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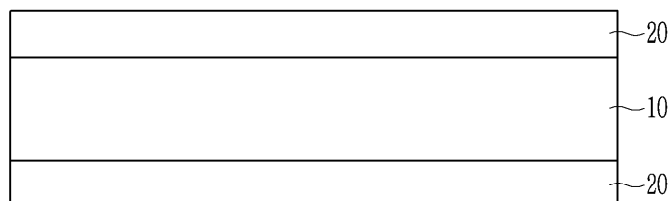
(54) **NON-ORIENTED ELECTRICAL STEEL SHEET AND METHOD FOR MANUFACTURING SAME**

(57) An embodiment of the present invention provides a non-oriented electrical steel sheet including: in wt%, Si: 1.5 to 5.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, with the balance being Fe and inevitable impurities, wherein a maximum value of an orientation distribution function (ODF) shown in the $\phi 2=45^\circ$ cross-section of

the Euler space is 3.0 or less, the non-oriented electrical steel sheet includes a surface portion and center portion up to a depth of 50 μm from a steel sheet surface toward an inner direction, and a ratio of an average grain size in the surface portion to an average grain size in the center portion is 0.4 to 0.6.

FIG. 1

100



Description**[Technical Field]**

5 **[0001]** An embodiment of the present invention relates to a non-oriented electrical steel sheet and a method for manufacturing the same. Specifically, an embodiment of the present invention relates to a non-oriented electrical steel sheet and a method for manufacturing the same in which the diameter of a work roll and a friction coefficient between the work roll and a steel sheet are controlled during cold rolling to uniformly develop a texture according to each orientation, thereby minimizing anisotropy.

[Background Art]

10 **[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 the electrical energy to the 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.

15 **[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 magnetization 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

20 improving the driving range and output of environmentally-friendly vehicles.

25 **[0004]** Depending on operational conditions of the motor, the characteristics of the non-oriented electrical steel sheet that should be considered is 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.

30 **[0005]** A commonly used method to increase 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 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 alloy elements such as Si, Al, and Mn added 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 able to be commercially produced. 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.

35 **[0006]** A method for improving magnetic properties by controlling the texture of non-oriented electrical steel sheets are also known. Control of the texture is a method of promoting the development of crystal orientations favorable to magnetism and suppressing crystal orientations unfavorable to magnetism 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 magnetism, while a crystal orientation having a {111} plane is unfavorable for magnetism, and many methods for selectively developing several crystal orientations through changes in the manufacturing conditions of non-oriented electrical steel sheets are known.

40 **[0007]** When a non-oriented electrical steel sheet is produced by a double rolling and double annealing process, it is possible to suppress the {111}//ND crystal orientation, which is unfavorable to magnetism, and to strengthen crystal orientations such as {001}//ND and {110}//ND, which are favorable to magnetism. The above process is well-known to have an excellent effect on improving texture, but it has a disadvantage in that a cold rolling intermediate annealing process is added, which increases manufacturing costs. In addition, depending on the developed texture, the magnetic properties in the rolling direction are improved, but the magnetic properties in the direction rotated by 45 to 60° from the rolling direction are degraded, so when used in rotating machines, the improvement in magnetic properties is often minimal, which limits practical application.

[Disclosure]

[Technical Problem]

[0008] An embodiment of the present invention provides a non-oriented electrical steel sheet and a method for manufacturing the same. Specifically, an embodiment of the present invention provides a non-oriented electrical steel sheet and a method for manufacturing the same in which the diameter of a work roll and a friction coefficient between the work roll and a steel sheet are controlled during cold rolling to uniformly develop a texture according to each orientation, thereby minimizing anisotropy.

[Technical Solution]

[0009] An embodiment of the present invention provides a non-oriented electrical steel sheet including: in wt%, Si: 1.5 to 5.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, with the balance being Fe and inevitable impurities, wherein a maximum value of an orientation distribution function (ODF) shown in the $\phi_2=45^\circ$ cross-section of the Euler space is 3.0 or less.

[0010] The non-oriented electrical steel sheet according to the embodiment of the present invention includes a surface portion and center portion up to a depth of 50 μm from a steel sheet surface toward an inner direction, and a ratio of an average grain size in the surface portion to an average grain size in the center portion is 0.4 to 0.6.

[0011] The non-oriented electrical steel sheet according to the embodiment of the present invention 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%).

[0012] The non-oriented electrical steel sheet according to the embodiment of the present invention 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.

[0013] The non-oriented electrical steel sheet according to the embodiment of the present invention 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%).

[0014] The non-oriented electrical steel sheet according to the embodiment of the present invention 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%).

[0015] The non-oriented electrical steel sheet according to the embodiment of the present invention may satisfy the following Formula 1.

[Formula 1]

$$B_{50L} - B_{50(55^\circ)} \leq 0.05 T$$

[0016] (In Formula 1, B_{50L} represents the magnetic flux density B_{50} measured in the rolling direction, and $B_{50(55^\circ)}$ represents the magnetic flux density B_{50} measured in a direction having an angle of 55° with respect to the rolling direction.)

[0017] Another embodiment of the present invention provides a method for manufacturing a non-oriented electrical steel sheet, including: a step of hot rolling a slab including, in wt%, Si: 1.5 to 5.0%, 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 step of pre-cold rolling the hot-rolled steel sheet; a first annealing step of annealing the pre-cold rolled steel sheet; a step of cold rolling the annealed steel sheet to manufacture a cold-rolled steel sheet; and a second annealing step of annealing the cold-rolled steel sheet.

[0018] In at least one pass or more of the step of manufacturing the cold-rolled steel sheet, a value obtained by multiplying a diameter (mm) of a work roll by a friction coefficient (μ) between the work roll and the steel sheet may be 10 to 30.

[0019] 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%).

[0020] 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.

[0021] 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%), and Zn: 0.01 wt% or less (excluding 0%).

[0022] 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%).

[0023] After manufacturing the hot-rolled steel sheet, the subsequent steps may be performed while the scale remaining on the hot-rolled steel sheet remains.

[0024] After the first annealing step, an average grain size of the steel sheet may be 50 to 120 μm .

[0025] A reduction ratio in the step of manufacturing the cold-rolled sheet may be 20 to 55%.

[0026] A soaking temperature in the second annealing step may be 750 to 1150°C.

[Advantageous Effects]

[0027] The non-oriented electrical steel sheet according to the embodiment of the present invention has a uniformly developed texture, resulting in excellent magnetic properties.

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

[0029] It has high magnetic anisotropy, so it may obtain high torque when manufactured into vehicle motors.

[Description of the Drawings]

[0030]

FIG. 1 is a schematic view showing a cross-section of a non-oriented electrical steel sheet according to an embodiment of the present invention.

FIG. 2 is a graph showing the orientation distribution function (ODF) results of the non-oriented electrical steel sheet manufactured in Example B6.

[Mode for Invention]

[0031] It will 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 second part, component, area, layer, or section within the range of the present invention.

[0032] The technical terms used herein are to simply mention a particular embodiment and are not meant to limit the present invention. 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 is to be understood that the 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.

[0033] When referring to a part as 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 referring to a part being "directly above" another part, no other part is interposed therebetween.

[0034] Unless otherwise stated, % means wt%, and 1 ppm is 0.0001 wt%.

[0035] In embodiments of the present invention, inclusion of an additional element means replacing the remaining iron (Fe) by an additional amount of the additional elements.

[0036] Unless otherwise defined, 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 invention belongs. Terms defined in commonly used dictionaries are 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 defined otherwise.

[0037] The present invention 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 embodiments may be modified in various different ways, all without departing from the spirit or scope of the present disclosure.

[0038] An embodiment of the present invention provides a non-oriented electrical steel sheet including: in wt%, Si: 1.5 to 5.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, with the balance being Fe and inevitable impurities.

[0039] Hereinafter, the reason for limiting the components of the non-oriented electrical steel sheet will be described.

Si: 1.50 to 5.00 wt%

[0040] 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, and rolling productivity is rapidly deteriorated, and an oxide layer and an oxide on a surface that are harmful to magnetism may be formed. Accordingly, Si may be included in an amount of 1.50 to 5.00 wt%. More specifically, it may be included in an amount of 2.00 wt% to 4.50 wt%. More specifically, it may be included in an amount of 2.50 wt% to 4.30 wt%.

Al: 0.1 to 2.0 wt%

[0041] Aluminum (Al) serves to increase the specific resistance of the material, thereby lowering iron loss, improving rolling properties, and enhancing workability during cold rolling. If too little Al is added, it may be difficult to achieve the effect of reducing high-frequency iron loss, and the precipitation temperature of AlN may be lowered, resulting in the fine formation of nitrides that may degrade magnetism. If too much Al is added, the nitride is excessively formed, deteriorating the magnetism, 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 0.15 wt% to 1.7 wt%. More specifically, it may be included in an amount of 0.2 wt% to 1.6 wt%.

Mn: 0.1 to 2.0 wt%

[0042] 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 sulphide 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 unfavorable to magnetism is promoted, resulting in a rapid decrease in magnetic flux density. Accordingly, Mn 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 wt% to 1.7 wt%. More specifically, it may be included in an amount of 0.2 wt% to 1.6 wt%.

[0043] The non-oriented electrical steel sheet according to the embodiment of the present invention 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 at 0.1 wt% or less

[0044] Phosphorus (P) not only serves to increase the specific resistance of the material but also, as a grain boundary segregation element, may improve magnetic flux density. However, if too much P is added, it increases the brittleness of the steel sheet and deteriorates its weldability. More specifically, P may be included in an amount of 0.0001 to 0.0500 wt%. More specifically, P may be included in an amount of 0.0010 to 0.0200 wt%.

C: 0.0050 wt% or less

[0045] Carbon (C) may cause magnetic aging and combine with other impurity 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 0.0035 wt%. More specifically, C may be included in an amount of 0.0010 to 0.0030 wt%.

S: 0.0050 wt% or less

[0046] Sulfur (S) may form fine precipitates, MnS and CuS, which may worsen magnetic properties and hot workability. More specifically, S may be included in an amount of 0.0001 to 0.0050 wt%. More specifically, S may be included in an amount of 0.0005 to 0.0045 wt%.

Ti: 0.0050 wt% or less

[0047] 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. More specifically, Ti may be included in an amount of 0.0001 to 0.0050 wt%. More specifically, Ti may be included in an amount of 0.0005 to 0.0030 wt%.

N: 0.0050 wt% or less

[0048] 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 worsening 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 0.0030 wt%.

[0049] The non-oriented electrical steel sheet according to the embodiment of the present invention 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

[0050] Tin (Sn) may be segregated at grain boundaries and surfaces to improve the texture of the material and suppress surface oxidation, and thus may be added to improve magnetic properties. When too much Sn is added, grain boundary segregation is severe, the surface quality is deteriorated, hardness is increased, and the cold-rolled sheet is broken, thereby reducing rollability. Specifically, Sn may be further included in an amount of 0.005 to 0.200 wt%. More specifically, it may further include 0.010 to 0.080 wt%.

Sb

[0051] Antimony (Sb) may be segregated at grain boundaries and surfaces to improve the texture of the material and suppress surface oxidation, and thus may be additionally added to improve magnetic properties. When too much Sb is added, grain boundary segregation is severe, the surface quality is deteriorated, hardness is increased, and the cold-rolled sheet is broken, thereby reducing rollability. Specifically, Sb may be further included in an amount of 0.005 to 0.200 wt%. More specifically, it may further include 0.010 to 0.080 wt%.

Bi, Pb, Ge, and As

[0052] 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 too much, a large amount of segregation may occur, inhibiting grain growth and resulting in lower magnetic flux density and iron loss.

[0053] The non-oriented electrical steel sheet according to the embodiment of the present invention 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%

[0054] 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 magnetism may be degraded. If too much Cu is added, high temperature brittleness occurs, which may form cracks 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%

[0055] 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. More specifically, Cr may be contained in an amount of 0.050 to 0.20 wt%.

Ni: 0.05 wt% or less

[0056] Nickel (Ni) may react with impurity elements to form fine sulfides, carbides, and nitrides, which may have a detrimental effect on magnetism. More specifically, Ni may be included in an amount of 0.001 to 0.03 wt%.

Zn: 0.01 wt% or less

[0057] If the content of zinc (Zn) is excessive, it may act as an impurity and deteriorate magnetism. 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

[0058] Cobalt (Co), while not forming fine precipitates that degrade the magnetism of the steel sheet, may increase high-temperature strength, leading to poor coil shape after hot rolling.

[0059] The non-oriented electrical steel sheet according to the embodiment of the present invention 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

[0060] 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

[0061] If boron (B) is added in excessive amounts, it may cause deterioration of magnetism 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: 0.0050 wt% or less

[0062] 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 each 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

[0063] 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: 0.0050 wt% or less

[0064] 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

[0065] If zirconium (Zr) is added in excessive amounts, it may cause deterioration of magnetism 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 wt% to 0.0030 wt%.

Te: 0.0100 wt% or less

[0066] 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 unfavorable for magnetism

[0067] 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 wt% to 0.0030 wt%.

[0069] The balance includes Fe and inevitable impurities. The inevitable impurities are impurities mixed in the steel-making 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 the embodiment of the present invention, 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 invention. When the additional elements are further included, they replace the balance of Fe.

[0070] As described above, in the embodiment of the present invention, the alloy composition of the steel sheet is appropriately controlled, and in the process of performing preliminary cold rolling and cold rolling, the diameter of the work roll and the friction coefficient between the work roll and the steel sheet are controlled during cold rolling, so that this allows the texture to develop uniformly in each orientation, minimizing magnetic anisotropy.

[0071] Specifically, in the non-oriented electrical steel sheet according to the embodiment of the present invention, the maximum value of the orientation distribution function (ODF) appearing in a $\phi 2=45^\circ$ cross-section of Euler space may be 3.0 or less.

[0072] The orientation distribution function (ODF) is a method for quantitatively analyzing the texture distribution in a steel sheet, and may be used to quantify how much a specific crystal orientation is distributed within the steel sheet. The orientation intensity refers to how strongly a specific crystal orientation is developed compared to a random texture.

[0073] The Euler space is a three-dimensional space composed of three angles, $\phi 1$, Φ , and $\phi 2$, used to express crystal orientation, and among them, the $\phi 2=45^\circ$ cross-section is a region to be observed in detail because it is easy to understand the texture that develops in steel materials with symmetric deformation.

[0074] In the embodiment of the present invention, the measurement surface of the orientation distribution function (ODF) targets the rolling vertical direction surface (TD surface), and the measurement area is at least 5 mm $\times$ 5 mm. Data for a sufficiently large area must be measured to reduce errors due to the measurement position, and more than 20 specimens may be measured and the data combined for calculation at once.

[0075] The measurement method uses EBSD mounted on an SEM, and may be analyzed using OIM analysis software, and the error angle for orientation may be set to 15°.

[0076] A maximum value of the orientation distribution function (ODF) of 3.0 or less means that not just a specific orientation texture is developed, but textures are developed uniformly for each orientation. More specifically, the maximum value of the orientation distribution function (ODF) may be 1.5 to 2.5.

[0077] FIG. 1 schematically shows a cross-section of a non-oriented electrical steel sheet 100 according to an embodiment of the present invention. As shown in FIG. 1, the non-oriented electrical steel sheet 100 according to the embodiment of the present invention includes a surface portion 20 and a center portion 10 from the steel sheet surface inward to a depth of 50 μ m. As shown in FIG. 1, the surface portion 20 exists on both surfaces of the steel sheet, and the center portion 10 may be disposed between the two surface portions 20.

[0078] In the embodiment of the present invention, the ratio (surface portion/center portion) of the average grain size in the surface portion 20 to the average grain size in the center portion 10 may be 0.40 to 0.60. When the grains of the surface portion 20 are smaller than the grains of the center portion 10, hysteresis loss increases and permeability decreases at the surface portion, which may lead to the deterioration of magnetic properties. When the grains of the surface portion 20 are larger than the grains of the center portion 10, eddy current loss at the surface portion increases and a texture unfavorable for magnetization may develop. More specifically, the ratio (surface portion/center portion) of the average grain size in the surface portion 20 to the average grain size in the center portion 10 may be 0.45 to 0.57.

The grain size may be obtained by assuming a virtual circle having the same area as the corresponding grain and using the diameter of that circle. It is measured based on the rolling vertical surface (TD surface), and the average area of respective grains is obtained by counting the number of crystal grains in the surface portion 20 and the center portion 10, and calculated as a circle having this area. If the surface portion 20 in the steel sheet exists on both surfaces, the grain sizes of the upper and lower surface portions may be averaged and obtained.

[0079] As previously described, in the embodiment of the present invention, the magnetic anisotropy may be minimized by evenly developing the texture in each direction. Specifically, the non-oriented electrical steel sheet according to the embodiment of the present invention may satisfy the following Formula 1.

[Formula 1]

$$B_{50L} - B_{50(55^\circ)} \leq 0.05 \text{ T}$$

[0080] (In Formula 1, B_{50L} represents the magnetic flux density B_{50} measured in the rolling direction, and $B_{50(55^\circ)}$ represents the magnetic flux density B_{50} measured in a direction having an angle of 55° with respect to the rolling direction.)

[0081] Formula 1 represents the difference in magnetic flux density between the rolling direction (RD direction) and the direction having an angle of 55° with respect to the rolling direction, and the smaller this difference is, the smaller the magnetic anisotropy is. Specifically, the value of the left side of Formula 1 may be 0.01 to 0.03 T.

[0082] In the embodiment of the present invention, the core 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 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 the embodiment of the present invention, the core loss may be expressed based on a thickness of 0.25 mm.

[0083] A method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present invention includes a step of hot-rolling a slab to manufacture a hot-rolled steel sheet; a step of preliminarily cold-rolling the hot-rolled steel sheet; a first annealing step of annealing the preliminarily cold-rolled steel sheet; a step of cold-rolling the annealed steel sheet to manufacture a cold-rolled sheet; and a second annealing step of annealing the cold-rolled sheet.

[0084] Hereinafter, respective steps will be specifically described.

[0085] First, the slab is hot-rolled.

[0086] 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.

[0087] Specifically, the slab includes, in wt%, Si: 1.5 to 5.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, with the balance being Fe and inevitable impurities.

[0088] Other additional elements have been described in the alloy composition of the non-oriented electrical steel sheet, so duplicate descriptions will be omitted.

[0089] The slab may be heated before hot-rolling. The heating temperature of the slab is not limited, but the slab may be heated at 1200 °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 inhibiting grain growth and reducing magnetism.

[0090] Next, the slab is hot-rolled to manufacture the hot-rolled sheet. A thickness of the hot-rolled sheet may be 1.50 to 2.50 mm. If the hot-rolled sheet thickness is too thick, a coarse, elongated texture may strongly develop in the center portion 10 of the finally manufactured non-oriented electrical steel sheet, leading to the development of a texture in a specific orientation. Additionally, if the hot-rolled sheet thickness is too small, fine grains that have not grown sufficiently may remain on the surface portion 20 of the finally manufactured non-oriented electrical steel sheet, which may degrade iron loss. More specifically, the hot-rolled sheet thickness may be 1.60 to 2.30 mm.

[0091] In the manufacturing of the hot-rolled sheet, a finish rolling temperature may be 800 °C or higher. Specifically, it may be 870 to 950°C. The hot-rolled sheet may be wound at temperatures of 600°C or more.

[0092] After manufacturing the hot-rolled steel sheet, the subsequent steps may be performed while the scale remaining on the hot-rolled steel sheet remains. That is, after hot rolling, the subsequent steps may be performed without removing the scale, such as pickling, shot blasting, or surface grinding. By performing cold rolling in a state in which the pickling process is omitted, the friction between the rolling work roll and the steel sheet increases, so that shear deformation is simultaneously applied in addition to plane deformation during rolling, and a specific orientation develops during recrystallization annealing. In the embodiment of the present invention, scale refers to a portion where

elements such as Fe, Al, and Si combine with oxygen with oxygen on the surface of the steel sheet to form a phase different from that of the base material. The meaning that scale remains signifies that at least a 1 μm thick scale remains on the hot-rolled sheet. In this case, the scale thickness means the sum of the scale thicknesses formed on both surfaces of the steel sheet. If the remaining scale thickness is too thin, the effect due to the remaining scale may not be sufficiently achieved. Even if the scale thickness is thicker, the effect is not improved, and there is a problem that the yield of the steel sheet decreases. More specifically, a scale with a thickness of 0.1 to 1 μm may remain. In addition, preliminary cold rolling may be performed without applying heat from the outside of the steel sheet after hot rolling. That is, hot-rolled sheet annealing may be omitted.

[0093] Next, the hot-rolled steel sheet is subjected to preliminary cold rolling. 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.

[0094] The preliminary cold rolling may be performed in a reduction ratio range of 40 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 Reverse Mill is also possible in 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.

[0095] 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 is too low in the preliminary cold rolling step, 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> orientation recrystallization. Conversely, if the reduction ratio is too high, the cold rolling load increases, and the possibility of sheet breakage also increases.

[0096] Next, in the first annealing step, the preliminary cold-rolled steel sheet is annealed.

[0097] In the embodiment of the present invention, after the first annealing step, by appropriately controlling the average grain diameter or size of the grains in the steel sheet, the texture may be developed uniformly for each orientation. Specifically, after the first annealing step, the average grain size or diameter of the steel sheet may be 50 to 120 μm . If the average grain diameter is too small, the grain boundary fraction becomes excessively high, which may lead to the development of grains with a {111}/ND orientation during the secondary annealing process after secondary cold rolling, thereby deteriorating magnetic properties. If the average grain diameter is too large, the development of the {111}/ND orientation is suppressed, but the Cube orientation may develop, leading to a deterioration of magnetic properties at 55°. More specifically, after the first annealing step, the average grain diameter of the steel sheet may be 60 to 110 μm .

[0098] The first annealing step may be soaked for 5 to 20 seconds at a temperature of 750 to 1150°C. If the soaking temperature is too low, the coarse microstructure in the center portion is not sufficiently recovered, so the {001}<100> orientation of the final product cannot be sufficiently developed, and the magnetic properties may deteriorate. If the soaking temperature is too high, fine precipitates may be formed on the surface portion, which may prevent the {011}<100> orientation of the final product from developing sufficiently, thus deteriorating magnetic properties. More specifically, the first annealing step may be soaked at a temperature of 850 to 1050°C.

[0099] If the soaking time is too short, the microstructure of the surface portion is not sufficiently recrystallized, and the grains of the surface portion of the final product may become excessively small compared to the grains of the center portion. If the soaking time is too long, the grains of the surface portion may grow excessively. More specifically, the soaking may be for 7 to 17 seconds.

[0100] Again, returning to the description of the method for manufacturing the non-oriented electrical steel sheet, after the first annealing step, the annealed steel sheet is cold-rolled to manufacture a cold-rolled sheet.

[0101] In the embodiment of the present invention, the value obtained by multiplying the diameter (mm) of the work roll and the friction coefficient (μ) between the work roll and the steel sheet may be 10.0 to 30.0 in at least one pass.

[0102] In the embodiment of the present invention, the work roll diameter and friction coefficient in cold rolling are key factors for optimizing the difference in diameter between the grains of the center portion 10 and the grains of the surface portion 20 of the final non-oriented electrical steel sheet to be manufactured and for developing a random texture to obtain excellent magnetic properties in all directions.

[0103] If the work roll diameter is large, the area of contact between the work roll and the material increases at a given reduction ratio, allowing greater shear deformation to be applied, and if the work roll diameter is small, the amount of shear deformation decreases. The friction coefficient is determined by factors such as the roughness of the work roll and the steel sheet and the type of rolling oil, and under a given condition, the larger the friction coefficient, the greater the shear deformation that may be applied. If the product of the work roll diameter and the friction coefficient is large, the amount of shear deformation applied to the material increases, so that the grain size at the surface portion may be controlled to be smaller than that at the center portion. However, if the product of the work roll diameter and the friction coefficient is too large, an excessive number of fine grains may be formed on the surface

portion 20. If the product of the work roll diameter and the friction coefficient is too small, the grains on the surface portion may grow to a similar size to the grains in the center portion, which may result in inferior magnetic properties at high frequencies of 400 Hz or higher. More specifically, the product of the work roll diameter and the friction coefficient may be 11.0 to 29.5.

[0104] In the embodiment of the present invention, cold rolling may be performed through a plurality of passes, and the above-described work roll diameter and friction coefficient characteristics may be satisfied in one or more of the plurality of passes. More specifically, it may be satisfied in the last pass.

[0105] The work roll diameter may be 300 to 600 mm. More specifically, it may be 350 to 500 mm.

[0106] The friction coefficient between the work roll and the steel sheet may be 0.02 to 0.10 μ . The friction coefficient may be measured by the method of published patent KR1996-0021206. More specifically, the friction coefficient may be 0.03 to 0.08 μ .

[0107] In the manufacturing of the cold rolled steel sheet, the reduction ratio may be 20 to 55 %. If the reduction ratio is too low, a Rotated cube orientation may develop, and the magnetism at 55° may be degraded. If the reduction ratio is too high, a {111}//ND orientation may develop, and the overall magnetism may be degraded. More specifically, the reduction ratio may be 25 to 50%. The final rolled thickness may be from 0.1 mm to 0.35 mm.

[0108] Next, in the second annealing step, the cold-rolled sheet is annealed. The second annealing step may be performed at 750 to 1150°C. If the soaking temperature is too low, the grains may not grow sufficiently, which may cause the hysteresis loss to increase and the iron loss to deteriorate. More specifically, it may be annealed at a temperature ranging from 900 to 1050°C. The second annealing step may be soaked for 50 to 120 seconds. The dew point may be -10°C or less.

[0109] 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.

[0110] After the cold-rolled sheet annealing, an insulating film may be formed. The insulating film may be formed as an organic, inorganic, and organic/inorganic composite film, and it may be formed with other insulating coating materials.

[0111] Hereinafter, the present invention will be described in more detail through examples. However, the examples are only for illustrating the present invention, and the present invention is not limited thereto.

Example 1

[0112] A slab was manufactured with components containing the following Table 1 and the balance Fe and other inevitable impurities. This was heated at 1150°C and hot-rolled at a finishing temperature of 950°C to manufacture a hot-rolled sheet having the thickness of the following Table 2.

[0113] Thereafter, the hot-rolled sheet was preliminarily cold-rolled to the thickness shown in Table 2 below, omitting annealing, and was first annealed by soaking for 15 seconds under conditions of 750 to 1050°C. The average grain size of the first annealed steel sheet was measured and summarized in Table 2 below. The first annealed steel sheet was cold-rolled under the conditions summarized in Table 3 below to have a final thickness of 0.25 mm. The cold-rolled steel sheet was second annealed for 70 seconds at a dew point of -20°C and a soaking temperature of 950°C.

[0114] To analyze the texture of the manufactured non-oriented electrical steel sheet, 30 specimens of 10 mm $\times$ 20 mm size were cut from each sample, and the observation surfaces were mounted in 3 sets of 10 each so that they were the TD surfaces, and the observation surfaces were polished to a mirror-like surface without scratches. EBSD measurement was performed under conditions of a height of 5000 μ m, a width of approximately 2500 μ m (including all 10 specimens of 0.25 mm), and a step size of 1 μ m, and three sets of measurement data were merged using the merging function of the OIM software to calculate the ODF at once, and the results are shown in Table 4.

[0115] Magnetic properties such as magnetic flux density and iron loss were measured by cutting 60 mm wide $\times$ 60 mm long $\times$ 5 sheets of each specimen and measuring the magnetic flux density in the rolling direction and the 55° direction using a single sheet tester, with the results shown. The iron loss was measured in the rolling direction and the direction perpendicular to the rolling direction, and expressed as the average. In this case, $W_{10/400}$ is iron loss when a magnetic flux density of 1.0 T is induced at a frequency of 400 Hz, and B50 is a magnetic flux density induced in a magnetic field of 5000 A/m.

(Table 1)

Specimen number	Si [%]	Al [%]	Mn [%]	C [ppm]	S [ppm]	N [ppm]	Ti [ppm]	Nb [ppm]	V [ppm]
A1	2.70	1.6	0.7	28	14	16	11	19	15
A2	2.70	1.6	0.7	28	13	13	23	17	21
A3	2.70	1.6	0.7	20	18	18	24	8	19

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(continued)

Specimen number	Si [%]	Al [%]	Mn [%]	C [ppm]	S [ppm]	N [ppm]	Ti [ppm]	Nb [ppm]	V [ppm]
A4	2.70	1.6	0.7	13	18	17	17	18	10
A5	2.70	1.6	0.7	17	16	14	14	16	16
A6	2.70	1.6	0.7	24	43	17	17	17	14
A7	2.70	1.6	0.7	26	13	13	11	13	13
A8	2.70	1.6	0.7	14	14	16	14	14	18
B1	3.30	0.6	1.6	13	73	14	12	11	23
B2	3.30	0.6	1.6	35	13	15	65	13	9
B3	3.30	0.6	1.6	16	32	9	24	19	10
B4	3.30	0.6	1.6	17	20	12	14	20	21
B5	3.30	0.6	1.6	13	13	13	17	13	18
B6	3.30	0.6	1.6	28	17	16	14	17	15
B7	3.30	0.6	1.6	29	42	14	13	18	17
B8	3.30	0.6	1.6	31	13	18	18	13	13
C1	3.75	0.2	1.6	68	19	9	24	19	20
C2	3.75	0.2	1.6	21	16	11	21	23	16
C3	3.75	0.2	1.6	29	17	12	23	14	12
C4	3.75	0.2	1.6	21	8	8	17	18	18
C5	3.75	0.2	1.6	31	45	13	9	14	11
C6	3.75	0.2	1.6	28	15	16	13	15	12
C7	3.75	0.2	1.6	25	17	16	7	17	15
C8	3.75	0.2	1.6	27	42	17	14	14	18
D1	4.20	0.5	0.2	22	9	81	18	9	23
D2	4.20	0.5	0.2	17	16	11	12	16	11
D3	4.20	0.5	0.2	14	35	10	12	21	13
D4	4.20	0.5	0.2	9	16	14	14	16	14
D5	4.20	0.5	0.2	16	17	16	16	17	17
D6	4.20	0.5	0.2	21	33	20	15	18	21
D7	4.20	0.5	0.2	16	17	20	10	17	24
D8	4.20	0.5	0.2	31	13	12	13	13	13

(Table 2)

Specimen number	Hot-rolled sheet thickness [mm]	Thickness after first cold rolling [mm]	First cold rolling reduction ratio [%]	First annealing grain size [μm]
A1	2.18	0.50	77	36
A2	2.18	0.50	77	78
A3	2.18	0.50	77	81
A4	2.61	0.60	77	82
A5	2.18	0.50	77	76
A6	2.18	0.50	77	80
A7	2.18	0.50	77	84

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(continued)

	Specimen number	Hot-rolled sheet thickness [mm]	Thickness after first cold rolling [mm]	First cold rolling reduction ratio [%]	First annealing grain size [μm]
5	A8	2.18	0.50	77	82
	B1	1.76	0.40	77	58
	B2	1.76	0.40	77	76
	B3	1.27	0.29	77	102
10	B4	1.76	0.40	77	141
	B5	1.76	0.40	77	63
	B6	1.76	0.40	77	81
15	B7	1.76	0.40	77	97
	B8	1.76	0.40	77	108
	C1	1.76	0.40	77	58
	C2	1.26	0.40	68	103
20	C3	2.69	0.40	85	61
	C4	1.76	0.40	77	107
	C5	1.76	0.40	77	72
25	C6	1.76	0.40	77	101
	C7	1.76	0.40	77	63
	C8	1.76	0.40	77	104
	D1	1.51	0.35	77	103
30	D2	1.51	0.35	77	107
	D3	1.51	0.35	77	110
	D4	1.51	0.35	77	102
35	D5	1.51	0.35	77	105
	D6	1.51	0.35	77	104
	D7	1.51	0.35	77	101
	D8	1.51	0.35	77	107

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(Table 3)

	Specimen number	Secondary cold rolled reduction ratio [%]	Secondary cold rolled WR diameter [mm]	Secondary cold rolled friction coefficient (μ)	Diameter X Friction coefficient
45	A1	50	380	0.03	11.4
	A2	50	380	0.14	53.2
	A3	50	220	0.03	6.6
	A4	58	380	0.03	11.4
50	A5	50	420	0.07	29.4
	A6	50	420	0.07	29.4
	A7	50	420	0.07	29.4
55	A8	50	420	0.07	29.4
	B1	38	420	0.05	21.0
	B2	38	380	0.05	19.0

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(continued)

	Specimen number	Secondary cold rolled reduction ratio [%]	Secondary cold rolled WR diameter [mm]	Secondary cold rolled friction coefficient (μ)	Diameter X Friction coefficient
5	B3	14	420	0.05	21.0
	B4	38	380	0.05	19.0
	B5	38	420	0.06	25.2
	B6	38	380	0.06	22.8
10	B7	38	420	0.06	25.2
	B8	38	380	0.06	22.8
	C1	38	420	0.03	12.6
15	C2	38	380	0.03	11.4
	C3	38	420	0.03	12.6
	C4	38	380	0.03	11.4
	C5	38	420	0.07	29.4
20	C6	38	380	0.07	26.6
	C7	38	420	0.07	29.4
	C8	38	380	0.07	26.6
25	D1	28	400	0.05	20.0
	D2	28	650	0.05	32.5
	D3	28	400	0.01	4.0
	D4	28	400	0.05	20.0
30	D5	28	400	0.06	24.0
	D6	28	400	0.06	24.0
	D7	28	400	0.06	24.0
35	D8	28	400	0.06	24.0

(Table 4)

	Specimen number	$\phi 2=45^\circ$ Maximum oriented strength	Surface portion Grain size [μm]	Center portion Grain size [μm]	Surface portion/Center portion
40	A1	4.7	45	81	0.56
	A2	2.4	31	84	0.37
	A3	2.1	57	76	0.75
45	A4	5.1	28	81	0.35
	A5	2.2	47	84	0.56
	A6	2.4	38	76	0.50
50	A7	2.1	42	82	0.51
	A8	1.9	43	77	0.56
	B1	2.4	46	55	0.84
	B2	2.2	42	51	0.82
55	B3	2.3	51	76	0.67
	B4	5.3	38	81	0.47
	B5	2.1	41	83	0.49

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(continued)

	Specimen number	$\phi 2=45^\circ$ Maximum oriented strength	Surface portion Grain size [μm]	Center portion Grain size [μm]	Surface portion/Center portion
5	B6	2.4	35	81	0.43
	B7	2.3	46	79	0.58
	B8	2.4	44	82	0.54
10	C1	2.1	38	52	0.73
	C2	2.2	60	84	0.71
	C3	4.5	43	76	0.57
	C4	2.3	41	84	0.49
15	C5	2.4	43	84	0.51
	C6	2.3	37	81	0.46
	C7	2.1	43	78	0.55
	C8	2.6	39	77	0.51
20	D1	2.5	39	50	0.78
	D2	2.1	30	82	0.37
	D3	2.3	55	82	0.67
25	D4	2.4	43	81	0.53
	D5	2.4	38	76	0.50
	D6	2.3	37	78	0.47
	D7	2.1	44	78	0.56
30	D8	2.2	39	81	0.48

(Table 5)

	Specimen number	W10/400	B50L [T]	B50 55° [T]	ΔB50 [T]
35	A1	12.0	1.66	1.62	0.04
	A2	12.5	1.68	1.63	0.05
	A3	12.8	1.68	1.63	0.05
40	A4	12.6	1.66	1.62	0.04
	A5	11.3	1.68	1.66	0.02
	A6	11.3	1.68	1.66	0.02
45	A7	11.5	1.68	1.66	0.02
	A8	11.2	1.68	1.66	0.02
	B1	12.6	1.68	1.63	0.05
	B2	12.6	1.68	1.63	0.05
50	B3	12.4	1.68	1.63	0.05
	B4	11.9	1.66	1.62	0.04
	B5	11.2	1.68	1.66	0.02
	B6	11.5	1.68	1.66	0.02
55	B7	11.1	1.68	1.66	0.02
	B8	11.3	1.68	1.66	0.02
	C1	12.6	1.68	1.63	0.05

(continued)

Specimen number	W10/400	B50L [T]	B50 55° [T]	$\Delta B50$ [T]
C2	12.4	1.68	1.63	0.05
C3	11.9	1.66	1.62	0.04
C4	11.5	1.68	1.66	0.02
C5	11.3	1.68	1.66	0.02
C6	11.5	1.68	1.66	0.02
C7	11.3	1.68	1.66	0.02
C8	11.3	1.68	1.66	0.02
D1	12.5	1.68	1.63	0.05
D2	12.3	1.68	1.63	0.05
D3	12.6	1.68	1.63	0.05
D4	11.4	1.68	1.66	0.02
D5	11.2	1.68	1.66	0.02
D6	11.3	1.68	1.66	0.02
D7	11.4	1.68	1.66	0.02
D8	11.4	1.68	1.66	0.02

[0116] As shown in Table 1 to Table 5, it can be confirmed that the inventive example, in which the steel component is properly controlled and the process conditions are properly controlled so that the texture is uniformly formed, has excellent iron loss and magnetic flux density, and at the same time, minimizes magnetic anisotropy.

[0117] On the other hand, in the cases in which the steel component is not properly controlled or the process conditions are not properly controlled, and the texture is not properly formed, it can be confirmed that the iron loss and magnetic flux density are inferior or the magnetic anisotropy is increased.

[0118] The present invention may be embodied in many different forms, and should not be construed as being limited to the disclosed embodiments. In addition, it will 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 invention. Therefore, it is to be understood that the above-described embodiments are for illustrative purposes only, and the scope of the present invention is not limited thereto.

[Description of symbols]

[0119]

100: non-oriented electrical steel sheet 10: center portion
20: surface portion

Claims

1. A non-oriented electrical steel sheet comprising:

in wt%, Si: 1.5 to 5.0%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, with the balance being Fe and inevitable impurities, wherein a maximum value of an orientation distribution function (ODF) shown in the $\phi 2=45^\circ$ cross-section of the Euler space is 3.0 or less,
the non-oriented electrical steel sheet includes a surface portion and center portion up to a depth of 50 μm from a steel sheet surface toward an inner direction, and
a ratio of an average grain size in the surface portion to an average grain size in the center portion is 0.4 to 0.6.

2. 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%).

3. 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.

4. 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%).

5. 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%).

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

the non-oriented electrical steel sheet satisfies the following Formula 1:

[Formula 1]

$$B_{50L} - B_{50(55^\circ)} \leq 0.05 T$$

(In Formula 1, B_{50L} represents the magnetic flux density B_{50} measured in the rolling direction, and $B_{50(55^\circ)}$ represents the magnetic flux density B_{50} measured in a direction having an angle of 55° with respect to the rolling direction).

7. 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 5.0%, 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 step of pre-cold rolling the hot-rolled steel sheet;
a first annealing step of annealing the pre-cold rolled steel sheet;
a step of cold rolling the annealed steel sheet to manufacture a cold-rolled steel sheet; and
a second annealing step of annealing the cold-rolled steel sheet,
wherein, in at least one pass or more of the step of manufacturing the cold-rolled steel sheet, a value obtained by multiplying a diameter (mm) of a work roll by a friction coefficient (μ) between the work roll and the steel sheet is 10 to 30.

8. The method for manufacturing the non-oriented electrical steel sheet of claim 7, wherein the slab further includes 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%).

9. The method for manufacturing the non-oriented electrical steel sheet of claim 7, wherein the slab further includes 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.

10. The method for manufacturing the non-oriented electrical steel sheet of claim 7, wherein the slab further includes 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%).

11. The method for manufacturing the non-oriented electrical steel sheet of claim 7, wherein the slab further includes 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%).

12. The method for manufacturing the non-oriented electrical steel sheet of claim 7, wherein after manufacturing the hot-rolled steel sheet, a subsequent step is performed while a scale remaining on the hot-rolled steel sheet remains.

5 13. The method for manufacturing the non-oriented electrical steel sheet of claim 7, wherein after the first annealing step, an average grain size of the steel sheet is 50 to 120 μm .

14. The method for manufacturing the non-oriented electrical steel sheet of claim 7, wherein a reduction ratio in the step of manufacturing the cold-rolled sheet is 20 to 55%.

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15. The method for manufacturing the non-oriented electrical steel sheet of claim 7, wherein a soaking temperature in the second annealing step is 750 to 1150°C.

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FIG. 1

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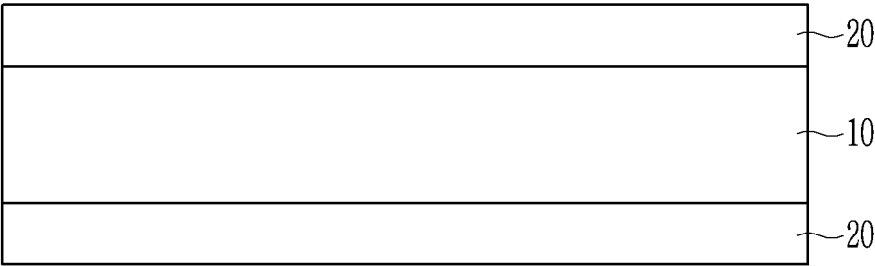


FIG. 2



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INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/097010

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/04(2006.01)i; C22C 38/06(2006.01)i; C22C 38/14(2006.01)i; C22C 38/00(2006.01)i;
C22C 38/58(2006.01)i; C22C 38/44(2006.01)i; C22C 38/52(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); B21B 1/22(2006.01); C21D 8/12(2006.01); C22C 38/00(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), 마찰계수(frictional coefficient), 방위분포함수(ODF)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2021-0056391 A (JFE STEEL CORPORATION) 18 May 2021 (2021-05-18) See paragraph [0104] and claims 1-2 and 4.	1-15
A	KR 10-2477535 B1 (JFE STEEL CORPORATION) 14 December 2022 (2022-12-14) See claim 1.	1-15
A	JP 2006-045641 A (NIPPON STEEL CORP.) 16 February 2006 (2006-02-16) See claims 1 and 9.	1-15
A	KR 10-2566590 B1 (JFE STEEL CORPORATION) 11 August 2023 (2023-08-11) See claim 1.	1-15
A	JP 2019-163509 A (NIPPON STEEL CORP.) 26 September 2019 (2019-09-26) See claims 1 and 3.	1-15

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

* Special categories of cited documents:

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“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

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Date of mailing of the international search report

19 March 2025

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/097010

Patent document cited in search report	Publication date (day/month/year)	Patent family member(s)	Publication date (day/month/year)
KR 10-2021-0056391 A	18 May 2021	BR 112021006711 A2	27 July 2021
		BR 112021006711 B1	24 October 2023
		CA 3116571 A1	07 May 2020
		CA 3116571 C	17 January 2023
		CN 112930412 A	08 June 2021
		EP 3859032 A1	04 August 2021
		EP 3859032 B1	29 March 2023
		JP 2021-036075 A	04 March 2021
		JP 6866935 B2	28 April 2021
		KR 10-2516331 B1	31 March 2023
		MX 2021004862 A	15 June 2021
		TW 202018102 A	16 May 2020
		TW 202122602 A	16 June 2021
		TW I732315 B	01 July 2021
		TW I768605 B	21 June 2022
		US 11525169 B2	13 December 2022
		US 11718891 B2	08 August 2023
		US 2021-0371948 A1	02 December 2021
		US 2023-0065674 A1	02 March 2023
		WO 2020-090160 A1	07 May 2020
KR 10-2477535 B1	14 December 2022	CA 3127170 A1	30 July 2020
		CA 3127170 C	08 August 2023
		CN 113366124 A	07 September 2021
		CN 113366124 B	17 January 2023
		EP 3916113 A1	01 December 2021
		JP 2021-153387 A1	18 February 2021
		JP 6767687 B1	14 October 2020
		KR 10-2021-0099111 A	11 August 2021
		MX 2021008802 A	24 August 2021
		RU 2771133 C1	26 April 2022
		TW 202028480 A	01 August 2020
		TW I717201 B	21 January 2021
		US 2022-0064751 A1	03 March 2022
		WO 2020-153387 A1	30 July 2020
JP 2006-045641 A	16 February 2006	JP 4403038 B2	20 January 2010
KR 10-2566590 B1	11 August 2023	CN 113727788 A	30 November 2021
		CN 113727788 B	01 September 2023
		EP 3943203 A1	26 January 2022
		EP 3943203 B1	11 September 2024
		JP 2021-217604 A1	06 May 2021
		JP 6954464 B2	27 October 2021
		KR 10-2021-0132166 A	03 November 2021
		MX 2021012533 A	12 November 2021
		TW 202039871 A	01 November 2020
		TW I732507 B	01 July 2021
		US 2022-0186338 A1	16 June 2022
		WO 2020-217604 A1	29 October 2020
JP 2019-163509 A	26 September 2019	JP 7040184 B2	23 March 2022

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

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- KR 19960021206 [0106]