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(71) Applicant: **POSCO Co., Ltd**
Gyeongsangbuk-do 37859 (KR)

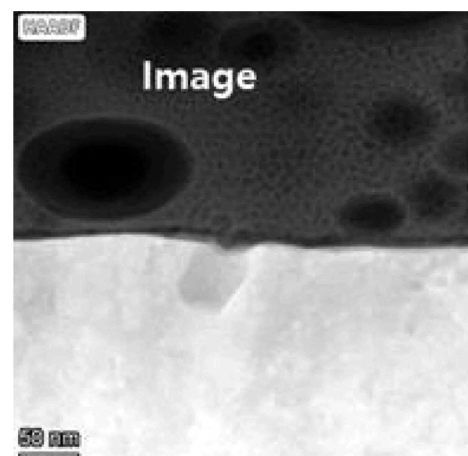
(72) Inventors:
• **KIM, Kwonil**
Pohang-si, Gyeongsangbuk-do 37859 (KR)
• **SOHN, Ilryoung**
Pohang-si, Gyeongsangbuk-do 37859 (KR)
• **PAIK, Doojin**
Pohang-si, Gyeongsangbuk-do 37859 (KR)

(74) Representative: **Meissner Bolte Partnerschaft**
mbB
Patentanwälte Rechtsanwälte
Postfach 86 06 24
81633 München (DE)

(54) **NON-ORIENTED ELECTRICAL STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) A non-oriented electrical steel sheet according to an embodiment of the present invention comprises, by wt%, Si: 1.5 to 6.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, and Cu: 0.002 to 0.100%, with the balance being Fe and unavoidable impurities, wherein a ratio ($Al_{MAX}/Al_{5\mu m}$) of a maximum Al content (Al_{MAX}) to an Al content ($Al_{5\mu m}$) at a point 5 μm inside the steel sheet from the steel sheet surface, when measuring the Al content in a thickness direction from the steel sheet surface to 5 μm inside the steel sheet, is 4.0 or less, and the number of unevenness portions having a width of 2 mm or more and a length of 10 mm or more per 300 mm $\times$ 300 mm area is 5 or less.

FIG. 1



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Description**[Technical Field]**

[0001] An embodiment of the present invention relates to a non-oriented electrical steel sheet and a manufacturing method thereof. Specifically, an embodiment of the present invention relates to a non-oriented electrical steel sheet and a manufacturing method thereof, which may simultaneously achieve excellent appearance characteristics and magnetic properties by appropriately controlling a steel composition and scale removal conditions to suppress the occurrence of surface Al enrichment and linear defects.

[Background Art]

[0002] Non-oriented electrical steel sheets are mainly used in motors that convert electrical energy into mechanical energy, and excellent magnetic properties of the non-oriented electrical steel sheet are required to exhibit high efficiency in such a process. In particular, in recent years, as eco-friendly vehicles driven by motors instead of internal combustion engines have attracted attention, the demand for non-oriented electrical steel sheets used as a core material for a driving motor is increasing, and for this purpose, a non-oriented electrical steel sheet having both excellent magnetic properties and strength is required.

[0003] Magnetic properties of the non-oriented electrical steel sheet are mainly evaluated by iron loss and magnetic flux density. Iron loss refers to energy loss occurring at a specific magnetic flux density and frequency, and magnetic flux density refers to the degree of magnetization obtained under a specific magnetic field. As the iron loss is lower, a motor having higher energy efficiency under the same conditions may be manufactured, and as the magnetic flux density is higher, the motor may be downsized or copper loss may be reduced. Therefore, a driving motor having excellent efficiency and torque may be made by using a non-oriented electrical steel sheet having low iron loss and high magnetic flux density, and through this, the driving distance and output of an eco-friendly vehicle may be improved.

[0004] Characteristics of the non-oriented electrical steel sheet to be considered also change according to operating conditions of the motor. As a general criterion for evaluating characteristics of a non-oriented electrical steel sheet used for a motor, W15/50, which is iron loss when a magnetic field of 1.5 T is applied at a commercial frequency of 50 Hz, is widely used. However, in a non-oriented electrical steel sheet having a thickness of 0.35 mm or less used for a driving motor of an eco-friendly vehicle, magnetic properties are often important in a low magnetic field of 1.0 T or less and a high frequency of 400 Hz or more, and therefore, characteristics of the non-oriented electrical steel sheet are often evaluated by W10/400 iron loss.

[0005] A method commonly used to increase magnetic properties of a non-oriented electrical steel sheet is to add alloying elements such as Si, Al, and Mn. However, these elements are strong oxidation-promoting elements and form scale such as stable oxides or nitrides on the surface in the manufacturing process, thereby adversely affecting the surface quality of the product. As a result, not only the appearance of the steel sheet but also the adhesion of insulation coating and the lamination adhesion of the steel sheet may be damaged.

[Disclosure]**[Technical Problem]**

[0006] An embodiment of the present invention provides a non-oriented electrical steel sheet and a manufacturing method thereof. Specifically, an embodiment of the present invention provides a non-oriented electrical steel sheet and a manufacturing method thereof, which exhibit excellent appearance characteristics and magnetic properties by appropriately controlling a steel composition and scale removal conditions to suppress the occurrence of surface Al enrichment and linear defects.

[Technical Solution]

[0007] A non-oriented electrical steel sheet according to an embodiment of the present invention comprises, by wt%, Si: 1.5 to 6.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, and Cu: 0.002 to 0.100%, with the balance being Fe and unavoidable impurities, wherein a ratio ($Al_{MAX}/Al_{5\mu m}$) of a maximum Al content (Al_{MAX}) to an Al content ($Al_{5\mu m}$) at a point 5 μm inside the steel sheet from the steel sheet surface, when measuring the Al content in a thickness direction from the steel sheet surface to 5 μm inside the steel sheet, is 4.0 or less, and the number of unevenness portions having a width of 2 mm or more and a length of 10 mm or more per 300 mm $\times$ 300 mm area is 5 or less.

[0008] In the non-oriented electrical steel sheet according to an embodiment of the present invention, there may be

5 or less Al aggregates having a particle diameter of 500 nm or more per 100 μm of steel sheet length in a region from the steel sheet surface to 5 μm inside the steel sheet.

[0009] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise one or more of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.010 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

[0010] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise one or two or more of Sn, Sb, Bi, Pb, Ge, and As each or in a total content thereof of 0.005 to 0.200 wt%.

[0011] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise one or more of Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

[0012] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise one or more of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

[0013] The non-oriented electrical steel sheet according to an embodiment of the present invention comprises an insulating coating located on the steel sheet surface, and a whiteness of the surface of the insulating coating is 50 or more.

[0014] A manufacturing method of a non-oriented electrical steel sheet according to an embodiment of the present invention comprises: a step of manufacturing a hot-rolled steel sheet by hot rolling a slab comprising, by wt%, Si: 1.5 to 6.0%, Al: 0.1 to 2.0%, Mn: 2.0% or less (excluding 0%), and Cu: 0.002 to 0.100%, with the balance being Fe and unavoidable impurities; a first annealing step of annealing the hot-rolled steel sheet; a scale removal step of removing scale from the first annealed steel sheet; a step of manufacturing a cold-rolled sheet by cold rolling the descaled steel sheet; and a second annealing step of annealing the cold-rolled sheet.

[0015] The scale removal step comprises spraying cooling water having a pH of 4.0 to 8.5 onto a surface of the steel sheet, and a step of polishing with a brush.

[0016] The slab may further comprise one or more of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.010 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

[0017] The slab may further comprise one or two or more of Sn, Sb, Bi, Pb, Ge, and As, individually or in a total content thereof of 0.005 to 0.200 wt%.

[0018] The slab may further comprise one or more of Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), and Zn: 0.01 wt% or less (excluding 0%).

[0019] The slab may further comprise one or more of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), Co: 0.05 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

[0020] Before the first annealing step, scale remaining on the surface of the steel sheet may be 5 area % or less, and a surface roughness (Ra) may be 3.0 μm or less.

[0021] Before the first annealing step, a step of removing scale by immersion for 30 to 150 seconds in a 15 to 30 wt% acidic aqueous solution may be further included.

[0022] Before the first annealing step, a preliminary cold rolling step of cold rolling the hot-rolled steel sheet may be further included, and the first annealing step may anneal the preliminarily cold-rolled steel sheet.

[0023] The first annealing step may be performed in an atmosphere containing 3 vol% or more of hydrogen at a temperature of 870 to 1050°C.

[0024] The scale removal step may further include a step of immersing the steel sheet in a 5 to 20 wt% acidic aqueous solution for 2 to 30 seconds.

[0025] After the scale removal step, the ratio ($\text{Al}_{\text{MAX}}/\text{Al}_{5\mu\text{m}}$) of the maximum Al content (Al_{MAX}) to the Al content ($\text{Al}_{5\mu\text{m}}$) at a point 5 μm inside the steel sheet from the steel sheet surface, when measuring the Al content in a thickness direction from the steel sheet surface to 5 μm inside the steel sheet, may be 10.0 or less.

[0026] After the scale removal step, a surface roughness of the steel sheet may be 1.5 μm or less.

[0027] In the second annealing step, annealing may be performed in an atmosphere containing 10 to 50 vol% hydrogen and at a temperature of 900 to 1050°C.

[Advantageous Effects]

[0028] A non-oriented electrical steel sheet according to an embodiment of the present invention has excellent surface quality and electromagnetic properties at the same time.

[0029] A non-oriented electrical steel sheet according to an embodiment of the present invention has a high surface

whiteness due to a reduction in residual oxide on the surface and exhibits excellent adhesion of an insulation coating.

[0030] In addition, a non-oriented electrical steel sheet according to an embodiment of the present invention contributes to performance improvement of an eco-friendly vehicle driving motor.

[0031] Because the magnetic anisotropy is high, high torque may be obtained when the motor for vehicles is manufactured.

[Brief Description of the Drawings]

[0032]

FIG. 1 shows a TEM cross-section of a steel sheet manufactured in Inventive Example 10.

FIG. 2 shows an Al element map of the steel sheet manufactured in Inventive Example 10.

FIG. 3 is a graph showing the Al content of the steel sheet manufactured in Inventive Example 10, as analyzed by GDS.

FIG. 4 is a diagram illustrating the surface morphology of the steel sheet manufactured in Inventive Example 10 and a graph showing a surface profile along the horizontal axis of the diagram.

FIG. 5 shows a TEM cross-section of a steel sheet manufactured in Comparative Example 8.

FIG. 6 shows an Al element map of the steel sheet manufactured in Comparative Example 8.

FIG. 7 is a graph showing the Al content of the steel sheet manufactured in Comparative Example 8, as analyzed by GDS.

FIG. 8 is a diagram illustrating the surface morphology of the steel sheet manufactured in Comparative Example 8 and a graph showing a surface profile along the horizontal axis of the diagram.

[Mode for Invention]

[0033] Terms such as first, second and third are used to describe various parts, components, regions, layers and/or sections, but are not limited thereto. These terms are only used to distinguish any part, component, region, layer or section from another part, component, region, layer or section. Accordingly, a first part, component, region, layer or section described below may be referred to as a second part, component, region, layer or section without departing from the scope of the present invention.

[0034] Technical terms used herein are only for referring to specific embodiments and are not intended to limit the present invention. Singular forms used herein include plural forms unless the phrases clearly indicate the opposite meaning. The meaning of "comprising" used in the specification specifies a specific characteristic, region, integer, step, operation, element and/or component, and does not exclude the presence or addition of another characteristic, region, integer, step, operation, element and/or component.

[0035] When a part is referred to as being "on" or "above" another part, it may be directly on or above the other part or another part may be interposed therebetween. In contrast, when a part is referred to as being "directly on" another part, no other part is interposed therebetween.

[0036] In addition, unless otherwise specified, % means wt%, and 1 ppm is 0.0001 wt%.

[0037] In an embodiment of the present invention, further comprising an additional element means that the additional element is included in place of the balance of iron (Fe) by an amount corresponding to the addition amount of the additional element.

[0038] Unless otherwise defined, all terms, including technical and scientific terms, used herein have the same meaning as commonly understood by a person having ordinary skill in the art to which this invention belongs. Terms defined in commonly used dictionaries are to be interpreted as having a meaning consistent with their meaning in the context of the relevant technical literature and the present disclosure, and are not to be interpreted in an ideal or overly formal sense unless expressly so defined herein.

[0039] Hereinafter, embodiments of the present invention will be described in detail so that a person having ordinary skill in the art to which the present invention belongs may easily carry out the same. However, the present invention may be implemented in various different forms and is not limited to the embodiments described herein.

[0040] A non-oriented electrical steel sheet according to an embodiment of the present invention comprises, by wt%, Si: 1.5 to 6.0%, Al: 0.1 to 2.0%, Mn: 2.0% or less, and Cu: 0.002 to 0.100%, with the balance being Fe and unavoidable impurities.

[0041] Hereinafter, the reasons for the limitation of components of the non-oriented electrical steel sheet will be described first.

Si: 1.50 to 6.00 wt%

[0042] Silicon (Si) serves to lower iron loss by increasing electrical resistivity of a material and to increase strength by solid solution strengthening. When Si is added in too small an amount, the effect of improving iron loss and strength may be insufficient. When Si is added in too large an amount, brittleness of the material increases, so that rolling productivity is sharply lowered, and a surface oxidation layer and oxides harmful to magnetic properties may be formed. Accordingly, Si may be included in an amount of 1.50 to 6.00 wt%. More specifically, it may be included in an amount of 2.00 to 5.95 wt%. More specifically, it may be included in an amount of 2.10 to 4.50 wt%.

Al: 0.1 to 2.0 wt%

[0043] Aluminum (Al) serves to lower iron loss by increasing electrical resistivity of a material, to improve rollability, and to improve workability during cold rolling. When Al is added in too small an amount, it may be difficult to obtain a high-frequency iron loss reduction effect, and nitrides may be finely formed as a precipitation temperature of AlN is lowered, thereby lowering magnetic properties. When Al is added in too large an amount, nitrides are excessively formed to deteriorate magnetic properties, and problems occur in all processes such as steelmaking and continuous casting, which may significantly lower productivity. Accordingly, Al may be included in an amount of 0.1 to 2.0 wt%. More specifically, it may be included in an amount of 0.15 to 1.7 wt%. More specifically, it may be included in an amount of 0.2 to 1.6 wt%.

Mn: 2.00 wt% or less

[0044] Manganese (Mn) serves to improve iron loss by increasing electrical resistivity of a material and to form sulfides. When Mn is added in too large an amount, brittleness increases during slab and hot rolling. More specifically, Mn may be included in an amount of 0.01 to 2.00 wt%. More specifically, it may be included in an amount of 0.05 to 1.80 wt%.

Cu: 0.002 to 0.100 wt%

[0045] Copper (Cu) has an effect of suppressing the formation of oxides and nitrides by being enriched on the surface of the base metal under a specific range of hot rolling process conditions and an annealing process. In addition, since it has an effect of weakening the adhesion between the scale formed on the surface and the base metal, it is also advantageous for descaling. By adding copper, oxides and nitrides on the surface are reduced, and by increasing the grain diameter of the steel sheet, the effects of increasing the magnetic flux density and reducing the iron loss of a product may be obtained. However, when the amount of Cu is too small, it is difficult to sufficiently obtain the above effects. In addition, when it is added in an excessively large amount, it is concentrated and enriched on a specific portion of the steel sheet surface, so that descaling becomes non-uniform, which may cause surface defects. More specifically, Cu may be included in an amount of 0.002 to 0.050 wt%.

[0046] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise one or more of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.010 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

P: 0.1 wt% or less

[0047] Phosphorus (P) not only serves to increase the electrical resistivity of a material, but also may improve the magnetic flux density as a grain boundary segregation element. However, when P is added in an excessive amount, the brittleness of the steel sheet is increased, leading to inferior weldability. More specifically, the steel sheet may comprise P in an amount of 0.0001 to 0.0900 wt%. Still more specifically, the steel sheet may comprise P in an amount of 0.0010 to 0.0750 wt%.

C: 0.0050 wt% or less

[0048] Carbon (C) may cause magnetic aging and combine with other impurity elements to generate carbides, thereby hindering grain boundary or magnetic domain wall movement and deteriorating magnetic properties. More specifically, C may be present in an amount of 0.0001 to 0.0035 wt%. More specifically, C may be present in an amount of 0.0010 to 0.0045 wt%.

S: 0.0100 wt% or less

[0049] Sulfur (S) may form fine precipitates, such as MnS and CuS, which may deteriorate magnetic properties and hot workability. More specifically, S may be included in an amount of 0.0001 to 0.0080 wt%. More specifically, S may be included in an amount of 0.0005 to 0.0078 wt%.

Ti: 0.0050 wt% or less

[0050] Titanium (Ti) has a very strong tendency to form precipitates in steel, and may deteriorate iron loss by forming fine carbides, nitrides, or sulfides inside the base metal, thereby suppressing grain growth and magnetic domain wall movement. More specifically, Ti may be included in an amount of 0.0001 to 0.0050 wt%. More specifically, Ti may be included in an amount of 0.0005 to 0.0030 wt%.

N: 0.0050 wt% or less

[0051] Nitrogen (N) not only forms fine AlN precipitates inside the base metal, but also may deteriorate iron loss by combining with other impurities to form fine precipitates, which inhibit grain growth and magnetic domain wall movement. More specifically, the base metal may include N in an amount of 0.0001 to 0.0050 wt%. More specifically, the base metal may include N in an amount of 0.0005 to 0.0045 wt%.

[0052] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise one or two or more of Sn, Sb, Bi, Pb, Ge, and As each or in a total content thereof of 0.005 to 0.200 wt%.

Sn

[0053] Tin (Sn) serves to improve texture of a material and suppress surface oxidation by segregating at a grain boundary and the surface, and thus may be added to improve magnetic properties. When Sn is added in too large an amount, grain boundary segregation becomes severe to deteriorate surface quality, and hardness increases to cause fracture of a cold-rolled sheet, which may lower rollability. Specifically, Sn may be further included in an amount of 0.001 to 0.200 wt%.

Sb

[0054] Antimony (Sb) serves to improve texture of a material and suppress surface oxidation by segregating at a grain boundary and the surface, and thus may be additionally added to improve magnetic properties. When Sb is added in too large an amount, grain boundary segregation becomes severe to deteriorate surface quality, and hardness increases to cause fracture of a cold-rolled sheet, which may lower rollability. Specifically, Sb may be further included in an amount of 0.001 to 0.200 wt%.

Bi, Pb, Ge and As

[0055] When additionally added, bismuth (Bi), lead (Pb), germanium (Ge), and arsenic (As) segregate at the grain boundary to alleviate stress concentration at the grain boundary during cold rolling, thereby suppressing recrystallization of <111>ND oriented grains during recrystallization annealing, which is a subsequent process, to improve magnetic flux density. When these are appropriately added, the above-described effects may be additionally obtained, but when they are included in an excessive amount, a large amount of segregation occurs to suppress grain growth, so that magnetic flux density and iron loss may rather become inferior.

[0056] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise one or more of Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

Cr: 0.01 to 0.50 wt%

[0057] Chromium (Cr) serves to improve iron loss by increasing electrical resistivity. When Cr is added in too small an amount, an electrical resistivity upward effect may not be sufficient. When Cr is included in too large an amount, magnetic flux density may decrease. More specifically, Cr may be included in an amount of 0.010 to 0.20 wt%.

Ni: 0.05 wt% or less

[0058] Nickel (Ni) may react with impurity elements to form fine sulfides, carbides, and nitrides, which may have a harmful effect on magnetic properties. More specifically, Ni may be included in an amount of 0.001 to 0.03 wt%.

Zn: 0.01wt% or less

[0059] Zinc (Zn), when its content is excessive, may act as impurities and deteriorate magnetic properties. Accordingly, Zn may be further added within the above-described range. More specifically, Zn may be included in an amount of 0.001 to 0.005 wt%.

Co: 0.05 wt% or less

[0060] Cobalt (Co) does not form fine-sized precipitates that lower the magnetic properties of a steel sheet, but it may increase the high-temperature strength, which may lead to a poor shape of the coil after hot rolling.

[0061] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise one or more of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.0050 wt% or less (excluding 0%), Te: 0.0100 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

Mo: 0.030 wt% or less

[0062] Molybdenum (Mo), when added in an excessive amount, may suppress segregation of segregation elements to decrease a texture improvement effect. Accordingly, Mo may be included in an amount of 0.03 wt% or less. Its lower limit is not particularly limited, but since it serves to improve texture by segregating at the surface and grain boundary, it may be included in an amount of 0.001 wt% or more. More specifically, Mo may be included in an amount of 0.001 to 0.010 wt%. More specifically, Mo may be included in an amount of 0.005 to 0.010 wt%.

B: 0.0050 wt% or less

[0063] Boron (B), when added in an excessive amount, may cause deterioration of magnetic properties through formation of inclusions in steel and the like. Accordingly, B may be included in an amount of 0.005 wt% or less. Its lower limit is not particularly limited, but it may be 0.0001 wt% due to steelmaking cost. More specifically, B may be included in an amount of 0.0001 to 0.0030 wt%.

V: 0.0050wt% or less

[0064] Vanadium (V) has a very strong tendency to form precipitates in steel, and it deteriorates iron loss by forming fine carbides or nitrides within the base metal, thereby suppressing grain growth and magnetic domain wall movement. Accordingly, the V content may be 0.0050 wt% or less. The lower limit is not particularly limited, but it may be 0.0003 wt% due to steelmaking costs. That is, the V content may be in a range of 0.0003 to 0.0050 wt%. More specifically, the V content may be in a range of 0.0003 to 0.0030 wt%.

Ca: 0.0050 wt% or less

[0065] Calcium (Ca) has a very strong tendency to form precipitates in steel, and it deteriorates iron loss by forming fine sulfides inside the base metal, which suppresses grain growth and magnetic domain wall movement.

Nb: 0.0050wt% or less

[0066] Niobium (Nb) has a very strong tendency to form precipitates in steel, and it deteriorates iron loss by forming fine carbides or nitrides inside the base metal, which suppresses grain growth and magnetic domain wall movement. Accordingly, the Nb content may be 0.0050 wt% or less. The lower limit is not particularly limited, but it may be 0.0003 wt% due to steelmaking costs. That is, the Nb content may be 0.0003 to 0.0050 wt%. More specifically, the Nb content may be 0.0003 to 0.0030 wt%.

Zr: 0.0050 wt% or less

[0067] Zirconium (Zr), when added in an excessive amount, may cause deterioration of magnetic properties through formation of inclusions in steel and the like. Accordingly, Zr may be included in an amount of 0.005 wt% or less. Its lower limit is not particularly limited, but it may be 0.0001 wt% due to steelmaking cost. That is, Zr may be included in an amount of 0.0001 to 0.0050 wt%. More specifically, it may be included in an amount of 0.0005 to 0.0030 wt%.

Te: 0.0100 wt% or less

[0068] Tellurium (Te) diffuses into an oxide layer on a surface of a hot-rolled coil and increases a friction coefficient between the oxide layer and a rolling work roll, while being enriched under the oxide layer to improve hardness; therefore, Te may be added to facilitate removal of the oxide layer fractured during rolling so that it is not pressed into the base metal. If the addition amount of Te is too small, its effect may be insignificant. If Te is added in too large an amount, the oxide layer easily falls off, causing the base metal to directly contact the work roll, thereby reducing the aforementioned effect; furthermore, deformation bands may be excessively generated in the steel sheet during cold rolling, which may result in the development of a {111}/ND texture that is disadvantageous for magnetic properties. More specifically, the steel may comprise 0.0001 to 0.007 wt% of tellurium.

Mg: 0.0050 wt% or less

[0069] Magnesium (Mg) is an element that mainly combines with S to form sulfides and may affect a surface of the base metal oxide layer. Accordingly, the steel may comprise Mg in an amount of 0.0050 wt% or less. The lower limit thereof is not particularly limited, but it may be 0.0001 wt% due to steelmaking costs. That is, the steel may comprise Mg in an amount of 0.0001 to 0.0050 wt%. More specifically, it may comprise Mg in an amount of 0.0005 to 0.0030 wt%.

[0070] The balance comprises Fe and unavoidable impurities. Unavoidable impurities are impurities incorporated during the steelmaking step and the manufacturing process of the non-oriented electrical steel sheet; since these are widely known in the art, a detailed description thereof is omitted. In an embodiment of the present invention, the addition of elements other than the above-described alloying components is not excluded, and they may be included in various ways within a range that does not impair the technical spirit of the present invention. When additional elements are further included, they are included by replacing Fe, which is the balance.

[0071] As described above, in an embodiment of the present invention, by appropriately controlling alloying components of the steel sheet and suppressing occurrence of surface Al enrichment and linear defects, appearance characteristics and magnetic properties may be improved at the same time.

[0072] A ratio ($Al_{MAX}/Al_{5\mu m}$) of a maximum Al content (Al_{MAX}) to an Al content ($Al_{5\mu m}$) at a point 5 μm inside the steel sheet from the steel sheet surface, when measuring the content of Al in a thickness direction from the steel sheet surface to 5 μm inside the steel sheet, is 4.0 or less. By controlling this ratio in this way, appearance, insulation coating adhesion, and iron loss properties may be improved. If this ratio is too large, the above characteristics may become inferior. More specifically, the ratio ($Al_{MAX}/Al_{5\mu m}$) of the maximum Al content (Al_{MAX}) to the Al content ($Al_{5\mu m}$) at the point 5 μm inside the steel sheet from the steel sheet surface, when measuring the content of Al in the thickness direction from the steel sheet surface to 5 μm inside the steel sheet, may be 1.0 to 3.5. More specifically, it may be 1.5 to 3.3. As an example of an evaluation method for enriched Al, it may be analyzed using a Glow Discharge Spectrometer (GDS). In an embodiment of the present invention, a model GDS850A manufactured by LECO may be used for the analysis by the Glow Discharge Spectrometer. In this case, measurement may be performed under conditions of an acceleration voltage of 700 KV and a current of 30 mA. Even if the manufacturer or acceleration voltage of the Glow Discharge Spectrometer is changed, the same criteria may be applied because the relative change of Al according to depth is similar. The steel sheet surface refers to the outermost surface of the steel sheet; when an insulation coating additionally exists on the steel sheet surface, it refers to the surface of the steel sheet in a state where the insulation coating is removed. An interface between the insulation coating and the steel sheet surface is defined as a point where the Fe content rapidly fluctuates.

[0073] In addition, in one embodiment of the present invention, the number of unevenness portions having a width of 2 mm or more and a length of 10 mm or more per a 300 mm $\times$ 300 mm area may be 5 or less. In one embodiment of the present invention, a portion where a protrusion or a groove of 1 μm or more is formed relative to the steel sheet surface is referred to as an unevenness portion. When the width and length of this unevenness portion are a certain size or more, the appearance and insulation coating adhesion may be deteriorated. The above-described unevenness portion may be measured based on the surface of the steel sheet substrate when there is no insulation coating, or based on the surface of the insulation coating when an insulation coating exists on the steel sheet substrate. The unevenness portion may be measured using a 3D measuring instrument capable of measuring a circular shape. More

specifically, the number of unevenness portions per a 300 mm × 300 mm area may be 4 or less.

[0074] In addition, in an embodiment of the present invention, the number of Al aggregates having a particle diameter of 500 nm or more per 100 μm of steel sheet length in a region from the steel sheet surface to a depth of 5 μm inside the steel sheet is 5 or less. These Al aggregates are evaluated as a type of defect and have an adverse effect on appearance, insulation coating adhesion, and iron loss properties. Accordingly, it is necessary to suppress the formation of Al aggregates having a particle diameter of 500 nm or more as much as possible. More specifically, the number of Al aggregates having a particle diameter of 500 nm or more may be 0.0 to 4.0 per 100 μm of steel sheet length. The Al aggregates may be identified as oxides and nitrides of Al. When observing a cross-section including the thickness direction of the steel sheet using TEM, the Al aggregates may be evaluated using an Al element map. The particle diameter of the Al aggregates may be obtained as an average value of the horizontal axis and vertical axis lengths of the Al element map.

[0075] In an embodiment of the present invention, the steel sheet comprises an insulating coating located on a surface thereof, and the whiteness of the surface of the insulating coating may be 50 or more. As the whiteness increases, observation of defects on the surface of the steel sheet is facilitated, which is advantageous for surface quality control. That is, as the amount of residual oxide on the surface increases, the whiteness decreases. Therefore, the degree of residual oxide may be simply identified by the whiteness. More specifically, the whiteness may be 51 to 65. The whiteness may be measured using a CM-3700D device manufactured by Minolta. Since the measured values are similar when using other instruments, the measuring instrument is not limited.

[0076] In an embodiment of the present invention, an iron loss ($W_{10/400}$) of the non-oriented electrical steel sheet may be 12.5 W/kg or less. The iron loss ($W_{10/400}$) is an iron loss when a magnetic flux density of 1.0 T is induced at a frequency of 400 Hz. More specifically, the iron loss ($W_{10/400}$) of the non-oriented electrical steel sheet may be 10.0 to 12.0 W/kg. In an embodiment of the present invention, the iron loss may be expressed based on a thickness of 0.20 mm.

[0077] A manufacturing method of a non-oriented electrical steel sheet according to an embodiment of the present invention comprises: a step of manufacturing a hot-rolled steel sheet by hot rolling a slab; a first annealing step of annealing the hot-rolled steel sheet; a scale removal step of removing scale from the first annealed steel sheet; a step of manufacturing a cold-rolled sheet by cold rolling the descaled steel sheet; and a second annealing step of annealing the cold-rolled sheet.

[0078] Hereinafter, each step will be described in detail.

[0079] First, a slab is hot-rolled.

[0080] Since the alloying components of the slab have been described with respect to the alloying components of the non-oriented electrical steel sheet above, redundant descriptions are omitted. Since the alloying components are not substantially changed during the manufacturing process of the non-oriented electrical steel sheet, the alloying components of the non-oriented electrical steel sheet and the slab are substantially the same.

[0081] Specifically, the slab comprises, by wt%, Si: 1.5 to 6.0%, Al: 0.1 to 2.0%, Mn: 2.0% or less, and Cu: 0.002 to 0.100%, with the balance being Fe and unavoidable impurities.

[0082] Since other additional elements have been described in the alloying components of the non-oriented electrical steel sheet, redundant descriptions will be omitted.

[0083] The slab may be heated before hot rolling. The heating temperature of the slab is not particularly limited, but the slab may be heated to 1000 to 1180°C. If the slab heating temperature is too low, a problem may occur in hot rollability. If the slab heating temperature is too high, the growth of oxides containing Si is accelerated, and Cu enrichment may not occur on the surface of the base metal.

[0084] Next, a hot-rolled sheet is manufactured by hot rolling the slab.

[0085] A hot-rolled product having a thickness of 0.8 mm to 2.7 mm may be produced by finish rolling after rough rolling to a thickness of 30 mm to 60 mm. If the rough rolling thickness is excessively large, the retained heat of the steel sheet surface is high and the rolling speed is reduced, which increases the growth of scale during rolling, thereby hindering the descaling of the hot-rolled coil. On the other hand, if the rough rolling thickness is excessively small, the cooling of the steel material is accelerated, which may result in reduced rollability. More specifically, the thickness may be 35 mm to 55 mm.

[0086] At this time, after the rough rolling, the scale may be removed. For example, by a mechanical method for removing the scale from the surface, such as by spraying highpressure water to remove the scale by the impact thereof, the scale may be removed. If an excessive amount of time elapses after the rough rolling, the surface temperature decreases and the adhesion of the scale increases. In such a case, removal of the scale is not easy. The temperature of the material immediately after the rough rolling must be 950°C or higher and lower than 1,050°C, and it is necessary to remove the scale within 25 seconds after the rough rolling. If the temperature of the material is too low, the scale growth rate is low, but the surface is cooled, making it difficult to remove the scale. If the temperature is too high, the scale growth rate is excessive and internal oxidation develops, increasing residual oxide on the surface. Therefore, the rough rolling may be finished within the above temperature range and the scale may be

removed within 25 seconds. In an embodiment of the present invention, the scale is an oxide or a nitride.

[0087] A hot-rolled sheet thickness may be 0.8 to 2.7 mm. More specifically, the hot-rolled sheet thickness may be 1.60 to 2.30 mm.

[0088] In the step of manufacturing a hot-rolled sheet, a finish rolling temperature may be 800°C or more. Specifically, it may be 870 to 950°C. The hot-rolled sheet may be wound at a temperature of 550°C or more.

[0089] After the step of manufacturing a hot-rolled steel sheet, the method may further include a step of removing scale. When scale remains, the scale is pressed into the base metal during a cold rolling process, which roughens the surface of the finally manufactured non-oriented electrical steel sheet and causes point defects and the like. In addition, scale remaining on the final non-oriented electrical steel sheet deteriorates magnetic properties, for example, by increasing iron loss. Therefore, scale on the hot-rolled steel sheet should be appropriately removed. In the present invention, the descaling method may be a mechanical method using a brush or shot peening, or a chemical method using an aqueous hydrochloric acid (HCl) solution. According to one aspect of the present invention, during the shot blasting treatment, metal balls having an average diameter of 1 to 100 μm may be used, the conveying speed of the steel sheet may be controlled to 50 to 150 mpm (meters per minute), or 300 to 3,000 kg/min of metal balls may be controlled to collide with the surface of the steel sheet. When an acidic aqueous solution is used, scale may be removed by immersion in a 15 to 30 wt% acidic aqueous solution for 30 to 150 seconds. More specifically, immersion may be performed for 70 to 140 seconds.

[0090] Through descaling, oxide remaining on the steel sheet surface before the first annealing step may be reduced to 5.0 area % or less, and surface roughness may be reduced to 3.0 μm or less. When pickling is performed too excessively, surface roughness increases, which may cause breakage during cold rolling. When pickling is performed too weakly, oxides remaining on the surface increase, which may lead to Al enrichment and Al aggregation on the surface. More specifically, the amount of oxides remaining on the hot-rolled steel sheet surface may be 1.0 to 4.8 area %. In addition, the surface roughness may be 0.5 to 2.8 μm . As an example of a method for measuring a residual scale area, it may be determined by observation using a scanning electron microscope (SEM). While observing in a scanning electron microscope observation mode using a Back Scattered Electron (BSE) detector, a photograph is taken at a magnification of 50 times or 100 times. At this time, the base metal and the oxide may be clearly distinguished by a difference in brightness, where the oxide appears relatively dark. The photographed image may be analyzed using an image analyzer to measure an area ratio of the residual oxide. As for observation positions of residual scale in the hot-rolled steel sheet, measurements may be taken at at least three positions, such as the center of the steel sheet and positions corresponding to 1/4 of the width from both ends.

[0091] The method of roughness measurement follows ISO4287-1997 and standards equivalent thereto, and the cut-off value is 2.5 μm .

[0092] Next, the hot-rolled steel sheet is subjected to first annealing. It may also be possible to perform preliminary cold rolling of the hot-rolled steel sheet without hot-rolled sheet annealing before annealing the hot-rolled steel sheet.

[0093] Preliminary cold rolling is distinguished from cold rolling, which will be described later, in that it is a first rolling step of a process of rolling to an intermediate thickness, not a final product thickness, then performing first annealing, and then cold rolling to the final product thickness.

[0094] Preliminary cold rolling may be performed at a reduction ratio in the range of 40 to 80% to improve the productivity of final cold rolling and the grain structure of the final product sheet. In addition, when rolling productivity is not considered, performing preliminary cold rolling in a reverse mill is also within the scope of the present invention. A preliminary cold-rolled sheet may have a thickness of 0.30 to 1.50 mm. More specifically, the reduction ratio may be 50 to 78% and the thickness may be 0.40 to 1.00 mm.

[0095] The preliminary cold reduction ratio may be calculated as (steel sheet thickness before rolling - steel sheet thickness after rolling) / steel sheet thickness before rolling. When the reduction ratio in the preliminary cold rolling step is too low, the rolling load increases during the final cold rolling, thereby lowering productivity, and the final reduction ratio increases, which may cause a problem of promoting fine <111> orientation recrystallization. Conversely, when the reduction ratio is too high, the cold rolling load increases and the probability of strip breakage also increases. The cold rolling mill may be a Tandem Cold Mill consisting of 4 to 6 stands, or may be a Z-mill (or Sendzimir Mill), and is not particularly limited.

[0096] Next, in the first annealing step, the hot-rolled steel sheet (when preliminary cold rolling is not performed) or the preliminarily cold-rolled steel sheet is annealed.

[0097] At this time, annealing may be performed at a temperature of 870 to 1050°C. When the temperature is too low, magnetic properties of the finally manufactured electrical steel sheet may become inferior. When the temperature is too high, breakage may occur during cold rolling. Before the preliminary cold rolling step or before the step of manufacturing a cold-rolled sheet (in case of omitting preliminary cold rolling), an average grain diameter of the steel sheet may be 180 μm or less. More specifically, it may be 50 to 180 μm .

[0098] The first annealing step may be performed in an atmosphere containing 3 vol% or more of hydrogen. As such, the step may be performed in an atmosphere that suppresses oxidation. The remainder is nitrogen. In addition,

a dew point of the atmosphere may be -20°C or less. More specifically, the hydrogen content may be 3 to 30 volume %. The dew point may be -30°C or less.

[0099] After the first annealing step, scale is removed from the first annealed steel sheet. There is a limit to suppressing growth of oxides in the first annealing step process. Accordingly, after the first annealing step, appearance quality of the steel sheet may be improved through descaling.

[0100] In an embodiment of the present invention, the method comprises spraying cooling water having a pH of 4.0 to 8.5 onto a surface of the steel sheet, and a step of polishing with a brush. A structure of the brush is not particularly limited as long as it is a structure that may remove scale from the steel sheet. Specifically, the brush may remove oxides on the surface of the steel sheet by mixing SiC abrasive with nylon to form wires, bundling the wires, and bringing a cylindrical brush into close contact with the top and bottom surfaces of the steel sheet and rotating it. The roughness (mesh) of the SiC abrasive, the thickness of the wires, the method of bundling the wires, etc., may be freely changed according to the purpose. For example, the roughness (mesh) of the SiC abrasive may be in a range of 40 to 120, the diameter of the wires may be 0.3 to 2.0 mm, and as for the bundling method, 8 to 15 wires may be bundled as one unit, and the bundled wires may be attached to a cylindrical core to form a cylindrical brush. The brushing may be performed for 1 to 6 cycles. More specifically, it may be performed for 1 to 3 cycles. When polishing is performed multiple times with the brush, the surface roughness of the steel sheet increases, which may cause strip breakage in a cold rolling process to be described later. The number of brushings may be based on a rotation speed of the cylindrical brush of 2,000 RPM (revolutions per minute), a strip speed of the steel sheet of 100 MPM (meters per minute), and 1 cycle of brushing.

[0101] Since excessive frictional heat may be generated when the brush polishes the steel sheet surface, cooling water is sprayed onto the brush and the steel sheet surface. In this regard, the pH of the cooling water shall be maintained within a range of 4.0 to 8.5. If the pH is outside this range, stains may occur on the steel sheet surface, and such stains may adversely affect the surface of the final product.

[0102] The step of removing scale may further include a chemical descaling step in addition to brush polishing. More specifically, the method may further include a step of immersion in a 5 to 20 wt% acidic aqueous solution for 2 to 30 seconds. In this case, the acidic aqueous solution may be hydrochloric acid. The temperature of the acidic aqueous solution may be 40 to 96°C. The acidic aqueous solution may further include an inhibitor to protect a base metal, and the inhibitor may be included in an amount of 0.1 wt% or less. The treatment with the acidic aqueous solution may be performed either before or after the brush treatment, but preferably it is performed after the brush treatment.

[0103] After descaling, a ratio ($Al_{MAX}/Al_{5\mu m}$) of a maximum Al content (Al_{MAX}) of Al when measuring the content of Al in a thickness direction from a steel sheet surface to 5 μm inside the steel sheet, relative to an Al content ($Al_{5\mu m}$) at a point 5 μm inside the steel sheet from the steel sheet surface, may be 10.0 or less. When the ratio ($Al_{MAX}/Al_{5\mu m}$) is too large, it means that surface scale is not sufficiently removed, and surface quality may be impaired. More specifically, it may be 1.5 to 9.7.

[0104] The surface roughness after descaling may be 1.5 μm or less. When descaling is performed, the unevenness roughly formed on the surface is removed, so that an average roughness is slightly decreased or maintained similar to that before descaling. However, if the surface roughness becomes too large due to excessive descaling, rollability is impaired in a subsequent rolling process, and there is a risk of the sheet being fractured. More specifically, the surface roughness after descaling may be 0.5 to 1.3 μm .

[0105] Returning to the description of the manufacturing method of a non-oriented electrical steel sheet, after descaling, the annealed steel sheet is cold-rolled to produce a cold-rolled sheet.

[0106] The cold rolling mill may be a Tandem Cold Mill comprising 4 to 6 stands, or may be a Z-mill (or Sendzimir Mill). The types of the rolling mill and rolling method are not particularly limited. The final rolling thickness may be in a range from 0.1 mm to 0.35 mm.

[0107] Next, in the second annealing step, the cold-rolled sheet is annealed. In the second annealing step, annealing may be performed at 900 to 1050°C. If the soaking temperature is too low, crystal grains may not sufficiently grow, causing an increase in hysteresis loss, which may lead to the degradation of iron loss. More specifically, annealing may be performed at a temperature of 920 to 1020°C. In the second annealing step, soaking may be performed for 50 to 120 seconds.

[0108] The atmosphere may have 10 to 50 volume % hydrogen and the remainder nitrogen, and a dew point may be -10°C or less.

[0109] In the cold-rolled sheet annealing process, the processed structures formed in the cold rolling step may be entirely (i.e., 99% or more) recrystallized. More specifically, the average grain diameter may be 100 to 200 μm . If the average grain diameter is too small, it is difficult to obtain appropriate magnetic properties. Even if the average grain diameter is larger, no additional improvement in magnetic properties occurs.

[0110] After annealing the cold-rolled sheet, an insulation coating may be formed. The insulation coating may be formed using an organic, an inorganic, or an organic-inorganic composite coating, or it may be formed using other insulation coating agents.

[0111] In order to increase flatness and improve workability of the manufactured electrical steel sheet, stress relief annealing may be additionally performed at a temperature of 750 to 950°C. However, since scale remaining in the manufacturing of the electrical steel sheet is in a stable state, it does not affect the size or distribution of oxides or nitrides generated on the surface.

[0112] Hereinafter, the present invention will be described in more detail through examples. However, these examples are only for illustrating the present invention, and the present invention is not limited thereto.

Example 1

[0113] A slab with a thickness of 250 mm was manufactured with a composition comprising the components in Table 1, balance Fe, and unavoidable impurities. The slab was maintained at 1120°C for 60 minutes. The slab was rolled to a thickness of 40 mm by rough rolling, and the temperature after passing rough rolling was 1,020°C. 23 seconds after the rough rolling was completed, scale was removed using 150 bar highpressure water, and finish rolling was performed to manufacture a hot-rolled steel sheet having a thickness of 2.0 mm in a coil form. In this case, the temperature immediately after finish rolling was 912°C, and the temperature when coiled was 630°C.

[0114] Descaling of the hot-rolled coil was performed in an 18 wt% HCl aqueous solution at 80°C for 100 seconds, except that for Comparative Example 6, the descaling was performed for 60 seconds. In Inventive Example 4 and Comparative Examples 4 and 13, pickling treatment was performed for 100 seconds after shot blasting treatment. In this process, metal balls having an average diameter of 400 μm were used for the shot blasting, the strip speed of the steel sheet was 50 MPM, and the metal ball collision rate was 3,000 kg/min. In Comparative Example 13, descaling was repeated for 2 cycles.

[0115] Thereafter, preliminary cold rolling was performed to a thickness of 0.9 mm, and first annealing was performed at a temperature and in an H_2 atmosphere as summarized in Table 2 below. Thereafter, scale was removed through a number of brushings and cooling water supply as summarized in Table 2 below. After brushing, additional descaling was performed for a duration and at a hydrochloric acid concentration as summarized in Table 2. After descaling, cold rolling was performed. The thickness after final rolling was 0.2 mm.

[0116] After performing the second annealing at 970°C for 30 seconds, a resin-based coating was applied to a thickness of 0.5 μm as an insulation coating.

[0117] $\text{Al}_{\text{MAX}}/\text{Al}_{5\mu\text{m}}$ was measured using a GDS850A model from LECO under conditions of an acceleration voltage of 700 KV and a current of 30 mA.

[0118] Al aggregates were measured by observing a cross-section of the steel sheet including the thickness direction thereof using TEM.

[0119] As an example of a method of checking a scale area of a hot-rolled steel sheet, it may be checked by observation using a scanning electron microscope (SEM). While observing in a scanning electron microscope observation mode using a back-scattered electron (BSE) detector, a photograph was taken at a magnification of 50x or 100x, and the scale area was measured by analyzing the image.

[0120] Whiteness was measured using a CM3700D colorimeter (manufactured by Minolta).

[Table 1]

	C	Si	Mn	Cu	Al	N	P	S	other elements
Inventive Example1	0.0022	5.91	0.62	0.030	0.70	0.0038	0.0045	0.0078	-
Inventive Example2	0.0041	2.50	0.07	0.040	0.70	0.0043	0.0055	0.0042	-
Inventive Example3	0.0025	3.00	0.18	0.050	0.70	0.0026	0.0070	0.0017	-
Inventive Example4	0.0015	4.50	0.80	0.002	0.50	0.0042	0.0080	0.0027	Ni 0.002
Inventive Example5	0.0035	3.50	0.50	0.025	0.70	0.0015	0.0120	0.0019	Ni 0.002, Sn 0.001
Inventive Example6	0.0025	2.50	0.50	0.010	0.55	0.0037	0.0750	0.0033	Sb 0.002
Inventive Example7	0.0021	3.60	0.35	0.050	1.92	0.0034	0.0600	0.0035	-
Inventive Example8	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Inventive Example9	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Inventive Example10	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Inventive Example11	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example1	0.0050	6.50	1.80	0.040	1.20	0.0018	0.0071	0.0042	-

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(continued)

	C	Si	Mn	Cu	Al	N	P	S	other elements
Comparative Example2	0.0037	4.50	2.10	0.030	0.80	0.0025	0.0086	0.0014	-
Comparative Example3	0.0045	3.70	0.50	0.001	0.50	0.0036	0.0119	0.0035	-
Comparative Example4	0.0043	3.50	0.40	0.135	0.80	0.0020	0.0117	0.0005	-
Comparative Example5	0.0021	2.20	0.30	0.030	2.10	0.0020	0.0073	0.0014	-
Comparative Example6	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example7	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example8	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example9	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example10	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example11	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example12	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example13	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-

[Table 2]

	residual oxide on hot-rolled surface (area %)	hot-rolled surface roughness (Ra, μm)	first annealing temperature (°C)	H ₂ in atmosphere (volume %)	number of brushings	cooling water (pH)	HCl concentration (%) and time (seconds)	cold-rolled surface roughness (Ra) after descaling	Al _{MAX} /Al 5 μm after scale removal
Inventive Example1	4.8	1.9	920	30	1cycle	4.2	10%, 5seconds	0.8	4.8
Inventive Example2	3.0	1.6	970	5	1cycle	8.3	10%, 5seconds	1.3	6.0
Inventive Example3	3.5	1.4	970	4	1cycle	6.5	10%, 5seconds	1.0	7.0
Inventive Example4	4.8	1.9	990	4	1cycle	6.5	10%, 5seconds	0.9	5.8
Inventive Example5	4.7	1.0	970	3	1cycle	6.5	10%, 5seconds	1.0	9.6
Inventive Example6	3.1	1.0	970	3	2cycles	6.5	10%, 5seconds	1.0	6.4
Inventive Example7	3.2	1.1	880	10	2cycles	6.5	18%, 10seconds	1.2	6.1
Inventive Example8	2.7	0.9	930	3	3cycles	6.2	-	1.0	5.1
Inventive Example9	2.7	0.9	1,050	3	3cycles	6.2	5%, 60seconds	1.0	7.3
Inventive Example10	2.7	0.9	930	3	2cycles	6.2	18%, 10seconds	1.2	4.7
Inventive Example11	2.7	0.9	970	3	3cycles	6.2	18%, 10seconds	0.9	3.0
Comparative Example1	5.8		970	5	-	-	-	1.1	21.5
Comparative Example2	-	-	-	-	-	-	-	-	-
Comparative Example3	4.5	1.0	970	3	1cycle	6.2	-	0.9	11.5
Comparative Example4	3.9	1.8	1,040	5	1cycle	6.2	-	1.1	12.5
Comparative Example5	4.5	0.8	970	3	-	-	-	1.2	31.5
Comparative Example6	11.5	0.9	970	3	-	-	-	1.1	36.0
Comparative Example7	2.7	0.9	1,070	3	-	-	-	0.9	37.0
Comparative Example8	2.7	0.9	970	2	-	-	-	0.9	26.4
Comparative Example9	2.7	0.9	930	3	-	-	-	0.9	16.7
Comparative Example10	2.7	0.9	970	3	1cycle	3.9	15%, 10seconds	0.7	9.1
Comparative Example11	2.7	0.9	970	3	1cycle	8.9	15%, 10seconds	0.9	7.3
Comparative Example12	2.7	0.9	970	3	5cycles	6.2	18%, 35seconds	1.7	1.1

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(continued)

	residual oxide on hot-rolled surface (area %)	0.0	hot-rolled surface roughness (Ra, μm)	3.5	first annealing temperature (°C)	-	H ₂ in atmosphere (volume %)	-	number of brushings	-	cooling water (pH)	-	HCl concentration (%) and time (seconds)	-	cold-rolled surface roughness (Ra) after descaling	-	Al _{MAX} /Al 5 _{um} after scale removal	-
	Comparative Example 13																	

[Table 3]

		Number of Al aggregates	Al _{MAX} /Al _{5μm} after second annealing	number of unevenness defects	whiteness
5	Inventive Example1	0	1.8	0	65
	Inventive Example2	3	2.3	1	61
	Inventive Example3	1	3.2	2	60
	Inventive Example4	0	1.8	1	62
10	Inventive Example5	2	1.6	4	62
	Inventive Example6	3	1.9	2	65
	Inventive Example7	2	3.3	1	66
	Inventive Example8	3	2.7	1	67
15	Inventive Example9	1	2.2	3	63
	Inventive Example10	1	2.0	2	68
	Inventive Example11	1	1.7	0	71
	Comparative Example1	7	5.4	6	49
20	Comparative Example2	-	-	-	-
	Comparative Example3	7	4.1	6	53
	Comparative Example4	5	4.4	5	51
	Comparative Example5	9	6.1	7	44
25	Comparative Example6	12	6.5	9	43
	Comparative Example7	7	6.0	8	47
	Comparative Example8	6	5.5	8	48
	Comparative Example9	3	2.5	6	55
30	Comparative Example10	3	4.2	3	58
	Comparative Example11	4	4.5	4	57
	Comparative Example12	-	-	-	-
	Comparative Example13	-	-	-	-

[0121] As shown in Tables 1 to 3, when the steel components are appropriately controlled and the process conditions are appropriately controlled to suppress surface Al enrichment and the occurrence of defects, it may be confirmed that the surface properties and magnetic properties are excellent.

[0122] In Comparative Example 1, Si was excessively included, resulting in the presence of a large amount of residual oxide on the hot-rolled sheet, as well as the occurrence of significant Al enrichment and a large number of defects.

[0123] In Comparative Example 2, Mn was included in an excessive amount, which caused the steel sheet surface to crack during the hot rolling process, resulting in the termination of the rolling operation.

[0124] Comparative Examples 3 and 4 represent cases in which the content of Cu was not appropriately controlled, resulting in significant Al enrichment and the occurrence of numerous defects.

[0125] Comparative Examples 5 to 9 are cases where descaling was not performed after the first annealing, resulting in the occurrence of significant Al enrichment and a large number of defects.

[0126] Comparative Examples 10 and 11 represent cases in which the pH of the cooling water was not appropriately controlled during a descaling process; excessive Al enrichment occurred, and stains were formed after the insulation coating formation.

[0127] Comparative Example 12 illustrates a case where descaling using a brush was performed multiple times; the descaling resulted in significant roughness, which led to strip breakage during a subsequent cold rolling process.

[0128] In Comparative Example 13, excessive descaling was performed during a descaling process after hot rolling, which resulted in significant surface roughness of the hot-rolled sheet, leading to strip breakage during a subsequent

preliminary cold rolling process.

[0129] FIGS. 1 to 4 show the results of the TEM cross-section, element mapping, and GDS analysis of the steel sheet manufactured in Inventive Example 10, as well as the results of the 3D shape analysis of the product surface. As can be seen from FIGS. 1 to 4, it is confirmed that Al is partially concentrated only at the boundary between the insulating coating and the base steel sheet, and is not concentrated within the base steel sheet. This is clearly confirmed in FIG. 3 as well. In addition, as shown in FIG. 4, it is confirmed that the occurrence of linear irregularities is suppressed.

[0130] On the other hand, FIGS. 5 to 8 show the results of TEM cross-section, element map, and GDS analysis of the steel sheet manufactured in Comparative Example 10. As can be identified from FIGS. 5 to 8, a large amount of Al is concentrated near the boundary with the insulation coating in the base steel sheet, and particularly, an aggregate is formed in an elliptical shape of about 1.5 μm in the horizontal direction and about 500 nm in the vertical direction in the drawings. In addition, the GDS results also confirm that Al is excessively concentrated with an $\text{Al}_{\text{MAX}}/\text{Al}_{5\mu\text{m}}$ ratio of about 5.5. Furthermore, it can be identified that a large number of linear irregularities occur.

[0131] The present invention is not limited to the embodiments, but may be manufactured in various different forms, and a person having ordinary skill in the art to which the present invention belongs may understand that it may be carried out in other specific forms without changing the technical spirit or essential features of the present invention. Therefore, it should be understood that the embodiments described above are illustrative in all respects and not restrictive.

Claims

1. A non-oriented electrical steel sheet, comprising:

by wt%, Si: 1.5 to 6.0%, Al: 0.1 to 2.0%, Mn: 2.0% or less (excluding 0%), and Cu: 0.002 to 0.100%, with the balance being Fe and unavoidable impurities,
wherein a ratio ($\text{Al}_{\text{MAX}}/\text{Al}_{5\mu\text{m}}$) of a maximum Al content (Al_{MAX}) to an Al content ($\text{Al}_{5\mu\text{m}}$) at a point 5 μm inside the steel sheet from the steel sheet surface, when measuring the Al content in a thickness direction from the steel sheet surface to 5 μm inside the steel sheet, is 4.0 or less,
wherein the number of unevenness portions having a width of 2 mm or more and a length of 10 mm or more per 300 mm $\times$ 300 mm area is 5 or less.

2. The non-oriented electrical steel sheet of claim 1,
wherein the number of Al aggregates having a particle diameter of 500 nm or more is 5 or less per 100 μm of steel sheet length in a region from the surface of the steel sheet to a depth of 5 μm inside the steel sheet.

3. The non-oriented electrical steel sheet of claim 1,
further comprising one or more of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.010 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

4. The non-oriented electrical steel sheet of claim 1,
further comprising one two or more of Sn, Sb, Bi, Pb, Ge, and As, each or in a total content thereof of 0.005 to 0.200 wt%.

5. The non-oriented electrical steel sheet of claim 1,
further comprising one or more of Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

6. The non-oriented electrical steel sheet of claim 1,
further comprising one or more of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

7. The non-oriented electrical steel sheet of claim 1,

comprising an insulating coating located on a surface of the steel sheet,
wherein the surface of the insulating coating has a whiteness of 50 or more.

8. A manufacturing method of a non-oriented electrical steel sheet, comprising:

a step of manufacturing a hot-rolled steel sheet by hot rolling a slab comprising, by wt%, Si: 1.5 to 6.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%2.0% or less (excluding 0%), and Cu: 0.002 to 0.100%, with the balance being Fe and unavoidable impurities;

a first annealing step of annealing the hot-rolled steel sheet;

a scale removal step of removing scale from the first annealed steel sheet;

a step of manufacturing a cold-rolled sheet by cold rolling the descaled steel sheet; and

a second annealing step of annealing the cold-rolled sheet,

wherein the scale removal step comprises spraying cooling water having a pH of 4.0 to 8.5 onto a surface of the steel sheet, and polishing with a brush.

9. The method of manufacturing a non-oriented electrical steel sheet of claim 8,

wherein the slab further comprises one or more of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.010 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

10. The method of manufacturing a non-oriented electrical steel sheet of claim 8,

wherein the slab further comprises one or two or more of Sn, Sb, Bi, Pb, Ge, and As, each or in a total content thereof of 0.005 to 0.200 wt%.

11. The method of manufacturing a non-oriented electrical steel sheet of claim 8,

wherein the slab further comprises one or more of Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

12. The method of manufacturing a non-oriented electrical steel sheet of claim 8,

wherein the slab further comprises one or more of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

13. The method of manufacturing a non-oriented electrical steel sheet of claim 8,

wherein, before the first annealing step, scale remaining on the surface of the steel sheet is 5 area% or less, and the surface roughness (Ra) is 3.0 μm or less.

14. The method of manufacturing a non-oriented electrical steel sheet of claim 8,

further comprising a step of removing scale by immersion for 30 to 150 seconds in a 15 to 30 wt% acidic aqueous solution before the first annealing step.

15. 3 The method of manufacturing a non-oriented electrical steel sheet of claim 8,

further comprising a preliminary cold-rolling step of cold-rolling the hot-rolled steel sheet before the first annealing step, and

wherein the first annealing step is annealing a preliminarily cold-rolled steel sheet.

16. The method of manufacturing a non-oriented electrical steel sheet of claim 8,

wherein the first annealing step is performed in an atmosphere containing 3 vol% or more of hydrogen at a temperature of 870 to 1050°C.

17. The method of manufacturing a non-oriented electrical steel sheet of claim 8,

wherein the scale removal step further comprises a step of immersing the steel sheet in a 5 to 20 wt% acidic aqueous solution for 2 to 30 seconds.

18. The method of manufacturing a non-oriented electrical steel sheet of claim 8,

wherein after the scale removal step, a ratio ($\text{Al}_{\text{MAX}}/\text{Al}_{5\mu\text{m}}$) of a maximum Al content (Al_{MAX}) to an Al content ($\text{Al}_{5\mu\text{m}}$) at a point 5 μm inside the steel sheet from the steel sheet surface, when measuring the Al content in a thickness direction from the steel sheet surface to 5 μm inside the steel sheet, is 10.0 or less.

19. The method of manufacturing a non-oriented electrical steel sheet of claim 8,
wherein, after the scale removal step, a surface roughness of the steel sheet is 1.5 μm or less.

20. The method of manufacturing a non-oriented electrical steel sheet of claim 8,
wherein in the second annealing step, annealing is performed at an atmosphere of 10 to 50 vol% of hydrogen and
at a temperature of 900 to 1050°C.

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FIG. 1

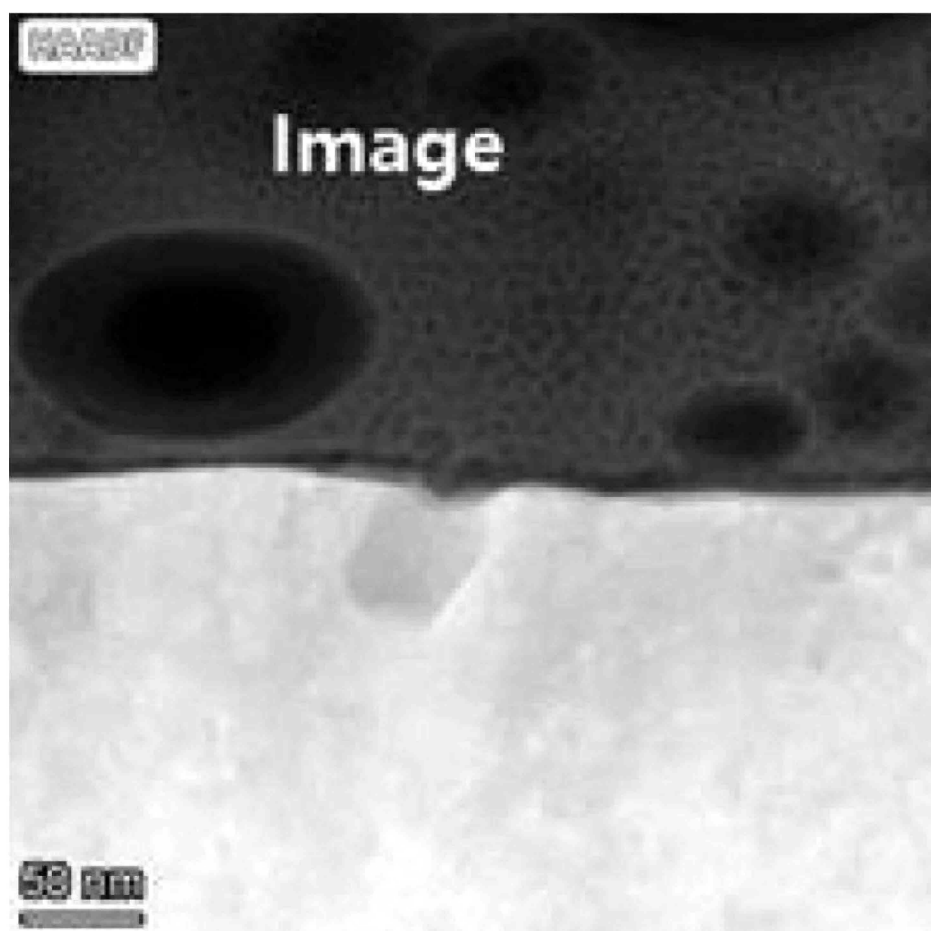


FIG. 2

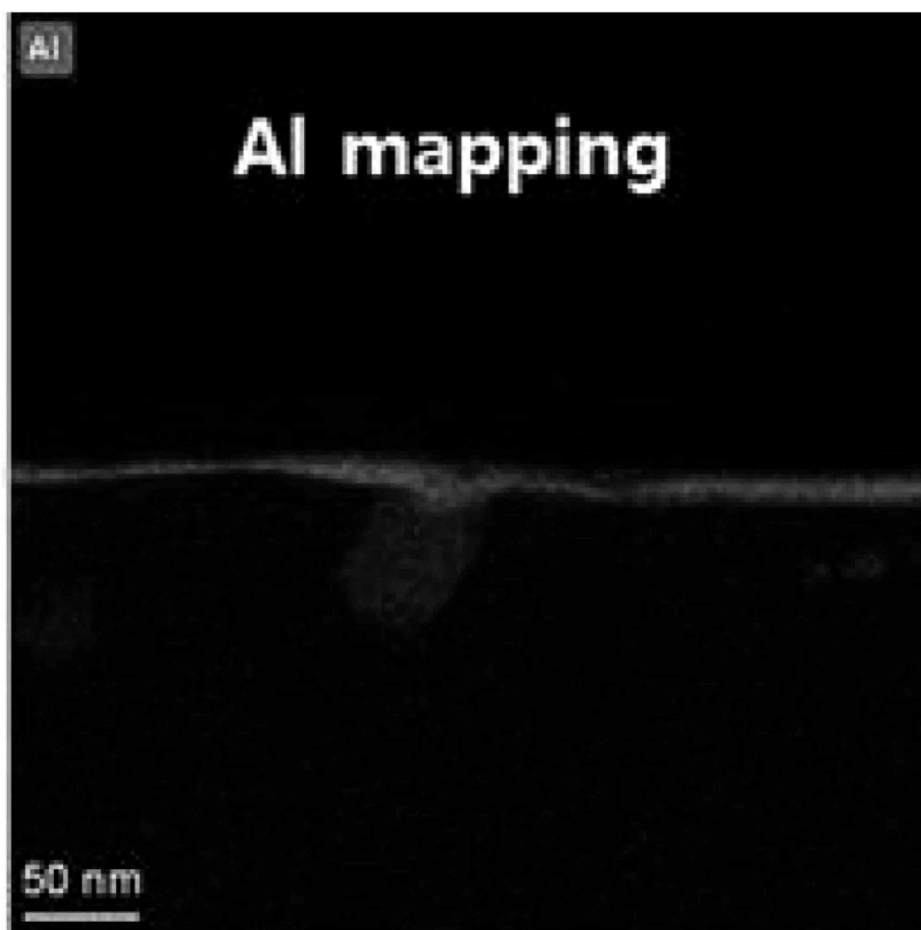


FIG. 3

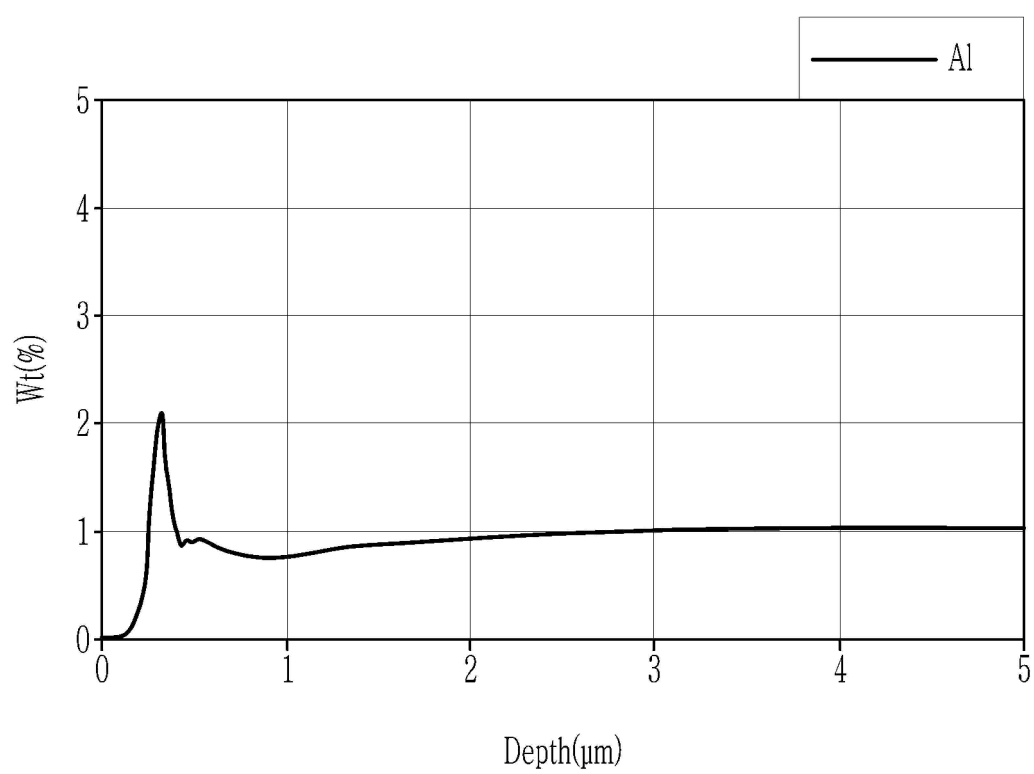


FIG. 4

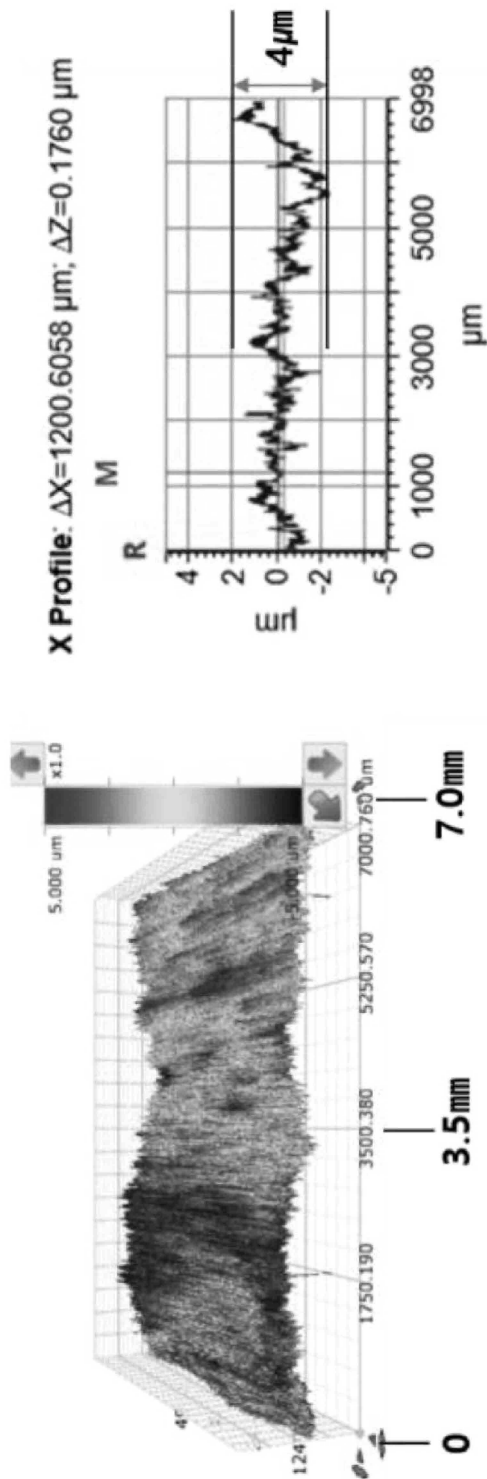


FIG. 5

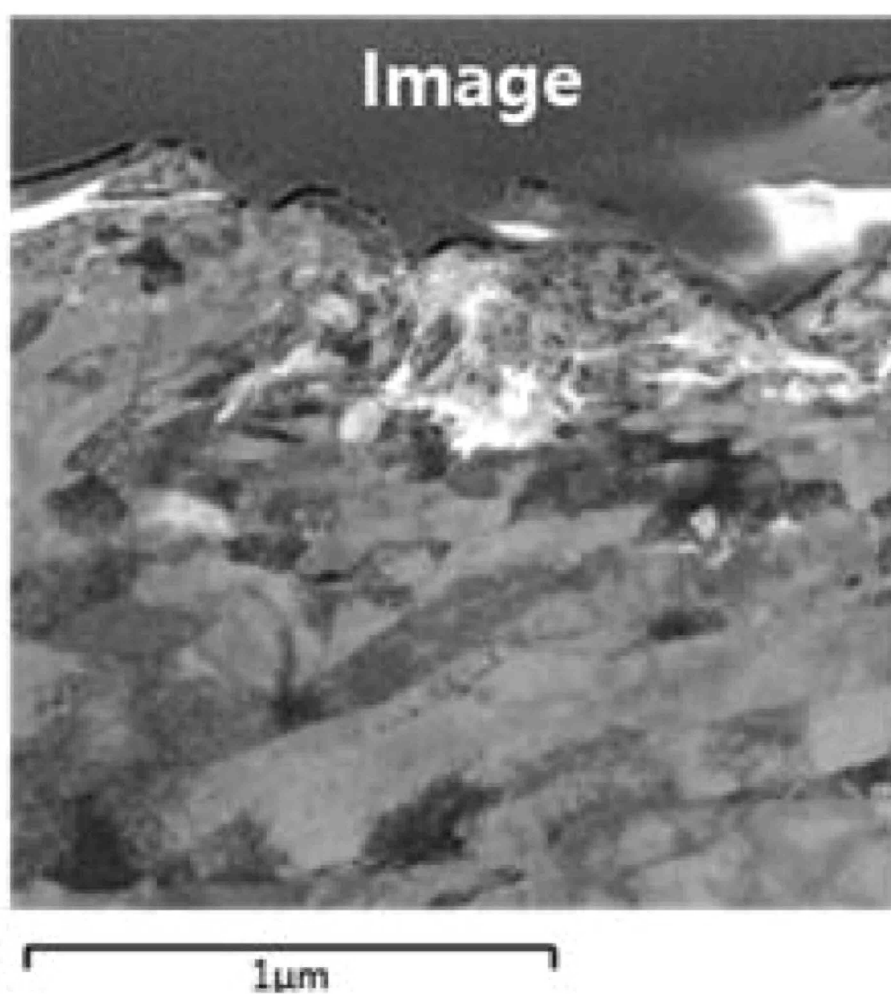


FIG. 6

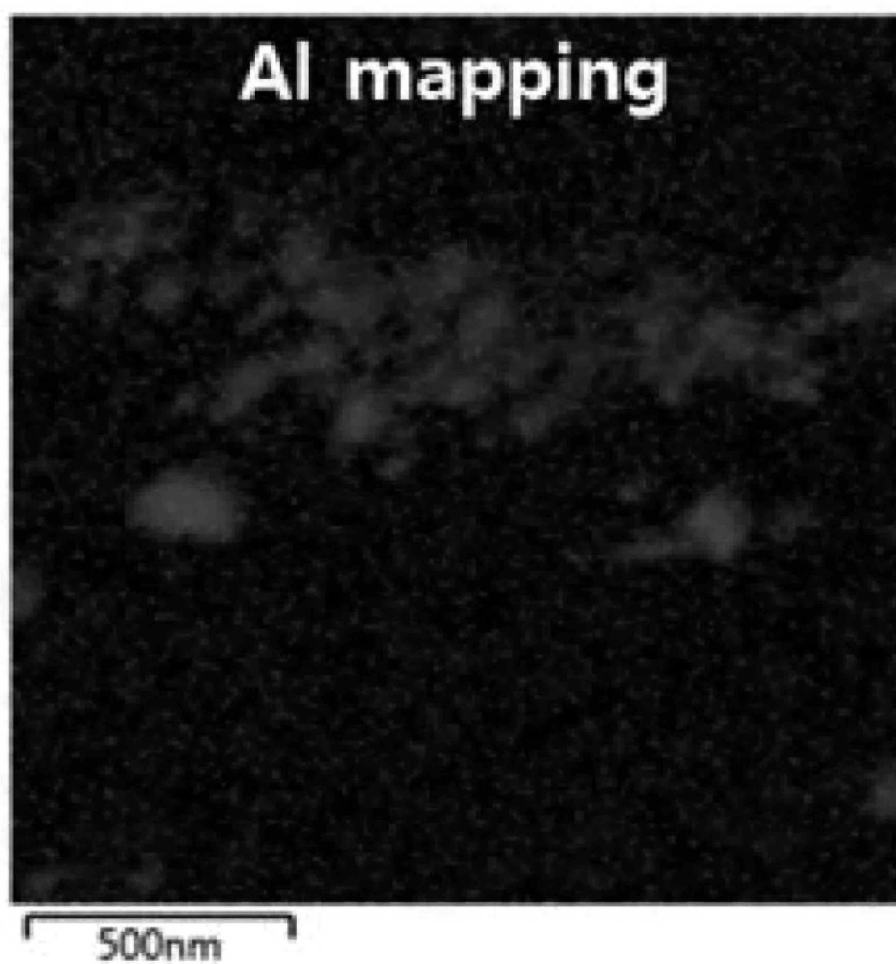


FIG. 7

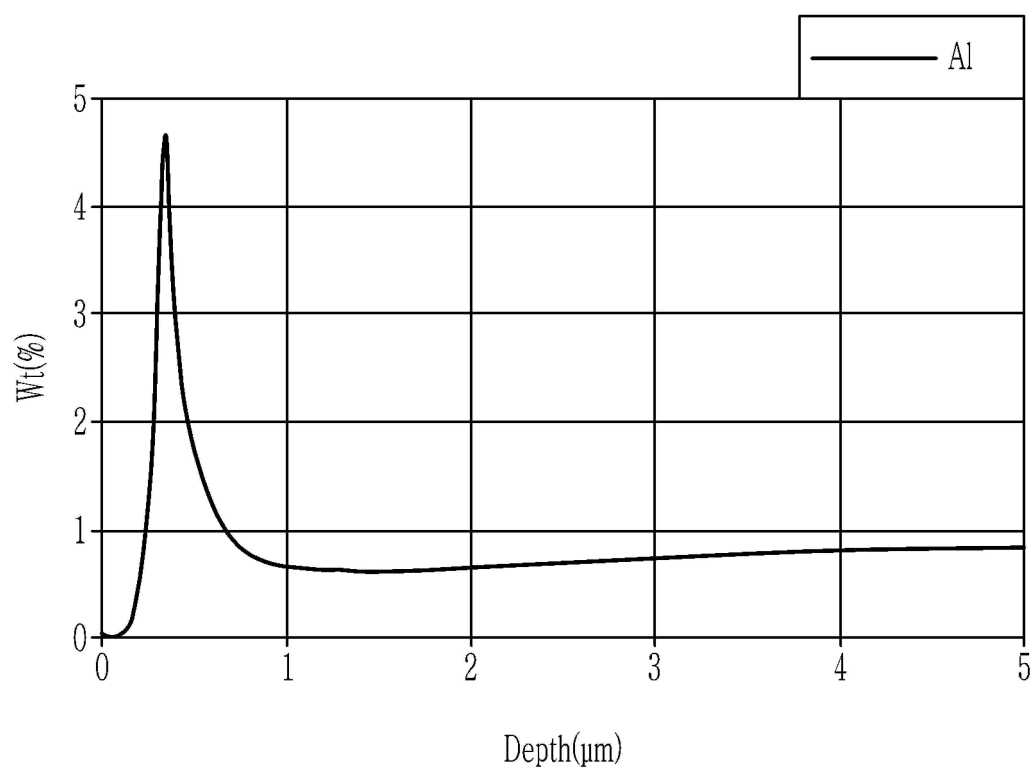
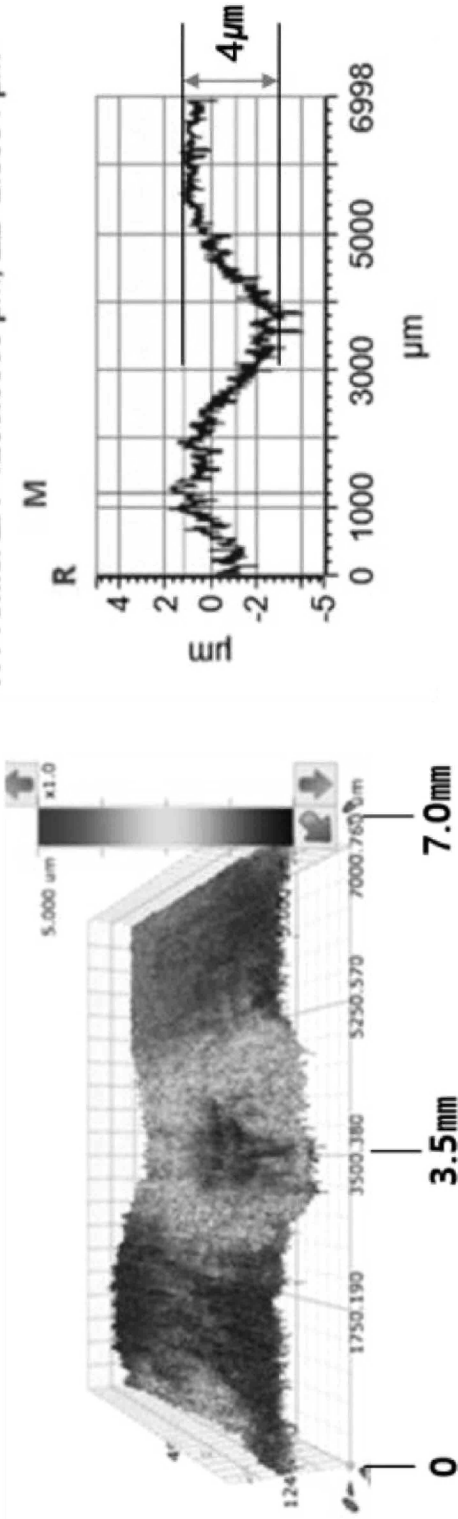


FIG. 8



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/096698

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/04(2006.01)i; C22C 38/06(2006.01)i; C22C 38/16(2006.01)i; C22C 38/14(2006.01)i;
C22C 38/00(2006.01)i; C22C 38/58(2006.01)i; C22C 38/52(2006.01)i; C22C 38/12(2006.01)i; C21D 8/12(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/02(2006.01); C21D 7/06(2006.01); C21D 8/12(2006.01); C21D 9/00(2006.01); C21D 9/46(2006.01);
C22C 38/00(2006.01)

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

Korean utility models and applications for utility models: IPC as above

Japanese utility models and applications for utility models: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS (KIPO internal) & keywords: 무방향(non-oriented), 전기강판(electrical steel sheet), 스케일(scale), 산세
(pickling), 함량(concentration)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2023-0096878 A (POSCO) 30 June 2023 (2023-06-30) See paragraphs [0117]-[0119], [0123] and [0127] and claims 1-4, 7 and 11-12.	1-20
A	KR 10-2019-0077891 A (POSCO) 04 July 2019 (2019-07-04) See claims 1, 3, 5 and 18-19.	1-20
A	KR 10-2164113 B1 (POSCO) 13 October 2020 (2020-10-13) See claim 11.	1-20
A	KR 10-2010-0084643 A (NIPPON STEEL CORPORATION) 27 July 2010 (2010-07-27) See claims 1 and 3 and figures 1a-1b.	1-20
A	KR 10-1565510 B1 (POSCO) 03 November 2015 (2015-11-03) See paragraph [0057] and claim 1.	1-20

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

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“&” document member of the same patent family

Date of the actual completion of the international search 12 March 2025	Date of mailing of the international search report 13 March 2025
Name and mailing address of the ISA/KR Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208 Facsimile No. +82-42-481-8578	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/096698

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		TW I406957 B	01 September 2013
		WO 2009-072394 A1	11 June 2009
KR 10-1565510 B1	03 November 2015	KR 10-2015-0073787 A	01 July 2015

Form PCT/ISA/210 (patent family annex) (July 2022)