.

[0065]

[Table 2]

No.	Steel No.	Hot Rolling Conditions							Note
		finish rolling delivery temperature (°C)	sheet thickness (mm) after finish rolling	average cooling rate (°C/s) from finish rolling delivery temperature to 750°C	average cooling rate (°C/s) from 750°C to temperature at start of coiling	coiling temperature (°C)	cooling stop temperature (°C) at coil edge portion	average cooling rate (°C/s) at coil edge portion	
1	A	820	24	40	2	520	440	0.8	Inventive Example
2	A	<u>780</u>	24	40	2	520	420	1.5	Comparative Example
3	A	<u>970</u>	24	40	2	520	420	1.5	Comparative Example
4	B	880	21	30	4	560	420	1.5	Inventive Example
5	B	880	21	<u>3</u>	4	560	420	1.5	Comparative Example
6	C	940	18	10	12	560	390	3.0	Inventive Example
7	C	940	18	10	<u>0.3</u>	560	390	3.0	Comparative Example
8	D	820	15	8	28	580	390	3.0	Inventive Example
9	D	820	15	8	<u>33</u>	580	390	3.0	Comparative Example
10	E	880	12	6	4	580	390	3.0	Inventive Example
11	E	880	12	6	4	<u>490</u>	390	3.0	Comparative Example
12	F	940	12	30	4	600	360	4.5	Inventive Example
13	F	940	12	30	4	<u>660</u>	360	4.5	Comparative Example
14	G	820	9	10	4	600	360	4.5	Inventive Example
15	G	820	9	10	4	600	<u>480</u>	<u>0.3</u>	Comparative Example
16	H	880	6	8	4	620	360	4.5	Inventive Example
17	H	880	6	8	4	620	<u>480</u>	1.0	Comparative Example
18	I	940	3	6	4	640	330	5.5	Inventive Example
19	I	940	3	6	4	640	<u>280</u>	<u>6.5</u>	Comparative Example
20	<u>J</u>	840	12	10	4	620	390	3.0	Comparative Example
21	<u>K</u>	880	12	10	4	620	390	3.0	Comparative Example
22	<u>L</u>	920	12	10	4	620	390	3.0	Comparative Example

Underlined entries are outside the scope of the present invention.

[0066]

[Table 3]

No.	Steel No.	Scale Microstructure and Adhesion in Central Portion in Width Direction						Scale Microstructure and Adhesion in Portion at 200 mm from Edge in Width Direction						Scale Microstructure and Adhesion in Portion at 5 mm from Edge in Width Direction						variation (μm) in scale thickness in width direction	laser cuttability	Note
		area fraction (%) of magnetite grains	area fraction (%) of eutectoid transformation microstructure	area fraction (%) of wustite	mass fraction (%) of hematite	scale thickness (μm)	scale adhesion	area fraction (%) of magnetite grains	area fraction (%) of eutectoid transformation microstructure	area fraction (%) of wustite	mass fraction (%) of hematite	scale thickness (μm)	scale adhesion	area fraction (%) of magnetite grains	area fraction (%) of eutectoid transformation microstructure	area fraction (%) of wustite	mass fraction (%) of hematite	scale thickness (μm)	scale adhesion			
1	A	33	62	5	3	16	A	35	59	6	4	17	A	38	55	7	3	18	A	2	A	Inventive Example
2	A	42	54	4	<u>6</u>	14	<u>C</u>	45	48	7	<u>9</u>	16	<u>C</u>	45	47	8	<u>8</u>	18	<u>C</u>	4	<u>C</u>	<u>Comparative Example</u>
3	A	56	40	4	1	<u>21</u>	<u>C</u>	56	38	6	3	<u>23</u>	<u>C</u>	57	37	6	2	<u>23</u>	<u>C</u>	2	<u>C</u>	<u>Comparative Example</u>
4	B	40	58	2	0	15	A	51	44	5	2	15	A	51	44	5	5	16	A	1	A	Inventive Example
5	B	29	68	3	1	<u>22</u>	<u>C</u>	58	38	4	1	<u>23</u>	<u>C</u>	58	38	4	4	<u>25</u>	<u>C</u>	3	<u>C</u>	<u>Comparative Example</u>
6	C	47	51	2	2	13	A	55	42	3	2	13	A	57	38	5	4	15	A	2	A	Inventive Example
7	C	45	53	2	1	<u>21</u>	<u>C</u>	49	48	3	3	<u>24</u>	<u>C</u>	52	44	4	2	<u>24</u>	<u>C</u>	3	<u>C</u>	<u>Comparative Example</u>
8	D	28	71	1	1	13	A	48	48	4	3	14	A	50	44	6	3	16	A	3	A	Inventive Example
9	D	24	76	0	<u>7</u>	12	<u>C</u>	54	44	2	<u>10</u>	13	<u>C</u>	58	38	4	<u>9</u>	13	<u>C</u>	1	<u>C</u>	<u>Comparative Example</u>
10	E	34	65	1	2	10	A	55	43	2	2	11	A	57	40	3	2	14	A	4	A	Inventive Example
11	E	56	<u>27</u>	<u>17</u>	1	8	<u>C</u>	53	<u>29</u>	<u>18</u>	4	10	<u>C</u>	55	<u>25</u>	<u>20</u>	2	10	<u>C</u>	2	<u>C</u>	<u>Comparative Example</u>
12	F	23	77	0	1	12	A	27	71	2	1	13	A	57	40	3	2	13	A	1	A	Inventive Example
13	F	<u>15</u>	85	0	0	<u>22</u>	<u>C</u>	25	74	1	3	<u>23</u>	<u>C</u>	30	69	1	2	<u>22</u>	<u>C</u>	1	<u>C</u>	<u>Comparative Example</u>
14	G	24	76	0	0	8	A	54	45	1	2	10	A	58	41	1	4	10	A	2	A	Inventive Example
15	G	55	45	0	2	7	A	<u>63</u>	36	1	<u>11</u>	14	<u>C</u>	<u>66</u>	33	1	<u>9</u>	12	<u>C</u>	<u>7</u>	<u>C</u>	<u>Comparative Example</u>
16	H	31	69	0	1	6	A	45	55	0	3	7	A	51	47	2	0	7	A	1	A	Inventive Example
17	H	24	76	0	1	6	A	29	70	1	<u>7</u>	12	<u>C</u>	54	44	2	<u>6</u>	9	<u>C</u>	<u>6</u>	<u>C</u>	<u>Comparative Example</u>
18	I	27	73	0	1	5	A	36	62	2	3	6	A	48	50	2	2	6	A	1	A	Inventive Example
19	I	36	61	3	2	7	A	54	33	13	2	8	A	58	24	<u>18</u>	4	7	<u>C</u>	1	<u>C</u>	<u>Comparative Example</u>
20	<u>J</u>	46	54	0	0	11	<u>C</u>	51	47	2	4	12	<u>C</u>	58	40	2	2	12	<u>C</u>	1	<u>C</u>	<u>Comparative Example</u>
21	<u>K</u>	50	50	0	1	10	<u>C</u>	55	43	2	2	10	<u>C</u>	57	41	2	0	12	<u>C</u>	2	<u>C</u>	<u>Comparative Example</u>
22	<u>L</u>	30	70	0	0	11	<u>C</u>	46	51	3	1	11	<u>C</u>	57	39	4	3	12	<u>C</u>	1	<u>C</u>	<u>Comparative Example</u>

Underlined entries are outside the scope of the present invention.

[0067]

The area fractions of the magnetite grains, the eutectoid transformation microstructure containing iron and magnetite, and the wustite were measured by cutting out cross-sections in the sheet thickness direction that were perpendicular to the steel sheet surface and parallel to the rolling direction, mirror-polishing the cross-sections, and then observing the backscattered electron image of each scale cross-section using an SEM at a magnification of 3,000 $\times$. In the backscattered electron image obtained using the SEM, the magnetite grains appear as the darkest region, the steel substrate appears as the brightest region, wustite appears as a region having intermediate contrast, and the eutectoid transformation microstructure containing iron and magnetite is a region containing magnetite and iron in a layered form.

[0068]

The mass fraction of hematite was determined as follows. The integrated intensities of diffraction peaks of the respective phases in the scale were measured by using an X-ray diffractometer with a Co K α radiation source. The mass fraction was determined using the following formula (2) from the ratios between the integrated intensities of the respective phases in a standard sample (a mixture of Fe, FeO (wustite), Fe₂O₃ (hematite), and Fe₃O₄ (magnetite) at equal

weights) and the integrated intensities of respective phases in a test sample.

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

(2)

In formula (2),

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

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

A: Fe, FeO, Fe₂O₃, or Fe₃O₄.

[0069]

The average thickness of the scale was determined as follows. Cross-sections in the sheet thickness direction that were perpendicular to the steel sheet surface and parallel to the rolling direction were cut out from a central portion in the width direction of each of the obtained hot-rolled sheets, from a portion 200 mm from an edge in the width direction, and from a portion 5 mm from the edge in the width direction. Next, the cross-sections were mirror-polished, and the scale thickness at arbitrary positions was then measured at three locations for each cross-section using an SEM, and the measured values were averaged to obtain the scale thickness at each position in the width direction.

[0070]

The scale adhesion was determined as follows. Test specimens were taken from a central portion in the width direction of each of the hot-rolled sheets after leveler processing, from a portion 200 mm from an edge in the width direction, and from a portion 5 mm from the edge in the width direction, and the scale was peeled off by applying tape to the steel sheet surface. Subsequently, the scale adhesion was evaluated based on the presence of exposure of the steel substrate on the steel sheet surface and the amount of scale adhered to the tape. Specifically, the tape was applied to the steel sheet surface, then peeled, and attached to a transparent sheet, this sheet was then scanned using a scanner, and the amount of peeled scale was measured by image processing. When the area fraction of the scale adhered to the peeled tape was less than 10%, the scale adhesion was rated as excellent and denoted by A in Table 3. When the area fraction of the scale adhered to the peeled tape was 10% or more, the scale adhesion was rated as poor and denoted by C in Table 3.

[0071]

Laser cuttability was determined by performing linear laser cutting parallel to the width direction on the hot-rolled sheets after leveler processing, using a laser cutting machine ENSIS3015AJ available from Amada Machinery Co., Ltd. and a fiber laser oscillator. When cutting

failed, or when a stable cut surface was not obtained due to adhesion of dross or molten droplets to the cut surface or occurrence of notches, the laser cuttability was rated as poor and denoted by C in Table 3. When none of the above phenomena occurred and a stable cut surface was obtained in the width direction, the laser cuttability was rated as excellent and denoted by A in Table 3. During laser cutting, oxygen was used as an assist gas, the cutting speed was set to 1500 mm/min, the laser output was set to 3 kW, and the focal position was set at a position 3.0 mm from the steel sheet surface.

[0072]

Inventive Examples shown in Table 3 exhibited excellent uniform scale adhesion at a central portion in the width direction of the hot-rolled sheets, at a portion 5 mm from an edge in the width direction, and at a portion 200 mm from the edge in the width direction, and also exhibited excellent laser cuttability. In contrast, Comparative Examples exhibited poor adhesion at any one or more positions in the width direction or exhibited poor laser cuttability.

CLAIMS

[Claim 1]

A hot-rolled steel sheet comprising:

a chemical composition containing,

in mass%,

C: 0.01% to 0.30%,

Si: 0.50% or less,

Mn: 0.01% to 2.0%,

P: 0.10% or less,

S: 0.10% or less,

sol. Al: 0.10% or less, and

N: 0.015% or less,

with the balance being Fe and unavoidable
impurities; and

a scale on a surface of the steel sheet,

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

in terms of area fraction,

magnetite grains: 20% or more and 60% or less,

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

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

wustite: 15% or less, and,

in terms of mass fraction, hematite: 5% or less,
an average thickness of the scale in the width
direction of the steel sheet is 5 μm or more and 20 μm or
less, and

a variation in a thickness of the scale in the width
direction of the steel sheet is 4 μm or less.

[Claim 2]

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

Cu: 1.0% or less,

Ni: 0.50% or less, and

Cr: 2.0% or less.

[Claim 3]

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

Mo: 1.0% or less,

Nb: 0.1% or less,

V: 0.1% or less,

Ti: 0.03% or less,

B: 0.01% or less, and

Sb: 0.03% or less.

[Claim 4]

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

method comprising:

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

descaling after hot rough rolling;

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

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

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

coiling at a coiling temperature of 500°C or higher and 650°C or lower; and

after start of coiling, cooling such that an entire coil is cooled so that a temperature of an edge portion of the coil decreases at an average cooling rate of 0.5 °C/s or higher and 6.0 °C/s or lower from the coiling temperature to a cooling stop temperature of 300°C or higher and 450°C or lower.