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

(57) An iron core according to an embodiment of the present disclosure includes a laminate in which a plurality of non-oriented electrical steel sheets are laminated, wherein each of the non-oriented electrical steel sheets includes, by weight, 1.5 to 5.0% of Si, 0.1 to 2.5% of Al, and 0.1 to 2.5% of Mn, with the balance

being Fe and inevitable impurities, wherein the non-oriented electrical steel sheet has a nitrogen diffusion layer present up to 30 μm inward from a side surface of the laminate, and a nitrogen content in the nitrogen diffusion layer is 0.005 to 0.020 wt%.

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Description**[Technical Field]**

5 **[0001]** The present disclosure relates to an iron core comprising a non-oriented electrical steel sheet and a manufacturing method thereof. Specifically, an embodiment of the present disclosure relates to an iron core including a non-oriented electrical steel sheet with improved strength, and a method for manufacturing the same, by controlling atmospheric conditions during stress-relief annealing (SRA) to partially permeate nitrogen into a side surface of a steel sheet laminate.

[Background Art]

10 **[0002]** Non-oriented electrical steel sheets are mainly used in motors that convert electrical energy into mechanical energy, and in order to achieve high efficiency, non-oriented electrical steel sheets require excellent magnetic properties. In particular, in recent years, as eco-friendly vehicles driven by motors instead of internal combustion engines have attracted attention, the demand for non-oriented electrical steel sheets used as materials for driving motor cores has been increasing. Consequently, there is a demand for non-oriented electrical steel sheets that possess both excellent magnetic properties and high strength. The magnetic properties of the non-oriented electrical steel sheet are typically evaluated through core loss and magnetic flux density. Core loss means energy loss occurring at a specific magnetic flux density and frequency, and magnetic flux density means the degree of magnetization obtained under a specific magnetic field. The lower the core loss, the more energy-efficient motors may be manufactured under the same conditions, and the higher the magnetic flux density, the smaller the motor and the lower the core loss. Therefore, by using non-oriented electrical steel sheets with low core loss and high magnetic flux density, it is possible to manufacture a drive motor with excellent efficiency and torque, thereby improving the driving range and output of eco-friendly vehicles. Depending on the operating conditions of the motor, the required characteristics of the non-oriented electrical steel also vary. As a general criterion for evaluating the characteristics of a non-oriented electrical steel sheet used in a motor, W15/50, which is a core loss when a magnetic field of 1.5 T is applied at a commercial frequency of 50 Hz, is widely used. However, in non-oriented electrical steel sheets having a thickness of 0.35 mm or less used for a driving motor of an eco-friendly vehicle, magnetic properties are often important at a low magnetic field of 1.0 T or less and a high frequency of 400 Hz or more, and thus, the characteristics of the non-oriented electrical steel sheet are frequently evaluated by W10/400 core loss. In addition, due to the increase in rotational speed, strength characteristics, which were previously not considered very important, are also being evaluated as an important property. Therefore, considering recent trends in energy efficiency improvement policies and the utilization direction of non-oriented electrical steel sheets, it is essential to develop a technology for non-oriented electrical steel sheets having low high-frequency core loss, high magnetic flux density, and excellent strength. Among the important magnetic properties of a non-oriented electrical steel sheet, the most fundamental and efficient method for reducing core loss is to increase the content of elements having high resistivity, such as Si, Al, and Mn, or to reduce the thickness of the steel sheet. An increase in the addition amount of Si, Al, and Mn increases the electrical resistivity of steel, thereby reducing eddy current loss among the core losses of the non-oriented electrical steel sheet, which has an effect of lowering the total core loss. In the case of high-frequency core loss, since the proportion of eddy current loss to the total core loss is greater, this can be a highly effective method for reducing high-frequency core loss. However, the effect varies depending on the addition ratio, and the magnetic flux density deteriorates as the addition amount of alloying elements increases. Therefore, in order to secure excellent core loss and magnetic flux density, it is necessary to appropriately control the optimum addition amount and the addition ratio among the addition amounts of Si, Al, and Mn. The method of reducing the thickness is also highly effective in lowering core loss by significantly decreasing eddy current loss; however, a thin steel sheet has a disadvantage of lower productivity and poorer workability. As methods for lowering the core loss of the non-oriented electrical steel sheet while also improving the magnetic flux density thereof, various technologies have been reported, such as improving magnetic properties by improving texture using a special addition element like REM, or introducing an additional manufacturing process such as warm rolling, two-stage rolling, and two-stage annealing. However, since all of these techniques cause an increase in manufacturing costs or are accompanied by difficulties in mass production, it is necessary to develop a technology that enables easy commercial production while exhibiting excellent magnetic properties. In addition, technologies have been developed to suppress and control the formation of inclusions by minimizing the addition amount of impurities and adding elements such as Ca; however, these also cause an increase in manufacturing costs, and it is not easy to ensure the effects thereof. The strength of steel sheets tends to increase as the alloying content increases. However, since Si and Al are brittle elements and have different effects on strength, it is necessary to optimize the component contents and ratios thereof in order to secure high-strength characteristics. On the other hand, although the strength increases as the grain size becomes finer, there is an optimum grain size at which the core loss is minimized. There-

fore, in order to simultaneously secure the characteristics of low core loss and high strength, a technology for appropriately controlling the grain size is also required. On the other hand, when a motor is manufactured using the non-oriented electrical steel sheet, characteristics required for a rotor and a stator of the motor are different from each other. In other words, in the case of the stator, mechanical properties are not of great importance in addition to magnetic properties, but in the case of the rotor, since the temperature increases during high-speed rotation and the mechanical properties are deteriorated, the mechanical properties are also required along with the magnetic properties. As such, despite the differing property requirements for the stator and the rotor, manufacturing both the stator and the rotor from the identical non-oriented electrical steel sheet is highly demanded to enhance production yield during the manufacturing of a motor.

[Disclosure]

[Technical Problem]

[0003] 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 an iron core including a non-oriented electrical steel sheet with improved strength, and a method for manufacturing the same, by controlling atmospheric conditions during stress-relief annealing (SRA) to partially permeate nitrogen into a side surface of a steel sheet laminate.

[Technical Solution]

[0004] An iron core according to an embodiment of the present disclosure includes a laminate in which a plurality of non-oriented electrical steel sheets are laminated, wherein each of the non-oriented electrical steel sheets includes, by weight, 1.5 to 5.0% of Si, 0.1 to 2.5% of Al, and 0.1 to 2.5% of Mn, with the balance being Fe and inevitable impurities, wherein the non-oriented electrical steel sheet has a nitrogen diffusion layer present up to 30 μm inward from a side surface of the laminate, and a nitrogen content in the nitrogen diffusion layer is 0.005 to 0.020 wt%.

[0005] The non-oriented electrical steel sheet may further include one or more selected from the group consisting of 0.1 wt% or less (excluding 0%) of P, 0.005 wt% or less (excluding 0%) of C, 0.005 wt% or less (excluding 0%) of S, 0.005 wt% or less (excluding 0%) of Ti, and 0.020 wt% or less (excluding 0%) of N.

[0006] The non-oriented electrical steel sheet 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.

[0007] The non-oriented electrical steel sheet may further include one or more selected from the group consisting of 0.005 to 0.2 wt% of Cu, 0.01 to 0.5 wt% of Cr, 0.05 wt% or less (excluding 0%) of Ni, 0.01 wt% or less (excluding 0%) of Zn, and 0.05 wt% or less (excluding 0%) of Co.

[0008] The non-oriented electrical steel sheet may further include one or more selected from the group consisting of 0.03 wt% or less (excluding 0%) of Mo, 0.0050 wt% or less (excluding 0%) of B, 0.0050 wt% or less (excluding 0%) of V, 0.0050 wt% or less (excluding 0%) of Ca, 0.0050 wt% or less (excluding 0%) of Nb, 0.005 wt% or less (excluding 0%) of Zr, 0.01 wt% or less (excluding 0%) of Te, and 0.0050 wt% or less (excluding 0%) of Mg.

[0009] The non-oriented electrical steel sheet may satisfy Equation 1 below:

[Equation 1]

$$0.45 \leq (V_A + V_B + V_C) / (V_D + V_E + V_F) \leq 1.45$$

(In Equation 1, V_A , V_B , V_C , V_D , V_E , and V_F represent area fractions (%) of textures having orientations within 15° from (001)[0-10], (001)[-1-10], (100)[025], (223)[1-10], (111)[3-41], and (112)[1-10], respectively.)

[0010] The non-oriented electrical steel sheet may satisfy Equation 2 below:

[Equation 2]

$$0.35 \leq V_C / V_E \leq 1.35$$

(In Equation 2, V_C and V_E represent area fractions (%), of textures having orientations within 15° from (100)[025] and (111)[3-41], respectively.)

[0011] A method for manufacturing an iron core according to an embodiment of the present disclosure includes

preparing a non-oriented electrical steel sheet comprising, by weight, 1.5 to 5.0% of Si, 0.1 to 2.5% of Al, and 0.1 to 2.5% of Mn, with the balance being Fe and inevitable impurities, manufacturing a laminate by punching and laminating the non-oriented electrical steel sheet, and annealing the laminate in an atmosphere containing a nitriding gas.

[0012] The atmosphere may contain 0.7 to 95 vol% of nitriding gas.

[0013] The atmosphere may contain the remaining nitrogen and hydrogen.

[0014] The stress-relief annealing process may be performed at a temperature of 530 to 920°C for 550 seconds to 60 minutes.

[0015] The non-oriented electrical steel sheet may satisfy Equation 1 below:

[Equation 1]

$$0.45 \leq (V_A+V_B+V_C)/(V_D+V_E+V_F) \leq 1.45$$

(In Equation 1, V_A , V_B , V_C , V_D , V_E , and V_F represent area fractions (%) of textures having orientations within 15° from (001)[0-10], (001)[-1-10], (100)[025], (223)[1-10], (111)[3-41], and (112)[1-10], respectively.)

[0016] The non-oriented electrical steel sheet may satisfy Equation 2 below:

[Equation 2]

$$0.35 \leq V_C/V_E \leq 1.35$$

(In Equation 2, V_C and V_E represent area fractions (%) of textures having orientations within 15° from (100)[025] and (111)[3-41], respectively.)

[0017] The preparing of the non-oriented electrical steel sheet may include manufacturing a hot-rolled steel sheet by hot-rolling a slab comprising, by weight, 1.5 to 5.0% of Si, 0.1 to 2.5% of Al, and 0.1 to 2.5% of Mn, with the balance being Fe and inevitable impurities, manufacturing a cold-rolled steel sheet by cold-rolling the hot-rolled steel sheet, and annealing the cold-rolled steel sheet.

[0018] The manufacturing of the hot-rolled steel sheet may include a rough rolling and a finish rolling, the finish rolling may be performed through n passes, where n is an integer of 2 or more, and the method may satisfy Equation 3 below:

[Equation 3]

$$R_1/(R_1+R_2+\cdots+R_n) \geq 0.2$$

(In Equation 3, R_1 to R_n represent reduction ratios (%) of a first pass to an n-th pass, respectively.)

[0019] The finish rolling satisfies Equation 4 below:

[Equation 4]

$$R_1/R_n \leq 8$$

(In Equation 4, R_1 to R_n represent reduction ratios (%) of the first pass to the n-th pass, respectively.)

[0020] The preparing of the non-oriented electrical steel sheet may include manufacturing a hot-rolled steel sheet by hot-rolling a slab comprising, by weight, 1.5 to 5.0% of Si, 0.1 to 2.5% of Al, and 0.1 to 2.5% of Mn, with the balance being Fe and inevitable impurities, manufacturing a cold-rolled steel sheet by cold-rolling the hot-rolled steel sheet, and annealing the cold-rolled steel sheet.

[0021] The manufacturing of the hot-rolled steel sheet may include a rough rolling and a finish rolling, the finish rolling may be performed through n passes, where n is an integer of 2 or more, and the finish rolling satisfies Equation 3 below:

[Equation 3]

$$R_1/(R_1+R_2+\cdots+R_n) \geq 0.2$$

(In Equation 3, R1 to Rn represent reduction ratios (%) of a first pass to an n-th pass, respectively.)

[0022] The slab may further include one or more selected from the group consisting of 0.1 wt% or less (excluding 0%) of P, 0.005 wt% or less (excluding 0%) of C, 0.005 wt% or less (excluding 0%) of S, 0.005 wt% or less (excluding 0%) of Ti, and 0.005 wt% or less (excluding 0%) of N.

[0023] 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.

[0024] The slab may further include one or more selected from the group consisting of 0.005 to 0.2 wt% of Cu, 0.01 to 0.5 wt% of Cr, 0.05 wt% or less (excluding 0%) of Ni, and 0.01 wt% or less (excluding 0%) of Zn.

[0025] The slab may further include one or more selected from the group consisting of 0.03 wt% or less (excluding 0%) of Mo, 0.0050 wt% or less (excluding 0%) of B, 0.0050 wt% or less (excluding 0%) of V, 0.0050 wt% or less (excluding 0%) of Ca, 0.0050 wt% or less (excluding 0%) of Nb, 0.005 wt% or less (excluding 0%) of Zr, 0.01 wt% or less (excluding 0%) of Te, 0.05 wt% or less (excluding 0%) of Co, and 0.0050 wt% or less (excluding 0%) of Mg.

[Advantageous Effects]

[0026] An iron core according to an embodiment of the present disclosure may have improved strength due to penetration of nitrogen during a stress-relief annealing process, and may also have improved magnetic properties during the stress-relief annealing process. Therefore, it may be usefully applied when used as a rotor of a motor.

[0027] An iron core according to an embodiment of the present disclosure may have an improved texture of a non-oriented electrical steel sheet, thereby concurrently exhibiting excellent magnetic flux density, core loss, and yield strength, and improving the efficiency of a motor.

[0028] Ultimately, an iron core according to an embodiment of the present disclosure may enable the manufacture of motors for eco-friendly vehicles, motors for high-efficiency home appliances, and super-premium electric motors.

[Mode for Invention]

[0029] 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.

[0030] The technical terms used herein are to simply refer to particular embodiments and are not meant to limit the present disclosure. An expression used in the singular encompasses an expression in 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.

[0031] 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.

[0032] Unless otherwise stated, % means weight %, and 1 ppm is 0.0001 wt%.

[0033] 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 element.

[0034] Unless otherwise stated, all terms used herein, including technical or scientific terms, have the same meanings as those that would be 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.

[0035] 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 embodiments may be modified in various different ways, all without departing from the spirit or scope of the present invention.

[0036] An iron core according to an embodiment of the present disclosure includes a laminate in which a plurality of non-oriented electrical steel sheets are laminated, wherein each of the non-oriented electrical steel sheets includes, by weight, 1.5 to 5.0% of Si, 0.1 to 2.5% of Al, and 0.1 to 2.5% of Mn, with the balance being Fe and inevitable impurities, wherein the non-oriented electrical steel sheet includes a nitrogen diffusion layer inward from a side surface of the laminate.

[0037] In an embodiment of the present disclosure, the iron core may refer to an iron core used in a motor, and may

be used for a stator or a rotor. More specifically, the iron core may be an iron core for a stator.

[0038] In an embodiment of the present disclosure, the iron core may be a unitary punched iron core or a divided iron core, and more specifically, may be a unitary punched iron core.

[0039] The iron core may be formed by laminating two or more non-oriented electrical steel sheets, and an insulation coating may be present between the non-oriented electrical steel sheets.

[0040] The non-oriented electrical steel sheet includes, by weight, 1.5 to 5.0% of Si, 0.1 to 2.5% of Al, and 0.1 to 2.5% of Mn, 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: 1.50 to 5.00 wt%

[0042] Silicon (Si) increases the resistivity of the material, lowers core loss, and increases strength through solid solution strengthening. When the content of Si added is too low, the effects of improving core loss and strength may be insufficient. When too much Si is added, the magnetic flux density is significantly reduced, and rollability may deteriorate due to an increase in brittleness. Accordingly, Si may be included in an amount of 1.5 to 5.0 wt%. More specifically, it may be included in an amount of 2.50 to 4.50 wt%. More specifically, it may be included in an amount of 2.70 to 3.85 wt%.

Al: 0.10 to 2.50 wt%

[0043] Aluminum (Al) serves to increase the resistivity of the material to lower core loss, improve rollability, and reduce magnetic anisotropy, thereby decreasing magnetic deviation between a rolling direction and a transverse direction. When the content of Al is too low, it may be difficult to obtain the effect of reducing high-frequency core loss. When too much Al is added, nitrides are excessively formed, which may cause the magnetic properties to deteriorate. Accordingly, Al may be included in an amount of 0.10 to 2.50 wt%. More specifically, it may be included in an amount of 0.50 to 2.50 wt%. More specifically, it may be included in an amount of 0.60 to 2.30 wt%.

Mn: 0.10 to 2.50 wt%

[0044] Manganese (Mn) serves to improve core loss by increasing the resistivity of the material and to improve the texture. When too little Mn is added, fine sulfides are formed to cause magnetic deterioration, whereas an the addition of too much Mn may adversely affect the magnetic flux density. Accordingly, Mn may be included in an amount of 0.10 to 2.50 wt%. More specifically, it may be included in an amount of 0.2 to 1.8 wt%. More specifically, it may be included in an amount of 0.50 to 2.50 wt%.

[0045] In one embodiment of the present disclosure, the non-oriented electrical steel sheet may have a resistivity of $63.0 \mu\Omega \cdot \text{cm}$ or more at 25°C . The core loss of the non-oriented electrical steel sheet is divided into hysteresis loss and eddy current loss. By adding elements such as Si, Al, and Mn, the resistivity of the steel is increased, which can significantly reduce the eddy current loss. Particularly, as the frequency increases, the proportion of eddy current loss in the total core loss increases. Therefore, to ensure excellent high-frequency core loss properties, it is necessary to control the resistivity of the steel to a certain level or higher. According to the present disclosure, superior properties can be secured when the resistivity (ρ) of the steel is $63 \mu\Omega \cdot \text{cm}$ or more. More specifically, the resistivity (ρ) may be 64.0 to $90.0 \mu\Omega \cdot \text{cm}$.

[0046] In an embodiment of the present disclosure, the resistivity may be measured by a four-terminal method, a Van der Pauw method, a four-point probe method, an eddy current method, or the like.

[0047] 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: 0.020 wt% or less (excluding 0%).

P: 0.1 wt% or less

[0048] Phosphorus (P) is an interfacial and surface segregation element and has an effect of improving the texture of steel. However, when too much P is added, it inhibits grain growth, thereby causing core loss to deteriorate, and leads to a decrease in productivity by causing rollability to deteriorate through grain boundary segregation. 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 0.0020 to 0.0200 wt%.

C: 0.0050 wt% or less

[0049] 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 cause magnetic properties to deteriorate. More specifically, C may be included in an amount of 0.0005 to 0.0035 wt%.

S: 0.0050 wt% or less

[0050] Sulfur (S) may form fine precipitates, MnS and CuS, which may cause magnetic properties and hot workability to deteriorate. More specifically, S may be included in an amount of 0.0005 to 0.0040 wt%.

Ti: 0.0050 wt% or less

[0051] Titanium (Ti) has a strong tendency to form precipitates inside the steel, and may cause the core loss to deteriorate 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 0.0005 to 0.0035 wt%.

N: 0.0200 wt% or less

[0052] 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 causing core loss to deteriorate. More specifically, after annealing the slab and the cold-rolled steel sheet, N may be included in an amount of 0.0005 to 0.0040 wt%. In an embodiment of the present disclosure, a portion of N may be introduced through a nitriding gas in the atmosphere during a stress-relief annealing process. However, N penetrates in a small amount into the side portions of the steel sheet, and there may be no substantial change in the N content when considering the overall composition of the steel sheet. Specifically, after the stress-relief annealing, N may be included in an amount of 0.0200 wt% or less. Specifically, N may be included in an amount of 0.0010 to 0.0100 wt%.

[0053] 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

[0054] Sn segregates at grain boundaries and surfaces to improve the texture of the material and inhibit surface oxidation; therefore, it may be added to enhance magnetic properties. When too much Sn is added, grain boundary segregation becomes severe, leading to deteriorated surface quality; furthermore, an increase in hardness may cause fracture of the cold-rolled steel sheet, thereby resulting in degradation of rollability. Specifically, Sn may be included in an amount of 0.005 to 0.200 wt%. More specifically, it may be included in an amount of 0.010 to 0.080 wt%.

Sb

[0055] Antimony (Sb) segregates at grain boundaries and surfaces to improve the texture of the material and inhibit surface oxidation; therefore, it may be further added to enhance magnetic properties. When too much Sb is added, grain boundary segregation becomes severe, leading to deteriorated surface quality; furthermore, an increase in hardness may cause fracture of the cold-rolled steel sheet, thereby resulting in reduced rollability. Specifically, Sb may be included in an amount of 0.005 to 0.200 wt%. More specifically, it may be included in an amount of 0.010 to 0.080 wt%.

Bi, Pb, Ge, and As

[0056] Bismuth (Bi), lead (Pb), germanium (Ge), and arsenic (As) are additionally added to alleviate stress concentration at grain boundaries during cold rolling, and to improve the magnetic flux density by suppressing recrystallization of <111>/ND orientation grains in the subsequent recrystallization annealing process. If these are added appropriately, the aforementioned effects may be additionally obtained, but if they are included excessively, a large amount of segregation may occur, hindering grain growth and resulting in lower magnetic flux density and core loss.

[0057] 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%

[0058] 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. When too much Cu is added, high-temperature brittleness occurs, which may lead to cracks during continuous 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%

[0059] Chromium (Cr) serves to improve core loss by increasing resistivity. When too little Cr is added, the effect of increasing resistivity may not be sufficient. When too much Cr is added, the magnetic flux density may deteriorate. Specifically, it may be included in an amount of 0.050 to 0.20 wt%.

Ni: 0.05 wt% or less

[0060] 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: 0.01 wt% or less

[0061] If the content of zinc (Zn) is excessive, it may act as an impurity and cause magnetic properties to deteriorate. 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

[0062] 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.

[0063] 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

[0064] If too much molybdenum (Mo) is added, the effect of improving the texture may be reduced by suppressing the segregation of segregated 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

[0065] If too much boron (B) is added, 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: 0.0050 wt% or less

[0066] Vanadium (V) has a strong tendency to form precipitates inside the steel, and they cause the core loss to deteriorate 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

[0067] Calcium (Ca) has a strong tendency to form precipitates inside the steel, and they cause the core loss to deteriorate by forming fine sulfides inside the base material, thereby suppressing grain growth and domain wall movement.

Nb: 0.0050 wt% or less

[0068] Niobium (Nb) has a strong tendency to form precipitates inside the steel, and they cause the core loss to deteriorate 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

[0069] If too much zirconium (Zr) is added, 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

[0070] Tellurium (Te) diffuses into the oxide layer on the surface of hot-rolled coils, increasing the coefficient of friction between the oxide layer and the rolling work roll and improving 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 removed. If too little Te added, 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> 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

[0071] 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%.

[0072] 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.

[0073] As described above, according to an embodiment of the present disclosure, a specific texture of a non-oriented electrical steel sheet may be developed to simultaneously improve strength and magnetic properties.

[0074] Specifically, the non-oriented electrical steel sheet satisfies Equation 1 below:

[Equation 1]

$$0.45 \leq (VA+VB+VC)/(VD+VE+VF) \leq 1.45$$

(In Equation 1, VA, VB, VC, VD, VE, and VF represent area fractions (%) of textures having orientations within 15° from (001)[0-10], (001)[-1-10], (100)[025], (223)[1-10], (111)[3-41], and (112)[1-10], respectively.)

[0075] In an embodiment of the present disclosure, fractions of a plane (001) and a plane (111) parallel to a rolling plane, which have been conventionally considered as textures significantly affecting magnetic properties, are important, but fractions of a plane (223) and a plane (112), which are similar textures, may also be important. In an

embodiment of the present disclosure, magnetic properties may be improved as fractions and intensities of (001)[0-10], (001)[-1-10], and (100)[025] textures advantageous for magnetization are strengthened, and fractions and intensities of (223)[1-10], (111)[3-41], and (112)[1-10] textures disadvantageous for magnetization are decreased. If the value of Equation 1 is excessively small, core loss may increase due to poor magnetization. Even if the value of Equation 1 is larger, further improvement in magnetic properties does not occur, and a process for achieving this may become complicated. More specifically, the value of Equation 1 may be from 0.50 to 1.40. In Equation 1, the texture orientation represented by (hkl)<uvw> refers to the texture orientation representation in Miller indices. Miller indices are a notation for representing directions and planes of a crystal lattice in crystallography, and (hkl) refers to a plane parallel to a rolling plane of a steel sheet in a measured texture. In addition, a vector <uvw> refers to a direction parallel to the rolling direction in the measured texture.

[0076] In an embodiment of the present disclosure, the value of Equation 1 may be calculated by observing and analyzing texture fractions through electron backscatter diffraction (EBSD) measurement and using the results thereof. To ensure reliability of data, measurement may be performed such that at least 5000 or more grains are included. A tolerance angle may be set to 15° or less.

[0077] Further, the non-oriented electrical steel sheet may satisfy Equation 2 below:

[Equation 2]

$$0.35 \leq VC/VE \leq 1.35$$

(In Equation 2, VC and VE represent area fractions (%) of textures having orientations within 15° from (100)[025] and (111)[3-41], respectively.)

[0078] Equation 2 is formulated because a (100)[025] texture has a more favorable effect on magnetic properties and a (111)[3-41] texture has a more adverse effect on magnetic properties among the textures. If the value of Equation 2 is too small, magnetization may be insufficient during magnetization, which may lead to a significant deterioration in core loss. Even if the value of Equation 2 is larger, further improvement in magnetic properties does not occur, and a process for achieving this may become complicated. More specifically, the value of Equation 2 may be from 0.35 to 1.30.

[0079] In an embodiment of the present disclosure, the texture of the non-oriented electrical steel sheet is specified through cold-rolled steel sheet annealing, and subsequently, the texture characteristics may not be substantially changed through punching and stress-relief annealing.

[0080] As described above, in an embodiment of the present disclosure, both strength and magnetic properties can be simultaneously improved by developing a specific texture. Specifically, the non-oriented electrical steel sheet according to an embodiment of the present disclosure may have a core loss (W10/400) of 12.0 W/kg or less and a magnetic flux density (B50) of 1.60 T or more. A standard for the thickness may be 0.20 mm. More specifically, the core loss (W10/400) may be 9.0 to 11.0 W/kg. The magnetic flux density (B50) may be 1.61 to 1.70 T. The core loss (W10/400) refers to a core loss when a magnetic flux density of 1.0 T is induced at a frequency of 400 Hz. The magnetic flux density (B50) refers to the magnetic flux density induced in a magnetic field of 5000 A/m. The core loss (10/400) and the magnetic flux density (B50) may be measured with a single sheet tester in the rolling direction and the transverse direction, and may be determined as average values thereof.

[0081] In addition, an embodiment of the present disclosure exhibits excellent mechanical strength. More specifically, the yield strength may be 480 MPa or more and 570 MPa or less. The yield strength may be measured using a 0.2% off-set method in a tensile test. The characteristics of the non-oriented electrical steel sheet described above may be measured by separating the non-oriented electrical steel sheet from an iron core.

[0082] A core according to an embodiment of the present disclosure is formed by laminating the aforementioned non-oriented electrical steel sheet, resulting in high efficiency and excellent strength. A nitrogen diffusion layer exists inward from a side surface of the laminate, thereby further improving strength.

[0083] In the nitrogen diffusion layer, nitrogen content may be 0.005 to 0.020 wt% from the side surface of the laminate to a depth of 30 μm in an inward direction. If the nitrogen content in the nitrogen diffusion layer is too low, sufficient strength improvement may not be achieved. In addition, if the nitrogen content in the nitrogen diffusion layer inward from the side surface of the laminate is too high, it may hinder magnetic domain movement, thereby adversely affecting magnetic properties. In an embodiment of the present disclosure, only a rotor core among the cores may have the aforementioned characteristics. In the stator core, the importance of strength characteristics is relatively low, and thus the stator core may not have the aforementioned characteristics. More specifically, the nitrogen content in the nitrogen diffusion layer may be 0.010 to 0.015 wt% from the side surface of the laminate to a depth of 30 μm in the inward direction.

[0084] The side surface of the laminate refers to a surface parallel to a thickness direction of the non-oriented

electrical steel sheet (i.e., a stacking direction of the laminate). When the non-oriented electrical steel sheet is punched into a cylindrical shape, the circumferential surface becomes the side surface. The nitrogen content up to 30 μm from the side surface may be measured through methods such as combustion analysis, energy dispersive spectroscopy (EDS), and glow discharge spectroscopy (GDS). The nitrogen content refers to an average nitrogen content within 30 μm from the side surface.

[0085] A method for manufacturing an iron core according to an embodiment of the present disclosure includes preparing a non-oriented electrical steel sheet comprising, by weight, 1.5 to 5.0% of Si, 0.1 to 2.5% of Al, and 0.1 to 2.5% of Mn, with the balance being Fe and inevitable impurities, manufacturing a laminate by punching and laminating the non-oriented electrical steel sheet, and annealing the laminate in an atmosphere containing a nitriding gas.

[0086] First, a non-oriented electrical steel sheet is prepared. Since the steel composition and texture characteristics of the non-oriented electrical steel have been described in relation to the non-oriented electrical steel sheet in the iron core, a redundant description thereof will be omitted. As described above, the steel composition and texture characteristics of the non-oriented electrical steel in the core and the non-oriented electrical steel before manufacturing the core may not substantially change.

[0087] The non-oriented electrical steel sheet may be manufactured as follows. Specifically, the method may include manufacturing the hot-rolled steel sheet by hot-rolling the slab, manufacturing the cold-rolled steel sheet by cold-rolling the hot-rolled steel sheet, and annealing the cold-rolled steel sheet.

[0088] Hereinafter, each step will be described in detail.

[0089] First, the slab is hot-rolled.

[0090] Since the alloy components of the slab have been described in the alloy components of the aforementioned non-oriented electrical steel sheet, a redundant description thereof will be omitted. Since the alloy components do not substantially change during the manufacturing process of the non-oriented electrical steel sheet, the alloy components of the non-oriented electrical steel sheet and the slab are substantially identical.

[0091] Specifically, the slab includes, by weight, 1.5 to 5.0% of Si, 0.1 to 2.5% of Al, and 0.1 to 2.5% of Mn, with the balance being Fe and inevitable impurities.

[0092] Since other additional elements have been described in the alloy components of the non-oriented electrical steel sheet, a redundant description thereof will be omitted.

[0093] The slab may be heated before hot-rolling. The heating temperature of the slab is not particularly limited, but the slab may be heated to 1200°C or less. If the heating temperature of the slab is too high, precipitates such as AlN and MnS present in the slab may be re-dissolved and then finely precipitated during hot-rolling and annealing, which may inhibit grain growth and cause magnetic properties to deteriorate.

[0094] Next, a hot-rolled sheet is manufactured by hot-rolling the slab.

[0095] In an embodiment of the present disclosure, it has been discovered that it is necessary to precisely control conditions from the hot-rolling in order to improve the texture. Specifically, it has been discovered that it is necessary to adjust a reduction ratio of each pass in finishing rolling.

[0096] In an embodiment of the present disclosure, manufacturing of the hot-rolled steel sheet includes rough rolling and finish rolling.

[0097] Rough rolling is a process of manufacturing a bar by primary-rolling the slab moved from a caster into a steel sheet form, and includes about 3 to 4 rolling mills. Finish rolling is a process of rolling the rough-rolled steel sheet (bar) to a final target hot-rolled thickness to produce a hot-rolled coil, and includes continuous multi-stage rolling mills.

[0098] The finish rolling is performed through n passes, where n is an integer of 2 or more, and the method satisfies Equation 3 below:

[Equation 3]

$$R1 / (R1 + R2 + \dots + Rn) \geq 0.20$$

(In Equation 3, R1 to Rn represent reduction ratios (%) of a first pass to an n-th pass, respectively.)

[0099] In an embodiment of the present disclosure, since the reduction ratio of each finish rolling and the first reduction ratio significantly affect the formation of a texture, α -fiber and γ -fiber textures are weakened and magnetic properties are improved when the reduction ratio of each pass is appropriately controlled as shown in Equation 3. R1 means the first pass, and the number of passes may be determined based on passage through a work roll. Further, the n-th pass is a final pass, and R1+R2+.....+Rn means a total sum of reduction ratios of all passes. The reduction ratio may be calculated by: (thickness of steel sheet before pass - thickness of steel sheet after pass)/(thickness of steel sheet before pass) $\times$ 100(%). In Equation 3, R1+R2+.....+Rn means a total sum of reduction ratios from the reduction ratio (%) of the first pass to the reduction ratio (%) of the final pass in finish rolling.

[0100] In an embodiment of the present disclosure, the finish rolling may be performed in 3 to 7 passes (i.e., n is 3 to

7). If the number of passes is too small, rolling load may become excessively large, thereby making the operation difficult. If the number of passes is too large, productivity may be reduced.

[0101] When the reduction ratio R1 of the first pass of the finish rolling is too large to satisfy Equation 3, the γ -fiber is significantly strengthened, which may result in deteriorated magnetic properties. More specifically, the value of Equation 3 may be 0.21 to 0.45.

[0102] The finish rolling may satisfy Equation 4 below:

[Equation 4]

$$R1/Rn \leq 8.0$$

(In Equation 4, R1 to Rn represent reduction ratios (%) of the first pass to the n-th pass, respectively.)

[0103] When the reduction ratio Rn of the final pass of the finish rolling is too small to satisfy Equation 4, an effect of improving textures of (001)[0-10], (001)[-1-10], and (100)[025], which are easy magnetization directions, may be insufficient. More specifically, the value of Equation 4 may be 1.5 to 7.5.

[0104] In the finish rolling, the reduction ratio (R1) of the first pass may be 40 to 80%. More specifically, it may be 42 to 80%.

[0105] In the finish rolling, the reduction ratio (Rn) of the final pass may be 7 to 35%.

[0106] More specifically, it may be 10 to 30%.

[0107] The thickness of the hot-rolled steel sheet may be 1.0 to 4.5 mm. In the manufacturing of the hot-rolled steel sheet, a finishing rolling temperature may be 800°C or higher. Specifically, it may be 800 to 1000°C. The hot-rolled steel sheet may be coiled at a temperature of 700°C or lower. More specifically, the thickness of the hot-rolled steel sheet may be 1.5 to 4.3 mm.

[0108] After manufacturing the hot-rolled steel sheet, annealing the hot-rolled steel sheet may be further included. In this process, a soaking temperature may be 850 to 1100°C. If the annealing temperature is too low, a recrystallized structure may not be formed or may grow excessively fine, resulting in a minimal effect on increasing magnetic flux density. Conversely, if the annealing temperature is too high, magnetic properties may rather deteriorate, and rolling workability may worsen due to deformation of the sheet shape. More specifically, the temperature range may be 830 to 1080°C. A soaking time may be 10 to 300 seconds. The annealing of the hot-rolled steel sheet may be omitted.

[0109] Subsequently, the cold-rolled steel sheet is manufactured by cold-rolling the hot-rolled steel sheet. In this case, the cold-rolling may be performed at a reduction ratio of 40 to 85%. If the reduction ratio is too low, the strain energy accumulated in the rolled steel sheet is insufficient, making it difficult to recrystallize during a subsequent annealing process. This may result in residual rolling structures, leading to issues in improving magnetic flux density and core loss. Conversely, if the reduction ratio is too high, the recrystallization of grains in the <111>//ND orientation is promoted and the grain size becomes fine during the subsequent annealing process, which may lead to deteriorated magnetic flux density and increased core loss. More specifically, the reduction ratio may be 60 to 75%. For the cold-rolling, a tandem cold mill for continuously cold-rolling the steel sheet using a plurality of rolling stands, or a reversing mill for discontinuously cold-rolling using 12 or more stages of rolling rolls may be used. The final rolled thickness may be 0.1 to 0.35 mm.

[0110] Manufacturing the cold-rolled steel sheet may be performed once, or twice or more with intermediate annealing interposed therebetween.

[0111] Subsequently, annealing the cold-rolled steel sheet is performed. In the process of annealing the cold-rolled steel sheet, the annealing temperature is not particularly limited as long as it is a temperature typically applied to the non-oriented electrical steel sheet. The core loss of the non-oriented electrical steel sheet is closely related to the grain size. The core loss may be categorized into hysteresis loss and eddy current loss; since the hysteresis loss decreases as the grain size increases, while the eddy current loss increases as the grain size increases, an optimal grain size exists where the sum of the hysteresis loss and the eddy current loss is minimized. Therefore, it is important to derive and apply an annealing temperature capable of securing the optimal grain size, and an annealing temperature of 850 to 1100°C is suitable. If the annealing temperature is too low, the grains become excessively fine, increasing the hysteresis loss; if it is too high, the grains become excessively coarse, increasing the eddy current loss and thereby causing the core loss to deteriorate. Further, an annealing time of 10 to 300 seconds is suitable, and the annealing may be conducted in a mixed atmosphere of hydrogen, argon, or nitrogen to prevent magnetic degradation caused by the formation of an oxide layer.

[0112] During annealing of the cold-rolled steel sheet, the worked structure formed during the cold-rolling may be fully recrystallized (i.e., 99% or more).

[0113] After annealing of the cold-rolled steel sheet, forming an insulating coating may be performed. The insulating coating may be treated with an organic, inorganic, or organic-inorganic composite coating, and it is also possible to

treat it with other insulating coating agents.

[0114] The non-oriented electrical steel sheet manufactured in this manner has the steel composition and texture characteristics described above.

[0115] Returning to the description of the method for manufacturing the core, a laminate is manufactured by punching and laminating the non-oriented electrical steel sheet. Punching refers to cutting the non-oriented electrical steel sheet into a shape of a motor core, and may be performed in a ring shape. Laminating refers to stacking the electrical steel sheets in the thickness direction.

[0116] Subsequently, during stress-relief annealing, the laminate is annealed in an atmosphere containing a nitriding gas. In an embodiment of the present disclosure, by adding a nitriding gas to the atmosphere during the stress-relief annealing, a nitrogen diffusion layer may be formed from a side surface of the laminate toward the inward direction through nitriding.

[0117] As the nitriding gas, any gas capable of nitriding the side surface of the laminate during the stress-relief annealing may be used without limitation. However, although nitrogen (N_2) contains the element N, it is excluded from the nitriding gas because its reactivity is too weak to cause substantial nitriding. Specifically, for the nitriding gas, it is possible to use any gas, such as ammonia or cyanite, in which nitrogen is dissociated at a temperature higher than room temperature and is capable of nitriding by diffusing into the steel. More specifically, the nitriding gas may include ammonia.

[0118] The nitriding gas may be included in an amount of 0.7 to 95 vol% in the atmosphere. If too little nitriding gas is included, strength may not be sufficiently improved. If too much nitriding gas is included, a large amount of nitrides may be formed on the side surface, which may adversely affect magnetic properties. More specifically, the nitriding gas may be included in an amount of 1.0 to 15.0 vol% in the atmosphere.

[0119] The remainder of the atmosphere may include nitrogen (N_2) and hydrogen (H_2). Specifically, the atmosphere may include 5 to 15 vol% of hydrogen, with the remainder being nitrogen. More specifically, nitrogen may be included in an amount of 90 vol% or less.

[0120] The soaking temperature for stress-relief annealing may be 530 to 920°C. If the soaking temperature is too low, stress during punching remains, which may adversely affect magnetic properties. If the soaking temperature is too high, it may adversely affect the strength. More specifically, the soaking temperature may be 550 to 900°C. The soaking time may be 550 seconds to 60 minutes. More specifically, it may be 10 minutes to 30 minutes.

[0121] 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.

Example 1

[0122] Slabs were manufactured with the compositions shown in Table 1, with the balance being Fe and inevitable impurities. The slabs were heated to 1170°C, hot-rolled to a thickness of 2.2 mm, and then coiled at 680°C. At this time, finish rolling was performed in 7 passes, and the reduction ratio of each pass was conducted as shown in Table 2 below. The hot-rolled steel sheet was annealed at 1000°C for 50 seconds. After annealing of the hot-rolled steel sheet, a pickled specimen was cold-rolled to a thickness of 0.2 mm, and finally, cold-rolled steel sheet annealing was performed. At this time, the cold-rolled steel sheet was annealed at 1000°C for 50 seconds.

[0123] Textures were analyzed using electron backscatter diffraction (EBSD) after obtaining specimens by cutting the steel sheet in the rolling direction. At this time, a tolerance angle was set to 15°.

[0124] Subsequently, to simulate the manufacturing of a stator core, stress-relief annealing was performed at 750°C for 1800 seconds in an atmosphere of 90 vol% nitrogen and 10 vol% hydrogen.

[0125] In addition, to simulate the manufacturing of a rotor core, stress-relief annealing was performed under the conditions of temperature, time, and ammonia-containing atmosphere summarized in Table 3 below. The atmosphere consisted of ammonia as summarized in Table 3, 10 vol% hydrogen, and the remainder of nitrogen.

[0126] Yield strength was measured by a 0.2% off-set method during a tensile test.

[0127] Core loss (W10/400) and magnetic flux density (B50) were measured using a single sheet tester.

[0128] The nitrogen content within a nitrogen diffusion layer up to 30 μm from a side surface of the rotor was measured through an energy dispersive spectrometer.

(Table 1)

Steel Grade	Si	Mn	Al	C	P	S	Ti	N	Re-sis-tivity ($\mu\Omega \cdot \text{cm}$)
1	3.28	1.45	2.08	0.001 5	0.004	0.004 0	0.000 7	0.002 7	82.0
2	3.64	2.29	1.47	0.002 0	0.009	0.000 9	0.001 8	0.002 3	83.9
3	3.28	1.53	0.63	0.001 3	0.008	0.003 8	0.003 2	0.003 7	66.1

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(continued)

	Steel Grade	Si	Mn	Al	C	P	S	Ti	N	Re-sis-tivity ($\mu\Omega \cdot \text{cm}$)
5	4	3.11	0.75	1.07	0.001 1	0.013	0.001 4	0.002 9	0.001 8	64.7
	5	3.28	1.81	2.24	0.002 2	0.010	0.001 1	0.001 3	0.001 6	85.9
	6	3.48	2.07	0.63	0.001 4	0.009	0.001 4	0.001 5	0.001 5	71.4
	7	2.95	0.82	1.48	0.001 0	0.010	0.002 3	0.001 4	0.002 8	67.9
10	8	3.81	0.67	2.05	0.002 9	0.013	0.001 9	0.002 0	0.001 4	83.3
	9	3.34	0.56	0.96	0.001 4	0.010	0.000 9	0.002 7	0.002 8	65.0
	10	3.44	1.29	1.34	0.002 9	0.007	0.003 3	0.003 6	0.001 5	74.6
	11	2.86	1.50	1.56	0.002 4	0.007	0.003 6	0.002 4	0.002 2	71.7
15	12	3.26	1.10	0.99	0.001 1	0.009	0.002 7	0.001 8	0.003 7	67.5
	13	3.01	0.54	1.64	0.002 6	0.012	0.001 3	0.001 3	0.002 8	68.8
	14	2.74	2.50	2.12	0.003 2	0.012	0.001 6	0.000 9	0.002 7	82.3
20	15	3.55	1.34	1.51	0.001 3	0.006	0.002 6	0.002 8	0.002 7	78.0
	16	2.41	0.98	1.30	0.000 7	0.007	0.000 8	0.002 7	0.001 2	60.7
	17	2.99	0.85	0.45	0.003 7	0.003	0.001 9	0.001 5	0.003 4	56.9
	18	3.06	1.11	0.70	0.000 8	0.007	0.002 7	0.002 1	0.002 1	62.0
25	19	3.15	0.62	1.32	0.003 6	0.004	0.003 0	0.002 9	0.002 3	67.3
	20	3.72	0.38	1.54	0.001 2	0.005	0.003 7	0.002 6	0.001 4	74.8
	21	3.83	0.67	1.64	0.001 8	0.007	0.003 8	0.002 5	0.004 0	78.8
30	22	3.06	1.99	1.61	0.000 9	0.006	0.001 5	0.001 7	0.001 2	77.3
	23	2.62	0.75	2.03	0.001 2	0.010	0.001 0	0.003 2	0.002 6	70.0
	24	3.90	1.79	1.60	0.002 1	0.011	0.002 1	0.003 0	0.003 1	85.5
	25	3.30	1.61	0.54	0.003 2	0.010	0.003 7	0.002 3	0.001 5	65.7
35	26	3.71	1.44	0.89	0.003 5	0.003	0.002 7	0.003 4	0.001 6	73.4
	27	2.89	0.67	1.48	0.002 4	0.013	0.002 8	0.001 8	0.001 0	66.4
	28	3.51	2.05	0.50	0.001 9	0.008	0.001 2	0.002 2	0.003 8	70.1
40	29	2.98	1.03	0.83	0.003 9	0.013	0.001 5	0.003 6	0.003 4	62.1
	30	3.20	0.50	0.57	0.002 0	0.008	0.002 8	0.001 2	0.002 9	58.7

(Table 2)

	Steel Grade	R1 (%)	R1+R2+...+Rn (%)	Rn (%)	Equation 3	Equation 4
45	1	73	286	13	0.26	5.6
	2	53	235	29	0.23	1.8
	3	44	209	22	0.21	2.0
50	4	36	168	11	0.21	3.3
	5	58	228	25	0.25	2.3
	6	38	100	12	0.38	3.2
55	7	71	180	25	0.39	2.8
	8	52	180	14	0.29	3.7
	9	80	324	13	0.25	6.2

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(continued)

Steel Grade	R1 (%)	R1+R2+...+Rn (%)	Rn (%)	Equation 3	Equation 4
10	42	201	23	0.21	1.8
11	55	262	16	0.21	3.4
12	66	221	16	0.30	4.1
13	66	151	17	0.44	3.9
14	71	285	10	0.25	7.1
15	64	286	15	0.22	4.3
16	53	254	13	0.21	4.1
17	38	131	5	0.29	7.6
18	36	132	18	0.27	2.0
19	32	181	24	0.18	1.3
20	71	206	7	0.34	10.1
21	50	288	6	0.17	8.3
22	43	238	18	0.18	2.4
23	28	178	28	0.16	1.0
24	60	186	5	0.32	12.0
25	65	203	6	0.32	10.8
26	80	254	9	0.31	8.9
27	32	350	26	0.09	1.2
28	63	336	7	0.19	9.0
29	38	201	4	0.19	9.5
30	40	221	4	0.18	10.0

(Table 3)

Steel Grade	Equation 1	Equation 2	Holding Temperature (°C)	Holding Time (sec)	Ammonia (volume %)	Nitrogen Content in Nitrogen Diffusion Layer (wt%)
1	1.09	0.37	500	500	0.5	0.0018
2	1.37	0.92	500	500	1.0	0.0020
3	1.15	0.84	500	500	10.0	0.0023
4	0.55	0.88	500	500	90.0	0.0038
5	1.30	0.70	550	600	0.5	0.0037
6	0.77	0.42	550	600	1.0	0.0054
7	0.50	0.40	550	600	10.0	0.0075
8	0.65	1.28	550	600	90.0	0.0138
9	0.72	0.68	900	1800	0.5	0.0043
10	0.67	0.35	900	1800	1.0	0.0068
11	1.18	0.82	900	1800	10.0	0.0117
12	1.09	1.05	900	1800	90.0	0.0183
13	1.02	1.05	950	2000	0.5	0.0045
14	0.96	0.92	950	2000	1.0	0.0352

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(continued)

Steel Grade	Equation 1	Equation 2	Holding Temperature (°C)	Holding Time (sec)	Ammonia (volume %)	Nitrogen Content in Nitrogen Diffusion Layer (wt%)
15	1.29	0.38	950	2000	10.0	0.0473
16	1.20	0.37	500	500	0.5	0.0012
17	1.06	0.57	500	500	1.0	0.0019
18	0.89	0.60	500	500	10.0	0.0024
19	0.85	0.33	500	500	90.0	0.0035
20	0.38	0.65	550	600	0.5	0.0037
21	0.20	0.23	550	600	1.0	0.0054
22	0.43	0.29	550	600	10.0	0.0078
23	0.38	0.55	550	600	90.0	0.0143
24	0.56	0.33	900	1800	0.5	0.0041
25	0.35	0.33	900	1800	1.0	0.0071
26	0.36	0.47	900	1800	10.0	0.0129
27	0.48	0.28	900	1800	90.0	0.0173
28	0.41	0.29	950	2000	0.5	0.0041
29	0.37	0.33	950	2000	1.0	0.0243
30	0.40	0.26	950	2000	10.0	0.0457

(Table 4)

Steel Grade	Yield Strength (MPa)		W10/400 (W/Kg)		B50(T)		Type
	Stator	Rotor	Stator	Rotor	Stator	Rotor	
1	530	532	9.12	9.52	1.62	1.61	Comparative Example
2	521	522	9.20	9.23	1.62	1.61	Comparative Example
3	485	486	9.88	10.09	1.63	1.62	Comparative Example
4	487	491	10.02	10.15	1.63	1.63	Comparative Example
5	530	533	9.35	9.51	1.62	1.62	Comparative Example
6	517	527	9.80	9.94	1.63	1.62	Inventive Example
7	481	492	9.77	9.97	1.62	1.62	Inventive Example
8	523	553	9.19	9.35	1.62	1.61	Inventive Example
9	512	513	9.80	9.91	1.63	1.62	Comparative Example
10	544	551	9.65	9.71	1.62	1.61	Inventive Example
11	498	513	9.82	9.97	1.63	1.61	Inventive Example
12	504	525	10.18	10.52	1.64	1.63	Inventive Example
13	511	514	9.86	9.89	1.63	1.63	Comparative Example
14	530	557	9.50	12.08	1.62	1.59	Comparative Example
15	542	574	10.13	13.58	1.64	1.59	Comparative Example
16	414	416	13.15	15.21	1.59	1.57	Comparative Example
17	429	432	13.21	15.10	1.59	1.58	Comparative Example
18	458	461	12.53	14.89	1.58	1.57	Comparative Example

(continued)

		Yield Strength (MPa)		W10/400 (W/Kg)		B50(T)		
	Steel Grade	Stator	Rotor	Stator	Rotor	Stator	Rotor	Type
5	19	508	512	12.55	15.13	1.57	1.57	Comparative Example
	20	490	492	13.10	13.24	1.59	1.58	Comparative Example
	21	506	516	12.98	14.55	1.59	1.57	Comparative Example
10	22	520	536	12.80	14.86	1.59	1.58	Comparative Example
	23	490	512	12.73	13.98	1.58	1.57	Comparative Example
	24	587	590	13.12	15.42	1.59	1.57	Comparative Example
15	25	483	488	13.86	15.48	1.57	1.56	Comparative Example
	26	539	554	12.40	14.84	1.58	1.58	Comparative Example
	27	486	512	12.94	14.94	1.58	1.57	Comparative Example
20	28	502	503	12.82	14.75	1.58	1.56	Comparative Example
	29	467	472	13.20	15.42	1.59	1.58	Comparative Example
	30	461	473	13.68	15.76	1.58	1.56	Comparative Example

[0129] As shown in Tables 1 to 4, when the steel composition and the finish rolling reduction ratio are appropriately controlled and the conditions during SRA are appropriately controlled, both the stator and rotor exhibit excellent properties, and in particular, an improvement in the strength of the rotor can be confirmed.

[0130] On the other hand, as in Steel Grades 16 to 30, when the steel composition or the electrical steel sheet manufacturing process conditions are not appropriately controlled and a specific texture fails to develop, it can be confirmed that the properties of both the stator and rotor are inferior.

[0131] In addition, in Steel Grades 1 to 5, 9, and 13 to 15, the conditions during the SRA process of the rotor were inappropriate, so nitrogen did not appropriately penetrate into the nitrogen diffusion layer on the side surface of the rotor, and it can be confirmed that the strength improvement of the rotor is insufficient.

[0132] 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 would 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.

Claims

1. An iron core, comprising:

a laminate in which a plurality of non-oriented electrical steel sheets are laminated, wherein each of the non-oriented electrical steel sheets comprises: by weight, 1.5 to 5.0% of Si, 0.1 to 2.5% of Al, and 0.1 to 2.5% of Mn, with the balance being Fe and inevitable impurities;
wherein the non-oriented electrical steel sheet has a nitrogen diffusion layer present up to 30 μm inward from a side surface of the laminate, and a nitrogen content in the nitrogen diffusion layer is 0.005 to 0.020 wt%.

2. The iron core of claim 1, wherein

the non-oriented electrical steel sheet further comprises one or more selected from the group consisting of: 0.1 wt% or less (excluding 0%) of P; 0.005 wt% or less (excluding 0%) of C; 0.005 wt% or less (excluding 0%) of S; 0.005 wt% or less (excluding 0%) of Ti; and 0.020 wt% or less (excluding 0%) of N.

3. The iron core of claim 1, wherein

the non-oriented electrical steel sheet 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.

4. The iron core of claim 1, wherein

the non-oriented electrical steel sheet further comprises one or more selected from the group consisting of: 0.005 to 0.2 wt% of Cu; 0.01 to 0.5 wt% of Cr; 0.05 wt% or less (excluding 0%) of Ni; 0.01 wt% or less (excluding 0%) of Zn; and 0.05 wt% or less (excluding 0%) of Co.

- 5 5. The iron core of claim 1, wherein
the non-oriented electrical steel sheet further comprises one or more selected from the group consisting of: 0.03 wt% or less (excluding 0%) of Mo; 0.0050 wt% or less (excluding 0%) of B; 0.0050 wt% or less (excluding 0%) of V; 0.0050 wt% or less (excluding 0%) of Ca; 0.0050 wt% or less (excluding 0%) of Nb; 0.005 wt% or less (excluding 0%) of Zr; 0.01 wt% or less (excluding 0%) of Te; and 0.0050 wt% or less (excluding 0%) of Mg.

- 10 6. The iron core of claim 1, wherein
the non-oriented electrical steel sheet satisfies Equation 1 below:

15 [Equation 1]

$$0.45 \leq (VA+VB+VC)/(VD+VE+VF) \leq 1.45$$

20 (in Equation 1, VA, VB, VC, VD, VE, and VF represent area fractions (%), respectively, of textures having orientations within 15° from (001)[0-10], (001)[-1-10], (100)[025], (223)[1-10], (111)[3-41], and (112)[1-10].)

7. The iron core of claim 1, wherein
the non-oriented electrical steel sheet satisfies Equation 1 below:

25 [Equation 2]

$$0.35 \leq VC/VE \leq 1.35$$

30 (in Equation 2, VC and VE represent area fractions (%), respectively, of textures having orientations within 15° from (100)[025] and (111)[3-41].)

- 35 8. A method for manufacturing an iron core, comprising:

preparing a non-oriented electrical steel sheet comprising, by weight, 1.5 to 5.0% of Si, 0.1 to 2.5% of Al, and 0.1 to 2.5% of Mn, with the balance being Fe and inevitable impurities;
40 manufacturing a laminate by punching and laminating the non-oriented electrical steel sheet; and
stress-relief annealing the laminate by annealing the laminate in an atmosphere containing a nitriding gas.

9. The method for manufacturing the iron core of claim 8, wherein
the atmosphere contains 0.7 to 95 vol% of the nitriding gas.

- 45 10. The method for manufacturing the iron core of claim 8, wherein
The atmosphere contains the remainder of nitrogen and hydrogen.

11. The method for manufacturing the iron core of claim 8, wherein
50 the stress-relief annealing is performed at a temperature of 530 to 920°C for 550 seconds to 60 minutes.

12. The method for manufacturing the iron core of claim 8, wherein
the non-oriented electrical steel sheet satisfies Equation 1 below:

[Equation 1]

$$0.45 \leq (V_A + V_B + V_C) / (V_D + V_E + V_F) \leq 1.45$$

(in Equation 1, V_A , V_B , V_C , V_D , V_E , and V_F represent area fractions (%), respectively, of textures having orientations within 15° from (001)[0-10], (001)[-1-10], (100)[025], (223)[1-10], (111)[3-41], and (112)[1-10].)

13. The method for manufacturing the iron core of claim 8, wherein the non-oriented electrical steel sheet satisfies Equation 2 below:

[Equation 2]

$$0.35 \leq V_C / V_E \leq 1.35$$

(in Equation 2, V_C and V_E represent area fractions (%), respectively, of textures having orientations within 15° from (100)[025] and (111)[3-41].)

14. The method for manufacturing the iron core of claim 8, wherein

the preparing of the non-oriented electrical steel sheet comprises manufacturing a hot-rolled steel sheet by hot-rolling a slab comprising, by weight, 1.5 to 5.0% of Si, 0.1 to 2.5% of Al, and 0.1 to 2.5% of Mn, with the balance being Fe and inevitable impurities; manufacturing a cold-rolled steel sheet by cold-rolling the hot-rolled steel sheet; and annealing the cold-rolled steel sheet.

15. The method for manufacturing the iron core of claim 14, wherein

the manufacturing of the hot-rolled steel sheet comprises a rough rolling and a finish rolling, the finish rolling is performed through n passes, where n is an integer of 2 or more, and the finish rolling satisfies Equation 3 below:

[Equation 3]

$$R_1 / (R_1 + R_2 + \dots + R_n) \geq 0.2$$

(in Equation 3, R_1 to R_n represent reduction ratios (%) of a first pass to an n-th pass, respectively.)

16. The method for manufacturing the iron core of claim 15, wherein the finish rolling satisfies Equation 4 below:

[Equation 4]

$$R_1 / R_n \leq 8$$

(in Equation 4, R_1 to R_n represent reduction ratios (%) of the first pass to the n-th pass, respectively.)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2024/063295

A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/04(2006.01)i; C22C 38/06(2006.01)i; C22C 38/00(2006.01)i; C22C 38/14(2006.01)i;
C22C 38/42(2006.01)i; C22C 38/58(2006.01)i; C22C 38/52(2006.01)i; C22C 38/12(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/02(2006.01); B05D 3/00(2006.01); B21B 3/00(2006.01); B32B 15/04(2006.01); B32B 7/12(2006.01);
C09J 11/04(2006.01); C09J 201/00(2006.01); C21D 8/12(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), 응력제거소둔(stress relief annealing, SRA), 질화(nitriding), 질소(nitrogen), 적층(stack)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 10-2017-0075527 A (POSCO) 03 July 2017 (2017-07-03) See paragraphs [0004], [0135] and [0156] and claims 10 and 17-21.	1-14
Y		15-16
Y	KR 10-2020-0076831 A (POSCO) 30 June 2020 (2020-06-30) See paragraph [0160] and claims 1 and 18-19.	15-16
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☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

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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

14 April 2025

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2024/063295

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-2018-0074438 A (POSCO) 03 July 2018 (2018-07-03) See claims 4 and 8-11.	1-16

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Information on patent family members

International application No.

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