

Specification

Title of the Invention: LAMINATED CORE

Technical Field of the Invention

[0001]

5 The present invention relates to a laminated core.

 Priority is claimed on Japanese Patent Application No. 2022-063474, filed April 6, 2022, the content of which is incorporated herein by reference.

Related Art

[0002]

10 As a core (core) used in a rotary electric machine, a laminated core in which a plurality of electrical steel sheets are joined and laminated is known. As a method for joining electrical steel sheets, interlocking and welding are known. However, in interlocking and welding, the magnetic characteristics of the electrical steel sheet may be deteriorated due to mechanical stress and thermal stress at the time of processing, and
15 furthermore, interlayer short circuit, and the performance of the laminated core may be deteriorated.

 Therefore, in recent years, a joining method by adhesion has attracted attention as a joining method other than interlocking and welding. In joining using an adhesive, since the steel sheet is not processed like interlocking, deterioration of magnetic
20 characteristics is suppressed in a laminated core (bonded and laminated core) laminated and joined.

[0003]

 As an adhesive for bonding electrical steel sheets to each other, for example, as shown in Patent Document 1, an epoxy resin having a small volume change and excellent
25 heat resistance, oil resistance, and chemical resistance is known.

On the other hand, since it is necessary to set the temperature to a relatively high temperature in order to cure the epoxy resin, stress is applied to the steel sheet at the time of bonding, and there is a possibility that iron loss is deteriorated. Therefore, for example, Patent Document 2 to 7 proposes that a urethane resin is used as an adhesive
5 that can be bonded at a temperature lower than that of an epoxy resin.

Citation List

Patent Document

[0004]

Patent Document 1: Japanese Unexamined Patent Application, First Publication No.
10 2022-000888

Patent Document 2: Japanese Unexamined Patent Application, First Publication No.
2017-179233

Patent Document 3: Japanese Unexamined Patent Application, First Publication No.
2017-186542

15 Patent Document 4: Japanese Unexamined Patent Application, First Publication No.
H06-182929

Patent Document 5: Japanese Unexamined Patent Application, First Publication No.
H06-271834

Patent Document 6: Japanese Unexamined Patent Application, First Publication No.
20 H07-268051

Patent Document 7: Japanese Unexamined Patent Application, First Publication No.
2002-293864

Summary of Invention

Problems to be Solved by the Invention

25 [0005]

However, in the case of joining using an adhesive as described above, in general, it is known that a resin having a higher adhesive strength is harder, and strain is imparted to a steel sheet with curing shrinkage, resulting in deterioration of magnetic characteristics. That is, it has been considered that the adhesive strength and the
5 magnetic characteristics are contradictory.

Therefore, conventionally, it has not been easy to achieve both high adhesive strength and excellent magnetic characteristics in the bonded and laminated core.

Therefore, an object of the present invention is to provide a laminated core (bonded and laminated core) having high adhesive strength and excellent magnetic
10 characteristics.

Means for Solving the Problem

[0006]

The present inventors have studied a method for achieving both high adhesive strength and excellent magnetic characteristics in a laminated core formed by laminating
15 a plurality of electrical steel sheets with an insulating coating having adhesive ability.

As a result, the present inventors have found that it is possible to achieve both high adhesive strength and excellent magnetic characteristics by controlling the hardness in the order of μm measured by a nanoindenter in an insulating coating.

In addition, it has been found that by setting the weight-average molecular
20 weight of the sol component of the insulating coating within a predetermined range, the balance between suppression of deterioration of magnetic characteristics and improvement of adhesive strength is further improved.

[0007]

The present invention has been made on the basis of the above-described
25 findings. The gist of the present invention is as follows.

[1] A laminated core according to an embodiment of the present invention includes a plurality of electrical steel sheets laminated on each other; and an insulating coating that is provided between the electrical steel sheets adjacent to each other in a laminating direction and bonds the electrical steel sheets to each other, wherein the
5 insulating coating has a hardness of 200~300 MPa.

[2] In the laminated core according to [1], a weight-average molecular weight of a sol component of the insulating coating may be 10,000 to 100,000.

[3] In the laminated core according to [1] or [2], in the plurality of electrical steel sheets, when an area fraction of grains of the {hkl}<uvw> orientation with respect
10 to a total visual field when a surface parallel to a rolled surface having a depth of 1/2 of a sheet thickness from a surface is measured by SEM-EBSD is expressed as Ahkl-uvw, A411-011 may be 15.0% or more.

[4] In the laminated core according to [3], the electrical steel sheet may contain:
0.0100% or less of C, 1.50% to 4.00% of Si, 0.0001% to 1.0000% of sol.Al, 0.0100% or
15 less of S, 0.0100% or less of N, 2.50% to 5.00% in total of one or more selected from the group consisting of Mn, Ni, and Cu, 0.000% to 1.000% of Co, 0.000% to 0.400% of Sn, 0.000% to 0.400% of Sb, 0.000% to 0.400% of P, and 0.0000% to 0.0100% in total of one or more selected from the group consisting of Mg, Ca, Sr, Ba, Ce, La, Nd, Pr, Zn, and Cd, in terms of % by mass as a chemical composition, wherein when a Mn content is
20 denoted by [Mn], a Ni content is denoted by [Ni], a Cu content is denoted by [Cu], a Si content is denoted by [Si], a sol.Al content is denoted by [sol.Al], and a P content is denoted by [P] in terms of % by mass, the following formula (1) is satisfied, and a remainder is Fe and impurities.

$$(2 \times [\text{Mn}] + 2.5 \times [\text{Ni}] + [\text{Cu}]) - ([\text{Si}] + 2 \times [\text{sol.Al}] + 4 \times [\text{P}]) \geq 1.50\% \quad \cdots (1)$$

25 Effects of the Invention

[0008]

According to the above aspect of the present invention, it is possible to provide a laminated core having high adhesive strength and excellent magnetic characteristics.

Brief Description of the Drawing

5 [0009]

FIG. 1 is a diagram illustrating an example of a side view of a laminated core according to the present embodiment.

Embodiments of the Invention

[0010]

10 As illustrated in FIG. 1, a laminated core (laminated core according to the present embodiment) according to an embodiment of the present invention includes: a plurality of electrical steel sheets 21 laminated on each other; and an insulating coating 22 that is provided between the electrical steel sheets 21 and 21 adjacent to each other in a laminating direction and bonds the electrical steel sheets 21 and 21 to each other,
15 wherein the insulating coating has a hardness of 200 to 300 MPa.

Each will be described below.

[0011]

<Insulating coating>

[Hardness]

20 The insulating coating 22 included in the laminated core 1 according to the present embodiment secures insulation properties and joins the electrical steel sheets 21 and 21 adjacent to each other in the laminating direction by adhesion.

The insulating coating is an insulating coating having heating-curable adhesive ability at the time of being formed on the surface of the electrical steel sheet (Since it
25 does not have an insulating coating, it may be referred to as a base steel sheet.). An

insulating coating having an adhesive ability is formed on the base steel sheet, and a plurality of electrical steel sheets having the insulating coating are laminated and bonded through heating and pressure, whereby the electrical steel sheets are joined by adhesion.

At that time, in general, a resin having a higher adhesive strength is harder, and a strain is imparted to the steel sheet with curing shrinkage, resulting in deterioration of magnetic characteristics. Therefore, it is not easy to achieve both high adhesive strength and excellent magnetic characteristics at a high level.

In the laminated core 1 according to the present embodiment, it is possible to increase the adhesive strength while suppressing the deterioration of the magnetic characteristics by controlling the hardness of the insulating coating 22 in the order of μm , which is measured by a nanoindenter. Specifically, the hardness of the insulating coating is set to 200 to 300 MPa.

When the hardness of the insulating coating is less than 200 MPa, sufficient adhesive strength (for example, 10.0 MPa or more) cannot be obtained. On the other hand, when the hardness of the insulating coating exceeds 300 MPa, deterioration of magnetic characteristics becomes remarkable.

[0012]

The hardness of the insulating coating can be determined in the following manner.

For example, a sample is taken out by cutting out from several sheets which are delaminated from laminated core with a precision cutter so that the cross section of the insulating coating can be observed. A sample for measurement is prepared by performing CP processing (ion milling processing) on the center portion in the thickness direction of the portion bonded through heating and pressure of the insulating coating of the sample. The hardness is measured at room temperature (25°C) under a load of 250

μN using TRIBOINDENTER manufactured by HYSITRON or a nanoindenter equivalent thereto. Five points are measured, and the average value is taken as the hardness of the insulating coating.

[0013]

5 [Weight-average molecular weight of sol component]

In the insulating coating 22 included in the laminated core 1 according to the present embodiment, the weight-average molecular weight (M_w) of the sol component of the insulating coating is preferably 10,000 to 100,000. When the weight-average molecular weight of the sol component is 10,000 or more, a resin structure having
10 rigidity can be obtained, and sufficient adhesive strength can be obtained. When the weight-average molecular weight of the sol component is 100,000 or less, the resin is not excessively hard, and deterioration of magnetic characteristics can be suppressed. That is, when the weight-average molecular weight of the sol component is in a predetermined range, a balance between suppression of deterioration of magnetic characteristics and
15 improvement of adhesive strength is further improved.

The weight-average molecular weight of the sol component of the insulating coating is more preferably 20,000 to 70,000 and still more preferably 30,000 to 50,000.

Not the weight-average molecular weight of the entire insulating coating but the weight-average molecular weight of the sol component is specified because the weight-
20 average molecular weight of the uncrosslinked part of the adhesive affects the magnetic characteristics.

[0014]

The weight-average molecular weight of the sol component of the insulating coating can be measured using, for example, a GPC(Gel Permeation Chromatography:
25 Gel Permeation Chromatography) such as a high speed GPC system HLC-8320GPC

manufactured by Toyo Soda Co., Ltd., for a measurement sample prepared by immersing a solidified insulating coating (functioning as an adhesive) cut out from several sheets which are delaminated from laminated core with a precision cutter in 10mM lithium bromide-containing N,N-dimethylformamide for 24 hours. Conditions at that time are
5 as follows.

Column: PLgel 5 μ m Guard, PLgel 5 μ m MIXED-C $\times$ 2 (Polymer Laboratories)

Mobile phase: 10mM lithium bromide containing N,N-dimethylformamide

Flow rate: 1.0 mL/min

Column temperature: 40°C

10 Data Processing: EcoSEC-WorkStation

[0015]

The insulating coating preferably contains 90 wt% or more of an acrylic resin that has a certain degree of rigidity after curing, can secure adhesive strength, and has little compressive stress on the steel sheet due to curing.

15 Other components may include a resin, an inorganic salt, and inorganic fine particles. Examples of the resin as the other component include an epoxy resin, a urethane resin, and a phenol resin. Examples of the inorganic salt include phosphate, chromate, and borate. Examples of the inorganic fine particles include silicon dioxide, titanium oxide, magnesium oxide, and zirconium hydroxide. The type of the acrylic
20 resin mainly composing the insulating coating is not particularly limited.

[0016]

In the laminated core according to the present embodiment, another coating having insulation properties may be provided as a base layer between the electrical steel sheet 21 and the insulating coating 22. In this case, the insulating coating bonds the
25 electrical steel sheets to each other via the base layer.

The base layer is not limited, and a known coating can be used. However, in order to avoid a decrease in adhesive strength while improving insulation properties, for example, a coating formed by applying a general treatment agent such as a chromic acid-containing treatment agent or a phosphate-containing treatment agent and baking it is
5 preferable.

The base layer contributes to improvement of insulation properties between the laminated steel sheets in the core. When this effect is obtained, the thickness of the base layer is preferably set to 0.1 μm or more. On the other hand, when the thickness of the base layer is thick, the adhesion is reduced and the base layer is easily peeled off.
10 Therefore, the thickness of the base layer is preferably 1.0 μm or less.

[0017]

If the thickness of the insulating coating is too thick, deterioration of magnetic characteristics due to stress of curing increases, and if the thickness is too thin, the bonding area is significantly reduced due to the influence of the surface roughness of the electrical steel sheet to be bonded, and there is a concern that the adhesive strength is
15 insufficient.

Therefore, when the thickness of the adhesive portion is A in a unit of μm, A and the arithmetical average roughness Ra of the surface of the electrical steel sheet to be bonded, which is defined in JISB0601 (2013), preferably satisfy the following formula
20 (3).

$$3.0 \times Ra \leq A \leq 3.0 \quad (3)$$

[0018]

The thickness A of the insulating coating can be measured by a magnetic method shown in JISK5600-1-7 (2014) using, for example, an electromagnetic coating thickness
25 meter LE-370 manufactured by Kett Electric Laboratory Co. Ltd. or an electromagnetic

coating thickness meter equivalent thereto.

The arithmetical average roughness Ra of the surface of the electrical steel sheet can be measured using, for example, a surface roughness measuring machine SE3500 manufactured by Kosaka Laboratory Ltd. or a stylus roughness meter equivalent thereto.

5 At this time, the measurement direction is the sheet width direction (C direction), the measurement length is 8 mm, the speed is 0.1 mm/s, and the cut-off value is 0.8 mm.

When the arithmetical average roughness of the surface of the electrical steel sheet is measured when an insulating coating or a base layer is present on the surface of the electrical steel sheet, such as after the electrical steel sheet becomes a laminated core,
10 the arithmetical average roughness may be measured after the insulating coating or the base layer is removed from the surface of the electrical steel sheet.

The insulating coating can be removed by, for example, immersing insulating coating in DMF (dimethylformamide) for 10 to 60 minutes. The base layer can be removed by, for example, immersing the base layer in a 20% NaOH aqueous solution for
15 1 to 10 minutes.

[0019]

<Electrical steel sheet>

The electrical steel sheet included in the laminated core 1 according to the present embodiment may be a known electrical steel sheet (oriented electrical steel sheet
20 or non-oriented electrical steel sheet), and when application to a motor or the like is assumed, the electrical steel sheet is preferably a non-grain-oriented electrical steel sheet.

In the case of a non-oriented electrical steel sheet, it is preferable to have the following texture and chemical composition.

[0020]

25 [Texture]

In the electrical steel sheet, the texture is controlled in order to obtain a low iron loss and a high magnetic flux density. For example, the magnetic characteristics are improved by developing a microstructure (α fiber) which has an easy magnetization axis in the plane of the steel sheet, is advantageous for improving the magnetic characteristics, and can be relatively easily increased in development by a rolling process in hot rolling and cold rolling which are essential steps of steel sheet manufacture. Specifically, it is effective to form a microstructure in which the $\langle 110 \rangle$ direction is substantially parallel to the rolling direction (RD).

On the other hand, when the $\{100\}\langle 011 \rangle$ orientation is developed, a change in magnetic characteristics with respect to stress, specifically, deterioration (stress sensitivity) of the magnetic characteristics increases in a case where compressive stress acts.

On the other hand, by developing a special orientation of $\{411\}\langle 011 \rangle$, the magnetic characteristics (particularly, the magnetic characteristics in the 45° direction from the rolling direction) are further improved.

Therefore, it is preferable to control the texture when a surface parallel to the rolled surface having a depth of $1/2$ of the sheet thickness from the surface is measured with a scanning electron microscope with an electron backscatter diffraction function (SEM-EBSD). Specifically, when the area fraction of grains of the $\{hkl\}\langle uvw \rangle$ orientation (tolerance of 10° or less) to the total visual field, obtained by the above measurement, is expressed as $A_{hkl-uvw}$, $A_{411-011}$ (hereinafter, sometimes referred to as $\{411\}\langle 011 \rangle$ fraction) is preferably set to 15.0% or more.

The $\{411\}\langle 011 \rangle$ fraction is more preferably 25.0% or more, still more preferably 30.0% or more, still more preferably 35.0% or more, and particularly preferably 40.0% or more. The upper limit is not particularly limited, but may be

80.0% or less from the viewpoint of manufacture load.

[0021]

The area fraction of the specific oriented grain can be measured by the following method. That is, for the area fraction of specific oriented grain, a target-specific

5 orientation is extracted (tolerance is set to 10° , and hereinafter, expressed as tolerance of 10° or less) from a measurement region by a scanning electron microscope (SEM) with an electron backscatter diffraction (EBSD: Electron Back Scattering Diffraction) function observed under the following measurement conditions using OIM Analysis 7.3 (manufactured by TSL). The extracted area is divided by the area of the measurement
10 region to obtain the percentage. This percentage is defined as the area fraction of the specific oriented grain.

In the present embodiment, the “area fraction of grain having crystal orientation of $\{hkl\}\langle uvw \rangle$ orientation (tolerance of 10° or less) to measurement region” and the “area fraction of grains having a $\{hkl\}$ orientation (tolerance: 10° or less) to a
15 measurement region” may also be simply referred to as “ $\{hkl\}\langle uvw \rangle$ ratio” and “ $\{hkl\}$ ratio”, respectively. In the description of the crystal orientation, it is assumed that the tolerance is 10° or less.

[0022]

Details of the measurement conditions for obtaining the area fraction of each
20 oriented grain are as follows.

- Measuring device: SEM model number “JSM-6400 (manufactured by JEOL Ltd.)”, EBSD detector model number “HIKARI (manufactured by TSL)”, or an apparatus similar thereto was used.

- Step interval: $5.0\ \mu\text{m}$

25 • Magnification: 100 times

• Measuring object: a surface parallel to a rolled surface having a depth of 1/2 of the sheet thickness from the surface

• Measuring region: rectangular region of 1000 μm or more × 1000 μm or more

[0023]

5 (Chemical composition)

In addition, the chemical composition of the electrical steel sheet included in the laminated core according to the present embodiment is not limited and may be in a known range, but in a case where the above-described {411}<011> fraction is obtained and excellent magnetic characteristics are obtained, the following chemical composition

10 is preferable.

In the following description, “%”, which is a unit of the content of each element, means “% by mass” unless otherwise specified. In addition, a numerical range represented by “to” means a range including numerical values described before and after “to” as a lower limit and an upper limit.

15 [0024]

The electrical steel sheet included in the laminated core according to the present embodiment has a chemical composition in which ferrite-austenite transformation (hereinafter, α-γ transformation) can occur to some extent (chemical composition in which a certain amount of γ is generated when heated even if the entire γ is not

20 transformed), and preferably has a chemical composition including 0.0100% or less of C, 1.50% to 4.00% of Si, 0.0001% to 1.0000% of sol.Al, 0.0100% or less of S, 0.0100% or less of N, 2.50% to 5.00% in total of one or more selected from the group consisting of Mn, Ni, and Cu, 0.000% to 1.000% of Co, 0.000% to 0.400% of Sn, 0.000% to 0.400% of Sb, 0.000% to 0.400% of P, and 0.0000% to 0.0100% in total of one or more selected
25 from the group consisting of Mg, Ca, Sr, Ba, Ce, La, Nd, Pr, Zn, and Cd, by mass as a

chemical composition, and a remainder of Fe and impurities. Furthermore, it is preferable that the contents of Mn, Ni, Cu, Si, sol.Al and P satisfy predetermined conditions described later. Examples of the impurities include impurities contained in raw materials such as ore and scrap, and impurities contained in a manufacturing step.

5 [0025]

(C: 0.0100% or less)

C is an element that increases iron loss or causes magnetic aging by precipitation of fine carbides to inhibit grain growth. Therefore, the lower the C content, the better. Such a phenomenon is remarkable when the C content is more than 0.0100%.

10 Therefore, the C content is preferably set to 0.0100% or less. The C content is more preferably 0.0050% or less, still more preferably 0.0025% or less. The lower limit of the C content is not particularly limited, but the C content is preferably set to 0.0005% or more in consideration of the cost of the decarburization treatment at the time of refining.

[0026]

15 (Si: 1.50% to 4.00%)

Si is an element that increases electric resistance, reduces eddy-current loss, reduces iron loss, or increases a yield ratio to improve punching workability into a core.

When the Si content is less than 1.50%, these effects cannot be sufficiently obtained.

Therefore, in the case of obtaining the above effect, the Si content is preferably set to

20 1.50% or more.

On the other hand, when the Si content is more than 4.00%, the magnetic flux density decreases, punching workability decreases or cold rolling becomes difficult due to an excessive increase in hardness. Therefore, the Si content is preferably set to 4.00% or less.

25 [0027]

(sol.Al: 0.0001% to 1.0000%)

Sol.Al is an element that increases electrical resistance, reduces eddy-current loss, and reduces iron loss. Sol.Al is an element that also contributes to improvement of the relative magnitude of the magnetic flux density B₅₀ with respect to the saturation magnetic flux density. Here, the magnetic flux density B₅₀ is a magnetic flux density in a magnetic field of 5000 A/m. When the content of sol.Al is less than 0.0001%, these effects cannot be sufficiently obtained. Al also has an effect of promoting desulfurization in steelmaking. Therefore, the content of sol.Al is preferably set to 0.0001% or more. The content of sol.Al is more preferably 0.0010% or more, still more preferably 0.1000% or more.

On the other hand, when the content of sol.Al is more than 1.0000%, the magnetic flux density decreases. Therefore, the content of sol.Al is preferably set to 1.0000% or less.

[0028]

15 (S: 0.0100% or less)

S is not an essential element, and is, for example, an element contained in steel as an impurity. S is precipitated as fine MnS and inhibits recrystallization and grain growth in annealing. Therefore, the lower the S content, the better. Such increase in iron loss and decrease in magnetic flux density due to the inhibition of recrystallization and grain growth are remarkable when the S content is more than 0.0100%. Therefore, the S content is preferably set to 0.0100% or less. The lower limit of the S content is not particularly limited, but the S content is preferably set to 0.0003% or more in consideration of the cost of the desulfurization treatment at the time of refining.

[0029]

25 (N: 0.0100% or less)

N is an element that deteriorates magnetic characteristics through formation of fine precipitates such as TiN and AlN. Therefore, the lower the N content, the better. Such deterioration of magnetic characteristics is remarkable when the N content is more than 0.0100%, and thus the N content is preferably set to 0.0100% or less. The lower
5 limit of the N content is not particularly limited, but the N content is preferably set to 0.0010% or more in consideration of the cost of the denitrification treatment at the time of refining.

[0030]

(One or more selected from the group consisting of Mn, Ni, and Cu: 2.50% to
10 5.00% in total)

These elements are necessary for causing α - γ transformation. At least one of these elements is preferably contained at 2.50% or more in total.

On the other hand, when the content of these elements exceeds 5.00% in total, not only does the cost increase but also the magnetic flux density may decrease.

15 Therefore, at least one of these elements is preferably set to 5.00% or less in total.

The amount of each of Mn, Ni, and Cu is not limited, but the Mn content is preferably 1.50% or more from the viewpoint of specific resistance.

[0031]

In addition, α - γ transformation occurs, and the following conditions are further
20 satisfied as conditions for obtaining good magnetic characteristics. That is, when the Mn content (% by mass) is denoted by [Mn], the Ni content (% by mass) is denoted by [Ni], the Cu content (% by mass) is denoted by [Cu], the Si content (% by mass) is denoted by [Si], the sol.Al content (% by mass) is denoted by [sol.Al], and the P content (% by mass) is denoted by [P], the following formula (1) is preferably satisfied.

25
$$(2 \times [\text{Mn}] + 2.5 \times [\text{Ni}] + [\text{Cu}]) - ([\text{Si}] + 2 \times [\text{sol.Al}] + 4 \times [\text{P}]) \geq 1.50\% \quad \cdots (1)$$

When the above-described formula (1) is not satisfied, the α - γ transformation does not occur, or even if the α - γ transformation occurs, the transformation point is high, so that a sufficient magnetic flux density may not be obtained even if the below-described manufacturing method is applied.

5 [0032]

The chemical composition of the electrical steel sheet is based on the fact that the electrical steel sheet contains the above elements and the remainder of Fe and impurities (impurities other than the above), but instead of a part of the remaining Fe, one or more of Co, Sn, Sb, P, Mg, Ca, Sr, Ba, Ce, La, Nd, Pr, Zn, and Cd may be contained in
10 the following ranges. Since these elements are not necessarily contained, the lower limit is 0%. In addition, these elements are not intentionally added and are acceptable even if they are contained as impurities.

[0033]

(Co: 0.000% to 1.000%)

15 Co is an element that increases the magnetic flux density. Therefore, it may be contained as necessary.

On the other hand, when Co is excessively contained, the cost increases. Therefore, the Co content is preferably set to 1.000% or less.

[0034]

20 (Sn: 0.000% to 0.400%, Sb: 0.000% to 0.400%)

Sn and Sb are elements that improve the texture after cold rolling and recrystallization to improve the magnetic flux density. Therefore, these elements may be contained as necessary. In the case of imparting a further effect such as magnetic characteristics, it is preferable to contain one or more selected from the group consisting
25 of 0.020% to 0.400% of Sn and 0.020% to 0.400% of Sb.

On the other hand, when these elements are excessively contained, the steel embrittles. Therefore, the Sn content and the Sb content are both set to 0.400% or less.

[0035]

(P: 0.000% to 0.400%)

5 P is an element effective for ensuring the hardness of the steel sheet after recrystallization. P is also an element having a suitable influence on magnetic characteristics. Thus, it may be contained. In the case of obtaining these effects, the P content is preferably set to 0.020% or more.

On the other hand, when P is excessively contained, the steel embrittles.

10 Therefore, the P content is preferably set to 0.400% or less.

[0036]

(One or more selected from the group consisting of Mg, Ca, Sr, Ba, Ce, La, Nd, Pr, Zn, and Cd: 0.0000% to 0.0100% in total)

Mg, Ca, Sr, Ba, Ce, La, Nd, Pr, Zn, and Cd are elements that react with S in the
15 molten steel during casting of the molten steel and generate a sulfide or an oxysulfide or precipitates of both of them. Hereinafter, Mg, Ca, Sr, Ba, Ce, La, Nd, Pr, Zn, and Cd may be collectively referred to as a “coarse precipitate forming element”. The grain size of the precipitate of the coarse precipitate forming element is about 1 μm to 2 μm, and is much larger than the grain size (about 100 nm) of fine precipitates such as MnS,
20 TiN, and AlN. Therefore, these fine precipitates adhere to the precipitate of the coarse precipitate forming element, and it becomes difficult to inhibit recrystallization and grain growth in annealing such as intermediate annealing. In order to sufficiently obtain these effects, these elements are preferably 0.0005% or more in total. The content is more preferably 0.0010% or more.

25 On the other hand, when the total amount of these elements exceeds 0.0100%,

the total amount of sulfide or oxysulfide or both is excessive, and recrystallization and grain growth in annealing such as intermediate annealing are inhibited. Therefore, the content of the coarse precipitate forming element is preferably set to 0.0100% or less in total.

5 [0037]

The chemical composition may be measured by a general analysis method of steel. For example, the chemical composition may be measured using ICP-AES (Inductively Coupled Plasma-Atomic Emission Spectrometry). Specifically, the chemical composition is specified by measuring a test piece collected from the steel sheet
10 with a predetermined measuring device under a condition based on a calibration curve prepared in advance. C and S may be measured using a combustion-infrared absorption method, and N may be measured using an inert gas fusion-thermal conductivity method.

When the electrical steel sheet has an insulating coating on its surface, the insulating coating may be mechanically removed by polishing, grinder, or the like, and
15 then subjected to analysis.

[0038]

The laminated core according to the present embodiment can obtain the effect as long as it has the above characteristics regardless of the manufacturing method. However, according to the following method, it is preferable because it can be stably
20 manufactured.

(I) An insulating coating forming step of forming an insulating coating having an adhesive ability on a surface of an electrical steel sheet, and

(II) A laminating step of punching an electrical steel sheet on which an insulating coating is formed into a predetermined shape as necessary, then laminating a
25 plurality of the electrical steel sheets, and heating and pressure bonding the electrical

steel sheets to form a laminated core.

Hereinafter, preferred conditions will be described. Known conditions can be applied to conditions that are not described.

[0039]

5 <Insulating coating forming step >

In the insulating coating forming step, an insulating coating having adhesive ability is formed on an electrical steel sheet composed of a base steel sheet. The insulating coating may be formed only on one surface or on both surfaces.

The insulating coating is formed by applying a treatment liquid to the base steel
10 sheet and then performing baking. At the time of baking, the material is heated so that the achieving temperature T_{max} (°C) of the material is less than 200°C and the following formula (4) is satisfied, where T_r (°C) is a curing temperature of the insulating coating, in a unit of °C. In addition, it is preferable that the temperature rising rate be set to 6.0°C/sec or less, and the time t_r at which the material temperature is T_r or more be set to
15 30 to 60 seconds.

$$T_r + 30 \leq T_{max} \leq T_r + 50 \quad (4)$$

[0040]

When the achieving temperature T_{max} (°C) of the material during baking is 200°C or higher, there is a concern that the resin becomes oxidized.

20 In addition, when T_{max} exceeds $T_r + 50^\circ\text{C}$, stress increases due to excessive curing and the magnetic characteristics deteriorate, and when T_{max} is less than $T_r + 30^\circ\text{C}$, the adhesive strength decreases due to insufficient curing.

When the temperature rising rate is more than 6.0°C/sec, curing does not suitably proceed, resulting in insufficient adhesive strength. In general, when the
25 temperature rising rate is lowered, it is considered that it is necessary to increase the

furnace length or reduce the line speed, which is not preferable in terms of equipment restriction and productivity. However, in the laminated core manufacturing method according to the present embodiment, the temperature rising rate is intentionally lowered based on the new finding that the above effect can be obtained by lowering the temperature rising rate.

[0041]

The curing temperature T_r is a temperature at which the logarithmic decrement measured by a rigid body pendulum type physical property tester decreases with curing. When the crosslinked structure is developed as the curing reaction proceeds, the movement of the pendulum is restricted, and the swing cycle of the pendulum rapidly decreases. Therefore, the curing temperature T_r can be determined based on the change in the swing period of the pendulum.

The logarithmic decrement is measured at a temperature rising rate of $10^{\circ}\text{C}/\text{sec}$ by a rigid pendulum test using a rigid pendulum with a cylinder edge according to ISO12013-2. By measuring the logarithmic decrement, the dynamic viscoelasticity of the coating can be evaluated. The logarithmic decrement can be measured using, for example, RPT-3000W manufactured by A & D Company, Limited or a rigid body pendulum type physical property tester equivalent thereto. The measurement temperature range of the logarithmic decrement can be appropriately set, and can be, for example, from room temperature (25°C) to 300°C .

[0042]

Regarding the treatment liquid used for forming an insulating coating having adhesive ability, it is preferable that an acrylic resin having a certain degree of rigidity after curing, capable of securing adhesive strength, and small compressive stress on the steel sheet due to curing be 90 wt% or more of the entire treatment liquid in terms of

solid content. Other components may include a resin, an inorganic salt, and inorganic fine particles. Examples of the resin include an epoxy resin, a urethane resin, and a phenol resin. Examples of the inorganic salt include phosphate, chromate, and borate. Examples of the inorganic fine particles include silicon dioxide, titanium oxide,
5 magnesium oxide, and zirconium hydroxide. However, when the inorganic fine particles are foamable fine particles, air bubbles are generated in the insulating coating, and coating adhesion is deteriorated, so that foamable inorganic fine particles are not used.

From the viewpoint of adhesive strength, the inorganic fine particles are
10 preferably set to 0.05 % by mass or less.

[0043]

The acrylic resin contained in the treatment liquid is not particularly limited. Examples of the monomer used for the acrylic resin include unsaturated carboxylic acids such as acrylic acid and methacrylic acid, and (meth)acrylates such as methyl
15 (meth)acrylate, ethyl (meth)acrylate, n-butyl (meth)acrylate, isobutyl (meth)acrylate, cyclohexyl (meth)acrylate, 2-ethylhexyl (meth)acrylate, 2-hydroxyethyl (meth)acrylate, and hydroxypropyl (meth)acrylate. The (meth)acrylate means acrylate or methacrylate. As the acrylic resin, one kind may be used alone, or two or more kinds may be used in combination.

20 [0044]

<Laminating step>

In the laminating step, the electrical steel sheet on which the insulating coating is formed is punched into a predetermined shape (shape required when applied to stator core, rotor core, etc.) required as necessary, and then bonded through heating and
25 pressure to form a laminated core.

At this time, in order to set the hardness of the insulating coating after forming the laminated core to 200 to 300 MPa, it is preferable to set the conditions in which the press-bonding force is 10 to 60 kgf/cm² and the press-bonding temperature T_p (°C) satisfies the following formula (2).

5
$$T_r + 60 \leq T_p \leq T_r + 100 \quad (2)$$

[0045]

In addition, in a case where A411-011 is 15.0% or more in the laminated electrical steel sheets, a manufacturing method including the following steps can be applied.

10 Hereinafter, in the present embodiment, as the Ar₃ temperature, the Ar₁ temperature, and the Ac₁ temperature (all in a unit of °C), those obtained by the following methods are used.

The Ar₃ temperature and the Ar₁ temperature are determined from a change in thermal expansion of the steel (steel sheet) during cooling at an average cooling rate of 1°C/sec, and the Ac₁ temperature is determined from a change in thermal expansion of the steel (steel sheet) during heating at an average heating rate of 1°C/sec.

[0046]

<Hot rolling step>

In the hot rolling step, hot rolling is performed on a steel satisfying a predetermined chemical composition (preferably the above-described chemical composition) to manufacture a hot rolled steel sheet. The hot rolling step includes a heating process and a rolling process.

[0047]

The steel is, for example, a slab manufactured by normal continuous casting, and the steel having the above-described chemical composition is manufactured by a known

method. For example, molten steel is manufactured in a converter, an electric furnace, or the like. The manufactured molten steel is secondarily refined by degassing equipment or the like to obtain molten steel having the above chemical composition (the chemical composition does not substantially change in the subsequent steps). A slab is
5 cast by a continuous casting method or an ingot-making method using molten steel. Blooming of the cast slab may be performed.

[0048]

In the heating process, it is preferable to heat the steel having the above-described chemical composition to 1000 to 1200°C. Specifically, the steel is charged
10 into a heating furnace or a soaking furnace and heated in the furnace. The holding time at the heating temperature in the heating furnace or the soaking furnace is not particularly limited, and is, for example, 1 to 200 hours.

[0049]

In the rolling process, multi-pass rolling is performed on the steel heated in the
15 heating process to manufacture a hot rolled steel sheet. The “pass” means that the steel sheet passes through one rolling stand having a pair of work rolls and undergoes rolling. The hot rolling may be performed, for example, by performing tandem rolling using a tandem rolling mill including a plurality of rolling stands (each rolling stand has a pair of work rolls) arranged in a line to perform multi-pass rolling, or by performing reverse
20 rolling having a pair of work rolls to perform multi-pass rolling. From the viewpoint of productivity, it is preferable to perform a plurality of rolling passes using a tandem rolling mill.

[0050]

The rolling in the rolling process (rough rolling and finish rolling) is preferably
25 performed at a temperature in the γ region (Ar₃ temperature or higher). That is, it is

preferable to perform hot rolling so that the temperature at the time of passing through the final pass of finish rolling (finish rolling temperature FT (°C)) is equal to or higher than the Ar₃ temperature.

[0051]

5 The finish rolling temperature FT means the surface temperature (°C) of the steel sheet on the rolling stand exit side where the final pass rolling is performed in the rolling process during the hot rolling step. The finish rolling temperature FT can be measured by, for example, a thermometer installed on the rolling stand exit side on which the final pass rolling is performed. The finish rolling temperature FT means, for
10 example, an average value of the measured temperatures of portions excluding one section at the front end and one section at the rear end in a case where the total length of the steel sheet is equally divided into 10 sections in the rolling direction to obtain 10 sections.

[0052]

15 <Cooling step>

 In the cooling step, the steel sheet (hot rolled steel sheet) after the hot rolling step (after completion of finish rolling) is cooled. By transformation from austenite to ferrite by this cooling, moderately fine grains with high strain are obtained. As cooling conditions, it is preferable that cooling be started 0.10 seconds or more after passing
20 through the final pass of finish rolling (after elapse of 0.10 seconds or more), and cooling be performed so that the surface temperature of the hot rolled steel sheet becomes 300°C or more and Ar₁ temperature or less after 3 seconds (rapid cooling is not performed immediately after). In this way, by avoiding rapid cooling immediately after hot rolling, a special rapid cooling device becomes unnecessary, which is also advantageous in terms
25 of manufacture (cost). In addition, the texture of the hot rolled steel sheet becomes a

microstructure in which the non-recrystallized austenite is transformed when being quenched immediately after, and tends to become a texture accumulated in the $\{100\}<011>$ orientation in the microstructure after the final annealing to be performed thereafter. On the other hand, when rapid cooling is not performed immediately after, microstructure which is transformed from the partially recrystallized austenite is generated, and it is presumed that the $\{411\}<011>$ orientation is likely to accumulate in the microstructure after the subsequent final annealing. That is, in order to increase the $\{411\}<011>$ fraction, it is important to transform partially recrystallized austenite, and it is preferable not to immediately perform rapid cooling.

The cooling condition is preferably set such that the average grain size of the hot rolled steel sheet before the cold rolling is 3 to 10 μm . At a suitable grain size, which is not excessively refined, subsequent cold rolling allows the development of α -fibers after intermediate annealing, and the $\{411\}<011>$ orientation, which is normally less likely to develop after skin pass and final annealing, can be developed. On the other hand, when the grains are excessively coarsened, the α fiber is hardly developed after cold rolling and intermediate annealing, and a desired $\{411\}<011>$ fraction may not be obtained.

In order to set the average grain size in the hot rolled steel sheet before cold rolling to 3 to 10 μm , the temperature may be set to the A_{r1} temperature or lower within 3 seconds after passing through the final pass of finish rolling. On the other hand, when the cooling stop temperature is lower than 300°C, there is a concern that the average grain size in the hot rolled steel sheet is excessively refined. Therefore, the cooling stop temperature is preferably set to 300°C or higher.

[0053]

The hot rolled steel sheet temperature (especially the finish rolling temperature) and the surface temperature of the hot rolled steel sheet 3 seconds after passing through

the final pass of the finish rolling are measured by the following method.

In a hot rolling equipment line used for manufacturing an electrical steel sheet, in a case where a cooling device and a conveying line (for example, a conveying roller) are disposed downstream of a hot rolling mill, a thermometer for measuring a surface
5 temperature of a hot rolled steel sheet is disposed on an exit side of a rolling stand for performing a final pass of the hot rolling mill, and a plurality of thermometers is disposed along the conveying line also on the conveying roller disposed downstream of the rolling stand, the hot rolling temperature and the surface temperature of the hot rolled steel sheet 3 seconds after passing through the final pass of the finish rolling may be measured by
10 the thermometer disposed in the hot rolling equipment line.

The cooling is performed using a cooling device disposed downstream of the rolling stand on which the final pass is performed. A plurality of water cooling apparatuses is generally disposed, and a thermometer is disposed on the inlet side of each water-cooling device. The cooling device may be, for example, a well-known water
15 cooling apparatus or a well-known forced air cooling device. Preferably, the cooling device is a water cooling apparatus. The coolant of the water cooling apparatus may be water or a mixed fluid of water and air.

[0054]

<Cold rolling step>

20 In the cold rolling step, the hot rolled steel sheet is subjected to cold rolling to obtain a cold rolled steel sheet. The hot rolled steel sheet is preferably not subjected to hot-band annealing before the cold rolling step in order to develop the α -fiber after cold rolling. The hot-band annealing mentioned here means, for example, a heat treatment in which the heating temperature is A_{c1} temperature or lower and 300°C or higher.

25 The cold rolling may be performed, for example, by performing tandem rolling

using a tandem rolling mill including a plurality of rolling stands (each rolling stand has a pair of work rolls) arranged in a line to perform multi-pass rolling. Alternatively, reverse rolling may be performed by a Sendzimir rolling mill or the like having a pair of work rolls, and rolling may be performed by one-pass rolling or multi-pass rolling.

- 5 From the viewpoint of productivity, it is preferable to perform multi-pass rolling using a tandem rolling mill.

[0055]

- In the cold rolling, the cold rolling is performed without performing the annealing treatment in the middle of the cold rolling. For example, when the reverse
10 rolling is performed and the multi-pass cold rolling is performed, the multi-pass cold rolling is performed without interposing the annealing treatment between the passes of the cold rolling. When annealing is performed between the passes, a desired orientation cannot be developed in a step described later.

- The cold rolling may be performed in only one pass using a reverse type rolling
15 mill. When cold rolling using a tandem type rolling mill is performed, cold rolling is continuously performed in a plurality of passes (passes at each rolling stand).

[0056]

- In the present embodiment, in order to develop the α fiber, it is preferable to set the rolling reduction RR1 (%) in the cold rolling to 75 to 95%. The rolling reduction
20 RR1 is more preferably 78 to 92%. The rolling reduction RR1 is defined as follows.

Rolling reduction RR1 (%) = (1 - sheet thickness after rolling of final pass in cold rolling / sheet thickness before rolling of first pass in cold rolling) $\times$ 100

[0057]

<Intermediate annealing step>

- 25 In the intermediate annealing step, the steel sheet after the cold rolling step (cold

rolled steel sheet) is subjected to intermediate annealing.

In the present embodiment, it is preferable to perform annealing of raising the temperature (heating) to an annealing temperature (intermediate annealing temperature T1) ($^{\circ}\text{C}$) of 600°C to Ac1 temperature or less at a temperature rising rate of $300^{\circ}\text{C}/\text{sec}$ or
5 more.

When the temperature rising rate to the annealing temperature is less than $300^{\circ}\text{C}/\text{sec}$, there is a concern that sufficient recovery does not occur and a desired texture cannot be obtained. The temperature rising rate is preferably $400^{\circ}\text{C}/\text{sec}$ or more. The faster the temperature rising rate, the more preferable it is for the formation of the
10 texture, and in the case of obtaining a temperature rising rate of more than $2000^{\circ}\text{C}/\text{sec}$, the cost is greatly increased because a special device or control is required, and thus the temperature rising rate may be $2000^{\circ}\text{C}/\text{sec}$ or less. More preferably, it is $1000^{\circ}\text{C}/\text{sec}$ or less.

The temperature rising rate is calculated by dividing the temperature change
15 from room temperature (for example, 25°C) to the annealing temperature by the time required for temperature rises.

In addition, when the annealing temperature of the intermediate annealing exceeds the Ac1 temperature, a part of the microstructure of the steel sheet is transformed into austenite, and the $\{411\}<011>$ oriented grains may not sufficiently grow during the
20 subsequent skin pass rolling and final annealing due to the change in crystal orientation accompanying the transformation, and the magnetic flux density may not increase.

On the other hand, if the temperature of the intermediate annealing is too low, recrystallization does not occur, and $\{411\}<011>$ oriented grains do not sufficiently grow during subsequent skin pass rolling and final annealing, and the magnetic flux density
25 may not increase. Therefore, the intermediate annealing temperature T1 ($^{\circ}\text{C}$) is

preferably set to 600°C or higher.

The intermediate annealing temperature T1 (°C) is a sheet temperature (surface temperature) in the vicinity of the extraction port of the annealing furnace.

The holding time at the intermediate annealing temperature T1 (°C) in the
5 intermediate annealing step may be a time well known to those skilled in the art. The holding time at the intermediate annealing temperature T1 (°C) is, for example, 5 to 60 seconds, but is not limited thereto.

In addition, the atmosphere at the time of intermediate annealing is not particularly limited, and for example, an atmosphere gas (drying) containing 20% of H₂
10 by volume percentage and N₂ as the remainder is used. The cooling rate of the steel sheet after the intermediate annealing is not particularly limited, and is, for example, 5.0 to 60.0°C/sec.

[0058]

<Skin pass rolling step>

15 In the skin pass rolling step, the cold rolled steel sheet after the intermediate annealing step is subjected to rolling (cold rolling) at room temperature in the air. For the skin pass rolling, for example, a reverse rolling mill typified by the above-described Sendzimir rolling mill, or a tandem rolling mill are used.

In the skin pass rolling step, rolling is performed without performing an
20 annealing treatment in the middle. For example, when reverse rolling is performed and skin pass rolling is performed in a plurality of passes, the rolling is performed without interposing an annealing treatment between the passes. The skin pass rolling may be performed with only one pass using a reverse type rolling mill. When skin pass rolling using a tandem type rolling mill is performed, rolling is continuously performed in a
25 plurality of passes (passes at each rolling stand).

In the present embodiment, after the strain is introduced into the steel sheet by hot rolling and cold rolling, the strain introduced into the steel sheet is temporarily reduced by intermediate annealing. Then, skin pass rolling is performed. As a result, by performing the intermediate annealing while reducing the strain excessively introduced by the cold rolling in the intermediate annealing, the {111} grains are suppressed from preferentially recrystallizing in the sheet surface of the steel sheet, and the {411}<011> crystal oriented grains remain. Then, an appropriate strain amount is introduced into each grain in the steel sheet in the skin pass rolling, and grain growth by bulging is easily generated in the final annealing of the next step.

The rolling reduction RR2 in the skin pass rolling is preferably set to 10 to 15%. When the rolling reduction RR2 is less than 10%, the strain amount becomes too small, and the final annealing time required for grain growth by bulging becomes long. On the other hand, when the rolling reduction RR2 exceeds 15%, the strain amount becomes too large, normal grain growth occurs instead of bulging, and {411}<148> or {111}<112> grows by final annealing.

[0059]

Here, the rolling reduction RR2 is defined as follows.

Rolling reduction RR2 (%) = $(1 - \text{Sheet thickness after final pass rolling in skin pass rolling} / \text{Sheet thickness before first pass rolling in skin pass rolling}) \times 100$

[0060]

The number of passes in the skin pass rolling may be only one pass (that is, only one rolling is performed) or it may be multi-pass.

The skin pass rolling performed in the present embodiment is significantly different in effect from the skin pass rolling performed after the final annealing. By performing hot rolling, cooling, cold rolling, intermediate annealing, skin pass rolling,

and final annealing in this order under predetermined conditions, a predetermined microstructure can be obtained.

[0061]

<Final annealing step>

5 In the final annealing step, the steel sheet after the skin pass rolling step is annealed by holding the steel sheet at an annealing temperature T_2 (°C) of 750°C or more and A_{c1} temperature or less for 2 hours or more. When the final annealing temperature T_2 (°C) is lower than 750°C, there is a concern that grain growth due to bulging does not sufficiently occur. In this case, the development degree of the
10 {411}<011> orientation decreases.

On the other hand, when the final annealing temperature T_2 (°C) exceeds the A_{c1} temperature, a part of the microstructure of the steel sheet is transformed to austenite, grain growth due to bulging does not occur, and a desired {411}<011> fraction cannot be obtained.

15 In addition, in a case where the annealing time is less than 2 hours, even if the final annealing temperature T_2 (°C) is 750°C or higher and the A_{c1} temperature or lower, grain growth due to bulging does not sufficiently occur, and there is a concern that the development degree of the {411}<011> orientation may decrease.

On the other hand, the annealing time of the final annealing is not particularly
20 limited, and may be 10 hours or less because the effect is saturated even if the annealing time exceeds 10 hours.

[0062]

The temperature rising rate TR_2 to the final annealing temperature T_2 in the final annealing step may be any temperature rising rate known to those skilled in the art.
25 40°C/hour or more and less than 200°C/hour are exemplified, but the present invention is

not limited to this range.

[0063]

The temperature rising rate TR2 is obtained by the following method.

A thermocouple is attached to the steel sheet having the above chemical
5 composition and obtained by performing hot rolling to a skin pass to obtain a sample
steel sheet. The temperature of the sample steel sheet to which the thermocouple is
attached is raised, and the time from the start of the temperature rise until the temperature
reaches the final annealing temperature T2 is measured. The temperature rising rate
TR2 is obtained based on the measured time.

10 [0064]

The atmosphere during the final annealing step is not particularly limited. The
atmosphere at the time of the final annealing step may be, for example, an atmosphere
gas (dry) containing 20% of H₂ by volume percentage and N₂ as the remainder, a 100%
of hydrogen (H₂) atmosphere, or the like. The cooling rate of the steel sheet after final
15 annealing is not particularly limited. The cooling rate is, for example, 5 to 20°C/sec.

[0065]

In the method for manufacturing an electrical steel sheet, for example, shot
blasting and/or pickling may be performed after the cooling step and before the cold
rolling step in the manufacturing step. In the shot blasting, the steel sheet after hot
20 rolling is subjected to shot blasting to break and remove the scale formed on the surface
of the steel sheet after hot rolling. In the pickling, the steel sheet after hot rolling is
subjected to a pickling treatment. In the pickling treatment, for example, a hydrochloric
acid aqueous solution is used as a pickling bath. The scale formed on the surface of the
steel sheet is removed by pickling. After the cooling step and before the cold rolling
25 step, shot blasting may be performed and then pickling may be performed. Further,

after the cooling step and before the cold rolling step, pickling may be performed and shot blasting may not be performed. After the cooling step and before the cold rolling step, shot blasting may be performed, and the pickling treatment may not be performed. Shot blasting and pickling are optional steps. Therefore, both the shot blasting step and
5 the pickling step may not be performed.

[0066]

< Base layer forming step>

In the method for manufacturing an electrical steel sheet according to the present embodiment, a coating (base layer) may be formed on the surface of the steel sheet
10 (electrical steel sheet) after the final annealing by coating after the final annealing step. For example, a coating may be formed by applying and baking a general treatment agent such as a chromic acid-containing treatment agent or a phosphate-containing treatment agent.

Examples

15 [0067]

An ingot having the chemical composition shown in Table 1 was produced by casting molten steel. In Table 1, the left side of formula (1) represents the value of the left side of formula (1) described above. In addition, the coarse precipitate forming element such as Mg represents a total of one or more selected from the group consisting
20 of Mg, Ca, Sr, Ba, Ce, La, Nd, Pr, Zn, and Cd.

The steel sheet No. e was a component system in which α was stable and α - γ transformation did not occur.

This prepared ingot was heated to 1150°C, held for 1 hour, and then subjected to hot rolling to perform finish rolling so that the finish rolling temperature FT was the
25 temperature shown in Table 2.

After completion of hot rolling (after passing through the final pass), the time until the start of cooling was set as shown in Table 2, cooling was performed so that the temperature of the steel sheet after 3 seconds from the start of cooling was the temperature shown in Table 2, and cooling was stopped at that temperature.

5 The hot rolled steel sheet thus obtained was not subjected to hot-band annealing, scale was removed by pickling, and cold rolling was performed at a rolling reduction RR1 shown in Table 2 to obtain a steel sheet having a sheet thickness of 0.30 mm.

 Then, intermediate annealing was performed in which heating was performed to an intermediate annealing temperature T1 shown in Table 2 at a temperature rising rate
10 shown in Table 2 in an atmosphere composed of 20% of hydrogen and 80% of nitrogen in terms of volume percentage, and holding at T1 for 30 seconds.

 The steel sheet after the intermediate annealing was subjected to skin pass rolling at a rolling reduction RR2 shown in Table 2.

 Next, the steel sheet after the skin pass rolling was subjected to final annealing
15 at a temperature rising rate of 100°C/hour and a final annealing temperature T2 shown in Table 1 in an atmosphere of 100% of hydrogen. At this time, the holding time at the final annealing temperature T2 was set to 2 hours.

 After the final annealing, baking was performed under the conditions shown in Table 3 to form an insulating coating on the surface of the steel sheet.

20 [0068]

 From the electrical steel sheet having an insulating coating obtained by the above method, two steel sheets of 30 mm×60 mm were cut out, and the steel sheets were laminated in the sheet thickness direction such that the areas of 10 mm×30 mm overlapped each other.

25 Thereafter, heating and pressure bonding was performed under the conditions

shown in Table 3.

[0069]

For the bonded electrical steel sheet, the thickness, hardness, and weight-average molecular weight of the insulating coating were measured by the above-described method.

[0070]

Separately from the above, two steel sheets of 30 mm×60 mm were cut out from an electrical steel sheet having an insulating coating on the surface, and the steel sheets were laminated in the sheet thickness direction so that the areas of 10 mm×30 mm overlapped each other.

Thereafter, heating and pressure bonding was performed under the conditions shown in Table 3.

[0071]

[Adhesive strength]

The adhesive strength was measured by the following method.

<Analysis device>

Autograph AGS-10kNX

<Measurement conditions>

Tensile form: Shear tensile test

Tensile temperature: 25°C

Tensile speed: 10 mm/min

For the measurement, a tensile test was performed at n = 5 until fracture, and the average value of the maximum strengths until fracture was taken as the adhesive strength.

The results are shown in Table 4.

When the adhesive strength was 10.0 MPa or more, it was determined that sufficient adhesive strength was obtained.

[0072]

In addition, separately from the above, three steel sheets of 55 mm×55 mm were cut out from an electrical steel sheet having an insulating coating on the surface, and two of them were applied with an adhesive and then the steel sheets were laminated in the sheet thickness direction so that all surfaces overlapped each other. Thereafter, heating and pressure bonding was performed under the conditions shown in Table 3.

[0073]

10 [Magnetic characteristics]

The deterioration ratio of the magnetic characteristics of the obtained electrical steel sheet was measured by the following method.

First, an iron loss W10/400 (W/Kg) in the 0° direction and the 90° direction from the rolling direction was measured according to JISC2556 (2015) for one steel sheet different from the two steel sheets overlapped after cutting, and the average value thereof was taken as an iron loss W1 without adhesion.

Thereafter, the iron loss W10/400 (W/Kg) of the bonded electrical steel sheets in the 0° direction and the 90° direction from the rolling direction was measured according to JISC2556 (2015), and the average value thereof was taken as the iron loss W2 after bonding.

From W1 and W2, the iron loss degradation rate Wa (%) was calculated based on the following equation.

$$Wa = (W2 - W1)/W1 \times 100$$

The results are shown in Table 4.

25 When Wa was 10.0% or less, it was determined that deterioration of magnetic

characteristics was suppressed.

[0074]

[Table 1]

Steel sheet No.	Chemical composition (Remainder is Fe and impurities)												Mn + Ni + Cu	Left side of formula (1)
	C	Si	sol.Al	S	N	Mn	Ni	Cu	Co	Sn	Sb	P	Coarse precipitate forming element such as Mg	
	[mass%]	[mass%]	[mass%]	[mass%]	[mass%]	[mass%]	[mass%]	[mass%]	[mass%]	[mass%]	[mass%]	[mass%]	[mass%]	
a	0.0018	2.50	0.0050	0.0018	0.0011	3.00	0.00	0.00	0.000	0.000	0.000	0.020	0.0000	3.00
b	0.0012	2.40	0.1200	0.0015	0.0014	2.80	0.20	0.00	0.000	0.030	0.010	0.010	0.0040	3.00
c	0.0009	2.50	0.8000	0.0008	0.0008	4.00	0.00	0.00	0.000	0.000	0.110	0.100	0.0000	4.00
d	0.0012	2.60	0.5000	0.0015	0.0014	2.60	0.00	0.15	0.000	0.150	0.000	0.000	0.0000	2.75
e	0.0018	2.50	0.3000	0.0018	0.0011	2.00	0.00	0.00	0.000	0.000	0.000	0.020	0.0000	2.00
f	0.0018	2.50	0.0050	0.0018	0.0011	3.00	0.00	0.00	0.000	0.000	0.000	0.020	0.0000	3.00
g	0.0034	2.50	0.0050	0.0018	0.0019	3.00	0.00	0.00	0.000	0.000	0.000	0.020	0.0000	3.00
h	0.0022	3.43	0.0200	0.0042	0.0023	3.70	0.00	0.00	0.000	0.000	0.000	0.006	0.0050	3.70

[0075]

[Table 2]

Steel sheet No.	Transformation point			Hot rolling step	Cooling step		Cold rolling step	Intermediate annealing step		Skin pass rolling step	Final annealing step	Texture
	Ar3 temperature	Ar1	Ac1		Finish rolling temperature FT	Time until start of cooling		Temperature after 3 seconds	Rolling reduction RR1			
	[°C]	[°C]	[°C]	[°C]			[Second]			[°C]	[%]	[°C/ Second]
a	812	779	932	950	0.10	700	88	500	700	15	800	47.9
b	809	777	929	950	0.50	400	88	1200	700	15	800	51.9
c	787	759	908	850	0.12	600	88	300	700	15	800	49.2
d	918	953	1059	950	0.50	400	88	800	700	15	800	49.3
e	-	-	-	950	0.10	700	88	600	700	15	800	8.7
f	812	779	932	650	0.10	550	88	300	700	15	800	12.4
g	812	779	932	950	0.00	200	88	400	700	15	800	14.3
h	805	699	897	950	0.10	500	88	500	700	0	800	12.8

[0076]

[Table 3]

Manufacture No.	Manufacture conditions							
	Steel sheet No.	Composition of the treatment solution for forming insulating coating (Solid content)	Surface roughness of electrical steel sheet Ra (μm)	Curing temperature of insulating coating Tr ($^{\circ}\text{C}$)	Achieving of temperature of material during baking Tmax ($^{\circ}\text{C}$)	Temperature rising rate ($^{\circ}\text{C/s}$)	Time at which material temperature is Tr or more tr (second)	Press-bonding temperature Tp ($^{\circ}\text{C}$)
1	a	Acrylic resin	0.32	122	167	3.2	55	202
2	b	Acrylic resin + 5wt% epoxy resin	0.51	138	173	3.2	48	218
3	c	Acrylic resin + 1wt% AlPO_4	0.47	131	171	3.2	45	211
4	d	Acrylic resin + 0.05wt% MgO	0.61	127	159	3.2	36	207
5	e	Acrylic resin	0.32	122	157	3.2	55	212
6	a	Acrylic resin	0.32	122	212	4.2	55	217
7	b	Acrylic resin	0.32	122	172	1.7	120	202
8	c	Acrylic resin	0.32	122	167	8.5	20	202
9	e	Acrylic resin	0.32	122	132	3.2	55	187
10	f	Acrylic resin	0.32	122	162	3.2	55	187
11	g	Acrylic resin	0.32	122	162	3.2	55	152
12	h	Acrylic resin	0.32	122	162	3.2	55	272
13	a	Epoxy resin + 5wt% acrylic resin	0.32	122	162	3.2	55	202
14	b	Urethane resin	0.32	147	187	3.2	55	227
15	c	Melamine resin	0.32	166	206	3.2	55	246
16	d	Phenolic resin	0.32	193	233	3.2	55	273

[0077]

[Table 4]

Manufacture No.	Adhesive Core						Electrical steel sheet
	Steel sheet No.	Hardness of insulating coating (MPa)	Weight-average molecular weight of insulating coating	Thickness of insulating coating (μm)	Adhesive strength (MPa)	Deterioration ratio of magnetic characteristics (W10/400) Wa (%)	Iron loss (W10/400) W1 (W/Kg)
1	a	236	42070	2.7	14.7	5.4	12.9
2	b	265	31644	1.9	13.5	6.3	13.2
3	c	281	58764	2.1	11.5	8.1	13.4
4	d	225	26108	2.5	12.2	5.2	13.3
5	e	242	48647	2.8	13.8	8.3	14.3
6	a	<u>321</u>	143290	2.7	3.2	12.2	12.9
7	b	<u>311</u>	86731	2.7	8.9	11.1	13.2
8	c	<u>173</u>	5899	2.7	4.7	6.2	13.4
9	e	<u>159</u>	5438	2.7	3.8	5.9	14.3
10	f	<u>188</u>	7536	2.7	4.4	6.8	14.5
11	g	<u>167</u>	6431	2.7	3.1	7.7	13.0
12	h	<u>181</u>	123057	2.7	2.5	7.5	14.3
13	a	<u>328</u>	1191	2.7	13.6	13.3	12.9
14	b	<u>338</u>	5167	2.7	14.3	13.7	13.2
15	c	<u>356</u>	1876	2.7	15.1	14.5	13.4
16	d	<u>372</u>	167841	2.7	14.5	15.7	13.3

[0078]

As can be seen from Tables 1 to 4, in manufacture Nos. 1 to 5, which are examples of the present invention, the composition and manufacture conditions of the electrical steel sheet and the composition and manufacture conditions of the insulating coating were within the scope of the present invention, the hardness of the insulating coating was within the scope of the present invention, the adhesive strength was high, and the deterioration in magnetic characteristics was small.

On the other hand, in manufacture Nos. 6 to 16 of the comparative examples, the predetermined insulating coating was not provided, and the deterioration ratio of the adhesive strength or the magnetic characteristics fell below the target.

Field of Industrial Application

[0079]

According to the present invention, it is possible to provide a laminated core having high adhesive strength and excellent magnetic characteristics. This core can be
5 used for a rotary electric machine or the like, and has high industrial applicability.

Brief Description of the Reference Symbols

[0080]

- 1 Laminated core
- 21 Electrical steel sheet (Base steel sheet)
- 10 22 Insulating coating

Claims

What is claimed is:

[Claim 1]

A laminated core, comprising:

- 5 a plurality of electrical steel sheets laminated on each other; and
- an insulating coating that is provided between the electrical steel sheets adjacent to each other in a laminating direction and bonds the electrical steel sheets to each other, wherein the insulating coating has a hardness of 200 to 300 MPa.

[Claim 2]

- 10 The laminated core according to claim 1, wherein
- a weight-average molecular weight of a sol component of the insulating coating is 10,000 to 100,000.

[Claim 3]

- The laminated core according to claim 1 or 2, wherein
- 15 in the plurality of electrical steel sheets, when an area fraction of grains of the {hkl}<uvw> orientation with respect to a total visual field when a surface parallel to a rolled surface having a depth of 1/2 of a sheet thickness from a surface is measured by SEM-EBSD is expressed as Ahkl-uvw, A411-011 is 15.0% or more.

[Claim 4]

- 20 The laminated core according to claim 3,
- wherein the electrical steel sheet contains:
- 0.0100% or less of C,
- 1.50% to 4.00% of Si,
- 0.0001% to 1.0000% of sol.Al,
- 25 0.0100% or less of S,

0.0100% or less of N,

2.50% to 5.00% in total of one or more selected from the group consisting of

Mn, Ni, and Cu,

0.000% to 1.000% of Co,

5 0.000% to 0.400% of Sn,

0.000% to 0.400% of Sb,

0.000% to 0.400% of P, and

0.0000% to 0.0100% in total of one or more selected from the group consisting

of Mg, Ca, Sr, Ba, Ce, La, Nd, Pr, Zn, and Cd, in terms of % by mass as a chemical

10 composition,

wherein

when a Mn content is denoted by [Mn], a Ni content is denoted by [Ni], a Cu content is denoted by [Cu], a Si content is denoted by [Si], a sol.Al content is denoted by [sol.Al], and a P content is denoted by [P] in terms of % by mass, the following formula

15 (1) is satisfied, and

a remainder is Fe and impurities,

$$(2 \times [\text{Mn}] + 2.5 \times [\text{Ni}] + [\text{Cu}]) - ([\text{Si}] + 2 \times [\text{sol.Al}] + 4 \times [\text{P}]) \geq 1.50\% \quad \cdots (1).$$