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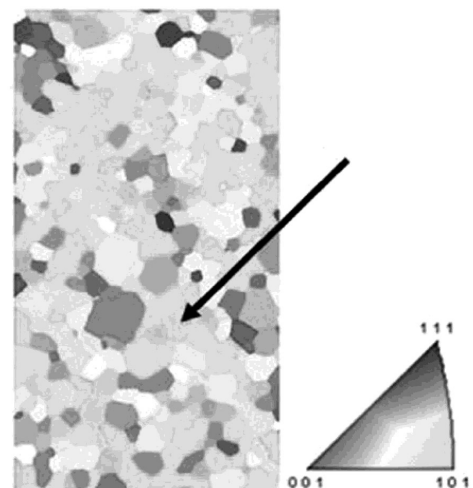
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(54) **NON-ORIENTED ELECTRICAL STEEL SHEET AND MANUFACTURING METHOD THEREFOR**

(57) A method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present disclosure includes: hot rolling a slab and manufacturing a hot rolled steel sheet; performing primary cold rolling on the hot rolled steel sheet; decarburization annealing the primary cold rolled steel sheet; performing secondary cold rolling on the decarburization annealing completed steel sheet; and annealing the secondary cold rolling completed steel sheet at a non-oxidizing atmosphere to thus perform non-oxidation annealing.

FIG. 1



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

[0001] The present disclosure relates to a non-oriented electrical steel sheet and a manufacturing method thereof. In particular, the present disclosure relates to a non-oriented electrical steel sheet for increasing magnetism in a rolling direction including cold rollings and a decarburization annealing process among the cold rollings, and a manufacturing method thereof.

(b) Description of the Related Art

[0002] A non-oriented electrical steel sheet is used as a material for an iron core in rotary devices such as motors and generators, and stationary devices such as small transformers, and plays an important role in determining energy efficiency in electric devices.

[0003] Recently, the use of high-efficiency motors has significantly increased due to the strengthening of motor efficiency regulations. To improve the efficiency of such motors, it is necessary to lower iron loss thereof or lower copper loss thereof.

[0004] The iron loss and the copper loss are substantially influenced by a magnetic characteristic of an electrical steel sheet that is a motor core material. Therefore, motor manufacturers use the electrical steel sheets with low iron loss instead of the conventional electrical steel sheets with high iron loss.

[0005] To reduce the copper loss, a method of making design magnetic flux density lower than existing magnetic flux density or lowering an excitation current in the design magnetic flux is used, and in this case, in order to use the latter method, it is necessary to improve the magnetic flux density of the electrical steel sheet.

[0006] Particularly, the electrical steel sheet with high magnetic flux density may improve torque, so a motor with frequent power on/off may generate large outputs in a short time. A content of Si must be reduced to manufacture the electrical steel sheet with high magnetic flux density, but there is a problem of high iron loss because the content of Si, which is a resistivity increasing element, is low. Hence, it is needed to develop an electrical steel sheet with low iron loss and high magnetic flux density.

[0007] From a structural perspective, typically, torque in a radial motor is generated in proportion to a square of a diameter of a rotor and a length of a cylindrical stator. Therefore, to increase the torque, the length of the cylindrical stator of the motor is to be increased, resulting in the increase of a volume of the motor.

[0008] Unlike the conventional radial motor structure, the axial flux motor has a stator and a rotor arranged in parallel to an axial direction so that a magnetic force is transmitted to the rotor in the axial direction through the stator to generate torque. A size of the torque is proportional to a cube of the diameter of the cylindrical rotor. That is, it may be referred to as a structure that may produce high torque even in a small space. The magnetic force generated by the current applied to the stator is transmitted to a magnet of the rotor in the axial direction so it is needed to apply a magnetic material with excellent magnetic characteristics in one direction.

[0009] The conventional oriented electrical steel sheet is a soft magnetic material with excellent magnetic characteristics in a rolling direction, made of grains having the so-called Goss orientation, where the crystal orientation of the steel sheet is $\{110\}<001>$.

[0010] The oriented electrical steel sheet undergoes slab heating, hot rolling, hot rolled plate annealing, and cold rolling to be rolled to have a final thickness, and undergoes high-temperature annealing to form primary recrystallization annealing and secondary recrystallization, and is manufactured.

[0011] Decarburization annealing is performed, MgO is coated on a surface, and during high-temperature annealing, a metal oxide layer (or a base coating layer) with Mg_2SiO_4 as a primary component is formed, so, unlike non-oriented electrical steel sheets used in the conventional motor core, the problem of a mold being damaged during a punching process is generated due to the metal oxide layer on the surface.

[0012] In addition, the conventional oriented electrical steel sheet has many Goss grains, so its magnetic characteristics in the rolling direction are excellent, but the magnetic characteristics in the vertical rolling direction are inferior, so when used for an axial flux motor, there is a problem that the efficiency of the motor is reduced.

SUMMARY OF THE INVENTION

[0013] An embodiment of the present disclosure relates to a non-oriented electrical steel sheet and a manufacturing method thereof. In particular, an embodiment of the present disclosure relates to a non-oriented electrical steel sheet for increasing magnetism in a rolling direction including cold rollings and a decarburization annealing process among

the cold rollings, and a manufacturing method thereof.

[0014] An embodiment of the present disclosure provides a method for manufacturing a non-oriented electrical steel sheet including: hot rolling a slab and manufacturing a hot rolled steel sheet; performing primary cold rolling on the hot rolled steel sheet; decarburization annealing the primary cold rolled steel sheet; performing secondary cold rolling on the decarburization annealing completed steel sheet; and annealing the secondary cold rolling completed steel sheet at a non-oxidizing atmosphere to thus perform non-oxidation annealing.

[0015] The slab may include, in wt%, 0.3% to 4.0% of Si, 0.03% to 0.4% of C, and remainders including Fe and inevitable impurities.

[0016] The slab may further include 0.1 wt% or less of Mn and 0.005 wt% or less of S.

[0017] The method may further include performing hot rolled plate annealing on the hot rolled steel sheet, wherein the hot rolled plate annealing may include a decarburization process.

[0018] The hot rolled plate annealing may be performed at the temperature of 850 °C to 1000 °C and at the dew point temperature of 70 °C or below.

[0019] The decarburization annealing may be performed at the temperature of 750 °C to 1000 °C and at the dew point temperature of 25 °C to 70 °C.

[0020] The decarburization annealing may be performed in an austenite single-phase area or a region in which a composite phase of ferrite and austenite exists.

[0021] An amount of carbon in the steel sheet may be equal to or less than 0.005 wt% after performing the decarburization annealing.

[0022] The decarburization annealing and the secondary cold rolling may be performed at least twice.

[0023] A reduction ratio of the primary cold rolling may be 70 to 80%.

[0024] The non-oxidation annealing may be performed for 60 seconds to 5 minutes at a soaking temperature of 750 to 1050 °C.

[0025] The non-oxidation annealing may be performed in an atmosphere of the dew point temperature of -20 °C or below.

[0026] Another embodiment of the present disclosure provides a non-oriented electrical steel sheet wherein an area fraction of a grain forming an angle of equal to or less than 15° from {110}<001> is 20 to 60%, and an area fraction of a grain forming an angle of equal to or less than 15° from {100}<001> is 5 to 20%.

[0027] The grains having a ratio D2/D1 of a diameter D1 of a circumscribed circle to a diameter D2 of an inscribed circle, that is equal to or greater than 0.5 from among entire grains may be equal to or greater than 95 area%.

[0028] A fraction of grains having grain particle diameters of 30 μm to 200 μm from among the entire grains may be equal to or greater than 80 area%. The electrical steel sheet may include, in wt%, 0.3% to 4.0% of Si, 0.005% or less of C, (excluding 0%), and remainders including Fe and inevitable impurities.

[0029] The electrical steel sheet may further include 0.1 wt% or less of Mn and 0.005 wt% or less of S.

[0030] The non-oriented electrical steel sheet according to an embodiment of the present disclosure has excellent magnetism in the entire direction and has excellent magnetism in the rolling direction, making it particularly useful for axial flux motors.

Additionally, it may be manufactured through a continuous process so the manufacturing time may be relatively shortened and productivity may be improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031]

FIG. 1 shows a photograph on a surface of a non-oriented electrical steel sheet manufactured by Steel No. 2, analyzed by EBSD.

FIG. 2 shows a photograph on a surface of a non-oriented electrical steel sheet manufactured from steel No. 2, analyzed by EBSD.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0032] 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. Thus, a first element, component, region, layer, or section discussed below could be termed a second element, component, region, layer, or section without departing from the teachings of the present disclosure.

[0033] The technical terms used herein are to simply mention a particular embodiment and are not meant to limit the present disclosure. An expression used in the singular encompasses an expression of the plural, unless it has a

clearly different meaning in the context. In the specification, it is to be understood that terms such as "including", "having", etc., are intended to indicate the existence of specific features, regions, numbers, stages, operations, elements, components, or combinations thereof disclosed in the specification, and are not intended to preclude the possibility that one or more other specific features, regions, numbers, operations, elements, components, or combinations thereof may exist or may be added.

[0034] When a part is referred to as being "on" another part, it may be directly on the other part or intervening parts may also be present. In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements therebetween.

[0035] 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 disclosure belongs. Such terms as those defined in a generally used dictionary are to be interpreted to have the meanings equal to the contextual meanings in the relevant field of art, and are not to be interpreted to have idealized or excessively formal meanings unless clearly defined in the present application.

[0036] Unless mentioned in a predetermined way, % represents wt%, and 1 ppm is 0.0001 wt%.

[0037] In an embodiment of the present disclosure, "further including an additional element" signifies including the additional element in substitute for iron (Fe) that is a remainder.

[0038] An embodiment of the present disclosure will be described more fully hereinafter so that a person skilled in the art may easily realize the same. 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.

[0039] A method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present disclosure includes: hot rolling a slab to manufacture a hot rolled steel sheet; performing a hot rolled plate annealing on the hot rolled steel sheet; performing a primary cold rolling on the hot rolled plate annealed hot rolled steel sheet; performing a decarburization annealing on the primarily cold rolled steel sheet; performing a secondary cold rolling on the decarburization annealed steel sheet; and annealing the secondarily cold rolled steel sheet at a non-oxidizing atmosphere to thus perform a non-oxidation annealing.

[0040] Respective stages will now be described in detail.

[0041] The slab is hot rolled.

[0042] The slab may include, in wt%, 0.3% to 4.0% of Si, 0.03% to 0.4% of C, and a remainder of Fe and inevitable impurities.

[0043] A reason for limiting the composition is given as follows.

[0044] Si improves iron loss by lowering magnetic anisotropy of the electrical steel sheet and increasing resistivity thereof. When the content of Si is less than 0.3 wt%, iron loss is deteriorated, and when it is greater than 4.0 wt%, brittleness increases. Therefore, the content of Si in the slab and the non-oriented electrical steel sheet after final non-oxidation annealing may be 0.3% to 4.0 wt%. In detail, the content of Si may be 0.4 to 3.0 wt%. In detail, the content of Si may be 0.5 to 2.0 wt%.

[0045] The carbon (C) in a center portion needs to escape to a surface layer so as to allow Goss grains on the surface layer to be diffused to the center portion during decarburization annealing, so the content of carbon (C) in the slab may be 0.03 to 0.4 wt%. In detail, the content of carbon (C) in the slab may be 0.15 to 0.3 wt%. The amount of carbon (C) in the finally manufactured non-oriented electrical steel sheet after decarburization is completed may be 0.0050 wt% or less. In detail, it may be 0.002 wt% or less. In detail, it may be 0.0005 to 0.0020 wt%.

[0046] The slab may further include 0.1 wt% or less of Mn and 0.005 wt% or less of S.

[0047] Mn and S form deposition of MnS to hinder the growth of Goss grains diffused to the center portion during the decarburization process. Therefore, it is preferable that Mn and S are not added. However, Mn and S in the slab and the non-oriented electrical steel sheet after final annealing stages may be controlled so that Mn is 0.1 wt% or less and S is 0.005 wt% or less, by considering the amount that is inevitably mixed during the steelmaking process.

[0048] The remainder includes Fe and inevitable impurities. The inevitable impurities refer to the impurities introduced during a steelmaking process and the process for manufacturing a non-oriented electrical steel sheet, which is widely known in the field and a detailed description will be omitted. In detail, components such as Al, N, Ti, Mg, and Ca react with oxygen in the steel to form oxides, so strong suppression is required, and the respective components may be managed to be equal to or less than 0.005 wt%. In addition to the alloy component described above in an embodiment of the present disclosure, the addition of elements 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 as a replacement for the remainder of Fe.

[0049] In detail, the slab may be made of, in wt%, 0.3% to 4.0% of Si, 0.03% to 0.4% of C, and the remainders of Fe and inevitable impurities.

[0050] The slab may be heated before hot rolling the slab. The slab heating temperature may be 1050 °C to 1350 °C which is higher than the normal heating temperature.

[0051] There is a problem that when the temperature is high during reheating the slab, the hot-rolled texture

coarsens to cause a negative effect to the magnetism. However, the method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present disclosure has a higher carbon content than before, so when the slab reheating temperature is high, the hot-rolled texture does not coarsen, and the method is advantageous in hot rolling by reheating the same at a higher temperature than usual. However, when the reheating temperature is too high, the solubility of the deposition such as TiN, AlN, etc. increases, and a large number of microdepositions are distributed during cooling, which hinders the growth of grains on the surface.

[0052] Hot rolling may be used to manufacture a hot rolled plate with the thickness of 1.50 to 4.00 mm by applying an appropriate rolling rate in the final cold rolling stage so that the final product with the thickness may be manufactured. In detail, it may manufacture the hot rolled plate with the thickness of 1.80 to 2.60 mm.

[0053] There are no specific restrictions on the hot rolling temperature or cooling temperature, but as an example of excellent magnetism, a hot rolling ending temperature may be set to 950 °C or lower, and cooling is done rapidly with water so that it may be wound at 600 °C or lower.

[0054] The method may further include, after hot rolling, hot rolled plate annealing the hot rolled steel sheet. At this time, the hot rolled plate annealing may include a decarburization process. In detail, hot rolled plate annealing may be performed at a temperature of 850 °C to 1000 °C and a dew point temperature of 70 °C or lower. In detail, annealing may be performed at the dew point temperature of -70 °C to 70 °C. After the aforementioned annealing, further annealing may be performed at the temperature of 1000 to 1200 °C and the dew point temperature of 0 °C or lower. After performing the hot rolled plate annealing, pickling may be performed.

[0055] A cold rolled steel sheet is manufactured by performing primary cold rolling.

[0056] In the conventional process for manufacturing an oriented electrical steel sheet, it is known that cold rolling is effective when it is performed once with a high reduction ratio of close to 90%. This is because among the primary recrystallized grains, the Goss grains generate an environment favorable for particle growth. However, the method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present disclosure internally diffuses the Goss grains on the surface layer generated by decarburization annealing and cold rolling without using abnormal particle growth of Goss-oriented grains, so it is advantageous to form a large number of Goss-oriented grains distributed on the surface layer. To be used as a core for AFM, a reduction ratio that may simultaneously form cubic orientation may be applied because a structure in which not only Goss but also cube-oriented grains are mixed in an appropriate ratio is advantageous in generating magnetic force lines.

[0057] Therefore, when cold rolling is performed at the reduction ratio of 70% to 80%, a large amount of Goss texture may be formed on the surface. More specifically, it may be 72% to 80%.

[0058] The primary cold rolled steel sheet undergoes decarburization annealing. The decarburization annealing may be performed in an austenite single-phase area or a region where a composite phase of ferrite and austenite exists. Specifically, it may be annealed at the temperature of 750 °C to 1000 °C and the dew point temperature of 25 °C to 70 °C. The atmosphere may be a mixed gas atmosphere of hydrogen and nitrogen. When decarburization annealing is performed, the amount of carbon in the steel sheet may be equal to or less than 0.005 wt%. In detail, it may be annealed at the temperature of 750 °C to 900 °C. The annealing may be performed for 60 seconds to 5 minutes. In detail, it may be performed for 90 to 300 seconds.

[0059] In the decarburization annealing process, the grain size on the surface of the electrical steel sheet grows coarsely, but the grain inside the electrical steel sheet remains as a fine texture. When decarburization annealing is performed, the average diameter of the grain may be 150 μm to 250 μm. The grain is a surface ferrite grain, and the diameter of the grain refers to the diameter of a virtual circle having the same area as the grain. The reference surface is parallel to the vertical rolling surface (TD surface).

[0060] Secondary cold rolling is performed on the steel sheet having undergone decarburization annealing. Secondary cold rolling is the same as primary cold rolling, so no detailed description will be provided. The reduction ratio of the secondary cold rolling may be 50 to 80%. In detail, it may be 50 to 70%.

[0061] The above-mentioned decarburization annealing and the secondary cold rolling may be repeated at least twice. By repeating the process at least twice, a large amount of Goss texture and cubic texture may be formed on the surface. In an embodiment of the present disclosure, the Goss texture refers to a texture that forms an angle of 15° or less with the Goss direction. That is, it refers to a grain in which the rolling surface (ND surface) and the rolling direction (RD direction) of the steel sheet form the angle of 15° or less with the direction {110}<001> of the grain. The cubic texture refers to grains forming the angle of equal to or less than 15° with the direction {100}<001>.

[0062] The steel sheet on which secondary cold rolling has been completed is annealed in the non-oxidizing atmosphere.

[0063] In an embodiment of the present disclosure, annealing is performed in the non-oxidizing atmosphere after secondary cold rolling is performed, and additional decarburization annealing may be omitted. If decarburization annealing is added after the secondary cold rolling, the cubic texture in the steel sheet may be converted to Goss texture, and the remaining cubic texture may not be sufficient. Due to this, magnetism in the rolling direction may be improved, but magnetism in directions other than the rolling direction may be significantly deteriorated.

[0064] The non-oxidation annealing may be performed at a soaking temperature of 750 to 1050 °C for sixty seconds to five minutes.

[0065] The purpose of the non-oxidation annealing is to grow the grains to a predetermined size or larger. This may result in improved magnetism, particularly high-frequency iron loss. If the soaking temperature is too low or the time is too short, the Goss grains and the cubic grains may not develop properly. When the soaking temperature is too high or the time is too long, the Goss grains and the cubic grains do not remain in a fine size that is advantageous for high-frequency iron loss, but they grow, and the problem of the fraction of the Goss grains and the cubic grains actually decreasing during the growth process may be generated. In detail, the soaking temperature of non-oxidation annealing may be 800 to 1000 °C. In detail, it may be 900 to 970 °C.

[0066] The secondary non-oxidation annealing may be performed at the dew point temperature of -20 °C or lower. If the dew point temperature is too high, an oxide layer may be formed on the surface, which may adversely affect magnetism. In detail, the same may be performed at the atmosphere of more than 99 volume% of hydrogen at the dew point temperature of -50 to -30 °C.

[0067] After the primary cold rolling is performed, it may be performed as a continuous process up to the non-oxidation annealing. The continuous process means that there is no batch process for winding a steel sheet into a coil and annealing it. As described above, the continuous process is possible because the decarburization annealing or the non-oxidation annealing is completed in less than a few minutes.

[0068] The finally manufactured non-oriented electrical steel sheet after performing the non-oxidation annealing may have an area fraction of grains forming the angle of equal to or less than 15° with {110}<001> as 20 to 60%, and an area fraction of grains forming an angle of less than 15° with {100}<001> as 5 to 20%.

[0069] The area fraction of grains may be measured with respect to the surface parallel to the rolling surface (ND surface), and the point 1/4t to 3/4t of the thickness of the steel sheet may be measured. There are no specific restrictions on the measuring method, but EBSD may be used for measurement.

[0070] The Goss grains and the cubic grains are appropriately present in the steel sheet, thereby improving magnetism in the entire directions, and particularly, further improving magnetism in the rolling direction, so that it may be usefully used for the axial flux motor. In detail, the area fraction of grains forming the angle of 15° or less with {110}<001> may be 40 to 55%, and the area fraction of grains forming the angle of 15° or less with {100}<001> may be 7 to 15%.

[0071] The grains having a ratio D2/D1 of a diameter D1 of a circumscribed circle to a diameter D2 of an inscribed circle, that is equal to or greater than 0.5 from among the entire grains may be equal to or greater than 95 area%.

[0072] The fraction of grains with the diameter of the grain particle of 30 μm to 200 μm from among the entire grains may be 80 area% or more. This is because decarburization annealing and non-oxidation annealing were performed for a short period of time in an embodiment of the present disclosure. When annealing is performed for a long time, such as an hour or more, through batch annealing, as in the conventional production of oriented electrical steel sheets, the average grain particle diameter increases by 5 mm or more, which is completely different from the shape and size distribution of the grain particle diameter of the non-oriented electrical steel sheet according to an embodiment of the present disclosure. In detail, the fraction of grains having a grain particle diameter of 30 μm to 200 μm from among the entire grains may be 90% to 99%. The fine grains contribute to improving high-frequency iron loss. The grain fraction refers to the area fraction, and may be obtained by calculating the area of grains having the corresponding particle diameter in an arbitrary cross-section of the steel sheet. In detail, it may be found by using the vertical rolling surface (ND surface) of the steel sheet as a reference. The particle diameter of the grain may be calculated as the diameter of a virtual circle that has the same area as the grain.

[0073] In an embodiment of the present disclosure, the effect may be realized by a unique manufacturing process and a unique micro-texture generated by the manufacturing process rather than by the alloy component of the non-oriented electrical steel sheet. Regarding the alloy components of the non-oriented electrical steel sheet, the non-oriented electrical steel sheet may include, in wt%, 0.3% to 4.0% of Si, 0.005% or less (excluding 0%) of C, and remainders including Fe and inevitable impurities. The non-oriented electrical steel sheet may further include 0.1 wt% or less of Mn and 0.005 wt% or less of S. The description on the alloy component of the non-oriented electrical steel sheet is the same as the description on the alloy component of the slab described above, so no repeated description will be provided.

[0074] The non-oriented electrical steel sheet has excellent magnetism, particularly the magnetism in the rolling direction and the vertical rolling direction. In detail, the average magnetic flux density (B_{50}) in the rolling direction and the vertical rolling direction may be 1.78 to 1.88 T. The average iron loss ($W_{15/50}$) in the rolling direction and the vertical rolling direction may be 1.5 to 2.0 W/kg. The magnetic flux density (B_{50}) in the rolling direction may be 1.95 to 2.05 T. Iron loss in the rolling direction ($W_{15/50}$) may be 0.80 to 1.5 W/kg.

[0075] In an embodiment of the present disclosure, the non-oriented electrical steel sheet may have small magnetic flux density deviations in the rolling direction and the vertical rolling direction. In detail, the deviation may be 5.0 to 15.0%. In detail, the deviation may be 10.0 to 14.5%. Deviation may be calculated as (rolling direction magnetic flux

density - vertical rolling direction magnetic flux density)/rolling direction magnetic flux density $\times 100$.

[0076] The magnetic flux density (B_{50}) refers to the magnetic flux density induced in a magnetic field of 5000 A/m. Iron loss ($W_{15/50}$) is the size (W/kg) of iron loss induced under the condition of 1.5 Tesla and 50 Hz. Embodiments of the present disclosure will now be described. However, the following embodiments are merely specific embodiments of the present disclosure, and the present disclosure is not limited to the same.

Embodiment 1

[0077] The slab including, in wt%, 2.0% of Si, 0.085% of Si, and the remainder of Fe and inevitable impurities are heated at the temperature of 1150 °C, are hot rolled according to the thickness listed in Table 1, and is hot rolled plate annealed at the annealing temperature of 920 °C. After cooling the steel sheet, pickling is performed, and cold rolling is performed at the reduction ratio listed in Table 1 to manufacture a cold-rolled sheet. The cold rolled plate is heat treated at the dew point temperature of 55 °C according to the decarburization annealing temperature and the annealing time listed in Table 1. Cold rolling is performed again at the reduction ratio of 56% to manufacture the cold-rolled sheet with the thickness of 0.22 mm. Non-oxidation annealing is performed for two minutes at the temperature of 950 °C, in a mixed gas atmosphere of hydrogen and nitrogen, and at the dew point temperature of -30 °C. The final content of C, magnetic flux density, iron loss, and magnetic flux density deviation of the specimens having undergone non-oxidation annealing are measured and summarized in Table 2.

[0078] The grain area fraction is measured on the ND surface using EBSD. Magnetism is measured using a method using a single sheet tester.

(Table 1)

Steel No.	Hot-rolled sheet thickness(mm)	Primary cold-rolling reduction ratio(%)	Decarburization annealing temperature(°C)	Decarburization annealing time(seconds)
1	1.25	60	880	125
2	1.80	72	880	125
3	2.20	77	880	125
4	2.55	80	880	125
5	2.80	82	880	125
6	3.34	85	880	125
7	1.80	72	750	125
8	1.80	72	820	125
9	1.80	72	1050	125
10	2.20	77	750	125
11	2.20	77	820	125
12	2.20	77	1050	125
13	1.80	72	680	125
14	2.20	77	680	125
15	2.55	80	680	125
16	1.80	72	880	45
17	2.20	77	880	45
18	2.55	80	880	45

(Table 2)

Steel No.	Final content of C (ppm)	{110}<0 01> grain fraction(area%)	{100}<0 01> grain fraction(area%)	Grain fraction(area%) with D2/D1 of more than 0.5	Grain fraction (area%) of 30μm to 200μm	Rolling direction B50(T)	Vertical rolling direction B50(T)	Deviation (%)	Etc.,
1	15	78	3	97	96	2.03	1.65	18.7	Comparative example
2	11	55	7	97	96	1.99	1.71	14.1	Embodiment
3	13	50	10	96	97	1.99	1.73	13.1	Embodiment
4	15	33	15	98	96	1.98	1.75	11.6	Embodiment
5	15	18	18	97	98	1.87	1.69	9.6	Comparative example
6	11	25	21	96	97	1.82	1.68	7.7	Comparative example
7	13	53	9	97	96	1.98	1.72	13.1	Embodiment
8	15	55	7	97	96	1.99	1.71	14.1	Embodiment
9	59	33	25	98	98	1.88	1.69	10.1	Comparative example
10	17	46	13	97	96	1.96	1.74	11.2	Embodiment
11	8	50	9	96	96	1.98	1.72	13.1	Embodiment
12	85	39	22	95	96	1.86	1.67	10.2	Comparative example
13	101	52	17	95	96	1.84	1.67	9.2	Comparative example
14	97	41	22	95	96	1.86	1.67	10.2	Comparative example
15	85	36	27	95	96	1.87	1.71	8.6	Comparative example
16	59	56	14	95	96	1.87	1.69	9.6	Comparative example
17	66	43	19	97	95	1.88	1.71	9.0	Comparative example
18	74	39	22	96	96	1.89	1.73	8.5	Comparative example

[0079] As expressed in Table 1 and Table 2, depending on the conditions during hot rolling, primary cold rolling, decarburization annealing, and non-oxidation annealing, a large number of cubic grains and Goss grains are formed, and it may be confirmed that the magnetism is oriented in the entire directions and the rolling direction.

[0080] On the other hand, No. 1, No. 5, and No. 6, which have primary cold-rolling reduction ratios outside the range, show poor magnetism because many cubic grains or Goss grains are not generated.

[0081] No. 9 and No. 12, which had too high a temperature during decarburization annealing, show delayed decarburization and slow grain growth due to the formation of a dense oxide layer on the surface, which made it difficult to form Goss and Cube orientations, thereby allowing poor magnetism.

[0082] During decarburization annealing, No. 13 to No. 15, where the temperature is too low, have a low carbon activation level for decarburization, delay decarburization and thus slow grain growth, and delay the formation of Goss and Cube grains, resulting in poor magnetism.

[0083] No. 16 to No. 18, which have too short decarburization annealing times, show poor magnetism due to incomplete decarburization, incomplete grain growth, and delayed formation of Goss and Cube grains.

[0084] While this disclosure has been described in connection with what is presently considered to be practical embodiments, it is to be understood that the disclosure is not limited to the disclosed embodiments, but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims. Therefore, the embodiments described above are only examples and should not be construed as being limitative in any respects.

Claims

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

hot rolling a slab and manufacturing a hot rolled steel sheet;
performing primary cold rolling on the hot rolled steel sheet;
decarburization annealing the primary cold rolled steel sheet;
performing secondary cold rolling on the decarburization annealing completed steel sheet; and
annealing the secondary cold rolling completed steel sheet at a non-oxidizing atmosphere to thus perform non-oxidation annealing.

2. The method of claim 1, wherein the slab includes, in wt%, 0.3% to 4.0% of Si, 0.03% to 0.4% of C, and remainders including Fe and inevitable impurities.

3. The method of claim 2, wherein the slab further includes 0.1 wt% or less of Mn and 0.005 wt% or less of S.

4. The method of claim 1, further comprising

performing hot rolled plate annealing on the hot rolled steel sheet,
wherein the hot rolled plate annealing includes a decarburization process.

5. The method of claim 4, wherein the hot rolled plate annealing is performed at the temperature of 850 °C to 1000 °C and at the dew point temperature of 70 °C or below.

6. The method of claim 1, wherein the decarburization annealing is performed at the temperature of 750 °C to 1000 °C and at the dew point temperature of 25 °C to 70 °C.

7. The method of claim 1, wherein the decarburization annealing is performed in an austenite single-phase area or a region in which a composite phase of ferrite and austenite exists.

8. The method of claim 1, wherein an amount of carbon in the steel sheet is equal to or less than 0.005 wt% after performing the decarburization annealing.

9. The method of claim 1, wherein the decarburization annealing and the secondary cold rolling are performed at least twice.
10. The method of claim 1, wherein
5 a reduction ratio of the primary cold rolling is 70 to 80%.
11. The method of claim 1, wherein the non-oxidation annealing is performed for 60 seconds to 5 minutes at a soaking temperature of 750 to 1050 °C.
- 10 12. The method of claim 1, wherein the non-oxidation annealing is performed in an atmosphere of the dew point temperature of -20 °C or below.
13. A non-oriented electrical steel sheet wherein
15 an area fraction of a grain forming an angle of equal to or less than 15° from {110}<001> is 20 to 60%, and an area fraction of a grain forming an angle of equal to or less than 15° from {100}<001> is 5 to 20%.
14. The non-oriented electrical steel sheet of claim 13, wherein
20 a difference of magnetic flux density between a rolling direction and a vertical rolling direction is 10% to 20%.
15. The non-oriented electrical steel sheet of claim 13, wherein the grains having a ratio D2/D1 of a diameter D1 of a circumscribed circle to a diameter D2 of an inscribed circle, that is equal to or greater than 0.5 from among entire grains are equal to or greater than 95 area%.
- 25 16. The non-oriented electrical steel sheet of claim 13, wherein a fraction of grains having grain particle diameters of 30 μm to 200 μm from among the entire grains is equal to or greater than 80 area%.
17. The non-oriented electrical steel sheet of claim 13, wherein
30 the electrical steel sheet includes, in wt%, 0.3% to 4.0% of Si, 0.005% or less of C, (excluding 0%), and remainders including Fe and inevitable impurities.
18. The non-oriented electrical steel sheet of claim 17, wherein
35 the electrical steel sheet further includes 0.1 wt% or less of Mn and 0.005 wt% or less of S.

FIG. 1

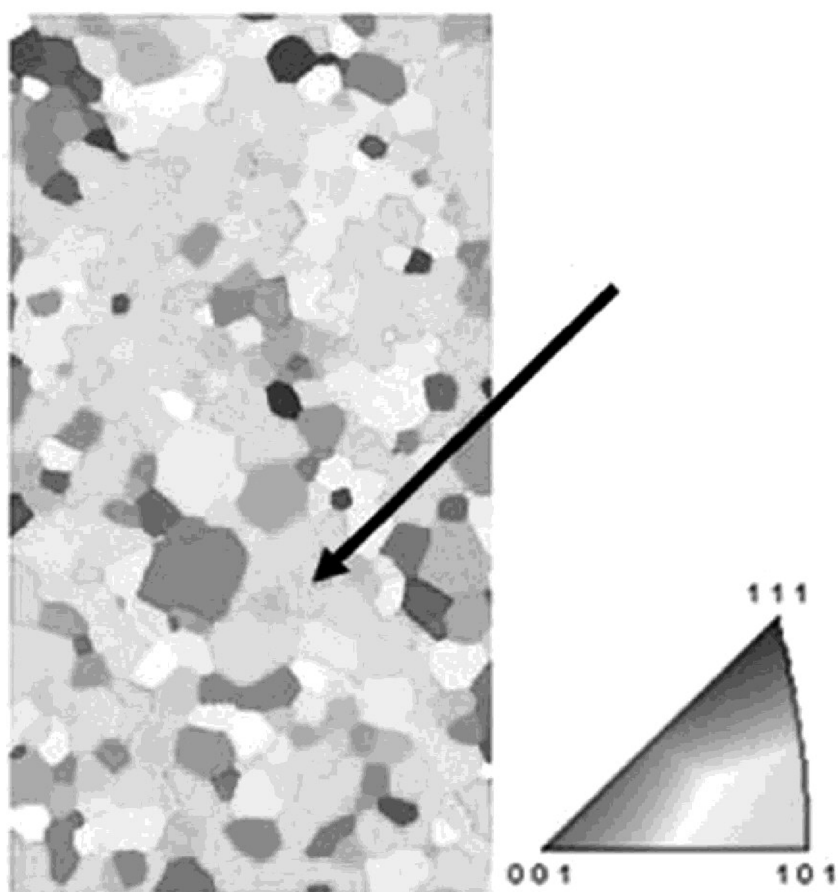
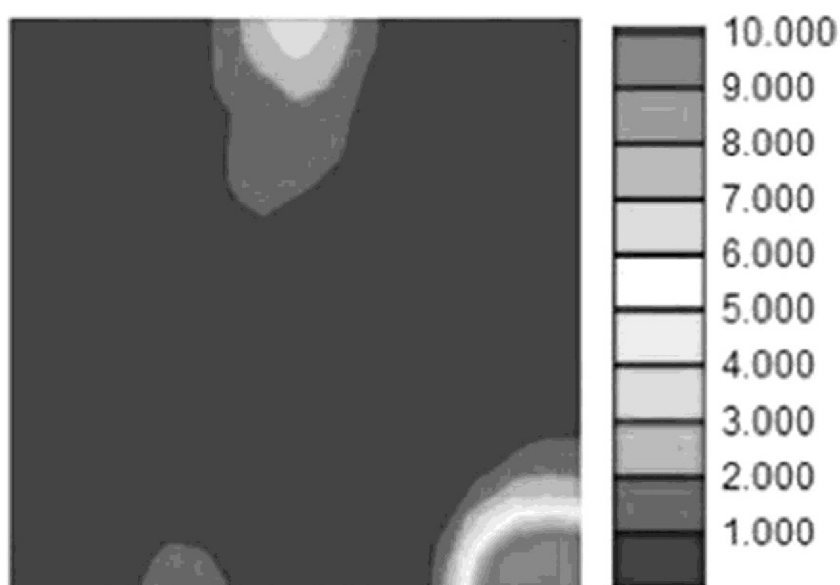


FIG. 2



INTERNATIONAL SEARCH REPORT

International application No.

PCT/KR2024/020326

A. CLASSIFICATION OF SUBJECT MATTER**C21D 8/12**(2006.01)i; **C22C 38/02**(2006.01)i; **C22C 38/04**(2006.01)i; **H01F 1/147**(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)

C21D 8/12(2006.01); C22C 38/02(2006.01); C22C 38/04(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: 무방향성(non-oriented), 전기강판(electrical steel sheet), 냉간 압연(cold rolling), 소둔(annealing), 탈탄(decarburizing) 및 비산화(non-oxidizing)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	KR 10-1995-0004934 B1 (POHANG IRON & STEEL CO., LTD. et al.) 16 May 1995 (1995-05-16) See paragraphs [0008]-[0029].	1-12
A		13-18
Y	KR 10-2021-0094027 A (JFE STEEL CORPORATION) 28 July 2021 (2021-07-28) See paragraphs [0066]-[0078], [0089]-[0090], [0095]-[0096] and [0101] and claim 1.	1-12
A	CN 112430779 A (BAOSHAN IRON & STEEL CO., LTD.) 02 March 2021 (2021-03-02) See claims 1-5.	1-18
A	KR 10-2021-0079753 A (POSCO) 30 June 2021 (2021-06-30) See claims 1-19.	1-18
A	KR 10-2023-0095281 A (POSCO) 29 June 2023 (2023-06-29) See claims 1-20.	1-18

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

* Special categories of cited documents:

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

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“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

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Name and mailing address of the ISA/KR

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/KR2024/020326

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