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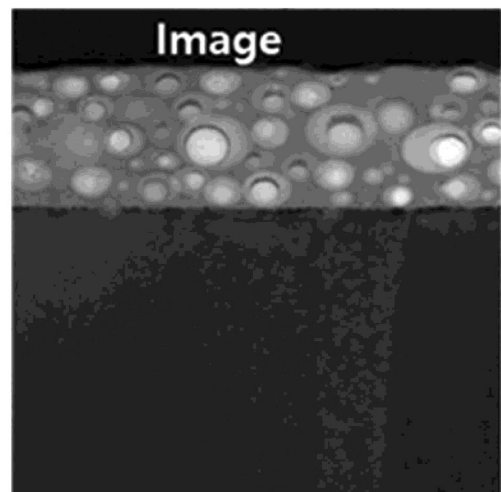
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(54) **NON-ORIENTED ELECTRICAL STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) A non-oriented electrical steel sheet according to an embodiment of the present invention comprises, in 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 ($Al_{MAX}/Al_{5\mu m}$) of a maximum content of Al(Al_{MAX}), as measured when determining the Al content in the thickness direction from the surface of the steel sheet to a point 5 μm inside the steel sheet, to an Al content($Al_{5\mu m}$) at the point 5 μm inside the steel sheet from the surface of the steel sheet is 5.0 or less, and wherein number of Al aggregates having a particle diameter of 500 nm or more in a region from the surface of the steel sheet to 5 μm inside the steel sheet is 5 or less per 100 μm of the length of the steel sheet.

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 having excellent appearance characteristics and magnetic properties, achieved by appropriately controlling a steel composition, descaling conditions, and annealing conditions to control Al enrichment of the surface and Al aggregation.

[Background Art]

[0002] Non-oriented electrical steel sheets are mainly used for 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 that process. Particularly, as eco-friendly vehicles driven by motors instead of internal combustion engines have recently attracted attention, demand for non-oriented electrical steel sheets used as materials for driving motor cores is increasing, and for this purpose, non-oriented electrical steel sheets having excellent magnetic properties and strength simultaneously are required.

[0003] The magnetic properties of a 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 with higher energy efficiency under the same conditions may be manufactured, and as the magnetic flux density is higher, the motor may be miniaturized or copper loss may be reduced. Therefore, by using a non-oriented electrical steel sheet having low iron loss and high magnetic flux density, a driving motor with excellent efficiency and torque may be made, and through this, the driving range and output of an eco-friendly vehicle may be improved.

[0004] Depending on the operating conditions of the motor, the characteristics of the non-oriented electrical steel sheet to be considered also vary. As a general standard for evaluating characteristics of non-oriented electrical steel sheets used for motors, $W_{15/50}$, which is iron loss when a magnetic flux density of 1.5 T is applied at a commercial frequency of 50 Hz, is widely used. However, in a non-oriented electrical steel sheet with a thickness of 0.35 mm or less used for a driving motor for eco-friendly vehicles, magnetic properties are often important at a low magnetic field of 1.0 T or less and a high frequency of 400 Hz or more, and thus the characteristics of the non-oriented electrical steel sheet are often evaluated by $W_{10/400}$ 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 strongly pro-oxidizing elements and form stable scales such as oxide or nitride on the surface in a 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 the insulation coating and the lamination adhesion of the steel sheet may be impaired.

[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 have excellent appearance characteristics and magnetic properties simultaneously by appropriately controlling a steel composition, descaling conditions, and annealing conditions to control Al enrichment of the surface and Al aggregation.

[Technical Solution]

[0007] A non-oriented electrical steel sheet according to an embodiment of the present invention comprises, in 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 content of Al (Al_{MAX}), as measured when determining the Al content in the thickness direction from the surface of the steel sheet to a point 5 μm inside the steel sheet, to an Al content ($Al_{5\mu m}$) at the point 5 μm inside the steel sheet from the surface of the steel sheet is 5.0 or less, and wherein number of Al aggregates having a particle diameter of 500 nm or more in a region from the surface of the steel sheet to 5 μm inside the steel sheet is 5 or less per 100 μm of the length of the steel sheet.

[0008] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise at least one 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%).

[0009] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise one or more of Sn, Sb, Bi, Pb, Ge, and As, in a total amount of 0.005 to 0.200 wt%.

[0010] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise at least one 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%).

[0011] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise at least one 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%).

[0012] The non-oriented electrical steel sheet according to an embodiment of the present invention comprises an insulating coating located on the surface of the steel sheet, wherein the whiteness of the surface of the insulating coating is 50 or more.

[0013] A method for manufacturing 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, in 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 step of manufacturing a cold-rolled sheet by cold rolling the annealed steel sheet; and a second annealing step of annealing the cold-rolled sheet.

[0014] Before the first annealing step, the residual scale on the surface of the steel sheet is 5 area % or less, and the surface roughness (Ra) is 3.0 μm or less.

[0015] The slab may further comprise at least one 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%).

[0016] The slab may further comprise one or more of Sn, Sb, Bi, Pb, Ge, and As, each or in a total amount of 0.005 to 0.200 wt%.

[0017] The slab may further comprise at least one 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%).

[0018] The slab may further comprise at least one 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%).

[0019] 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 be annealing the preliminary cold-rolled steel sheet.

[0020] Before the step of manufacturing the cold-rolled sheet, the average grain diameter of the steel sheet may be 180 μm or less.

[0021] In the step of manufacturing the hot-rolled steel sheet, a descaling step may be included after rough rolling.

[0022] The method may further comprise a descaling step of immersing in a 15 to 30 wt% acid aqueous solution for 30 to 150 seconds before the first annealing step.

[0023] In the first annealing step, annealing may be performed at an atmosphere of 3 vol% or more of hydrogen and at a temperature of 870 to 1050°C.

[0024] After the first annealing 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 surface, when measuring the Al content in the thickness direction from the surface of the steel sheet to the point 5 μm inside the steel sheet, may be 20.0 or less.

[0025] In the second annealing step, annealing may be performed at an atmosphere of 10 to 50 vol % of hydrogen and at a temperature of 900 to 1050°C.

[Advantageous Effects]

[0026] The non-oriented electrical steel sheet according to an embodiment of the present invention has excellent surface quality and electromagnetic properties simultaneously.

[0027] The non-oriented electrical steel sheet according to an embodiment of the present invention has high surface whiteness due to reduced residual oxides on the surface and exhibits excellent adhesion of the insulation coating.

[0028] In addition, the non-oriented electrical steel sheet according to an embodiment of the present invention contributes to improving performance of a driving motor for eco-friendly vehicles.

[0029] Since the magnetic anisotropy is high, high torque may be obtained when manufactured into an automotive motor.

[Brief Description of the Drawings]**[0030]**

- 5 FIG. 1 shows a TEM cross-section of a steel sheet manufactured in Inventive Example 10.
 FIG. 2 shows an Al elemental map of a steel sheet manufactured in Inventive Example 10.
 FIG. 3 is a graph analyzing Al content by GDS for a steel sheet manufactured in Inventive Example 10.
 FIG. 4 shows a TEM cross-section of a steel sheet manufactured in Comparative Example 9.
 FIG. 5 shows an Al elemental map of a steel sheet manufactured in Comparative Example 9.
 10 FIG. 6 is a graph analyzing Al content by GDS for a steel sheet manufactured in Comparative Example 9.

[Mode for Invention]

- 15 **[0031]** 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 used only to distinguish one part, component, region, layer, or section from another part, component, region, layer, or section. Therefore, a first part, component, region, layer, or section described below may be referred to as a second part, component, region, layer, or section within the range without departing from the scope of the present invention.

- 20 **[0032]** The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. The term "comprising," when used in this specification, specifies the presence of stated features, regions, integers, steps, operations, elements, and/or components, but does not preclude the presence or addition of one or more other features, regions, integers, steps, operations, elements, and/or components.

- 25 **[0033]** When a portion is referred to as being "on" or "above" another portion, it may be directly on or above the other portion, or other portions may be present therebetween. In contrast, when a portion is referred to as being "directly on" another portion, no other portion is interposed therebetween.

[0034] In addition, unless otherwise specified, % refers to wt%, and 1 ppm is 0.0001 wt%.

- 30 **[0035]** In one embodiment of the present invention, the inclusion of an additional element means that the additional element is included as a substitute for the balance, iron (Fe), by the amount added.

- [0036]** Unless otherwise defined, all terms, including technical and scientific terms, used herein have the same meaning as commonly understood by one of 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 art and the present disclosure, and are not to be interpreted in an idealized or overly formal sense unless expressly so defined herein.

- [0037]** Hereinafter, embodiments of the present invention will be described in detail with reference to the accompanying drawings so that those of ordinary skill in the art to which the present invention belongs may easily implement the same. However, the present invention may be implemented in various different forms and is not limited to the embodiments described herein.

- 40 **[0038]** A non-oriented electrical steel sheet according to an embodiment of the present invention comprises, in 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.

- [0039]** Hereinafter, the reasons for composition limitation of the non-oriented electrical steel sheet will be described first.

- 45 Si: 1.50 to 6.00 wt%

- [0040]** Silicon (Si) serves to increase the resistivity of a material to lower iron loss and to increase strength by solid solution strengthening. If Si is added in an insufficient amount, the effect of improving iron loss and strength may be insufficient. If Si is added in an excessive amount, the brittleness of the material increases, whereby rolling productivity is sharply decreased, and a surface oxidation layer and an oxide, which are harmful to magnetic properties, may be formed. Therefore, Si may be included in an amount of 1.50 to 6.00 wt%. More specifically, Si may be included in an amount of 2.00 to 5.95 wt%. Even more specifically, Si may be included in an amount of 2.10 to 4.50 wt%.

- 55 Al: 0.1 to 2.0 wt%

[0041] Aluminum (Al) serves to lower iron loss by increasing resistivity of a material, improve rollability, and improve workability during cold rolling. If too little Al is added, it may be difficult to obtain a high-frequency iron loss reduction

effect, and a precipitation temperature of AlN is lowered, so that nitride is finely formed, which may deteriorate magnetic properties. If too much Al is added, nitride is excessively formed to deteriorate magnetic properties, and problems occur in all processes such as steelmaking and continuous casting, thereby greatly decreasing productivity. Therefore, 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

[0042] Manganese (Mn) serves to improve iron loss by increasing the resistivity of a material and by forming sulfide. If an excessive amount of Mn is added, brittleness increases during slab and hot rolling. More specifically, Mn may be included in an amount of 0.01 to 2.00 wt%. Even more specifically, the Mn may be included in an amount of 0.05 to 1.80 wt%.

Cu: 0.002 to 0.100 wt%

[0043] Copper (Cu) has the effect of inhibiting the formation of oxides and nitrides by becoming enriched on the surface of the base steel within a specific range of hot rolling process conditions and an annealing process. In addition, since it has the effect of weakening the adhesion between the scale formed on the surface and the base steel, it is advantageous for descaling. By adding copper, the oxides and nitrides on the surface are reduced, and the grain diameter of the steel sheet is increased, thereby obtaining the effect of increasing the magnetic flux density and decreasing the iron loss of the product. However, if the Cu content is too low, it is difficult to sufficiently obtain the above effects. In addition, if it is added in an excessive amount, it is concentrated and enriched on specific portions of the surface of the steel sheet, whereby 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%.

[0044] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise at least one 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

[0045] Phosphorus (P) not only serves to increase the resistivity of a material, but also may improve magnetic flux density as a grain boundary segregation element. However, if an excessive amount of P is added, the brittleness of the steel sheet is increased, leading to inferior weldability. More specifically, P may be included in an amount of 0.0001 to 0.0900 wt%. More specifically, P may be included in an amount of 0.0010 to 0.0750 wt%.

C: 0.0050 wt% or less

[0046] Carbon (C) may cause magnetic aging and combine with other impurity elements to generate carbide, which hinders grain boundary or magnetic domain wall motion, thereby deteriorating magnetic properties. More specifically, C may be included in an amount of 0.0001 to 0.0035 wt%. More specifically, C may be included in an amount of 0.0010 to 0.0045 wt%.

S: 0.0100 wt% or less

[0047] 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%. Even more specifically, S may be included in an amount of 0.0005 to 0.0078 wt%.

Ti: 0.0050 wt% or less

[0048] Titanium (Ti) has a very strong tendency for the formation of precipitates in steel and may form fine carbide, nitride, or sulfide inside the base metal to inhibit grain growth and domain wall motion, thereby deteriorating iron loss. More specifically, the steel may comprise Ti in an amount of 0.0001 to 0.0050 wt%. More specifically, the steel may comprise Ti in an amount of 0.0005 to 0.0030 wt%.

N: 0.0050 wt% or less

[0049] Nitrogen (N) not only forms fine AlN precipitates inside the base metal but also combines with other impurities

to form fine precipitates, which may inhibit grain growth and domain wall motion, thereby increasing iron loss. More specifically, N may be included in an amount of 0.0001 to 0.0050 wt%. More specifically, N may be included in an amount of 0.0005 to 0.0045 wt%.

[0050] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise one or more of Sn, Sb, Bi, Pb, Ge, and As in a total amount of 0.005 to 0.200 wt%.

Sn

[0051] Tin (Sn) segregates at grain boundaries and on the surface to improve the texture of a material and inhibit surface oxidation, and thus may be added to improve magnetic properties. If too much Sn is added, grain boundary segregation becomes severe, so that the surface quality is deteriorated and hardness is increased, which may cause fracture of a cold-rolled sheet, thereby decreasing rollability. Specifically, the material may further comprise Sn in an amount of 0.001 to 0.200 wt%.

Sb

[0052] Antimony (Sb) segregates at grain boundaries and on the surface to improve the texture of a material and inhibit surface oxidation, and thus may be additionally added to improve magnetic properties. If Sb is added in an excessive amount, grain boundary segregation becomes severe, so that the surface quality is deteriorated and the hardness is increased, which may cause fracture of a cold-rolled sheet, thereby decreasing rollability. Specifically, Sb may be further included in an amount of 0.001 to 0.200 wt%.

Bi, Pb, Ge and As

[0053] When Bismuth (Bi), Lead (Pb), Germanium (Ge), and Arsenic (As) are added as additional additives, they segregate at grain boundaries to relieve stress concentration at the grain boundaries during cold rolling, thereby improving magnetic flux density by inhibiting recrystallization of <111>/ND oriented grains in recrystallization annealing, which is a subsequent process. If these are appropriately added, the aforementioned effects may be additionally obtained, but if they are included in excess, a large amount of segregation occurs to inhibit grain growth, which may cause magnetic flux density and iron loss to become inferior.

[0054] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise at least one 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%

[0055] Chromium (Cr) serves to improve iron loss by increasing resistivity. If too little Cr is added, the effect of increasing resistivity may not be sufficient. If too much Cr is included, magnetic flux density may decrease. More specifically, Cr may be included in an amount of 0.01 to 0.20 wt%.

Ni: 0.05 wt% or less

[0056] Nickel (Ni) reacts with impurity elements to form fine sulfides, carbides, and nitrides, which may have harmful effects on magnetic properties. More specifically, Ni may be included in an amount of 0.001 to 0.03 wt%.

Zn: 0.01 wt% or less

[0057] When zinc (Zn) content is excessive, it acts as an impurity to deteriorate magnetic properties. Therefore, Zn may be further added in the aforementioned range. More specifically, Zn may be included in an amount of 0.001 to 0.005 wt%.

Co: 0.05 wt% or less

[0058] Cobalt (Co) does not form precipitates of a fine size that deteriorate the magnetic properties of a steel sheet, but it may increase high temperature strength, thereby potentially causing the shape of a coil to be poor after hot rolling.

[0059] The non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise at least one of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt%

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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

[0060] When molybdenum (Mo) is added in an excessive amount, the texture improvement effect may decrease by inhibiting the segregation of segregating elements. Therefore, Mo may be included in an amount of 0.03 wt% or less. The lower limit thereof is not particularly limited, but it may be included in an amount of 0.001 wt% or more since it segregates on the surface and grain boundaries to improve the texture. More specifically, Mo may be included in an amount of 0.001 to 0.010 wt%. Even more specifically, Mo may be included in an amount of 0.005 to 0.010 wt%.

B: 0.0050 wt% or less

[0061] When boron (B) is added in an excessive amount, it may cause deterioration of magnetic properties through formation of inclusions in steel and the like. Therefore, B may be included in an amount of 0.005 wt% or less. The lower limit thereof is not particularly limited, but it may be set to 0.0001 wt% due to steelmaking cost. More specifically, B may be included in an amount of 0.0001 to 0.0030 wt%.

V: 0.0050 wt% or less

[0062] Vanadium (V) has a strong tendency to form precipitates in steel, and it forms fine carbides or nitrides inside the base metal to inhibit grain growth and domain wall motion, thereby deteriorating iron loss. Therefore, the V content may be 0.0050 wt% or less. The lower limit thereof is not particularly limited, but it may be set to 0.0003 wt% due to steelmaking costs. That is, V may be included in an amount of 0.0003 to 0.0050 wt%. More specifically, V may be included in an amount of 0.0003 to 0.0030 wt%.

Ca: 0.0050 wt% or less

[0063] Calcium (Ca) has a very strong tendency to form precipitates in steel, and it forms fine sulfides within the base metal to inhibit grain growth and domain wall motion, thereby increasing iron loss.

Nb: 0.0050 wt% or less

[0064] Niobium (Nb) has a very strong tendency to form precipitates in steel, and it forms fine carbides or nitrides inside the base metal to inhibit grain growth and domain wall motion, thereby deteriorating iron loss. Therefore, the Nb content may be 0.0050 wt% or less. The lower limit thereof is not particularly limited, but it may be 0.0003 wt% due to steelmaking costs. That is, Nb may be contained in an amount of 0.0003 to 0.0050 wt%. More specifically, Nb may be contained in an amount of 0.0003 to 0.0030 wt%.

Zr: 0.0050 wt% or less

[0065] When zirconium (Zr) is added in an excessive amount, it may cause deterioration of magnetic properties through the formation of inclusions in steel and the like. Therefore, the steel may comprise Zr in an amount of 0.005 wt% or less. The lower limit thereof is not particularly limited, but it may be set to 0.0001 wt% due to steelmaking costs. That is, the steel may comprise Zr in an amount of 0.0001 to 0.0050 wt%. More specifically, the steel may comprise 0.0005 to 0.0030 wt% of Zr.

Te: 0.0100 wt% or less

[0066] Tellurium (Te) diffuses into the oxide layer on the surface of a hot-rolled coil to increase the friction coefficient between the oxide layer and the rolling work roll and is enriched under the oxide layer to improve hardness; thus, it may be added to prevent the oxide layer, which is crushed during rolling, from being pressed into the base metal and instead facilitate its removal. If the addition amount of Te is too small, the effect may be insignificant. If too much Te is added, the oxide layer is easily removed, such that the base metal comes into direct contact with the work roll, reducing the above effect, and deformation bands are excessively generated in the steel sheet during cold rolling, so that a {111}/ND texture disadvantageous to magnetic properties may be developed. More specifically, tellurium may be included in an amount of 0.0001 to 0.007 wt%.

Mg: 0.0050 wt% or less

[0067] Magnesium (Mg) is an element that mainly combines with S to form sulfide, and may affect the oxide layer on the surface of the base steel. Therefore, Mg may be included 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, Mg 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%.

[0068] The balance consists of Fe and inevitable impurities. The inevitable impurities are impurities incorporated during the steelmaking step and the manufacturing process of the non-oriented electrical steel sheet; as such impurities are well known in the art, a detailed description thereof is omitted. In an embodiment of the present invention, the addition of elements other than the aforementioned alloy composition is not excluded, and such elements may be included in various ways within a range that does not impair the technical spirit of the present invention. When an additional element is further included, it is included in place of Fe, which is the balance.

[0069] As described above, in one embodiment of the present invention, appearance characteristics and magnetic properties may be improved simultaneously by appropriately controlling alloy components of the steel sheet and controlling Al enrichment of the surface and Al aggregation.

[0070] A ratio ($Al_{MAX}/Al_{5\mu m}$) of a maximum content of Al (Al_{MAX}), obtained when measuring Al content in the thickness direction from the surface of the steel sheet to a depth of 5 μm inside the steel sheet, to an Al content ($Al_{5\mu m}$) at a point 5 μm inside the steel sheet from the surface of the steel sheet is 5.0 or less. By controlling this ratio, 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, a ratio ($Al_{MAX}/Al_{5\mu m}$) of a maximum content of Al (Al_{MAX}), obtained when measuring Al content in the thickness direction from the surface of the steel sheet to a depth of 5 μm inside the steel sheet, to an Al content ($Al_{5\mu m}$) at a point 5 μm inside the steel sheet from the surface of the steel sheet may be 1.0 to 4.5. More specifically, it may be 2.0 to 4.3. As an example of an evaluation method for enriched Al, it may be analyzed using a glow discharge spectrometer. In an embodiment of the present invention, a GDS850A model from Leco may be used for analysis by the glow discharge spectrometer. At this time, the 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 relative change of Al according to the depth is similar, so the same standard may be applied. The surface of the steel sheet refers to the outermost surface of the steel sheet, and in the case where an insulating film additionally exists on the surface of the steel sheet, it refers to the surface of the steel sheet in a state where the insulating film is removed. The interface between the insulating film and the surface of the steel sheet is determined as a point where Fe content changes abruptly.

[0071] In addition, in an embodiment of the present invention, the number of Al aggregates having a particle diameter of 500 nm or more in a region from the surface of the steel sheet to a depth of 5 μm into the interior of the steel sheet is 5 or less per 100 μm of the length of the steel sheet. These Al aggregates are evaluated as a type of defect and adversely affect 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 the length of the steel sheet. Al aggregates may be determined to be oxides and nitrides of Al. When observing a cross section including the thickness direction of the steel sheet with a TEM, Al aggregates may be evaluated using an Al elemental map. The particle diameter of the Al aggregates may be obtained as an average value of the horizontal and vertical axes of the Al elemental map.

[0072] In an embodiment of the present invention, an insulating coating is located on the surface of the steel sheet, 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. As the amount of residual oxides on the surface increases, the whiteness decreases. Therefore, there is an advantage in that the degree of residual oxides may be simply determined by the whiteness. More specifically, the whiteness may be 51 to 65. The whiteness may be measured by a method of irradiating white light onto a portion of the steel sheet and analyzing a reflected spectrum. In the present invention, a CM-3700D from Minolta was used, and since the measured values are similar with other devices, the measuring device is not limited.

[0073] In an embodiment of the present invention, the 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 the 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.

[0074] A method for manufacturing 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 step of manufacturing a cold-rolled sheet by cold rolling the annealed steel sheet; and a second annealing step of annealing the cold-rolled sheet.

[0075] Each step will be described in detail below.

[0076] First, a slab is hot-rolled.

[0077] Since the alloy composition of the slab has been described in the alloy component of the non-oriented electrical steel sheet described above, redundant description will be omitted. Since the alloy composition is not substantially changed in the manufacturing process of the non-oriented electrical steel sheet, the alloy compositions of the non-oriented electrical steel sheet and the slab are substantially the same.

[0078] Specifically, the slab comprises, in wt%, 1.5 to 6.0% of Si, 0.1 to 2.0% of Al, 2.0% or less of Mn, and 0.002 to 0.100% of Cu, with the balance being Fe and unavoidable impurities.

[0079] Since the other additional elements have been described in relation to the alloy components of the non-oriented electrical steel sheet, redundant description is omitted.

[0080] The slab may be heated before hot rolling. The heating temperature of the slab is not limited, but the slab may be heated to 1000 to 1180°C. If the slab heating temperature is too low, problems in hot rollability may occur. If the slab heating temperature is too high, growth of oxides containing Si may be accelerated, and enrichment of Cu on the surface of the base steel may be inhibited.

[0081] Next, a hot-rolled sheet is manufactured by hot rolling the slab.

[0082] After rolling to a thickness of 30 mm to 60 mm by rough rolling, a hot-rolled product of 0.8 mm to 2.7 mm may be produced by finish rolling. If the rough rolling thickness is too thick, the latent heat of the surface of the steel sheet is high and the rolling speed is reduced, which increases the growth of scale during rolling, disadvantageously affecting the descaling of the hot-rolled coil. On the other hand, if the rough rolling thickness is too thin, cooling of the steel material becomes faster, which may decrease the rollability. More specifically, the thickness may be 35 mm to 55 mm.

[0083] At this time, scale may be removed after rough rolling. For example, as a method of removing scale from the surface via a mechanical method, high pressure water may be sprayed to remove the scale by the impact thereof. If excessive time passes after rough rolling, the temperature of the surface decreases and the adhesion of the scale becomes strong. In this case, removal of the scale is not easy. The temperature of the material immediately after rough rolling should be 950°C or more and less than 1,050°C, and it is necessary to remove the scale within 25 seconds after 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 growth rate of the scale is excessive, causing internal oxidation to develop and residual oxides to increase on the surface. Therefore, rough rolling may be finished within the above temperature range and the scale may be removed within 25 seconds. In one embodiment of the present invention, the scale is an oxide or a nitride.

[0084] The 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.

[0085] The finishing rolling temperature in the step of manufacturing the hot-rolled sheet may be 800°C or higher. Specifically, it may be 870 to 950°C. The hot-rolled sheet may be coiled at a temperature of 550°C or higher.

[0086] After the step of manufacturing the hot-rolled steel sheet, a descaling step may be further included. If scale remains, the scale is pressed into the base steel during cold rolling, making the surface of the finally manufactured non-oriented electrical steel sheet rough and causing point defects and the like. In addition, residual scale in the final non-oriented electrical steel sheet deteriorates electromagnetic properties, such as increasing iron loss. Therefore, the scale of the hot-rolled steel sheet must be appropriately removed. In the present invention, as a method of descaling, a mechanical method using a brush or shot peening and a chemical method using a hydrochloric acid (HCl) aqueous solution may be used. According to one aspect of the present invention, in the shot blasting treatment, an average diameter of metal balls used may be 1 to 1,000 μm , the traveling speed of the steel sheet may be controlled to 50 to 150 mpm (meter per minute), or metal balls at a rate of 300 to 3,000 kg/min may be controlled to collide with the surface of the steel sheet. When using a hydrochloric acid aqueous solution, scale may be removed by immersing the steel sheet in 15 to 30 wt% of an acid aqueous solution for 30 to 150 seconds. More specifically, the steel sheet may be immersed for 70 to 140 seconds.

[0087] Through descaling, prior to the first annealing step, the oxide remaining on the surface of the steel sheet may be reduced to 5.0 area % or less, and the surface roughness may be reduced to 3.0 μm or less. If descaling is performed excessively, surface roughness increases, which may cause fracture during cold rolling. If descaling is performed weakly, the amount of oxide remaining on the surface increases, which may lead to Al enrichment of the surface and Al aggregation. More specifically, the oxide remaining on the surface of the hot-rolled steel sheet 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 checking the residual area of scale, it may be checked by observation with a scanning electron microscope (SEM). While observing in the SEM observation mode using a backscattered electron detector, photographs are taken at 50x or 100x magnification. At this time, the base steel and the oxide may be clearly distinguished by the difference in contrast, where the oxide appears relatively dark. The area ratio of the residual oxides may be measured by analyzing the taken photographs using an image analyzer. The observation positions of the residual scale in the hot-rolled steel sheet may include at least three positions, such as the center of the steel sheet and points corresponding to 1/4 of the

width from both ends.

[0088] The method of measuring surface roughness follows ISO 4287-1997 and standards equivalent thereto, and the cut-off value is set to 2.5 μm .

[0089] Next, the hot-rolled steel sheet is subjected to a first annealing process. Before annealing the hot-rolled steel sheet, it may also be possible to perform preliminary cold rolling on the hot-rolled steel sheet without hot-rolled sheet annealing.

[0090] Preliminary cold rolling is distinguished from cold rolling, which will be described later, in that it is a primary rolling step in a process of rolling to an intermediate thickness rather than a final product thickness, performing first annealing, and then cold rolling to the final product thickness.

[0091] Preliminary cold rolling may be performed in a reduction ratio range of 40 to 80% to improve final cold rolling productivity and grain in 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. The 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.

[0092] The preliminary cold reduction ratio may be calculated as (thickness of the steel sheet before rolling - thickness of the steel sheet after rolling) / thickness of the steel sheet before rolling. If the reduction ratio is too low in the preliminary cold rolling step, the rolling load increases during the final cold rolling, which may result in decreased productivity, and the final reduction ratio increases, which may cause a problem of promoting fine <111> orientation recrystallization. Conversely, if the reduction ratio is too high, the cold rolling load increases and the probability of sheet breakage also increases. The cold rolling machine may be a tandem cold mill composed of 4 to 6 stands, or a Z-mill or Sendzimir mill, and is not particularly limited.

[0093] Next, in the first annealing step, the hot-rolled steel sheet (when preliminary cold rolling is not performed) or the preliminary cold-rolled steel sheet is annealed.

[0094] At this time, annealing may be performed at a temperature of 870 to 1050°C. If the temperature is too low, the magnetic properties of the finally manufactured electrical steel sheet may become inferior. If the temperature is too high, fracture may occur during cold rolling. Before the step of preliminary cold rolling or before the step of manufacturing the cold-rolled sheet (in case of skipping preliminary cold rolling), the average grain diameter of the steel sheet may be 180 μm or less. More specifically, it may be 50 to 180 μm .

[0095] The first annealing step may be performed in an atmosphere containing 3 vol% or more of hydrogen. In this way, it may be carried out in an oxide-inhibiting atmosphere. The balance is nitrogen. In addition, the dew point may be -20°C or lower. More specifically, the hydrogen content may be 3 to 30 vol %. The dew point may be -30°C or lower.

[0096] After the first annealing 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 from the surface of the steel sheet toward the interior of the steel sheet, when measuring the Al content in the thickness direction from the surface to the 5 μm point, may be 20.0 or less. More specifically, the ratio may be in the range of 5.0 to 19.5.

[0097] After the first annealing step, a descaling step may be additionally included. The descaling may be carried out mechanically, chemically, or in combination. The chemical descaling may use an acid solution capable of chemically dissolving scale. For example, a 10 to 30 wt% HCl aqueous solution may be used, and the process may be carried out for 5 to 100 seconds in a temperature range of 30 to 80°C. The concentration and temperature of the HCl solution, the descaling time, etc., may be varied to conditions effective for descaling. Mechanical descaling is also possible. The mechanical descaling is a method of removing scale by friction or impact. Both mechanical and chemical methods may be used.

[0098] Returning back to the description of the method for manufacturing a non-oriented electrical steel sheet, after the first annealing step, a cold-rolled sheet is manufactured by cold rolling the annealed steel sheet.

[0099] The cold rolling machine may be a tandem cold mill comprising 4 to 6 stands, or may be a Z-mill or a Sendzimir mill. The types of the rolling mill and the rolling method are not particularly limited. The final rolling thickness may be 0.1 mm to 0.35 mm.

[0100] 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 grow sufficiently, so that hysteresis loss increases, which may lead to the deterioration of iron loss. More specifically, annealing may be performed at a temperature of 920 to 1020°C. The second annealing step may be performed for a soaking time of 50 to 120 seconds.

[0101] The atmosphere may comprise 10 to 50 vol % of hydrogen and the balance nitrogen, and the dew point may be -10°C or lower.

[0102] In the cold-rolled sheet annealing process, all (that is, 99% or more) of the processed structure formed in the cold rolling step may be recrystallized.

[0103] After annealing the cold-rolled sheet, an insulating film may be formed. The insulating film may be formed by treating with an organic, inorganic, or organic/inorganic composite coating, or it may be treated with other insulating

coating agents.

[0104] In order to increase the flatness and improve workability of the manufactured electrical steel sheet, stress relief annealing may be additionally carried out at a temperature of 750 to 950°C. However, since scale remaining in the manufacture of the electrical steel sheet is in a stable state, it does not affect the size or distribution of oxide or nitride formed on the surface.

[0105] 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

[0106] A slab having a thickness of 250 mm was manufactured with components comprising those listed 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 through rough rolling was 1,020°C. 23 seconds after the rough rolling was completed, scale was removed using high-pressure water at 150 bar, and finish rolling was performed to manufacture a hot-rolled steel sheet with a thickness of 2.0 mm in the form of a coil. However, in Comparative Example 11 and Comparative Example 12, the descaling using high-pressure water was omitted. At this time, the temperature immediately after finish rolling was 912°C, and the coiling temperature was 630°C.

[0107] Descaling of the hot-rolled coil was carried out for 100 seconds in an 18 wt% HCl aqueous solution at 80°C, provided that for Comparative Example 7, it was carried out for 60 seconds. Inventive Examples 1 and 2 and Comparative Examples 1 and 10 were subjected to a pickling treatment for 100 seconds after performing a shot blasting treatment. In this process, metal balls with an average diameter of 400 μm were used for the shot blasting, the sheet passing speed was 50 MPM, and the metal ball collision rate was 3,000 kg/min. In Comparative Example 10, the descaling was repeated twice. Inventive Examples 1 and 2 and Comparative Examples 1 and 10 were thereafter subjected to a first annealing (hot-rolled sheet annealing) in an H_2 5 vol% atmosphere and were processed to a final thickness by a single cold rolling step. Other steel sheets were subjected to first annealing at the temperatures and in the atmospheres summarized in Table 1 below. Inventive Example 11 was subjected to an additional descaling treatment for 5 seconds in a 15 wt% HCl aqueous solution at 80°C after the first annealing.

[0108] After first annealing, preliminary cold rolling and cold rolling were performed. The thickness after preliminary cold rolling was 0.9 mm, and the thickness after final rolling was 0.2 mm.

[0109] After performing the second annealing at 970°C for 30 seconds, an insulation coating was applied to a thickness of 0.5 μm with a resin-based coating.

[0110] The average grain diameter was obtained by mirror-polishing a cross-section of the steel sheet, etching the cross-section to reveal crystal grains, measuring the particle diameters at five equally spaced locations from the top surface to the bottom surface, and calculating an average value thereof.

[0111] $\text{Al}_{\text{MAX}}/\text{Al}_{5\mu\text{m}}$ was measured using a GDS850A model (Leco Corporation) under conditions of an acceleration voltage of 700 KV and a current of 30 mA.

[0112] Al aggregates were measured by observing a cross section of the steel sheet in the thickness direction using a TEM.

[0113] As an example of a method for checking the area of scale of the hot-rolled steel sheet, it may be checked by observation with a scanning electron microscope (SEM). While observing in the SEM observation mode with a back-scattered electron detector, photographs were taken at 50x or 100x magnification, and the images were analyzed and measured.

[0114] Whiteness was measured using a CM-3700D colorimeter (Minolta Co., Ltd.).

[0115] Whitening evaluation was performed on a material finished with an insulating coating by conducting an ISO 1499 salt spray test for 72 hours, and the results were determined based on the following indicators.

Excellent (○): No change on the surface, and reduction in whiteness is less than 10%

Insufficient (△): A whitening phenomenon is visually observed but is present on less than 10% of the total area, or the decrease in whiteness is 10% or more and less than 20%.

Poor (×): The whitening phenomenon observed visually covers 10% or more of the total area, or the decrease in whiteness is 20% or more

[0116] Magnetic properties, such as magnetic flux density and iron loss, were determined for each specimen. Specimens of 60 mm in width, 60 mm in length, and 5 sheets in number were cut and evaluated using a Single Sheet Tester. For magnetic flux density, measurements were taken in the rolling direction and in a direction at 55° to the rolling direction, and the results were reported. Iron loss was measured in the rolling direction and in the direction perpendicular to the rolling direction, and the average value was reported. In this context, $W_{10/400}$ refers to the iron loss when a magnetic flux density of 1.0 T is induced at a frequency of 400 Hz, and B_{50} refers to the magnetic flux density induced

at a magnetic field of 5000 A/m.

[Table 1]

Remarks (wt%)	C	Si	Mn	Cu	Al	N	P	S	Other elements
Inventive Example 1	0.0035	2.15	0.45	0.030	0.80	0.0045	0.0076	0.0018	-
Inventive Example 2	0.0035	2.15	0.45	0.030	0.80	0.0045	0.0076	0.0045	-
Inventive Example 3	0.0022	5.91	0.62	0.030	0.70	0.0038	0.0045	0.0078	-
Inventive Example 4	0.0041	2.50	0.07	0.040	0.70	0.0043	0.0055	0.0042	-
Inventive Example 5	0.0025	3.00	0.18	0.050	0.70	0.0026	0.0070	0.0017	-
Inventive Example 6	0.0015	4.50	0.80	0.002	0.50	0.0042	0.0080	0.0027	Ni 0.002
Inventive Example 7	0.0035	3.50	0.50	0.025	0.70	0.0015	0.0120	0.0019	Ni 0.002, Sn 0.001
Inventive Example 8	0.0025	2.50	0.50	0.010	0.55	0.0037	0.0750	0.0033	Sb 0.002
Inventive Example 9	0.0021	3.60	0.35	0.050	1.92	0.0034	0.0600	0.0035	-
Inventive Example 10	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Inventive Example 11	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example 1	0.0035	2.15	0.45	0.030	0.80	0.0045	0.0076	0.0028	-
Comparative Example 2	0.0050	6.50	1.80	0.040	1.20	0.0018	0.0071	0.0042	-
Comparative Example 3	0.0037	4.50	2.10	0.030	0.80	0.0025	0.0086	0.0014	-
Comparative Example 4	0.0045	3.70	0.50	0.001	0.50	0.0036	0.0119	0.0035	-
Comparative Example 5	0.0043	3.50	0.40	0.135	0.80	0.0020	0.0117	0.0005	-
Comparative Example 6	0.0021	2.20	0.30	0.030	2.10	0.0020	0.0073	0.0014	-
Comparative Example 7	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example 8	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example 9	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example 10	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example 11	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-
Comparative Example 12	0.0019	3.70	0.32	0.007	0.82	0.0019	0.0070	0.0040	-

[Table 2]

Remarks	Hot-rolled sheet annealing(°C)	Average grain diameter of hot-rolled sheet(μm)	Residual scale of hot-rolled sheet(area %)	Surface roughness of hot-rolled sheet(Ra, μm)	First annealing temperature(°C)	First annealing g H ₂ (vol %)	Al _{MAX} /Al _{5μm} after first annealing g
Inventive Example 1	850	85	2.1	2.8	-	-	-
Inventive Example 2	1,050	170	4.5	2.0	-	-	-
Inventive Example 3	-	54	4.8	1.9	920	30	9.2
Inventive Example 4	-	73	3.0	1.6	970	5	15.5
Inventive Example 5	-	60	3.5	1.4	970	4	17.9
Inventive Example 6	-	69	4.8	1.9	990	4	19.3
Inventive Example 7	-	80	4.7	1.0	970	3	10.2
Inventive Example 8	-	64	3.1	1.0	970	3	11.3
Inventive Example 9	-	75	3.2	1.1	880	10	16.8
Inventive Example 10	-	54	2.7	1.2	930	3	16.7
Inventive Example 11	-	54	2.7	1.2	1,050	3	7.3
Comparative Example 1	1,100	190	2.3	0.9	-	-	-
Comparative Example 2	-	59	5.8	-	970	5	21.5
Comparative Example 3	-	-	-	-	-	-	-
Comparative Example 4	-	52	4.5	1.0	970	3	36.6
Comparative Example 5	-	52	3.9	1.8	1,040	5	28.3
Comparative Example 6	-	47	4.5	0.8	970	3	31.5
Comparative Example 7	-	54	11.5	0.9	970	3	36.0
Comparative Example 8	-	54	2.7	0.9	1,070	3	37.0
Comparative Example 9	-	54	2.7	1.2	970	2	26.4
Comparative Example 10	-	54	0.0	3.5	-	-	-
Comparative Example 11	-	54	5.2	0.9	970	3	32.5
Comparative Example 12	-	54	5.2	0.9	970	30	12.8

[Table 3]

	Remarks	Number of Al aggregates	Al _{MAX} /Al _{5μm} after second annealing	Whiteness	Evaluation of whitening of insulation coating
5	Inventive Example 1	1	2.8	58	○
	Inventive Example 2	0	2.5	57	○
	Inventive Example 3	0	2.9	60	○
10	Inventive Example 4	3	3.9	56	○
	Inventive Example 5	4	3.8	55	○
	Inventive Example 6	4	4.1	51	○
	Inventive Example 7	2	2.3	57	○
15	Inventive Example 8	3	2.7	55	○
	Inventive Example 9	2	3.5	56	○
	Inventive Example 10	3	2.5	55	○
	Inventive Example 11	1	2.2	63	○
20	Comparative Example 1	-	-	-	-
	Comparative Example 2	7	5.4	49	Δ
	Comparative Example 3	-	-	-	-
25	Comparative Example 4	7	5.7	44	Δ
	Comparative Example 5	5	5.2	46	Δ
	Comparative Example 6	9	6.1	44	-
	Comparative Example 7	12	6.5	43	×
30	Comparative Example 8	7	6.0	47	Δ
	Comparative Example 9	6	5.5	48	Δ
	Comparative Example 10	-	-	-	-
35	Comparative Example 11	9	5.8	45	Δ
	Comparative Example 12	8	4.5	49	Δ

[0117] As shown in Tables 1 to 3, it may be confirmed that when the steel composition is appropriately controlled and the process conditions are appropriately controlled such that Al enrichment of the surface and Al aggregation are appropriately suppressed, the surface properties are excellent and the magnetic properties are excellent.

[0118] In the case of Comparative Example 1, fracture occurred during cold rolling because the average grain diameter of the hot-rolled steel sheet was too large.

[0119] In Comparative Example 2, even though descaling treatment was performed on the hot-rolled steel sheet, the Si content in the steel sheet was too high, the residual scale amount on the hot-rolled surface of the steel sheet was too high, and Al enrichment of the surface and Al aggregation were not suppressed, resulting in inferior surface properties.

[0120] In Comparative Example 3, Mn was included in an excessive amount, and rolling was stopped because the surface of the steel sheet cracked during the hot rolling process.

[0121] Comparative Example 4 and Comparative Example 5 are cases where Cu was not appropriately included in the steel, and due to this, Al enrichment and Al aggregation were not suppressed, resulting in inferior surface properties.

[0122] In Comparative Example 6, Al was added in an excessive amount, and Al enrichment and Al aggregation were not suppressed, resulting in inferior surface properties.

[0123] In Comparative Example 7, descaling was not sufficient, the residual scale amount on the hot-rolled surface of the steel sheet was too much, and Al enrichment of the surface and Al aggregation were not suppressed, resulting in inferior surface properties.

[0124] In Comparative Examples 8 and 9, the temperature conditions and hydrogen content condition during first annealing were not satisfied, and Al enrichment of the surface and Al aggregation were not suppressed, resulting in

inferior surface properties.

[0125] In Comparative Example 10, descaling was performed excessively, resulting in increased roughness of the hot-rolled surface of the steel sheet, which caused sheet breakage during cold rolling.

[0126] In Comparative Example 11, descaling was omitted after rough rolling, a large amount of scale remained on the hot-rolled surface, and Al enrichment of the surface and Al aggregation were not suppressed, resulting in inferior surface properties.

[0127] In Comparative Example 12, descaling was omitted after rough rolling, and a large amount of scale remained on the hot-rolled surface, and although Al enrichment of the surface was suppressed by setting H_2 in the atmosphere to 30% during primary annealing, a large number of Al aggregates were formed, resulting in inferior surface properties.

[0128] FIGS. 1 to 3 show a TEM cross-section, an elemental map, and GDS analysis results of the steel sheet manufactured in Inventive Example 10. As may be seen in FIGS. 1 to 3, it may be confirmed that Al is partially enriched only at the boundary of the base steel sheet within the insulating coating and is not enriched within the base steel sheet. This may also be clearly confirmed in FIG. 3.

[0129] On the other hand, FIGS. 4 to 6 show a TEM cross-section, an elemental map, and GDS analysis results of the steel sheet manufactured in Comparative Example 9. As may be seen in FIGS. 4 to 6, it may be confirmed that a large amount of Al is enriched near the boundary with the insulating film within the base steel sheet, and in particular, an aggregate is formed in an elliptical shape of approximately 1.5 μm in the horizontal direction and approximately 500 nm in the vertical direction. In addition, the GDS results also confirm that Al is excessively enriched with an $Al_{MAX}/Al_{5\mu m}$ ratio of about 5.5.

[0130] The present invention is not limited to the embodiments, but may be manufactured in various different forms, and those of ordinary skill in the art to which the present invention pertains will understand that the present invention may be implemented 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, in 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 ($Al_{MAX}/Al_{5\mu m}$) of a maximum content of Al (Al_{MAX}), as measured when determining the Al content in the thickness direction from the surface of the steel sheet to a point 5 μm inside the steel sheet, to an Al content ($Al_{5\mu m}$) at the point 5 μm inside the steel sheet from the surface of the steel sheet is 5.0 or less, wherein number of Al aggregates having a particle diameter of 500 nm or more in a region from the surface of the steel sheet to 5 μm inside the steel sheet is 5 or less per 100 μm of the length of the steel sheet.

2. The non-oriented electrical steel sheet of Claim 1, further comprising at least one 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%).

3. The non-oriented electrical steel sheet of Claim 1, further comprising one or more of Sn, Sb, Bi, Pb, Ge, and As in a total amount of 0.005 to 0.200 wt%.

4. The non-oriented electrical steel sheet of Claim 1, further comprising at least one 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%).

5. The non-oriented electrical steel sheet of Claim 1, further comprising at least one 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%).

6. The non-oriented electrical steel sheet of Claim 1, comprising an insulating coating located on the surface of the steel sheet, wherein the whiteness of the surface of the insulating coating is 50 or more.

7. A method for manufacturing a non-oriented electrical steel sheet comprising:

a step of manufacturing a hot-rolled steel sheet by hot rolling a slab comprising, in 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 step of manufacturing a cold-rolled sheet by cold rolling the annealed steel sheet; and

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

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

8. The method for manufacturing a non-oriented electrical steel sheet of Claim 7,

wherein the slab further comprises at least one 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%).

9. The method for manufacturing a non-oriented electrical steel sheet of Claim 7,

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

10. The method for manufacturing a non-oriented electrical steel sheet of Claim 7,

wherein the slab further comprises at least one 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%).

11. The method for manufacturing a non-oriented electrical steel sheet of Claim 7,

wherein the slab further comprises at least one 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%).

12. The method for manufacturing a non-oriented electrical steel sheet of Claim 7,

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

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

13. The method for manufacturing a non-oriented electrical steel sheet of Claim 7,

wherein before the step of manufacturing the cold-rolled sheet, the average grain diameter of the steel sheet is 180 μm or less.

14. The method for manufacturing a non-oriented electrical steel sheet of Claim 7,

wherein the step of manufacturing the hot-rolled steel sheet comprises a descaling step after rough rolling.

15. The method for manufacturing a non-oriented electrical steel sheet of Claim 7,

further comprising a descaling step of immersing in a 15 to 30 wt% acid aqueous solution for 30 to 150 seconds before the first annealing step.

16. The method for manufacturing a non-oriented electrical steel sheet of Claim 7,

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

17. The method for manufacturing a non-oriented electrical steel sheet of Claim 7,

wherein after the first annealing 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 surface, when measuring the Al content in the thickness direction from the surface of the steel sheet to the point 5 μm inside the steel sheet, is 20.0 or less.

18. The method for manufacturing a non-oriented electrical steel sheet of Claim 7,

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

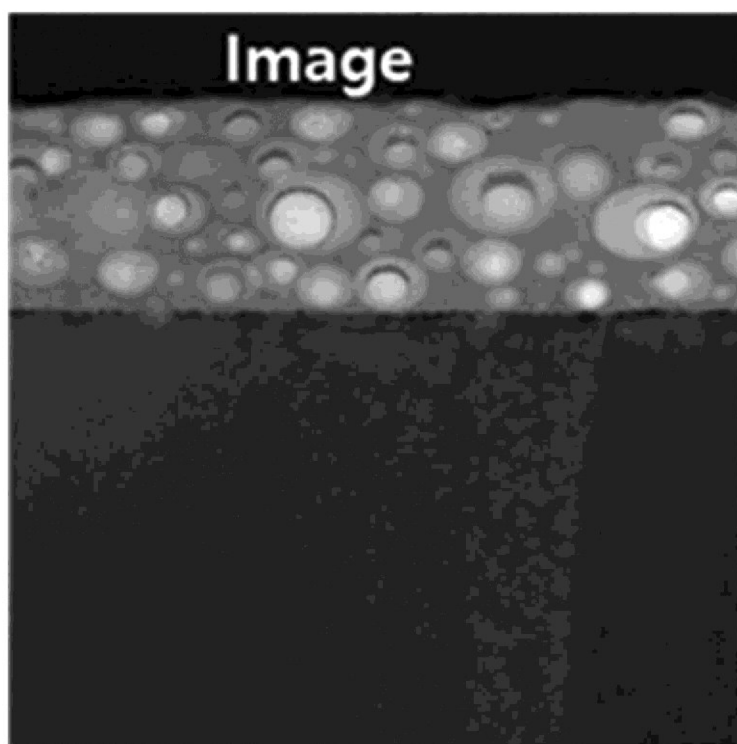


FIG. 2

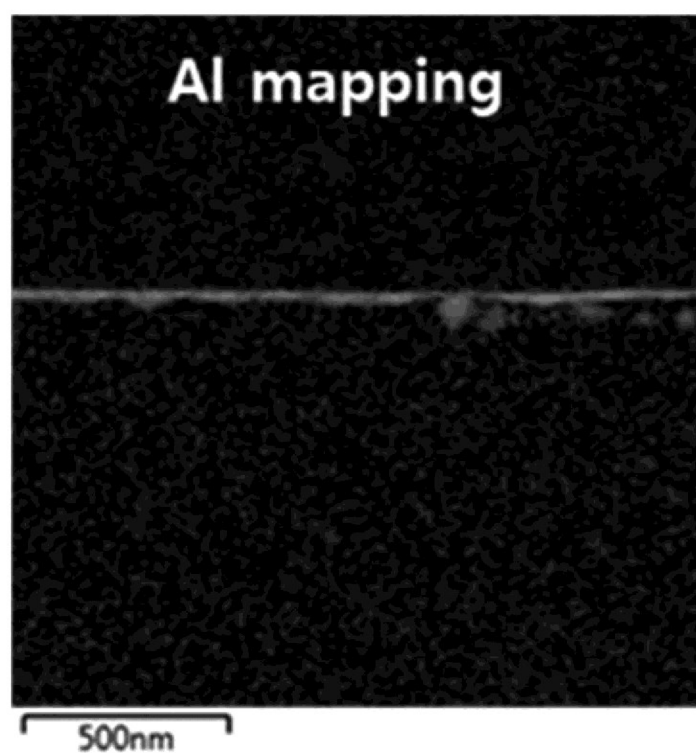


FIG. 3

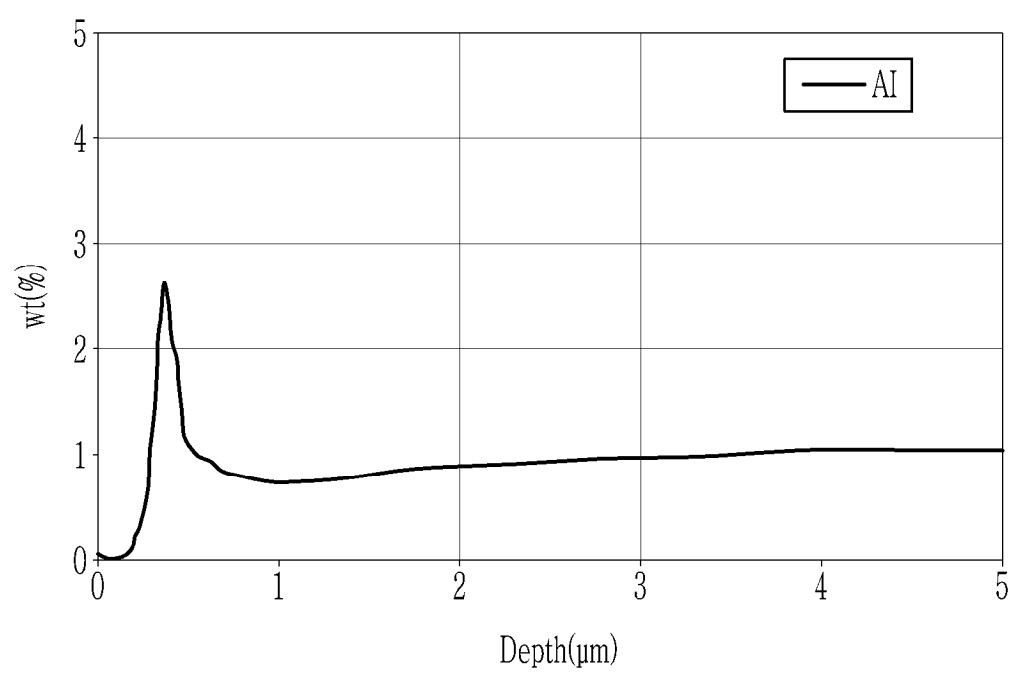


FIG. 4

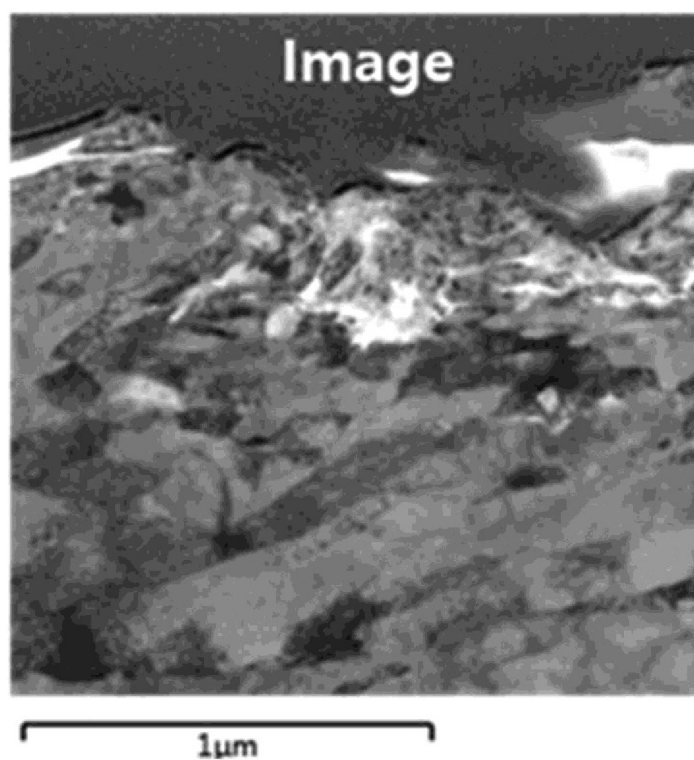


FIG. 5

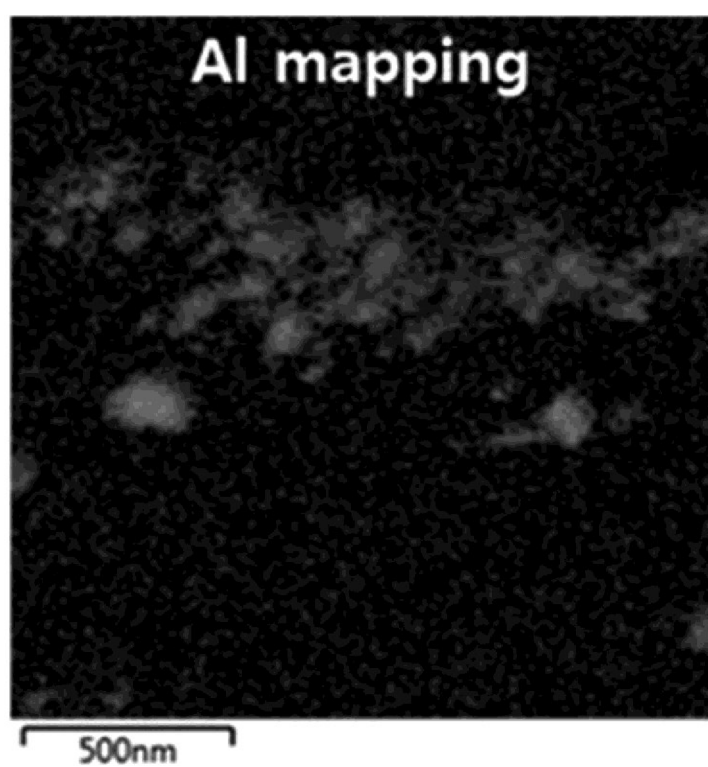
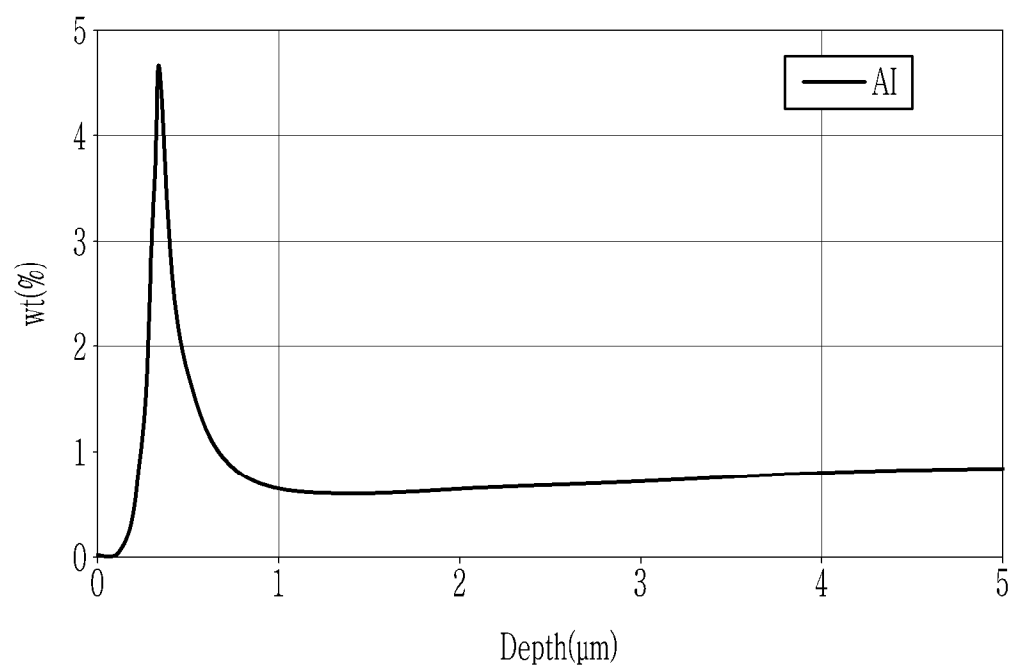


FIG. 6



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/096693

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/06(2006.01)i; C22C 38/04(2006.01)i; C22C 38/16(2006.01)i; C22C 38/00(2006.01)i;
C22C 38/14(2006.01)i; C22C 38/58(2006.01)i; C22C 38/52(2006.01)i; C22C 38/12(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.	1-18
A	KR 10-2019-0077891 A (POSCO) 04 July 2019 (2019-07-04) See claims 1, 3, 5 and 18-19.	1-18
A	KR 10-2164113 B1 (POSCO) 13 October 2020 (2020-10-13) See claim 11.	1-18
A	KR 10-2010-0084643 A (NIPPON STEEL CORPORATION) 27 July 2010 (2010-07-27) See claims 1 and 3 and figures 1a-1b.	1-18
A	KR 10-1565510 B1 (POSCO) 03 November 2015 (2015-11-03) See paragraph [0057] and claim 1.	1-18

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

* Special categories of cited documents:

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“L” document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

“O” document referring to an oral disclosure, use, exhibition or other means

“P” document published prior to the international filing date but later than the priority date claimed

“T” later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

“X” document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

“Y” document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

“&” document member of the same patent family

Date of the actual completion of the international search 11 March 2025	Date of mailing of the international search report 11 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.

Form PCT/ISA/210 (second sheet) (July 2022)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/KR2024/096693

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KR	10-2019-0077891	A	04 July 2019	CN	110004280	A	12 July 2019
				KR	10-2080167	B1	21 February 2020
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				WO	2020-111640	A1	04 June 2020
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				CN	101821418	B	18 April 2012
				JP	4585609	B2	24 November 2010
				JP	WO2009-072394	A1	21 April 2011
				KR	10-1259233	B1	07 May 2013
				TW	200932927	A	01 August 2009
				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