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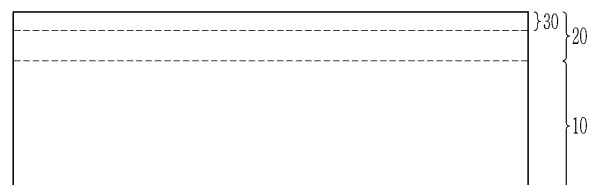
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(54) **NON-ORIENTED ELECTRICAL STEEL SHEET AND MANUFACTURING METHOD THEREFOR**

(57) A non-oriented electrical steel sheet according to one embodiment of the present disclosure includes Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, by weight, with the balance being Fe and inevitable impurities, wherein a ratio of the number (PS) of precipitates per unit area in the surface portion from the surface to 1/20 of the total thickness from the surface of the steel plate to the inside to the number (PI) of precipitates per unit area in the center portion from more than 1/20 to 1/2 of the total thickness is 1/2 or less.

FIG. 1

100



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Description**BACKGROUND OF THE DISCLOSURE****(a) Field of the Disclosure**

[0001] An embodiment of the present disclosure relates to a non-oriented electrical steel sheet and a method for manufacturing the same. Specifically, one embodiment of the present disclosure relates to a non-oriented electrical steel sheet and a method for manufacturing the same, which improves a magnetism by forming appropriate precipitates for each thickness of the steel sheet by controlling a dew point and a tension in an annealing process before a cold rolling.

(b) Description of the Related Art

[0002] A non-oriented electrical steel sheet is mainly used in a motor that converts electrical energy to mechanical energy, and an excellent magnetic characteristic of the non-oriented electrical steel sheet is required to achieve high efficiency while the motor converts 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.

[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. 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.

[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 W10/400 iron loss.

[0005] A commonly used method to improve the magnetic properties of non-oriented electrical steel sheets is to add alloying elements such as Si, Al, and Mn.

[0006] 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. There is a limit to the maximum total content of Si, Al, and Mn that may be commercially produced, and by optimizing the content of trace elements, it is possible to produce the highest quality non-oriented electrical steel with excellent magnetism and strength.

[0007] A method of improving magnetic properties by controlling the aggregate texture of the non-oriented electrical steel sheets is also widely used. The control of the aggregate texture is a method of promoting the development of the crystal orientations favorable to the magnetism and suppressing the crystal orientations unfavorable to the magnetism during the process of deforming, recovering, and recrystallizing the material in various ways. It is known that the crystal orientation having a {001} plane is favorable for the magnetism, and the crystal orientation having a {111} plane is unfavorable for the magnetism. Many methods are known for selectively developing the several crystal orientations by changing the manufacturing conditions of the non-oriented electrical steel sheets.

[0008] If the non-oriented electrical steel sheets are produced through a double rolling and double annealing process, the {111}/ND crystal orientation, which is unfavorable to the magnetism, may be suppressed, and the {001}/ND crystal orientation, which is advantageous to the magnetism, may be strengthened. The process is well known to be excellent in improving the texture, but compared to the conventional single-rolling method, it has the aspect of slightly increasing the manufacturing cost due to the addition of the cold rolling and intermediate annealing processes, and the surface oxide layer formation behavior is unstable during the annealing and cold rolling processes, so there is a

problem that the magnetic properties deteriorate due to the additional formation of precipitates on the surface or the uneven formation of the surface oxide layer, so there were limitations in applying it to actual mass production processes.

SUMMARY OF THE DISCLOSURE

[Technical Problem]

[0009] One embodiment of the present disclosure provides a non-oriented electrical steel sheet and a method for manufacturing the same. Specifically, one embodiment of the present disclosure provides a non-oriented electrical steel sheet and a method for manufacturing the same, which improve the magnetism by forming an appropriate precipitate for each thickness of the steel sheet by controlling the dew point and tension in the annealing process before the cold rolling.

[Technical Solution]

[0010] A non-oriented electrical steel sheet according to an embodiment includes Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, by weight, with the balance being Fe and inevitable impurities.

[0011] A ratio of the number (PS) of precipitates per unit area in the surface portion from the surface to 1/20 of the total thickness from the surface of the steel plate to the inside to the number (PI) of precipitates per unit area in the center portion from more than 1/20 to 1/2 of the total thickness is 1/2 or less.

[0012] The non-oriented electrical steel sheet may include an oxide layer that exists from the surface to the inside, and a thickness of the oxide layer may be from 5 to 300 nm.

[0013] A maximum length of a disconnection of an oxide layer of 5 nm or less of the oxide layer thickness may be 500 nm or less in a rolling direction in a cross-section including the rolling direction of the steel sheet.

[0014] A length of a disconnection of an oxide layer having an oxide layer thickness of 5 nm or less in a cross-section including the rolling direction of the steel sheet may be 0.01 to 1000 nm per 10 μ m in the rolling direction.

[0015] The non-oriented electrical steel sheet according to an embodiment may further include at least one 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%).

[0016] The non-oriented electrical steel sheet may further include one or more of Sn, Sb, Bi, Pb, Ge, and As with each or a combined amount of 0.005 to 0.200 wt%.

[0017] The non-oriented electrical steel sheet according to an embodiment may further include at least one 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%).

[0018] The non-oriented electrical steel sheet according to an embodiment may further include at least one of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

[0019] A method for manufacturing a non-oriented electrical steel sheet according to an embodiment includes manufacturing a hot-rolled steel sheet by hot-rolling a slab including Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, by weight, with the balance being Fe and inevitable impurities; a pre-cold rolling annealing of annealing the steel sheet is in an atmosphere including a dew point of -50°C to -10°C, 3 to 30 volume% of hydrogen, and a tension of 0.2 kgf/mm² to 3.0 kgf/mm²; manufacturing a cold-rolled sheet by cold rolling the annealed steel sheet, and a cold-rolled sheet annealing of annealing the cold-rolled sheet.

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

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

[0022] The slab may further include at least one of Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

[0023] The slab may further include at least one of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

[0024] The subsequent processes may be performed while the scale remaining on the hot-rolled steel sheet remains after manufacturing the hot-rolled steel sheet.

[0025] Pickling and preliminary cold rolling of the hot-rolled sheet may be further included before the pre-cold rolling annealing.

[0026] A compression ratio may be 30 to 80% in the preliminary cold rolling.

[0027] A soaking temperature in the pre-cold rolling annealing may be 800 to 1100°C, and an annealing time may be 1 to 30 minutes.

[0028] A compression ratio may be 40 to 85% in manufacturing the cold-rolled sheet.

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

[Advantageous Effects]

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

[0031] Ultimately, the non-oriented electrical steel sheet according to one embodiment of the present disclosure contributes to the manufacture of eco-friendly automobile motors, high-efficiency home appliance motors, and super-premium-class electric motors.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032]

FIG. 1 is a view schematically illustrating a cross-section of a non-oriented electrical steel sheet according to one embodiment of the present disclosure.

FIG. 2 is a view schematically illustrating a disconnection in a cross-section of a non-oriented electrical steel sheet according to one embodiment of the present disclosure.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0033] 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.

[0034] 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.

[0035] 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.

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

[0037] 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.

[0038] 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.

[0039] The present disclosure will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. As those skilled in the art would realize, the described embodiments may be modified in various different ways, all without departing from the spirit or scope of the present disclosure.

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

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

Si: 1.5 to 4.5 wt%

[0042] Silicon (Si) increases specific resistance of a material to lower an iron loss, and increases a strength through a solid solution strengthening. If too little Si is added, the effect of improving the iron loss and strength may be insufficient. If too much Si is added, the material becomes more brittle, which drastically reduces a rolling productivity and may form a surface oxide layer and oxides that are harmful to the magnetism. Therefore, it may include 1.5 to 4.5 wt% of Si. More specifically, it may include 2.0 to 4.3 wt%. More specifically, it may include 2.5 to 4.2 wt%.

Al: 0.1 to 2.0 wt%

[0043] Aluminum (Al) increases the specific resistance of the material, lowers the iron loss, and increases the strength through the solid solution strengthening. If too little Al is added, fine nitrides may be formed, making it difficult to obtain the effect of improving magnetic properties. If too much Al is added, the excessive nitride formation occurs, which deteriorates the magnetism and causes problems in all processes, including a steelmaking and a continuous casting, which may significantly reduce a productivity. Therefore, it may include 0.1 to 2.0 wt% of Al. More specifically, it may include 0.2 to 1.6 wt%. More specifically, it may include 0.3 to 1.5 wt%.

Mn: 0.1 to 2.0 wt%

[0044] Manganese (Mn) increases the specific resistance of the material, improves the iron loss, and plays a role in forming sulfides. If too little Mn is added, fine sulfides are formed, causing a magnetic deterioration, and if too much Mn is added, fine MnS is excessively precipitated, promoting the formation of a {111} texture, which is unfavorable for the magnetism, and causing a rapid decrease in the magnetic flux density. Therefore, it may include 0.1 to 2.0 wt% of Mn. More specifically, it may include 0.2 to 1.6 wt%. More specifically, it may include 0.3 to 1.5 wt%.

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

P: 0.1 wt% or less

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

C: 0.005 wt% or less

[0047] Carbon (C) may cause a magnetic aging and combine with other impurity elements to form carbides, which may impede a grain boundary or domain wall movement and deteriorate magnetic properties. More specifically, it may include 0.0001 to 0.003 wt% of C.

S: 0.005 wt% or less

[0048] Sulfur (S) may form fine precipitates, MnS and CuS, which may worsen the magnetic properties and then may worsen the hot workability. More specifically, it may include 0.0001 to 0.0030 wt% of S.

Ti: 0.005 wt% or less

[0049] Titanium (Ti) has a strong tendency to form precipitates within the steel, and may deteriorate the iron loss by forming fine carbides, nitrides, or sulfides within the mother material, thereby inhibiting the grain growth and the domain wall migration. More specifically, it may include 0.0001 to 0.003 wt% of Ti.

N: 0.005 wt% or less

[0050] Nitrogen (N) not only forms fine AlN precipitates inside the mother material, but also combines with other impurities to form fine precipitates, which may inhibit the grain growth and the domain wall movement, thereby worsening the iron loss. More specifically, it may include 0.0001 to 0.0030 wt% of N.

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

Sn and Sb

[0052] Tin (Sn) and antimony (Sb) segregate at the grain boundaries during the initial stage of the final recrystallization annealing and play a role in suppressing the development of the {111} orientation, which worsens the magnetism. If too much Sn and Sb are added, it may hinder the recovery and growth of coarse elongated band structures and deteriorate the surface quality. Therefore, one or more of Sn and Sb may be further added within the aforementioned range. More specifically, it may include 0.005 to 0.200 wt% of Sn or 0.005 to 0.200 wt% of Sb.

Bi, Pb, Ge, and As

[0053] When bismuth (Bi), lead (Pb), germanium (Ge), and arsenic (As) are added additionally, the segregation occurs at the grain boundaries, thereby relieving a stress concentration at the grain boundaries during the cold rolling, thereby suppressing recrystallization of <111>ND orientation grains in the subsequent recrystallization annealing process, thereby improving the 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 the segregation may occur, which may inhibit the grain growth and result in lower the magnetic flux density and iron loss.

[0054] The non-oriented electrical steel sheet according to one embodiment of the present disclosure may further include at least one of Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

Cu: 0.005 to 0.200 wt%

[0055] Copper (Cu) plays a role in forming sulfides together with Mn. When Cu is further added, if too little is added, (Cu · Mn)S may be finely precipitated, which may deteriorate the magnetism. If too much Cu is added, high-temperature embrittlement may occur, which may cause a crack formation during a casting or a hot rolling. More specifically, it may include 0.01 to 0.10 wt% of Cu.

Cr: 0.01 to 0.50 wt%

[0056] Chromium (Cr) plays a role in improving iron loss by increasing the resistivity. If too little Cr is added, the resistivity-increasing effect may not be sufficient. If too much Cr is included, the magnetic flux density may decrease. More specifically, it may include 0.050 to 0.20 wt% of Cr.

Ni: 0.05 wt% or less

[0057] Nickel (Ni) may react with impurity elements to form fine sulfides, carbides, and nitrides, which may have a detrimental effect on the magnetism. More specifically, it may include 0.001 to 0.03 wt% of Ni.

Zn: 0.01 wt% or less

[0058] Zinc (Zn) may act as an impurity and reduce the magnetism when the content is excessive. Therefore, Zn may be further added within the aforementioned range. More specifically, Zn may be included in an amount of 0.001 to 0.005 wt%.

Co: 0.05 wt% or less

[0059] Cobalt (Co) does not form fine precipitates that reduce the magnetism of the steel sheets, but it may increase a high-temperature strength and cause a poor coil shape after the hot rolling.

[0060] The non-oriented electrical steel sheet according to one embodiment of the present disclosure may further include at least one of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.0050 wt% or less (excluding 0%), Te: 0.0100 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

Mo: 0.030 wt% or less

[0061] If molybdenum (Mo) is added in excessive amounts, the effect of improving the texture may be reduced by suppressing the segregation of segregating elements. Therefore, it may include Mo in an amount of 0.03 wt% or less. The lower limit is not particularly limited, but it may be included in an amount of 0.001 wt% or more because it plays a

role in improving the aggregate structure by being segregated on the surface and grain boundaries. More specifically, it may include 0.001 to 0.010 wt% of Mo. More specifically, it may include 0.005 to 0.010 wt% of Mo.

B: 0.0050 wt% or less

[0062] If boron (B) is added in excessive amounts, it may cause the deterioration of the 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 is not particularly limited, but may be set to 0.0001 wt% due to steelmaking costs. More specifically, it may include 0.0001 to 0.0030 wt% of B.

V: 0.0050 wt% or less

[0063] Vanadium (V) has a strong tendency to form precipitates within the steel, and forms fine carbides or nitrides within the mother material, which inhibits the grain growth and the domain wall movement, thereby deteriorating the iron loss. Therefore, the V content may be 0.0050 wt% or less, respectively. The lower limit is not particularly limited, but may be set at 0.0003 wt% due to the steelmaking costs. That is, it may include 0.0003 to 0.0050 wt% of V. More specifically, it may include 0.0003 to 0.0030 wt% of V.

Ca: 0.0050 wt% or less

[0064] Calcium (Ca) has a strong tendency to form precipitates within the steel, and forms fine sulfides within the mother material, which inhibits the grain growth and the domain wall movement, thereby deteriorating the iron loss.

Nb: 0.0050 wt% or less

[0065] Niobium (Nb) has a strong tendency to form precipitates within the steel, and forms fine carbides or nitrides within the mother material, which inhibits the grain growth and the domain wall migration, thereby deteriorating the iron loss. Therefore, the Nb content may be 0.0050 wt% or less. The lower limit is not particularly limited, but may be set at 0.0003 wt% due to the steelmaking costs. That is, it may include 0.0003 to 0.0050 wt% of Nb. More specifically, it may include 0.0003 to 0.0030 wt% of Nb.

Zr: 0.0050 wt% or less

[0066] If zirconium (Zr) is added in excessive amounts, it may cause the deterioration of the magnetism through the formation of inclusions in the steel. Therefore, it may include Zr in an amount of 0.005 wt% or less. The lower limit is not particularly limited, but may be set to 0.0001 wt% due to the steelmaking costs. That is, it may include 0.0001 to 0.0050 wt% of Zr. More specifically, it may include 0.0005 to 0.0030 wt%.

Te: 0.0100 wt% or less

[0067] Tellurium (Te) diffuses into the oxide layer on the surface of a hot-rolled coil, increases a coefficient of friction between the oxide layer and a rolling work roll, and is concentrated under the oxide layer to improve a hardness. Therefore, it may be added to prevent the fractured oxide layer during the 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 minimal. If too much Te is added, the oxide layer is easily removed, and the base material comes into direct contact with the work roll, which reduces the above effect, and during the cold rolling, excessive deformation bands are generated within the steel sheet, which may lead to the development of the {111}/ND texture, which is unfavorable for the magnetism. More specifically, it may include 0.0001 to 0.007 wt% of tellurium.

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 the iron. Therefore, it may include Mg in an amount of 0.0050 wt% or less. The lower limit is not particularly limited, but may be set to 0.0001 wt% due to steelmaking costs. That is, it may include 0.0001 to 0.0050 wt% of Mg. More specifically, it may include 0.0005 to 0.0030 wt%.

[0069] The remainder includes iron and unavoidable impurities. As for unavoidable impurities, they are impurities mixed in during a steelmaking stage and the manufacturing process of the non-oriented electrical steel sheet, and since this is widely known in the field, a detailed description thereof will be omitted. In one embodiment of the present

disclosure, addition of elements other than the alloy components described above is not excluded, and various elements may be included within a range that does not harm the technical idea of the present disclosure. If additional elements are included, they are included to replace Fe of the remainder.

[0070] As described above, in one embodiment of the present disclosure, by appropriately controlling the alloy composition of the steel sheet and appropriately forming the precipitates for each thickness, the magnetism may be improved.

[0071] FIG. 1 is a view of a schematic diagram of a cross-section of a non-oriented electrical steel sheet according to one embodiment of the present disclosure.

[0072] As shown in FIG. 1, the non-oriented electrical steel sheet 100 includes a surface portion 20 from the surface of the steel sheet to 1/20 of the total thickness and a central portion 10 from more than 1/20 to 1/2 of the total thickness based on the cross-section including the thickness direction (an ND direction). In FIG. 1, for convenience, the surface portion 20 is shown only on one side, but the surface portion 20 is formed on both sides.

[0073] In one embodiment of the present disclosure, by appropriately controlling the ratio of precipitates present in the central portion 10 and the surface portion 20, the magnetic properties of the non-oriented electrical steel sheet may be improved without causing the deterioration of the surface portion.

[0074] Specifically, a ratio PS/PI of the number of the precipitates per unit area of the surface portion 20 to the number of the precipitates per unit area of the center portion 10 may be 1.20 or less. If this ratio is too high, it means that there are too many precipitates on the surface 20 or too few precipitates on the center 10. When a large number of the precipitates exist on the surface portion 20, the magnetism of the surface portion 20 deteriorates due to the large number of the precipitates, and ultimately, the magnetism of the entire non-oriented electrical steel sheet 100 deteriorates. If too little precipitate exists in the center 10, the crystal grains may grow significantly, which may also increase the iron loss. More specifically, the ratio PS/PI of the number of the precipitates per unit area of the surface portion 20 to the number of the precipitates per unit area of the center portion 10 may be 0.90 to 1.19.

[0075] In one embodiment of the present disclosure, the precipitates mean that elements present in the electrical steel sheet coagulate with each other and then form grain-shaped particles. More specifically, it means that one or more elements among Si, Al, Mn, Ti, Nb, Cu, and Zr are combined with one or more elements among C, N, S, and O to form particles. The precipitates may be measured by observing an area of at least 200 μm^2 through a TEM for the cross-section including the thickness direction (the ND direction), more specifically, the plane (the TD plane) perpendicular to the steel sheet rolling direction. The precipitates with a particle size of less than 0.03 μm do not have a significant effect on the magnetism, so they are excluded from the ratio calculation. Here, a particle diameter refers to a diameter of an imaginary circle having the same area as the area occupied by the precipitate. As described later, an oxide layer 30 may exist on the surface layer of the surface portion 20, but the oxide layer 30 is excluded from the calculation of the precipitate density (both the measurement area and the number of precipitates are excluded).

[0076] More specifically, the precipitate density of the surface portion 20 may be 0.5/ μm^2 to 2.5/ μm^2 , and the precipitate density of the center portion 10 may be 0.3/ μm^2 to 2.0/ μm^2 .

[0077] FIG. 2 is a view showing a schematic diagram of a cross-section of a non-oriented electrical steel sheet according to one embodiment of the present disclosure.

[0078] As shown in Fig. 2, it includes an oxide layer 30 formed from the surface of the non-oriented electrical steel sheet 100 toward the inside.

[0079] The oxide layer 30 may be formed when oxygen penetrates into the steel sheet during the manufacturing process of the electrical steel sheet.

[0080] The oxide layer 30 is defined as a portion in which oxygen is 0.01 wt% or more from the surface of the steel sheet in the inward direction. The detection and thickness of the oxide layer 30 may be determined by processing a TD surface of a specimen with a FIB and observing it with a TEM and an EDS, and determining that the part including oxygen of 0.01 wt% or more as the oxide layer. At this time, the steel sheet specimen may be a sample without an insulating film formed, or when an insulating film is formed, a sample may be used with the film removed. To reduce measurement errors depending on location, the specimen may be measured at least 20 times with a length of at least 200 μm in the RD direction and at an interval of at least 1 μm in the TD direction to obtain the average value thereof.

[0081] The thickness of the oxide layer 30 may be 5 to 300 nm. If the thickness of the oxide layer 30 is too thin, an Al concentration within the oxide layer 30 may not be properly achieved, and the AlN suppression effect described above may not be sufficiently achieved. If the thickness of the oxide layer 30 is too thick, a large amount of oxygen may penetrate into the steel sheet, which may result in the poor magnetism. More specifically, the thickness of the oxide layer 30 may be 10 to 290 nm. The thickness of the oxide layer 30 may be the average thickness of the oxide layer 30 in the measured specimen.

[0082] As shown in FIG. 2, the disconnection of the oxide layer having the thickness of 5 nm or less may be formed in the cross-section including the rolling direction of the steel sheet, and the maximum length of the disconnection of the oxide layer the thickness of 5 nm or less in the cross-section including the rolling direction of the steel sheet may be 500 nm or less in the rolling direction. When the disconnection exceeding 500 nm is formed, the magnetism may be

significantly adversely affected as oxides or nitrides are additionally formed by an atmospheric gas during the cold-rolled sheet annealing step. The measurement standard may be measured at 200 μm or more in the rolling direction. More specifically, the maximum length of the disconnection of the oxide layer having the thickness of 5 nm or less may be 50 to 490 nm in the rolling direction.

[0083] As shown in FIG. 2, there is a disconnection of an oxide layer having a thickness of 5 nm or less in a cross-section including the rolling direction of the steel sheet, and the length (DCL) of this disconnection may be 0.01 to 1000 nm per 10 μm in the rolling direction. As shown in FIG. 2, there may be multiple disconnections of the plurality of oxide layers within the specimen, in which case the combined lengths of all disconnections of the oxide layers may be included within the aforementioned range. Although it is ideal from a magnetic perspective of view to have almost no disconnections of the oxide layers, the formation of the disconnections due to the destruction of the oxide layer is inevitable during the annealing and final cold rolling under the tensions of 0.2 kgf/mm² to 3.0 kgf/mm². Therefore, except for the ideal case where there is no disconnection of the oxide layer, the shorter length of the disconnection may be advantageous from the magnetic perspective. Conversely, if the length of the disconnection of the oxide layer is too long, problems may arise in that additional oxidation and nitriding may occur at the disconnected area, which also increases the iron loss. More specifically, the length DC_L of the disconnection may be 1 to 900 nm per 10 μm in the rolling direction. More specifically, the length of the disconnection DC_L may be 100 to 800 nm per 10 μm in the rolling direction. More specifically, the length DCL of the disconnection may be 300 to 750 nm per 10 μm in the rolling direction. The measurement and determination of the disconnection may be performed in the same manner as the measurement and determination method of the oxide layer described above. When there are multiple disconnections, it may be expressed as the sum of the lengths of the multiple disconnections.

[0084] The oxide layer 30 and the disconnection may be appropriately formed by appropriately controlling the conditions in the annealing process prior to the cold rolling. A more specific method will be described later in relation to the method for manufacturing the non-oriented electrical steel sheets.

[0085] Due to the surface concentration of Al in the oxide layer 30, Al may be included in an amount of 50 wt% or more. More specifically, it may include 50 to 70 wt% of Al. Except for Al and O, the remaining alloy components are the same as those of the non-oriented electrical steel sheet described above. Since the thickness of the oxide layer 30 is very thin compared to the thickness of the entire non-oriented electrical steel sheet 100, it has practically no effect on the alloy composition of the non-oriented electrical steel sheet 100.

[0086] As described above, in one embodiment of the present disclosure, by appropriately controlling the steel component and controlling the thickness and the disconnection ratio of the surface oxide layer to a certain level or less, the magnetism may be improved by appropriately forming precipitates for each portion. In general, as the thickness of the steel sheet decreases, the iron loss tends to improve, and the iron loss according to the thickness of the steel sheet according to the present disclosure is implemented by a formula following.

[0087] Iron loss (W10/400) $\leq 9.8 \times \text{EXP}(1.5 \times t)$, t: a steel sheet thickness (a unit: mm)

[0088] Iron loss (W10/400) is the iron loss when a magnetic flux density of 1.0 T is induced at a frequency of 400 Hz. EXP represents a natural constant (e).

[0089] Specifically, the iron loss (W10/400) of the non-oriented electrical steel sheet of the present disclosure may be 14.0 W/Kg or less based on a thickness of 0.25 mm. Additionally, the magnetic flux density (B50) can be 1.63 T or more. The magnetic flux density (B50) refers to the magnetic flux density induced in a magnetic field of 5000 A/m. More specifically, the iron loss (W10/400) of the non-oriented electrical steel sheet may be 10.0 to 14.0 W/kg. The magnetic flux density (B50) may be 1.63 T to 1.75 T.

[0090] A method for manufacturing a non-oriented electrical steel sheet according to one embodiment of the present disclosure includes hot-rolling a slab to manufacture a hot-rolled steel sheet; a pre-cold rolling annealing for annealing the steel sheet before cold rolling; cold-rolling the annealed steel sheet to manufacture a cold-rolled sheet; and a cold-rolled sheet annealing of annealing the cold-rolled sheet.

[0091] Below, each step is explained in detail.

[0092] First, the slab is hot-rolled.

[0093] 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.

[0094] Specifically, the slab includes Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0% by weight, with the balance being Fe and inevitable impurities.

[0095] Other additional elements have been described in the alloy composition of the non-oriented electrical steel sheet, so duplicate descriptions will be omitted.

[0096] The slab may be heated before hot-rolling. The heating temperature of the slab is not limited, but the slab may be heated at 1,200 °C or less. When the slab heating temperature is too high, precipitates such as AlN and MnS present in the slab are re-dissolved and then finely precipitated during hot-rolling and annealing, thereby inhibiting

grain growth and reducing magnetism.

[0097] Next, the slab is hot-rolled to manufacture the hot-rolled sheet. The hot rolled sheet thickness can be 1.0 to 4.5 mm. In the manufacturing of the hot-rolled sheet, a finish rolling temperature may be 800 °C or higher. Specifically, it may be 800 to 1000 °C. The hot-rolled sheet may be wound at temperatures of 600 °C or more. More specifically, the thickness of the hot-rolled sheet may be 1.5 to 4.3 mm.

[0098] After manufacturing the hot-rolled steel sheet, subsequent steps may be performed while the scale remaining on the hot-rolled steel sheet remains. That is, after hot rolling, a scale removal such as a pickling, a shot blasting or a surface grinding may be omitted and subsequent processes may be performed. By cold rolling without the pickling process, a friction of the rolling work rolls and the steel sheet increases, so that a shear deformation is applied simultaneously in addition to a plane deformation during the rolling, and a specific orientation develops during a recrystallization annealing. In one embodiment of the present disclosure, the scale refers to a portion where elements such as Fe, Al, and Si combine with oxygen and then a phase different from that of the mother material is formed on the surface of the steel sheet. The presence of the scale means that at least 1 μm of the scale remains on the hot-rolled sheet. At this time, the scale thickness means the sum of the scale thicknesses generated on both surfaces of the steel sheet. If the remaining scale thickness is too thin, the effect of the remaining scale may not be fully realized. Even if the scale thickness is thicker, the effect is not improved, and there is a problem that the yield of the steel sheet is reduced. More specifically, the scales with the thickness of 0.1 to 1 μm may remain.

[0099] In one embodiment of the present disclosure, after manufacturing the hot-rolled steel sheet, a pre-cold rolling annealing for annealing the hot-rolled steel sheet may be performed immediately. Alternatively, a pre-cold rolling annealing to anneal the preliminary cold rolled steel sheet may be performed after preliminary cold rolling the hot rolled steel sheet.

[0100] The preliminary cold rolling is distinguished from the cold rolling, which will be described later, in that it is the first rolling stage of the process of rolling to an intermediate thickness rather than the final product thickness, then performing the intermediate annealing, and then cold rolling to the final product thickness.

[0101] The preliminary cold rolling may be performed at a compression ratio of 30 to 80% to improve a final cold rolling productivity and a grain size in the final product sheet. In addition, in cases where the rolling productivity is not taken into consideration, it is also possible in the present disclosure to perform the preliminary cold rolling in a reverse mill. The cold rolled sheet may have the thickness of 0.3 to 1.5 mm. More specifically, the compression ratio may be 60 to 75% and the thickness may be 0.6 to 1.3 mm.

[0102] The preliminary cold rolling compression ratio may be calculated as (a steel sheet thickness before a rolling - a steel sheet thickness after a rolling) / a steel sheet thickness before a rolling. If the compression ratio is too low in the preliminary cold rolling stage, the rolling load increases during the final cold rolling, which may result in a decrease in productivity, and the final compression ratio may increase, which may cause problems such as promoting the fine <111>//ND orientation recrystallization. Conversely, if the compression ratio is too high, the cold rolling load increases and the possibility of a sheet breakage also increases.

[0103] The preliminary cold rolling stage may be performed at a temperature of 60 to 300°C. This temperature may be raised by the temperature of the steel sheet rising naturally due to the friction between the steel sheet and the rolling roll, or by applying heat from the outside. If the temperature is too low, the rolling load increases significantly, and the steel sheet may slip between the rolling rolls instead of being rolled, which may cause problems such as a twisting. If the temperature is too high, the thick oxide layer may be formed on the surface of the steel sheet, which may cause problems such as the deterioration of the magnetism and the ignition of the rolling oil. More specifically, it is preferable to perform the process at a temperature of 70 to 250°C. The temperature mentioned above refers to the temperature of the steel sheet.

[0104] As mentioned above, the preliminary cold rolling stage may be omitted if necessary.

[0105] Next, in the pre-cold rolling annealing step, the hot-rolled steel sheet or the preliminary cold-rolled sheet is annealed. In one embodiment of the present disclosure, the oxide layer 30 may be appropriately formed by controlling the dew point and the tension in the annealing step prior to cold rolling.

[0106] In addition, in the pre-cold rolling annealing step, the atmosphere is performed in a hydrogen and nitrogen mixed gas atmosphere including at least 3 to 30 volume% of hydrogen. If the hydrogen content is low, an additional oxide layer may be formed during a heat treatment, which may remain in the final product and cause the increased iron loss. The higher the hydrogen content, the better, but using more than necessary increases the process load, which increases processing costs. Therefore, the annealing may be performed in an atmosphere including 3 to 30 volume% of hydrogen gas. More specifically, it may include 5 to 25 volume percent hydrogen. The rest of the atmosphere is nitrogen.

[0107] The dew point can be between -50°C and -10°C. If the dew point is too low, nitriding by nitrogen gas in the atmosphere can occur, promoting the formation of nitrides within the steel sheet and increasing iron loss. If the dew point is too high, an additional surface oxidation may occur, leaving a surface oxide layer that may increase the iron loss along with the pickling problem. More specifically, the dew point may be between -50 and -20°C. More specifically,

the dew point may be the dew point for the atmosphere during the soaking process.

[0108] Additionally, the tension of 0.2 kgf/mm² to 3.0 kgf/mm² may be applied. If the tension is too low, the steel sheet may come into contact with the inside of the furnace, causing scratches on the surface and problems in terms of a surface quality. If the tension is too high, problems may arise in terms of high-temperature deformation of the steel sheet during annealing, which deteriorates the magnetic flux density and the iron loss. More specifically, the tension may be 0.3 to 2.5 kgf/mm². More specifically, the tension may be the tension measured at the exit of the annealing furnace, and may be measured using a tension meter device.

[0109] The soaking temperature in the pre-cold rolling annealing stage may be 800 to 1100°C. If the annealing temperature is too low, the recrystallized structure is not formed or grows finely, so the effect of increasing the magnetic flux density is small. If the annealing temperature is too high, the magnetic properties may actually deteriorate, and the rolling workability may deteriorate due to the deformation of the sheet shape. More specifically, the temperature range may be 830 to 1080°C. A soaking time may range from 1 minute to 30 minutes.

[0110] The pre-cold rolling annealing mentioned above may be performed in a vertical continuous annealing facility or a horizontal continuous annealing facility. If the removal of the surface oxide layer after hot rolling is omitted, the removal of the surface oxide layer may be performed after the pre-cold rolling annealing. It is known that if the surface oxide layer remains excessively on the final manufactured non-oriented electrical steel sheet, it will damage the magnetism. As a result of studying the influence of the remaining surface oxide layer on the magnetic properties of the inventors, it was confirmed that there was almost no deterioration in the magnetic properties when it remains at 300 nm or less in the final product sheet. Also, even if the surface oxide layer is completely removed before cold rolling, it was confirmed that the surface oxide layer of about 3 nm is formed due to the influence of the atmosphere gas during the final annealing.

[0111] Meanwhile, when the cold rolling is performed with the scale remaining, the scale is pressed into the surface and exists in a state where the scale is segmented by the rolling. It is desirable that the length of the scale-free surface by the segmentation be 500 nm or less. If the segmented length is more than 500 nm, a problem may arise in which nitride is formed due to penetration of nitrogen (N₂) components in the atmospheric gas into the disconnected area during the final annealing step, thereby increasing the iron loss. Therefore, in the case where the surface oxide layer exists in the final product sheet to the thickness of 300 nm or less and the length of the surface oxide layer segmented exists to a maximum of 500 nm or less, the excellent magnetic properties as in the present disclosure may be secured.

[0112] Additionally, in the pickling process prior to the final cold rolling, the surface oxide layer may be completely removed or may exist with the thickness of less than 300 nm. The pickling refers to all physical and chemical descaling methods, not just an acid immersion. Acid immersion, shot blasting or surface grinding may be used as the pickling method.

[0113] Next, the annealed steel sheet is cold rolled to produce a cold rolled sheet. At this time, the cold rolling may be performed at the compression ratio of 40 to 85%. If the compression ratio is too low, the strain energy accumulated in the rolled steel sheet is small, making it difficult to be recrystallized in the subsequent annealing process, so the rolled structure remains, which may cause problems in improving the magnetic flux density and iron loss. Conversely, if the compression ratio is too high, the recrystallization of the <111>ND orientation grains may be promoted in the subsequent annealing process, and the grains may become finer, resulting in a problem of the poor magnetic flux density and increased iron loss. More specifically, the compression ratio may be 60 to 75%. The cold rolling may be performed using a tandem cold rolling mill that continuously cold rolls the steel sheet using multiple rolling stands, or a reverse rolling mill that discontinuously cold rolls the steel sheet using 12 or more stage rolling rolls. The final rolled thickness may be from 0.1 mm to 0.35 mm.

[0114] Next, the cold rolled sheet is annealed. The cold rolled sheet annealing may be performed in the atmosphere with the dew point below 0°C. More specifically, it may be annealed in the atmosphere with the dew point temperature of -50 to -10°C.

[0115] The cold rolled sheet annealing may be performed at a soaking temperature of 850 to 1100°C. If the soaking temperature is too low, the crystal grains may not grow sufficiently, which may cause a problem that a hysteresis loss increases and the iron loss deteriorates. If the soaking temperature is too high, problems such as an increased eddy current loss and a rapid decrease in the magnetic flux density may occur. More specifically, it may be annealed at the temperature of 900 to 1050°C. It may soak for 10 to 300 seconds.

[0116] During the cold-rolled sheet annealing process, all (i.e., more than 99%) of the processed structure formed during the cold rolling stage may be recrystallized.

[0117] After the cold-rolled sheet annealing, an insulating film may be formed. The insulating film may be treated with an organic, inorganic, and organic-inorganic composite films, and may also be treated with other insulating film agents.

[0118] Hereinafter, the present disclosure will be described in more detail through examples. However, these examples are only for illustrating the present disclosure, and the present disclosure is not limited thereto.

Example

[0119] A slab including 3.4% Si, 0.8% Al, 1.2% Mn and other impurities in wt% was manufactured. This was heated to 1150°C and hot-rolled at a finishing temperature of 900°C to produce a hot-rolled sheet having a thickness of 2.3 mm. The hot-rolled sheet was pickled, then preliminarily cold-rolled to a thickness of 0.8 mm, pre-cold rolling annealed under a temperature, dew point, hydrogen fraction, and tension conditions of Table 1, and then cold-rolled to a thickness of 0.25 mm, and finally recrystallization annealed for 100 seconds under the conditions of a dew point of -50°C and a soaking temperature of 1000°C.

[0120] The main characteristics of each specimen that went through the manufacturing process are summarized in Table 2.

[0121] The thickness of the oxide layer was measured at least 20 times at intervals of in minimum 1 μm or more in the area including 5 wt% or more of Al and 3 wt% or more of O existed on the surface of the mother material when a TD surface of the specimen was processed with a FIB and observed with a TEM, and an average value thereof was indicated.

[0122] The maximum length of the disconnection of the oxide layer was indicated as a maximum value that the length was measured in the rolling direction at the part where the oxide layer is not continuous but disconnected and the mother material was exposed when the Al-containing oxide layer was observed in the rolling direction for more than 200 μm using a TEM.

[0123] Additionally, the total length of the disconnection of the oxide layer per 10μm in the rolling direction was indicated.

[0124] Analysis of precipitates for the thickness for each part within the steel sheet was performed using a TEM measurements to obtain a ratio of precipitates with a diameter of 0.03 μm or more in the 200 μm² area of the surface and the center, respectively. Magnetic properties such as a magnetic flux density and an iron loss were measured in the rolling direction and the vertical rolling direction using a single sheet tester by cutting 5 sheets of 60 mm width × 60 mm length for each specimen, and the average value was presented. At this time, W10/400 is the iron loss when the magnetic flux density of 1.0 T is induced at the frequency of 400 Hz, and B50 means the magnetic flux density of the steel sheet induced in the magnetic field of 5000 A/m.

(Table 1)

No.	Annealing temperature(°C)	Dew point (°C)	Hydrogen fraction (volume%)	Annealing tension (kgf/mm ²)
A1	950	-25	15	1.5
A2	950	-25	15	2.5
A3	950	-50	15	1.5
A4	950	-25	15	3.5
A5	950	-25	25	1.5
A6	950	-5	25	2.5
A7	950	-25	25	1.5
A8	950	-60	25	1.5
A9	950	-25	25	2.5
A10	950	-10	2	1.0
A11	950	-10	35	1.0

(Table 2)

No.	Al-inclining oxide layer thickness (nm)	Disconnection maximum length of oxide layer (nm)	Disconnection total length of oxide layer (nm)	Precipitate ratio (P_S/P_I)	W10/400 (W/kg)	B50(Tesla)	Division
A1	12	450	685	1.05	12.9	1.65	Disclosure example
A2	28	400	615	1.10	12.9	1.65	Disclosure example

(continued)

5	No.	Al-inclining oxide layer thickness (nm)	Disconnection maximum length of oxide layer (nm)	Disconnection total length of oxide layer (nm)	Precipitate ratio (P_S/P_I)	W10/400 (W/kg)	B50(Tesla)	Division
	A3	75	330	653	1.19	13.1	1.66	Disclosure example
10	A4	120	710	1035	1.25	14.5	1.63	Comparative example
	A5	280	200	451	1.05	11.2	1.68	Disclosure example
15	A6	350	250	555	1.12	14.7	1.62	Comparative example
	A7	110	300	569	1.18	11.3	1.68	Disclosure example
20	A8	3	120	323	1.22	14.1	1.64	Comparative example
	A9	53	480	704	1.15	11.1	1.68	Disclosure example
25	A10	330	220	641	1.08	14.3	1.64	Comparative example
	A11	15	480	1153	1.21	14.8	1.64	Comparative example

30 **[0125]** As shown in Tables 1 and 2, the disclosure examples, in which the steel components are appropriately controlled and the process conditions are appropriately controlled, and the precipitate and the oxide layer characteristics are appropriately formed for each thickness, may be confirmed to have the excellent iron loss and magnetic flux density.

35 **[0126]** On the other hand, if the steel component is not properly controlled, the process conditions are not properly controlled, and the precipitates and oxide layers for each thickness are not properly formed, it may be confirmed that the iron loss and magnetic flux density are inferior.

40 **[0127]** 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.

[Explanation of symbols]

45 **[0128]**

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

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Claims

1. A non-oriented electrical steel sheet comprising:

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Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, by weight, with the balance being Fe and inevitable impurities,
wherein a ratio of the number (PS) of precipitates per unit area in the surface portion from the surface to 1/20

of the total thickness from the surface of the steel plate to the inside to the number (PI) of precipitates per unit area in the center portion from more than 1/20 to 1/2 of the total thickness is 1/2 or less.

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

an oxide layer that exists from the surface to the inside, and
a thickness of the oxide layer is from 5 to 300 nm.

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

a maximum length of a disconnection of an oxide layer of 5 nm or less of the oxide layer thickness is 500 nm or less in a rolling direction in a cross-section including the rolling direction of the steel sheet.

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

a total length of a disconnection of an oxide layer having an oxide layer thickness of 5 nm or less in a cross-section including the rolling direction of the steel sheet is 0.01 to 1000 nm per 10 μm in the rolling direction.

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

at least one of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

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

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

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

at least one of Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

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

at least one of Mo: 0.03 wt% or less (excluding 0%), B: 0.0050 wt% or less (excluding 0%), V: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Nb: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

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

manufacturing a hot-rolled steel sheet by hot-rolling a slab including Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, by weight, with the balance being Fe and inevitable impurities;
a pre-cold rolling annealing of annealing the steel sheet is in an atmosphere including a dew point of -50°C to -10°C , 3 to 30 volume% of hydrogen, and a tension of 0.2 kgf/mm² to 3.0 kgf/mm²;
manufacturing a cold-rolled sheet by cold rolling the annealed steel sheet, and
a cold-rolled sheet annealing of annealing the cold-rolled sheet.

10. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein:

the slab further includes at least one of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

11. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein:

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

12. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein:

the slab further includes at least one of Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

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

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

14. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein:
the subsequent processes are performed while the scale remaining on the hot-rolled steel sheet remains after
manufacturing the hot-rolled steel sheet.

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

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

17. The method for manufacturing the non-oriented electrical steel sheet of claim 9, wherein:
a soaking temperature in the pre-cold rolling annealing is 800 to 1100°C.

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

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

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FIG. 1

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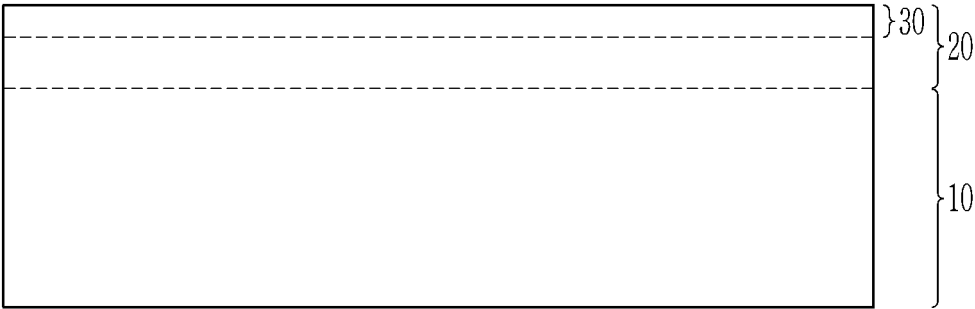
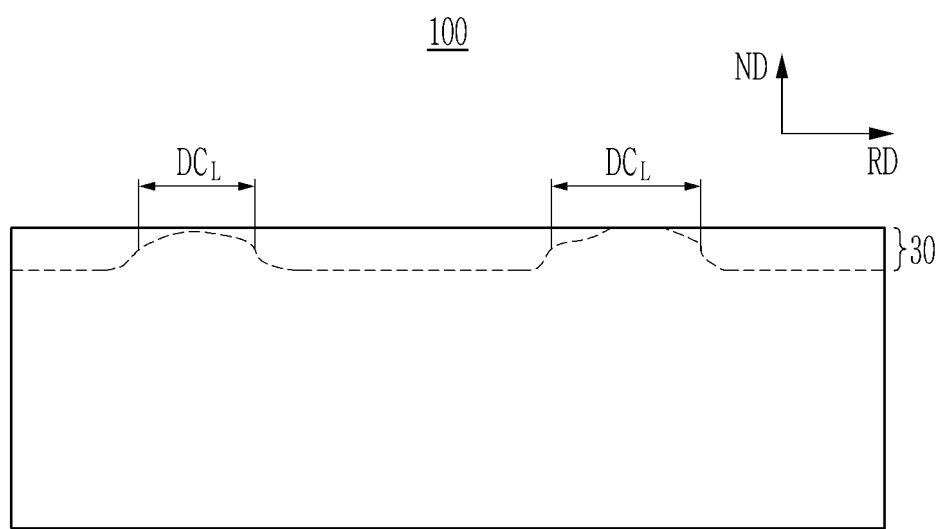


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2024/063281

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; 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); C09D 7/61(2018.01); C21D 8/12(2006.01); C21D 9/46(2006.01); C22C 38/00(2006.01);
C22C 38/34(2006.01); C22C 38/60(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: 석출물(precipitate), 중심부(center), 표면부(surface), 압연 방향(rolling Direction),
무방향성(non-oriented), 이슬점(dew Point), 장력(tension), 수소분위기(hydrogen atmosphere)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	KR 10-2022-0089734 A (POSCO) 29 June 2022 (2022-06-29) See paragraph [0116] and claims 1-5 and 10-15.	1-19
Y	CN 116623077 A (MAANSHAN IRON & STEEL CO., LTD.) 22 August 2023 (2023-08-22) See claim 7.	1-19
Y	KR 10-2020-0066510 A (POSCO) 10 June 2020 (2020-06-10) See claim 6	14
Y	KR 10-2015-0073787 A (POSCO) 01 July 2015 (2015-07-01) See claim 1.	15-16
A	JP 2000-256751 A (NKK CORP.) 19 September 2000 (2000-09-19) See paragraphs [0019]-[0022] and claim 1.	1-19

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

* Special categories of cited documents:

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

“D” document cited by the applicant in the international application

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

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

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

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

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

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

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

“&” document member of the same patent family

Date of the actual completion of the international search

15 April 2025

Date of mailing of the international search report

15 April 2025

Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB2024/063281

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Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
KR	10-2022-0089734	A	29 June 2022	CN	116635555	A	22 August 2023
				EP	4265779	A1	25 October 2023
				JP	2023-554663	A	28 December 2023
				KR	10-2493776	B1	31 January 2023
				MX	2023007355	A	04 September 2023
				US	2024-0309497	A1	19 September 2024
				WO	2022-139337	A1	30 June 2022
CN	116623077	A	22 August 2023	CN	116623077	B	07 February 2025
KR	10-2020-0066510	A	10 June 2020	KR	10-2142512	B1	10 August 2020
KR	10-2015-0073787	A	01 July 2015	KR	10-1565510	B1	03 November 2015
JP	2000-256751	A	19 September 2000	None			