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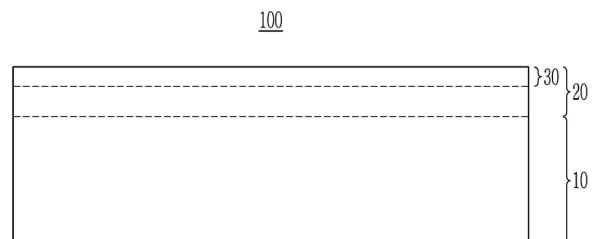
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(54) **NON-ORIENTED ELECTRICAL STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) An embodiment of the present disclosure provides a non-oriented electrical steel sheet including, in wt%, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, and Mn: 0.1 to 2.0%, with the balance being Fe and inevitable impurities, and the area fraction of <111>//ND grains is 30% or less, the sum of the area fraction of <110>//ND grains and <100>//ND grains is 28% or more, and the ratio of the area fraction of <100>//ND grains to the area fraction of <110>//ND grains is 0.4 or more. In this case, <111>//ND, <110>//ND and <100>//ND refer to grains in which the <111>, <110>, and <100> axes of the grains are parallel to the normal direction (ND direction) of a rolling surface of the steel sheet at an angle of 15° or less.

FIG. 1



EP 4 826 036 A1

Description

BACKGROUND OF THE INVENTION**(a) Field of the Invention**

[0001] An embodiment of the present disclosure relates to a non-oriented electrical steel sheet and a method for manufacturing the same. Specifically, an embodiment of the present disclosure relates to a non-oriented electrical steel sheet and a method for manufacturing the same, which improves magnetic properties by developing a specific texture by controlling a heating rate in an annealing process prior to cold rolling.

(b) Description of the Related Art

[0002] A non-oriented electrical steel sheet is mainly used in a motor that converts electrical energy to mechanical energy, and an excellent magnetic characteristic of the non-oriented electrical steel sheet is required to achieve high efficiency while the motor converts electrical energy to mechanical energy. In particular, recently, as environmentally friendly vehicles driven by motors instead of internal combustion engines have been gaining attention, the demand for non-oriented electrical steel sheets used as driving motor core materials is increasing, and for this purpose, non-oriented electrical steel sheets with excellent magnetic properties and strength are required.

[0003] The magnetic properties of non-oriented electrical steel sheets are mainly evaluated by iron loss and magnetic flux density. The iron loss means energy loss occurring at a specific magnetic flux density and frequency, and the magnetic flux density means a degree of magnetic properties obtained in a specific magnetic field. Lower iron loss allows for more energy-efficient motors to be manufactured under the same conditions, and higher magnetic flux density allows for smaller motors or reduced copper loss. Therefore, by using non-oriented electrical steel sheets with low iron loss and high magnetic flux density, a driving motor with excellent efficiency and torque may be manufactured, thereby improving the driving range and output of environmentally friendly vehicles.

[0004] Depending on operational conditions of the motor, the characteristics of which the non-oriented electrical steel sheet should be considered are also varied. The general standard for evaluating the characteristics of non-oriented electrical steel sheets used in motors is widely used as W15/50, which is the iron loss when a 1.5T magnetic field is applied at a commercial frequency of 50Hz. However, in the case of non-oriented electrical steel sheets with a thickness of 0.35 mm or less used in environmentally friendly vehicle driving motors, magnetic properties are often important at low magnetic fields of 1.0 T or less and high frequencies of 400 Hz or higher, so the properties of non-oriented electrical steel sheets are often evaluated using the $W_{10/400}$ iron loss.

[0005] A commonly used method to improve the magnetic properties of non-oriented electrical steel sheets is to add alloying elements such as Si, Al, and Mn. When the specific resistance of the steel increases through the addition of these alloying elements, the eddy current loss decreases, thus lowering the overall iron loss. Additionally, these alloying elements may be dissolved in iron as substitutional elements to cause a strengthening effect, thereby increasing strength. On the contrary, as the amount of added alloy elements such as Si, Al, and Mn increases, the magnetic flux density is deteriorated and brittleness increases, and when more than a certain amount thereof is added, it may not be cold rolled and may not be commercially producible. In particular, as the thickness of electrical steel sheets is reduced, high-frequency iron loss becomes better, but the reduction in rollability due to brittleness becomes a critical problem. The maximum total content of Si, Al, and Mn that may be commercially produced is known to be approximately 4.5 wt% and by optimizing the content of trace elements, it is possible to produce the highest quality non-oriented electrical steel with excellent magnetic properties and strength.

[0006] A method of improving magnetic properties by controlling the texture of non-oriented electrical steel sheets is also widely used. Control of the texture is a method of promoting the development of crystal orientations advantageous to magnetic properties and suppressing crystal orientations disadvantageous to magnetic properties during the process of deforming, recovering, and recrystallizing a material in various ways. It is known that a crystal orientation having a {001} plane is favorable for magnetic properties, and a crystal orientation having a {111} plane is disadvantageous for magnetic properties. Many methods are known for selectively developing several crystal orientations by changing the manufacturing conditions of non-oriented electrical steel sheets.

[0007] If non-oriented electrical steel sheets are produced through a double-rolling and double-annealing process, the {111}//ND crystal orientation, which is disadvantageous to magnetic properties, may be suppressed, and the {001}//ND crystal orientation, which is advantageous to magnetic properties, may be strengthened. It is well known that the above process is excellent in improving the aggregate organization, but compared to the existing single-rolling method, the manufacturing cost is somewhat higher due to the addition of cold rolling and intermediate annealing processes, and the surface oxide layer formation behavior is unstable during the annealing and cold rolling processes, resulting in deterioration of the magnetic properties due to additional formation of precipitates on the surface or uneven

formation of the surface oxide layer, thus limiting its application in actual mass production processes.

SUMMARY OF THE INVENTION

[Technical Problem]

[0008] An embodiment of the present disclosure provides a non-oriented electrical steel sheet and a method for manufacturing the same. Specifically, an embodiment of the present disclosure provides a non-oriented electrical steel sheet and a method for manufacturing the same, which improves magnetic properties by developing a specific texture by controlling a heating rate in an annealing process prior to cold rolling.

[Technical Solution]

[0009] A non-oriented electrical steel sheet according to an embodiment of the present disclosure includes, in wt%, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, and Mn: 0.1 to 2.0%, with the balance being Fe and inevitable impurities, and the area fraction of <111>//ND grains is 30% or less, the sum of the area fraction of <110>//ND grains and <100>//ND grains is 28% or more, and the ratio of the area fraction of <100>//ND grains to the area fraction of <110>//ND grains is 0.4 or more.

[0010] In this case, <111>//ND, <110>//ND and <100>//ND refer to grains in which the <111>, <110>, and <100> axes of the grains are parallel to the normal direction (ND direction) of a rolling surface of the steel sheet at an angle of 15° or less.

[0011] The non-oriented electrical steel sheet may include an oxide layer existing from a surface toward the inside, wherein a thickness of the oxide layer may be 200 nm or less.

[0012] In a cross-section including a rolling direction of the steel sheet, a length of an oxide layer disconnecting portion in which the maximum thickness of the oxide layer is 5 nm or less may be 750 nm or less per 100 μm in the rolling direction.

[0013] The ratio of the number of precipitates per unit area (P_S) in a surface portion from the surface to the inside of the steel sheet of up to 1/20 of the total thickness to the number of precipitates per unit area (P_I) in a center portion more than 1/20 to 1/2 of the total thickness may be 1.2 or less.

[0014] The non-oriented electrical steel sheet according to an embodiment of the present disclosure may further include one or more of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

[0015] The non-oriented electrical steel sheet according to an embodiment of the present disclosure may further include 0.005 to 0.200 wt% in each or a combined amount of one or two or more of Sn, Sb, Bi, Pb, Ge, and As.

[0016] The non-oriented electrical steel sheet according to an embodiment of the present disclosure may further include one or more of Cu: 0.005 to 0.2 wt%, 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%).

[0017] The non-oriented electrical steel sheet according to an embodiment of the present disclosure may further include 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%).

[0018] A method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present disclosure includes a step of hot rolling a slab including, in wt%, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, and Mn: 0.1 to 2.0%, with a balance being Fe and inevitable impurities, to manufacture a hot-rolled sheet, a pre-cold rolling annealing step of annealing the hot-rolled steel sheet, a step of cold rolling the annealed steel sheet to manufacture a cold-rolled steel sheet, and a cold-rolled sheet annealing step of annealing the cold-rolled sheet.

[0019] Before the pre-cold rolling annealing step, the method for manufacturing the non-oriented electrical steel sheet includes a first heating step of heating the steel sheet to 750°C at a heating rate of 22°C/sec or less before the pre-cold rolling annealing step, and a second heating step of heating it at a heating rate of 28°C/sec or more to a temperature exceeding 750°C and up to a soaking temperature.

[0020] The slab may further include one or more of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

[0021] The slab may further include 0.005 to 0.200 wt% in each or a combined amount of one or two or more of Sn, Sb, Bi, Pb, Ge, and As.

[0022] The slab may further include one or more of Cu: 0.005 to 0.2 wt%, 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%).

[0023] The slab may further include 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%).

[0024] The method for manufacturing the non-oriented electrical steel sheet may further include a step of preliminary cold rolling a hot-rolled sheet prior to the pre-cold rolling annealing step.

[0025] A reduction ratio in the step of preliminary cold rolling may be 30 to 80%.

[0026] The soaking temperature of the pre-cold rolling annealing step may be 850 to 1010°C.

[0027] The pre-cold rolling annealing step may be performed in an atmosphere of a mixture of hydrogen and nitrogen containing 0.1 to 50% by volume of hydrogen gas, at a dew point of -50 to -10°C while applying a tension of 0.2 to 3.0 kgf/mm².

[0028] The reduction ratio in the step of manufacturing the cold-rolled steel sheet may be 40 to 85%.

[0029] The cold-rolled sheet annealing step may be performed at a soaking temperature of 850 to 1100°C in an atmosphere with a dew point below 0°C.

[Advantageous Effects]

[0030] A non-oriented electrical steel sheet according to an embodiment of the present disclosure has further improved magnetic properties without causing surface deterioration.

[0031] Ultimately, the non-oriented electrical steel sheet according to an embodiment of the present disclosure contributes to the manufacture of environmentally friendly vehicle motors, high-efficiency home appliance motors, and super premium-grade electric motors.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032]

FIG. 1 illustrates a schematic cross-sectional view of a non-oriented electrical steel sheet according to an embodiment of the present disclosure.

FIG. 2 schematically illustrates a cut portion in a cross-section of the non-oriented electrical steel sheet according to an embodiment of the present disclosure.

DETAILED DESCRIPTION OF AN EMBODIMENTS

[0033] It should be understood that, although the terms "first," "second," "third," etc. may be used herein to describe various elements, components, regions, layers, and/or sections, they are not limited thereto. These terms are only used to distinguish one element, component, region, layer, or section from another element, component, region, layer, or section. Therefore, a first part, component, area, layer, or section to be described below may be referred to as a second part, component, area, layer, or section within the range of the present disclosure.

[0034] The technical terms used herein are to simply mention a particular embodiment and are not meant to limit the present disclosure. An expression used in the singular encompasses an expression of the plural, unless it has a clearly different meaning in the context. In the specification, it should be understood that terms such as "including," "having," etc., are intended to indicate the existence of specific features, regions, numbers, stages, operations, elements, components, and/or combinations thereof disclosed in the specification, and are not intended to preclude the possibility that one or more other features, regions, numbers, stages, operations, elements, components, and/or combinations thereof may exist or may be added.

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

[0036] Unless otherwise stated, % means wt%, and 1 ppm is 0.0001 wt%.

[0037] In an embodiment of the present disclosure, inclusion of an additional element means replacing the balance of iron (Fe) by an additional amount of the additional elements.

[0038] Unless otherwise stated, all terms used herein, including technical or scientific terms, have the same meanings as those generally understood by those with ordinary knowledge in the field of art to which the present disclosure belongs. Terms defined in commonly used dictionaries may be further interpreted as having meanings consistent with the relevant technical literature and the present disclosure, and are not to be construed as having idealized or very formal meanings unless stated otherwise.

[0039] The present disclosure will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. As those skilled in the art would realize, the described embodi-

ments may be modified in various different ways, all without departing from the spirit or scope of the present disclosure.

[0040] A non-oriented electrical steel sheet according to an embodiment of the present disclosure includes, in wt%, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, and Mn: 0.1 to 2.0%, with the balance being Fe and inevitable impurities.

[0041] Hereinafter, the reason for limiting the components of the non-oriented electrical steel sheet will be described.

Si: 1.5 to 4.5 wt%

[0042] Silicon (Si) increases the specific resistance of the material, lowers iron loss, and increases strength through solid solution strengthening. If too little Si is added, an effect of improving the iron loss and strength may be insufficient. If too much Si is added, brittleness of the material increases, rolling productivity is rapidly deteriorated, and an oxide layer and an oxide on a surface that are harmful to magnetic properties may be formed. Accordingly, Si may be included in an amount of 1.5 to 4.5 wt%. More specifically, it may be included in an amount of 2.0 wt% to 4.3 wt%. More specifically, it may be included in an amount of 2.5 wt% to 4.0 wt%.

Al: 0.1 to 2.0 wt%

[0043] Aluminum (Al) increases the specific resistance of the material, lowers iron loss, and increases strength through solid solution strengthening. If too little Al is added, fine nitrides may be formed, making it difficult to obtain the effect of improving magnetic properties. If too much Al is added, the nitride is excessively formed, deteriorating the magnetic properties, and causing problems in all processes such as steel making and continuous casting, which may considerably reduce 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 0.3 wt% to 1.5 wt%. More specifically, it may be included in an amount of 0.5 wt% to 1.0 wt%.

Mn: 0.1 to 2.0 wt%

[0044] Manganese (Mn) improves the iron loss by increasing the specific resistance of the material and serves to form a sulfide. If too little Mn is added, the sulfide is finely formed, causing magnetic deterioration, and when too much Mn is added, fine MnS is excessively precipitated and the formation of a {111} texture disadvantageous to magnetic properties is promoted, resulting in a rapid decrease in magnetic flux density. Accordingly, Mn may be included in an amount of 0.1 wt% to 2.0 wt%. More specifically, it may be included in an amount of 0.2 wt% to 1.5 wt%. More specifically, it may be included in an amount of 0.3 wt% to 1.0 wt%.

[0045] The non-oriented electrical steel sheet according to an embodiment of the present disclosure may further include one or more of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.005 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

[0046] Phosphorus (P) is a grain boundary segregation element that may improve the magnetic flux density, but if too much is added, it increases the brittleness of the steel sheet, resulting in poor weldability. More specifically, P may be included in an amount of 0.0001 to 0.0500 wt%.

C: 0.005 wt% or less

[0047] Carbon (C) may cause magnetic aging and combine with other impure elements to form carbides, which may impede grain boundary or domain wall movement and deteriorate magnetic properties. More specifically, C may be included in an amount of 0.0001 to 0.003 wt%.

S: 0.005 wt% or less

[0048] Sulfur (S) may form fine precipitates, MnS and CuS, which may deteriorate magnetic properties and hot workability. More specifically, S may be included in an amount of 0.0001 to 0.0030 wt%.

Ti: 0.005 wt% or less

[0049] Titanium (Ti) has a strong tendency to form precipitates inside the steel, and may deteriorate the iron loss by forming fine carbides, nitrides, or sulfides inside the base material, thereby suppressing grain growth and domain wall

movement. Specifically, Ti may be included in an amount of 0.0001 to 0.003 wt%.

N: 0.005 wt% or less

[0050] Nitrogen (N) not only forms fine AlN precipitates inside the base material, but also combines with other impurities to form fine precipitates, which may suppress grain growth and domain wall movement, thereby deteriorating iron loss. Specifically, N may be included in an amount of 0.0001 to 0.0030 wt%.

[0051] The non-oriented electrical steel sheet according to an embodiment of the present disclosure may further include 0.005 to 0.200 wt% of each or a combined amount of one or two or more of Sn, Sb, Bi, Pb, Ge, and As.

Sn and Sb

[0052] Tin (Sn) and antimony (Sb) segregate at the initial grain boundaries during final recrystallization annealing and serve to suppress the development of the {111} orientation, which deteriorates magnetic properties. If too much Sn and Sb are added, they may hinder the recovery and growth of coarse elongated grain structures and deteriorate surface quality. Therefore, one or more of Sn and Sb may be further added within the aforementioned range. More specifically, Sn may be included in an amount of 0.005 to 0.200 wt%, or Sb may be included in an amount of 0.005 to 0.200 wt%.

Bi, Pb, Ge and As

[0053] When additionally added, bismuth (Bi), lead (Pb), germanium (Ge), and arsenic (As) segregate at grain boundaries, thereby alleviating stress concentration at grain boundaries during cold rolling, thereby suppressing recrystallization of <111>ND orientation grains in the subsequent recrystallization annealing process, thereby improving magnetic flux density. If these are added appropriately, the aforementioned effects may be additionally obtained, but if they are included in excessive amounts, a large amount of segregation may occur, hindering grain growth and resulting in lower magnetic flux density and iron loss.

[0054] The non-oriented electrical steel sheet according to an embodiment of the present disclosure may further include one or more of Cu: 0.005 to 0.2 wt%, 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%).

Cu: 0.005 to 0.200 wt%

[0055] Copper (Cu) serves to form sulfides together with Mn. When Cu is further added, if too little Cu is added, (Cu-Mn)S may be finely precipitated and magnetic properties may be degraded. If too much Cu is added, high temperature brittleness occurs, which may cause cracks to form during casting or hot rolling. More specifically, Cu may be included in an amount of 0.01 to 0.10 wt%.

Cr: 0.01 to 0.50 wt%

[0056] Chromium (Cr) serves to improve iron loss by increasing specific resistance. If too little Cr is added, the effect of increasing specific resistance may not be sufficient. If too much Cr is included, the magnetic flux density may deteriorate. Specifically, Cr may be contained in an amount of 0.050 to 0.20 wt%.

Ni: 0.05 wt% or less

[0057] Nickel (Ni) may react with impure elements to form fine sulfides, carbides, and nitrides, which may have a detrimental 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

[0058] If the content of zinc (Zn) is excessive, it may act as an impurity and deteriorate magnetic properties. Therefore, Zn may be further added within the above-mentioned range. More specifically, Zn may be included in an amount of 0.001 to 0.005 wt%.

Co: 0.05 wt% or less

[0059] Cobalt (Co), while not forming fine precipitates that degrade the magnetic properties of the steel sheet, may

increase high-temperature strength, leading to poor coil shape after hot rolling.

[0060] The non-oriented electrical steel sheet according to an embodiment of the present disclosure may further include 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

[0061] If molybdenum (Mo) is added in excessive amounts, the effect of improving the texture may be reduced by suppressing the segregation of segregation 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 because it serves to improve the texture by segregating on the surface and grain boundaries. 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

[0062] If boron (B) is added in excessive amounts, it may cause deterioration of magnetic properties through the formation of inclusions in the steel. 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 at 0.0001 wt% due to steelmaking costs. More specifically, B may be included in an amount of 0.0001 to 0.0030 wt%.

V: 0.0050wt% or less

[0063] Vanadium (V) has a strong tendency to form precipitates inside the steel, and they deteriorate the iron loss by forming fine carbides or nitrides inside the base material, thereby suppressing grain growth and domain wall movement. Therefore, the content of V may be 0.0050 wt% or less. The lower limit thereof is not particularly limited, but it may be set at 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

[0064] Calcium (Ca) has a strong tendency to form precipitates inside the steel, and they deteriorate the iron loss by forming fine sulfides inside the base material, thereby suppressing grain growth and domain wall movement.

Nb: 0.0050wt% or less

[0065] Niobium (Nb) has a strong tendency to form precipitates inside the steel, and they deteriorate the iron loss by forming fine carbides or nitrides inside the base material, thereby suppressing grain growth and domain wall movement. Therefore, the Nb content may be 0.0050 wt% or less. The lower limit thereof is not particularly limited, but it may be set at 0.0003 wt% due to steelmaking costs. That is, Nb may be included in an amount of 0.0003 to 0.0050 wt%. More specifically, Nb may be included in an amount of 0.0003 to 0.0030 wt%.

Zr: 0.0050 wt% or less

[0066] If zirconium (Zr) is added in excessive amounts, it may cause deterioration of magnetic properties through the formation of inclusions in the steel. Therefore, Zr 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 at 0.0001 wt% due to steelmaking costs. 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

[0067] Tellurium (Te) diffuses into the oxide layer on the surface of a hot-rolled coil, increases the coefficient of friction between the oxide layer and the rolling work roll, and improves hardness by concentrating under the oxide layer, so that it may be added to prevent the oxide layer that is broken during rolling from being pressed into the base metal and to be removed. If the amount of Te added is too small, the effect may be insignificant. If too much Te is added, the oxide layer is easily removed, causing the base material to come into direct contact with the work roll, thereby reducing the above effect, and excessive deformation bands may be generated within the steel sheet during

cold rolling, which may lead to the development of <111>//ND texture, which is disadvantageous for magnetic properties. More specifically, tellurium may be included in an amount of 0.0001 to 0.007 wt%.

Mg: 0.0050 wt% or less

[0068] Magnesium (Mg) is an element that mainly combines with sulfur to form sulfides, and may affect the surface oxide layer of iron. 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 set at 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%.

[0069] The balance includes Fe and inevitable impurities. The inevitable impurities are impurities mixed in the steelmaking and the manufacturing process of the non-oriented electrical steel sheet, which are widely known in the field, and thus a detailed description thereof will be omitted. In an embodiment of the present disclosure, the addition of elements other than the above-described alloy components is not excluded, and various elements may be included within a range that does not hinder the technical concept of the present disclosure. When the additional elements are further included, they replace the balance of Fe.

[0070] As described above, in an embodiment of the present disclosure, by appropriately controlling the alloy composition of the steel sheet and appropriately developing a specific texture, magnetic properties may be improved.

[0071] The non-oriented electrical steel sheet according to an embodiment of the present disclosure has the area fraction of <111>//ND grains is 30% or less, the sum of the area fraction of <110>//ND grains and <100>//ND grains is 28% or more, and the ratio of the area fraction of <100>//ND grains to the area fraction of <110>//ND grains is 0.4 or more.

[0072] In this case, <111>//ND, <110>//ND and <100>//ND refer to grains in which the <111>, <110>, and <100> axes of the grain are parallel to the normal direction (ND direction) of a rolling surface of the steel sheet at an angle of 15° or less.

[0073] <111>//ND grains are grains that are disadvantageous to magnetic properties, so minimizing their proportion is advantageous to magnetic properties. The area fraction of <111>//ND grains is 30.0% or less. More specifically, it may be between 10.0 and 30.0%.

[0074] <110>//ND grains and <100>//ND grains are easier to magnetize than <111>//ND grains, and securing as many of these grains as possible is advantageous for magnetic properties. The sum of the area fraction of <110>//ND grains and <100>//ND grains is 28.0% or more. More specifically, the sum of the area fractions of <110>//ND grains and <100>//ND grains may be 29.0 to 75.0%.

[0075] Among <110>//ND grains and <100>//ND grains, <100>//ND grains are more advantageous for magnetic properties. Accordingly, the ratio of the area fraction of <100>//ND grains to the area fraction of <110>//ND grains ($\frac{\text{<100>//ND}}{\text{<110>//ND}}$) may be set to 0.40 or more. More specifically, $\frac{\text{<100>//ND}}{\text{<110>//ND}}$ may be set to 0.80 to 3.00.

[0076] The <111>//ND, <110>//ND, and <100>//ND grain fractions may be measured using an EBSD measuring device from TSL equipped with a JEOL scanning electron microscope (model number JSM-7200F) on a cross-section including the rolling direction of the steel sheet. Area fraction refers to the ratio of the area occupied by grains of a specific orientation to the total area of the steel sheet as measured by electron beam backscatter diffraction (EBSD). The range within 15° means that the angle between the vertical axis of the surface of the steel sheet and any plane including the corresponding orientation is within 15°, and may be measured using TSL's EBSD crystal orientation analysis program (OIM). More specifically, the steel sheet was cut parallel to the plate thickness direction, and the crystal orientation of the crystal grains was analyzed through EBSD measurement at the center of the cut surface. The measurement interval was 2 μm and the total measurement area may be 3000 μm × 3000 μm.

[0077] FIG. 1 illustrates a schematic cross-sectional view of a non-oriented electrical steel sheet according to an embodiment of the present disclosure.

[0078] As shown in FIG. 1, a non-oriented electrical steel sheet 100 includes a surface portion 20 from the surface of the steel sheet to 1/20 of the total thickness and a center portion 10 from more than 1/20 to 1/2 of the total thickness based on a cross-section including the thickness direction (ND direction). In FIG. 1, for convenience, the surface portion 20 is shown to exist only on one surface, but the surface portion 20 exists on both surfaces.

[0079] In an embodiment of the present disclosure, by appropriately controlling the ratio of precipitates present in the center portion 10 and the surface portion 20, the magnetic properties of the non-oriented electrical steel sheet may be improved without causing deterioration of the surface portion.

[0080] Specifically, the ratio of the number of precipitates per unit area (P_s) of the surface portion 20 to the number of precipitates per unit area (P_l) of the center portion 10 ($\frac{P_s}{P_l}$) may be 1.20 or less. If this ratio is too high, it means that there are too many precipitates on the surface portion 20 or too few precipitates on the center portion 10. When a large number of precipitates present on the surface portion 20, the magnetic properties of the surface portion 20 deteriorates due to the large number of precipitates, and ultimately, the magnetic properties of the entire non-oriented

electrical steel sheet 100 deteriorates. If too little precipitate presents in the center portion 10, grain growth may be promoted internally, causing the microstructure to become uneven and increasing iron loss. More specifically, the ratio of the number of precipitates per unit area (P_S) of the surface portion 20 to the number of precipitates per unit area (P_I) of the center portion 10 (P_S/P_I) may be 0.95 to 1.19.

[0081] In an embodiment of the present disclosure, precipitates refer to elements present in an electrical steel sheet that coagulate with each other to form grain-shaped particles. More specifically, precipitates refer to one or more elements among Si, Al, Mn, Ti, Nb, Cu, and Zr are combined with one or more elements among C, N, S, and O to form particles. Precipitates may be measured by observing a region of at least 200 μm^2 through TEM, including the thickness direction (ND direction), more specifically, the plane perpendicular to the steel sheet rolling direction (TD plane). Precipitates with a particle diameter of less than 0.03 μm do not have a significant effect on magnetic properties, so they are excluded from the ratio calculation. Here, the particle diameter refers to the diameter of an imaginary circle having the same area as the area occupied by the precipitate. As described later, an oxide layer 30 may present on the surface layer of the surface portion 20, but the oxide layer 30 is excluded from the calculation of the precipitate density (both the measurement area and the number of precipitates is excluded).

[0082] More specifically, the precipitate density of the surface portion 20 may be $0.5/\mu\text{m}^2$ to $2.5/\mu\text{m}^2$, and the precipitate density of the center portion 10 may be $0.3/\mu\text{m}^2$ to $2.5/\mu\text{m}^2$.

[0083] FIG. 2 illustrates a schematic view of a cross-section of a non-oriented electrical steel sheet according to an embodiment of the present disclosure.

[0084] As shown in FIG. 2, the oxide layer 30 is included that exists from the surface of the non-oriented electrical steel sheet 100 toward the inside.

[0085] The oxide layer 30 may be formed when oxygen penetrates the steel sheet during the manufacturing process of the electrical steel sheet.

[0086] The oxide layer 30 is defined as a portion containing 20 wt% oxygen from the surface of the steel sheet toward the inside. The detection and thickness of the oxide layer 30 may be determined by processing the TD surface of the specimen with FIB and observing it with TEM, and determining that the part containing oxygen of 0.01 wt% or more is the oxide layer. In this case, the steel sheet sample may be used as a sample without an insulating film formed or as a sample with an insulating film formed and removed. In order to reduce the measurement error according to the position, the specimen may be measured at least 20 times with a length of at least 200 μm in the RD direction and at intervals of at least 1 μm in the TD direction, and measured as the average value.

[0087] The thickness of the oxide layer 30 may be less than or equal to 200 nm. If the thickness of the oxide layer 30 is too thick, a large amount of oxygen may penetrate the steel sheet, which may deteriorate magnetic properties. More specifically, the thickness of the oxide layer 30 may be 5 to 190 nm. The thickness of the oxide layer 30 may be the average thickness of the oxide layer 30 within the measured specimen.

[0088] As shown in FIG. 2, in a cross-section including the rolling direction of the steel sheet, there is an oxide layer disconnecting portion having an oxide layer thickness of 5 nm or less, and a maximum length (DC_L) of this disconnecting portion may be 750 nm or less per 100 μm in the rolling direction. If the maximum length of the oxide layer disconnecting portion is too long, additional oxidation and nitriding may occur at the disconnecting portion, increasing iron loss. More specifically, the maximum length (DC_L) of the disconnecting portion may be 0.01 to 730 nm per 100 μm in the rolling direction. More specifically, the maximum length (DC_L) of the disconnecting portion may be 0.01 to 730 nm per 100 μm in the rolling direction. The measurement and determination of the disconnecting portion may be performed in the same manner as the measurement and determination of the oxide layer described above.

[0089] The oxide layer 30 and the oxide layer disconnecting portion may be appropriately formed by adjusting the conditions in the annealing process before cold rolling. A more specific method will be described later in relation to the method of manufacturing the non-oriented electrical steel sheet.

[0090] Due to the surface concentration of Al, the oxide layer 30 may include 40 wt% or more of Al. Specifically, Al may be included in an amount of 50 to 60 wt%. The remaining alloy components other than Al and O are the same as the alloy components of the non-oriented electrical steel sheet described above. Since the thickness of the oxide layer 30 is very thin compared to the thickness of the entire non-oriented electrical steel sheet 100, it does not substantially affect the alloy composition of the non-oriented electrical steel sheet 100.

[0091] As described above, in an embodiment of the present disclosure, it is possible to improve magnetic properties by appropriately controlling the steel component and appropriately forming precipitates according to thickness. Specifically, the iron loss ($W_{10/400}$) of the non-oriented electrical steel sheet may be 13.0 W/Kg or less based on a thickness of 0.25 mm. In addition, the magnetic flux density (B_{50}) may be 1.66T or more. The iron loss ($W_{10/400}$) refers to the iron loss when a magnetic flux density of 1.0 T is induced at a frequency of 400 Hz. The magnetic flux density (B_{50}) refers to the magnetic flux density induced in a magnetic field of 5000 A/m. More specifically, the iron loss ($W_{10/400}$) of the non-oriented electrical steel sheet may be 10.0 to 12.5W/kg. More specifically, it may be 10.5 to 135W/kg. The magnetic flux density (B_{50}) may be 1.68 T to 1.75 T.

[0092] A method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present

disclosure includes a step of hot-rolling a slab to manufacture a hot-rolled steel sheet, a pre-cold rolling annealing step of annealing the hot-rolled steel sheet, a step of cold-rolling the annealed steel sheet to manufacture a cold-rolled sheet, and a cold-rolled sheet annealing step of annealing the cold-rolled sheet.

[0093] Hereinafter, respective steps will be specifically described.

[0094] First, the slab is hot-rolled.

[0095] The alloy composition of the slab has been described in the alloy composition of the non-oriented electrical steel sheet described above, so duplicate descriptions will be omitted. Since the alloy composition does not substantially change during the manufacturing process of the non-oriented electrical steel sheet, the alloy composition of the non-oriented electrical steel sheet and the slab are substantially the same.

[0096] Specifically, the slab includes, in wt%, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, with the balance being Fe and inevitable impurities.

[0097] Other additional elements have been described in the alloy composition of the non-oriented electrical steel sheet, so duplicate descriptions will be omitted.

[0098] The slab may be heated before hot-rolling. The heating temperature of the slab is not limited, but the slab may be heated at 1,200°C or less. When the slab heating temperature is too high, precipitates such as AlN and MnS present in the slab are re-dissolved and then finely precipitated during hot-rolling and annealing, thereby hindering grain growth and reducing magnetic properties.

[0099] Next, the slab is hot-rolled to manufacture the hot-rolled sheet. A thickness of the hot-rolled sheet may be 1.0 to 4.5 mm. In the manufacturing of the hot-rolled sheet, a finish rolling temperature may be 800°C or higher. Specifically, it may be 800 to 1,000°C. The hot-rolled sheet may be wound at temperatures of 600°C or more. More specifically, the thickness of the hot-rolled sheet may be 1.5 to 4.3 mm.

[0100] In an embodiment of the present disclosure, after manufacturing the hot-rolled steel sheet, a pre-cold rolling annealing step of immediately annealing the hot-rolled steel sheet may be performed. Alternatively, after performing preliminary cold rolling on the hot-rolled steel sheet, a pre-cold rolling annealing step of annealing the preliminary cold-rolled sheet may be performed.

[0101] The preliminary cold rolling is distinguished from cold rolling, which will be described later, in that it is the first rolling step of the process of rolling to an intermediate thickness rather than the final product thickness, then performing intermediate annealing, and then cold rolling to the final product thickness.

[0102] The preliminary cold rolling may be performed in a reduction ratio range of 30 to 80% to improve the final cold rolling productivity and the grain size of the final product sheet. In addition, in the case in which rolling productivity is not considered, performing preliminary cold rolling in a reversing mill is also possible in the present disclosure. The preliminary cold-rolled sheet may have a thickness of 0.3 to 1.5 mm. More specifically, the reduction ratio may be 60 to 75%, and the thickness may be 0.6 to 1.3 mm.

[0103] The preliminary cold reduction ratio may be calculated by (steel sheet thickness before rolling - steel sheet thickness after rolling) / steel sheet thickness before rolling. If the reduction ratio in the preliminary cold rolling step is too low, the rolling load increases during the final cold rolling, which reduces productivity, and the final reduction ratio increases, which may cause problems such as promoting fine <111>/ND orientation recrystallization. Conversely, if the reduction ratio is too high, the cold rolling load increases, and the possibility of sheet breakage also increases.

[0104] The preliminary cold rolling step may be performed at a temperature ranging from 60 to 300°C. This temperature may be raised naturally by the temperature of the steel sheet rising due to friction between the steel sheet and the rolling rolls, or by applying heat from the outside. If the temperature is too low, the rolling load significantly increases, and the steel sheet may slip between the rolling rolls instead of being rolled, which may cause problems such as twisting. If the temperature is too high, a thick oxide layer may occur on the surface of the steel sheet, which may deteriorate magnetic properties, and issues such as ignition of rolling oil may occur. More specifically, it is preferably performed at a temperature of 70 to 250°C. The aforementioned temperature refers to the temperature of the steel sheet.

[0105] As described above, the preliminary cold rolling step may be omitted if necessary.

[0106] Subsequently, in the pre-cold rolling annealing step, the hot-rolled steel sheet or the preliminary cold-rolled sheet is annealed. In an embodiment of the present disclosure, by controlling the heating rate, dew point, and tension in the pre-cold rolling annealing step, the texture and the oxide layer within the steel sheet may be appropriately formed.

[0107] Before the pre-cold rolling annealing step, the method for manufacturing the non-oriented electrical steel sheet includes a first heating step of heating the steel sheet to 750°C at a heating rate of 22°C/sec or less before the pre-cold rolling annealing step, and a second heating step of heating it at a heating rate of 28°C/sec or more to a temperature exceeding 750°C and up to a soaking temperature.

[0108] The first heating step may be a step of heating it in a temperature range from 100 to 750°C. In this range, it is necessary to heat up at a heating rate of 22°C/sec or less. If the heating rate is faster than this, <111>/ND texture, which has a negative effect on magnetic properties, may develop. More specifically, the heating rate of the first heating

step may be 10 to 20°C/sec. The heating rate may vary during the first heating step, and the above-mentioned heating rate refers to an average heating rate within the temperature range of the first heating step. The temperature reference may be based on the surface temperature of the steel sheet.

[0109] The second heating step is a step of heating from 750°C to the soaking temperature of the pre-cold rolling annealing step. The temperature may be heated to a higher temperature than the soaking temperature if necessary, but the heating rate may be limited only to reaching the soaking temperature.

[0110] In the second heating step, the temperature may be heated at a heating rate of 28°C/sec or higher. If the heating rate is not sufficient, the development of <100>ND may be hindered. More specifically, in the second heating step, the temperature may be heated at a heating rate of 30 to 500°C/sec.

[0111] Further, in the pre-cold rolling annealing step, it is preferable that the atmosphere gas be a hydrogen-nitrogen mixed gas atmosphere containing at least 0.1% by volume of hydrogen. If the hydrogen content is low, an additional oxide layer may form during heat treatment, which may remain in the final product and cause increased iron loss. The higher the hydrogen content, the more advantageous it is for suppressing the oxide layer, but if used excessively, it becomes a factor in process load. Therefore, it is preferable to perform annealing in a mixed gas atmosphere containing 0.1 to 50% by volume of hydrogen gas. More specifically, in the pre-cold rolling annealing step, annealing may be performed in a mixed gas atmosphere of hydrogen and nitrogen gas containing 3 to 30% by volume of hydrogen gas in the atmosphere gas.

[0112] Additionally, the pre-cold rolling annealing step may have a dew point of -50 to -10°C during annealing. If the dew point is too low, a fine oxide layer is formed and a large number of disconnecting portions in the surface oxide layer may occur during cold rolling. If the dew point is too high, a thick oxide layer is formed, which may have a negative effect on the magnetic properties. More specifically, the dew point may be in the range of -50 to -20°C. More specifically, the dew point may be the dew point of the atmosphere during the soaking process.

[0113] Additionally, a tension of 0.20 kgf/mm² to 3.00 kgf/mm² may be applied. If the tension is too low, proper annealing may not occur. If the tension is too high, a large number of <111>ND grains are generated, and a large number of oxide layer disconnecting portions may occur. More specifically, the tension may be 0.30 to 1.00 kgf/mm². More specifically, the tension may be the tension measured at the exit side of the annealing furnace, and may be measured using a tension meter measuring device.

[0114] The soaking temperature in the pre-cold rolling annealing step may be 850 to 1010°C. If the annealing temperature is too low, the recrystallized structure is not formed or grows finely, resulting in a small increase in flux density, and if the annealing temperature is too high, the magnetic properties may actually deteriorate, and the rolling workability may deteriorate due to plate-shaped deformation. More specifically, the temperature range may be 900 to 1005°C. The soaking time may be between 30 and 1000 seconds.

[0115] The pre-cold rolling annealing mentioned above may be performed in a vertical continuous annealing facility or a horizontal continuous annealing facility. If scale removal is omitted after hot-rolling, scale removal may be performed after the pre-cold rolling annealing. If scale remains in the final manufactured non-oriented electrical steel sheet, it will harm the magnetic properties. In addition, when cold rolling is performed with scale remaining on the surface, the scale may be pressed into or removed from the surface and marks may form irregularities, which may deteriorate the operational stability and magnetic properties of the motor. After acid pickling, the scale may be completely removed or may be present at a thickness of 0.01 μm or less. Pickling refers to all physical and chemical descaling methods, not just acid immersion. Acid immersion, shot blasting or surface grinding may be used as pickling methods.

[0116] After the pre-cold rolling annealing, the average grain size of the steel sheet may be 75 to 200 μm. If the average grain size is too small, a large number of <111>ND grains are generated, and the magnetic properties may be poor. If the average grain size is too large, the cold rolling properties are deteriorated, and as the grains grow larger, the oxide layer thickness also increases, which may deteriorate the iron loss. More specifically, after the pre-cold rolling annealing, the average grain size of the steel sheet may be 80 to 195 μm. The average grain size may be obtained by calculating the number of grains contained in the specimen for the cross-section of the steel sheet and calculating the average area. The grain size may be obtained from the diameter of a circle having the same area as the corresponding area.

[0117] Next, the annealed steel sheet is cold-rolled to manufacture a cold-rolled sheet. At this time, cold rolling may be performed at the reduction ratio of 40 to 85%. If the reduction ratio is too low, strain energy accumulated in the rolled steel sheet will be small, making it difficult to recrystallize in the subsequent annealing process, so the rolled structure remains, which may cause problems in improving the magnetic flux density and iron loss. Conversely, if the reduction ratio is too high, the recrystallization of <111>ND orientation grains may be promoted during the subsequent annealing process, and the grains may become finer, resulting in a lower magnetic flux density and an increase in iron loss. More specifically, the reduction ratio may be 60 to 75%. The cold rolling step may be performed using a tandem cold rolling mill that continuously cold rolls the steel sheet using a plurality of rolling stands, or a reverse rolling mill that discontinuously cold rolls the steel sheet using 12 or more rolling rolls. The final rolled thickness may be from

0.1 to 0.35 mm.

[0118] Next, the cold-rolled sheet is annealed. The cold-rolled sheet annealing step may be annealed in an atmosphere with a dew point temperature of 0°C or lower. More specifically, it may be annealed in an atmosphere with a dew point temperature of -80 to -10°C.

[0119] The cold-rolled sheet annealing step may be annealed at a soaking temperature of 850 to 1100°C. If the soaking temperature is too low, the grains may not grow sufficiently, which may cause hysteresis loss to increase and the iron loss to deteriorate. If the soaking temperature is too high, problems such as increased eddy current loss and rapid decrease in magnetic flux density may occur. More specifically, annealing may be performed at a temperature of 900 to 1050°C. It may soak for 10 to 300 seconds.

[0120] In the cold-rolled sheet annealing process, the processed texture formed in the cold-rolling step may be entirely (that is, 99% or more) recrystallized.

[0121] After the cold-rolled sheet annealing, an insulating film may be formed. The insulating film may be formed as an organic, inorganic, or organic/inorganic composite film, and it may be formed with other insulating coating materials.

[0122] Hereinafter, the present disclosure will be described in more detail through an embodiment. However, the embodiment is only for illustrating the present disclosure, and the present disclosure is not limited thereto.

Embodiment

[0123] A slab containing 3.5% Si, 0.8% Al, 0.4% Mn, and other impurities in wt% was manufactured. This was heated to 1150°C and hot-rolled at a finishing temperature of 900°C to manufacture a hot-rolled sheet having a thickness of 2.0 mm. The hot-rolled sheet was pickled and then preliminarily cold-rolled to a thickness of 0.8 mm, and annealed before cold rolling under the conditions of a first heating rate (100 to 750°C), a second heating rate (750°C to the soaking temperature), the soaking temperature, the dew point, and the tension in Table 1. At this time, the annealing was performed in a hydrogen and nitrogen mixed-gas atmosphere containing 5% by volume of hydrogen. Next, the annealed steel sheet was cold-rolled to a thickness of 0.25 mm, and then final recrystallization annealing was performed for 100 seconds under the conditions of a dew point of -50°C and a soaking temperature of 1000°C.

[0124] The main characteristics of each specimen that has undergone the manufacturing process are summarized in Table 1.

[0125] The average grain size after the pre-cold rolling annealing was measured using an EBSD measuring device from TSL equipped with a JEOL scanning electron microscope (model number JSM-7200F).

[0126] The thickness of the oxide layer was measured at least 20 times at intervals of at least 1 μm in the area containing 5 wt% or more of Al and 3 wt% or more of O on the surface of the base material when the TD surface of the specimen was processed with FIB and observed with TEM, and the average value was indicated.

[0127] The maximum length of the oxide layer disconnecting portion is the maximum value measured in the rolling direction at the part where the oxide layer is not continuous but disconnected and the base material is exposed when the Al-containing oxide layer is observed in the rolling direction for 100 μm or more through TEM.

[0128] Analysis of precipitates by thickness within the steel sheet was performed using TEM measurements to obtain the ratio of the number of precipitates with a diameter of 0.03 μm or more in the 200 μm² regions of the surface and center, respectively.

[0129] <111>//ND, <110>//ND and <100>//ND grain fractions were measured using an EBSD measuring device from TSL equipped with a JEOL scanning electron microscope (model number JSM-7200F) on a cross-section including the rolling direction of the steel sheet. The error angle was set to 15°, and the measurement was performed using the crystal orientation analysis program (OIM) of TSL's EBSD. The steel sheet was cut parallel to the plate thickness direction, and the crystal orientation of the crystal grains was analyzed through electron beam backscatter diffraction (EBSD) measurement at the center of the cut surface. The measurement interval was 2 μm, and the total measurement area was 3000 μm × 3000 μm.

[0130] Magnetic properties such as magnetic flux density and iron loss were measured in the rolling direction and the vertical rolling direction using a single sheet tester by cutting 5 sheets of 60 mm width × 60 mm length for each specimen, and the average value was presented. In this case, W10/400 is the iron loss at a magnetic flux density of 1.0T with a frequency of 400Hz, and B₅₀ is the magnetic flux density of a steel sheet induced by a magnetic field of 5000A/m.

EP 4 826 036 A1

(Table 1)

	Category	First heating rate (°C /sec)	Second heating rate (°C /sec)	Soaking tem- perature (°C)	Dew point (°C)	Tension (kgf/mm ²)	Average grain size (μm)
5	A01	20	30	1000	-40	0.80	119
	A02	30	30	1000	-40	0.80	105
	A03	25	30	1000	-40	0.80	98
10	A04	15	30	1020	-40	0.80	150
	A05	15	30	1000	-40	0.09	Heat treatment failure
	A06	15	30	1000	-40	0.80	95
15	A07	20	50	1000	-40	3.20	100
	A08	20	50	1000	-40	0.80	88
	A09	20	50	1000	-40	0.80	106
	A10	20	25	1000	-40	0.30	194
20	A11	20	100	1000	-40	0.30	122
	A12	20	100	970	-40	0.30	116
	A13	20	250	970	-40	0.50	109
25	A14	20	500	950	-40	0.50	101
	A15	20	150	830	-40	0.50	68
	A16	15	150	950	-40	0.80	131
	A17	15	150	950	-40	0.80	118
30	A18	15	150	950	-40	0.80	124
	A19	15	150	950	-9	0.80	131
	A20	15	150	950	-40	0.80	118
35	A21	15	150	950	-60	0.80	124

(Table 2)

40	Category	<111>//ND (area%)	<110>//ND (area%)	<100>//ND (area%)	<110>//ND +<100>//N D (area%)	<100>//ND / <110>//ND
	A01	25.2	12.3	17.5	29.8	1.42
	A02	30.5	11.3	12.5	23.8	1.11
45	A03	29.8	15.8	6.2	22.0	0.39
	A04	22.5	14.2	18.5	32.7	1.30
	A05	-	-	-	-	-
	A06	21.8	10.4	22.5	32.9	2.16
50	A07	31.5	12.3	15.7	28.0	1.28
	A08	19.5	18.2	15.4	33.6	0.85
	A09	23.7	19.1	22.4	41.5	1.17
55	A10	33.5	10.8	15.9	26.7	1.47
	A11	24.8	11.9	25.8	37.7	2.17
	A12	23.1	15.4	20.8	36.2	1.35

(continued)

Category	<111>//ND (area%)	<110>//ND (area%)	<100>//ND (area%)	<110>//ND +<100>//N D (area%)	<100>//ND / <110>//ND
A13	18.4	14.7	25.1	39.8	1.71
A14	15.8	11.8	29.4	41.2	2.49
A15	34.8	22.7	8.7	31.4	0.38
A16	29.4	12.7	21.8	34.5	1.72
A17	28.5	10.5	23.3	33.8	2.22
A18	27.1	11.7	27.1	38.8	2.32
A19	29.4	12.7	21.8	34.5	1.72
A20	28.5	10.5	23.3	33.8	2.22
A21	27.1	11.7	27.1	38.8	2.32

(Table 3)

	Oxide layer thickness (nm)	Maximum length of oxide layer (nm)	Precipitates ratio (P _S /P _I)	W _{10/400} (W/kg)	B ₅₀ (Tesla)	Note
A01	50	450	1.00	12.1	1.66	Inventive material
A02	50	400	1.10	14.1	1.64	Comparative material
A03	50	330	1.19	13.9	1.65	Comparative material
A04	220	710	1.25	14.5	1.64	Comparative material
A05	-	-	-	-	-	Comparative material
A06	68	250	1.12	11.5	1.68	Inventive material
A07	180	1025	1.38	14.4	1.63	Comparative material
A08	115	120	1.08	11.8	1.67	Inventive material
A09	53	480	1.15	10.5	1.69	Inventive material
A10	75	430	1.05	13.6	1.64	Comparative material
A11	58	400	1.10	10.9	1.69	Inventive material
A12	175	330	1.19	11.3	1.68	Inventive material
A13	135	710	1.09	10.5	1.69	Inventive material
A14	120	200	1.05	10.2	1.71	Inventive material
A15	150	250	1.12	14.7	1.63	Comparative material
A16	110	300	1.11	11.3	1.68	Inventive material
A17	30	120	1.02	10.1	1.69	Inventive material
A18	53	480	1.09	10.9	1.68	Inventive material
A19	250	380	1.18	13.1	1.65	Comparative material
A20	30	120	1.02	10.1	1.69	Inventive material
A21	35	850	1.28	14.2	1.64	Comparative material

[0131] As shown in Tables 1 to 3, it can be seen that the remaining inventive examples with properly controlled steel components, properly controlled process conditions, developed specific texture, and properly formed thickness-specific precipitates and oxide layer characteristics have excellent iron loss and magnetic flux density.

[0132] On the other hand, if the process conditions are not properly controlled, specific texture is not developed, or thickness-specific precipitates and oxide layers by thickness are not properly formed, it can be seen that the iron loss and magnetic flux density are inferior.

[0133] The present disclosure may be embodied in many different forms, and should not be construed as being limited to the disclosed embodiments. In addition, it should be understood by those skilled in the art that various changes in form and details may be made thereto without departing from the technical spirit and essential features of the present disclosure. Therefore, it is to be understood that the above-described embodiments are for illustrative purposes only, and the scope of the present disclosure is not limited thereto.

[Description of symbols]

100:	Non-oriented electrical steel sheet	10:	Surface portion
20:	Center portion	30:	Oxide layer

Claims

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

in wt%, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, and Mn: 0.1 to 2.0%, with the balance being Fe and inevitable impurities, and
an area fraction of <111>//ND grains is 30% or less,
the sum of the area fraction of <110>//ND grains and <100>//ND grains is 28% or more,
the ratio of the area fraction of <100>//ND grains to the area fraction of <110>//ND grains is 0.4 or more,
wherein <111>//ND, <110>//ND, and <100>//ND refer to grains in which the <111>, <110>, and <100> axes of the grain are parallel to the normal direction (ND direction) of a rolling surface of the steel sheet at an angle of 15° or less.

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

an oxide layer existing from a surface toward the inside,
wherein a thickness of the oxide layer is 200 nm or less.

3. The non-oriented electrical steel sheet of claim 2, wherein

in a cross-section including a rolling direction of the steel sheet, a length of an oxide layer disconnecting portion in which the maximum thickness of the oxide layer is 5 nm or less is 750 nm or less per 100 μm in the rolling direction.

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

the ratio of the number of precipitates per unit area (P_S) in a surface portion from the surface to the inside of the steel sheet of up to 1/20 of the total thickness to the number of precipitates per unit area (P_I) in a center portion more than 1/20 to 1/2 of the total thickness is 1.2 or less.

5. 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: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

6. The non-oriented electrical steel sheet of claim 1, further comprising:

0.005 to 0.200 wt% in each or a combined amount of one or two or more of Sn, Sb, Bi, Pb, Ge, and As.

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

one or more of Cu: 0.005 to 0.2 wt%, 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%).

8. 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%).

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

a step of hot rolling a slab including, in wt%, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, and Mn: 0.1 to 2.0%, with a balance being Fe and inevitable impurities, to manufacture a hot-rolled sheet;
 a pre-cold rolling annealing step of annealing the hot-rolled steel sheet;
 a step of cold rolling the annealed steel sheet to manufacture a cold-rolled steel sheet; and
 a cold-rolled sheet annealing step of annealing the cold-rolled sheet,
 before the pre-cold rolling annealing step, comprising:

a first heating step of heating the steel sheet to 750°C at a heating rate of 22°C/sec or less before the pre-cold rolling annealing step; and
 a second heating step of heating the steel sheet at a heating rate of 28°C/sec or more to a temperature exceeding 750°C and up to a soaking temperature.

10. The method for manufacturing the non-oriented electrical steel sheet of claim 9, 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: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

11. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein the slab further comprises 0.005 to 0.200 wt% in each or a combined amount of one or two or more of Sn, Sb, Bi, Pb, Ge, and As.

12. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein the slab further comprises one or more of Cu: 0.005 to 0.2 wt%, 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%).

13. The method for manufacturing the non-oriented electrical steel sheet of claim 9, 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%).

14. The method for manufacturing the non-oriented electrical steel sheet of claim 9, further comprising a step of preliminarily cold rolling a hot-rolled sheet prior to the pre-cold rolling annealing step.

15. The method for manufacturing the non-oriented electrical steel sheet of claim 14, wherein a reduction ratio in the step of preliminary cold rolling is 30 to 80%.

16. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein the soaking temperature of the pre-cold rolling annealing step is 850 to 1010°C.

17. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein the pre-cold rolling annealing step is performed at a dew point of -50 to -10°C while applying a tension of 0.2 to 3.0 kgf/mm².

18. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein a reduction ratio in the step of manufacturing the cold-rolled steel sheet is 40 to 85%.

19. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein the cold-rolled sheet annealing step is performed at a soaking temperature of 850 to 1100°C in an atmosphere with a dew point below 0°C.

FIG. 1

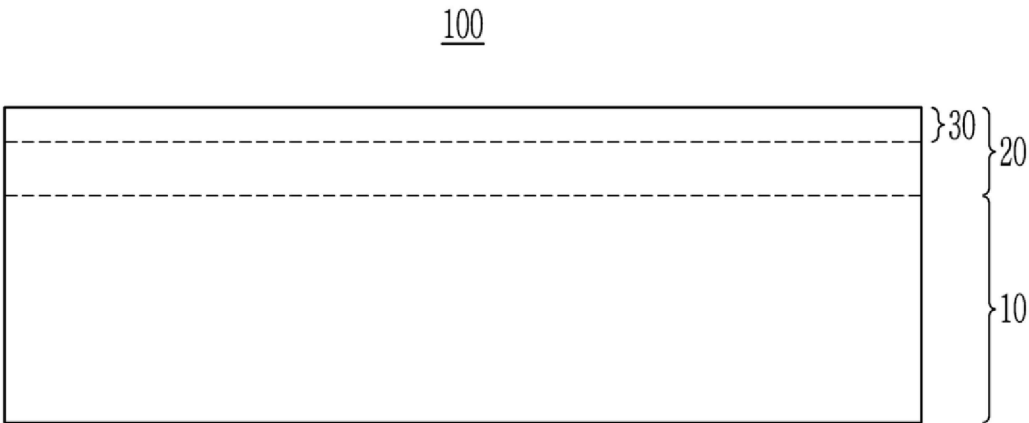
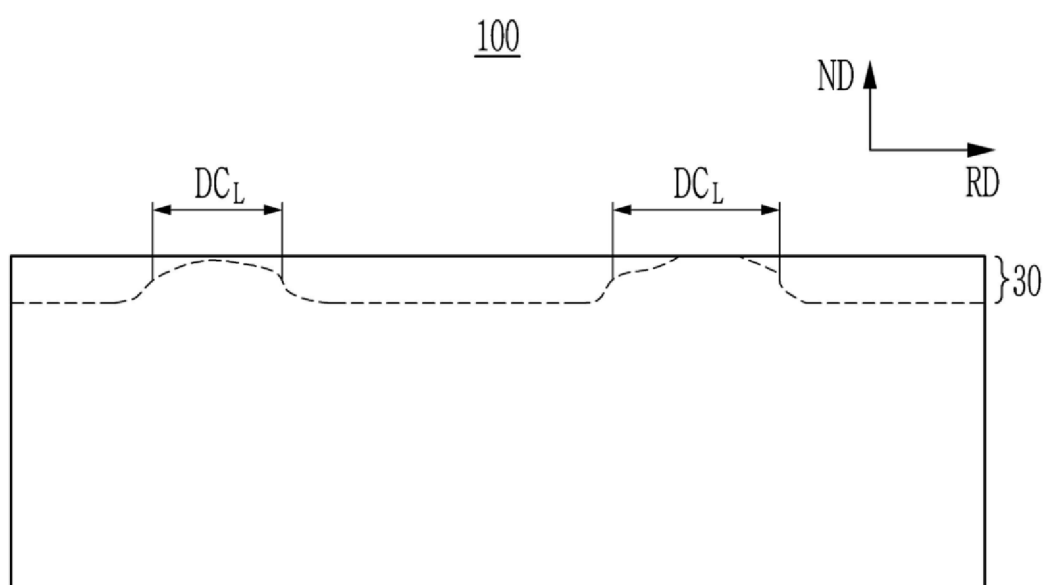


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/097009

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/06(2006.01)i; C22C 38/04(2006.01)i; C22C 38/14(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 8/12(2006.01); C22C 38/06(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), 집합조직(texture, aggregate structure), 방위(crystal orientation), 승온속도(heating velocity), 소둔(annealing)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-1728028 B1 (POSCO) 18 April 2017 (2017-04-18) See claims 1 and 10 and table 10.	1-19
A	KR 10-1263845 B1 (POSCO) 13 May 2013 (2013-05-13) See claims 1 and 6.	1-19
A	KR 10-2015-0074296 A (POSCO) 02 July 2015 (2015-07-02) See claim 11 and table 3.	1-19
A	KR 10-2012-0074012 A (POSCO) 05 July 2012 (2012-07-05) See claims 1 and 6.	1-19
A	KR 10-1263844 B1 (POSCO) 13 May 2013 (2013-05-13) See claims 1 and 7.	1-19

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

“A” document defining the general state of the art which is not considered to be of particular relevance

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“E” earlier application or patent but published on or after the international filing date

“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	Date of mailing of the international search report
18 March 2025	18 March 2025
Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office Government Complex-Daejeon Building 4, 189 Cheongsaro, Seo-gu, Daejeon 35208	
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/097009

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Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
KR 10-1728028 B1	18 April 2017	CN 108699658 A	23 October 2018
		EP 3395962 A1	31 October 2018
		EP 3395962 B1	28 October 2020
		EP 3395962 B9	14 April 2021
		JP 2019-507245 A	14 March 2019
		JP 7032314 B2	08 March 2022
		US 11230745 B2	25 January 2022
		US 2019-0017136 A1	17 January 2019
		WO 2017-111554 A1	29 June 2017
KR 10-1263845 B1	13 May 2013	KR 10-2012-0074021 A	05 July 2012
KR 10-2015-0074296 A	02 July 2015	CN 104674136 A	03 June 2015
		CN 104674136 B	14 November 2017
		KR 10-1665950 B1	13 October 2016
		KR 10-2015-0062250 A	08 June 2015
KR 10-2012-0074012 A	05 July 2012	KR 10-1263797 B1	13 May 2013
KR 10-1263844 B1	13 May 2013	KR 10-2012-0074011 A	05 July 2012

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