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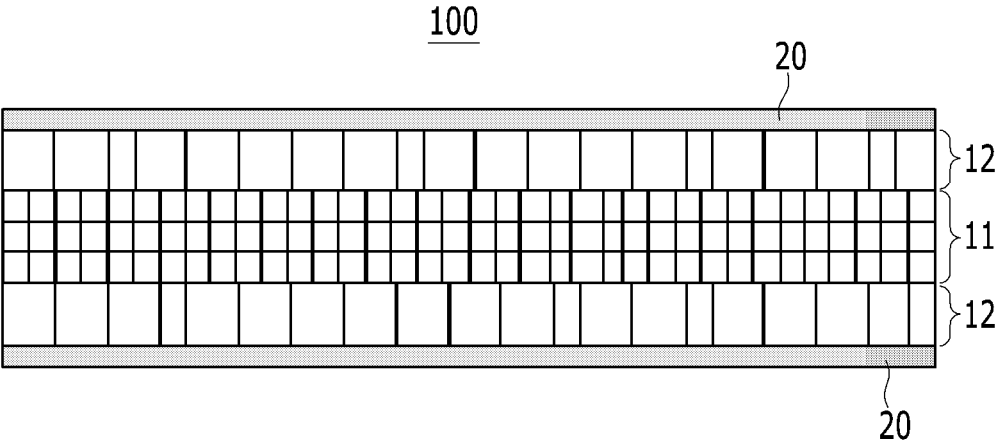
(54) **ELECTRICAL STEEL SHEET FOR ELECTROMAGNETIC SHIELDING AND MANUFACTURING METHOD THEREOF**

(57) An electrical steel sheet for electromagnetic shielding according to one embodiment of the present disclosure includes a steel-sheet substrate and a coating layer disposed on a surface of the steel sheet substrate, wherein among all grains present on a surface of the steel-sheet substrate, grains having a ratio (D2/D1) of an inscribed-circle diameter (D2) to a circumscribed-circle diameter (D1) of 0.5 or greater occupy 70 area% or more, an average grain size in a surface region extending from the surface of the steel-

sheet substrate to less than one-quarter of a thickness of the steel-sheet substrate is 80  $\mu\text{m}$  to 500  $\mu\text{m}$ , and the average grain size in a central region extending from one-quarter to one-half of the thickness of the steel sheet substrate is 50  $\mu\text{m}$  or less, and the coating layer includes 100 parts by weight of a metal phosphate containing one or more of Al, Mg, Co, Ca, Sr, Ba, Zn, and Mn, and 3 to 150 parts by weight, in total, of oxides containing two or more of Al, Si, Mg, and Fe.

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FIG. 1



**Description****[Technical Field]**

5 **[0001]** One embodiment of the present disclosure relates to an electrical steel sheet for electromagnetic shielding and a method for manufacturing the same. Particularly, it relates to an electrical steel sheet for electromagnetic shielding that exhibits excellent electromagnetic shielding performance and possesses insulation, oil resistance, and chemical resistance, as well as a method for manufacturing the same.

10 **[Background Art]**

**[0002]** Underground installation of transmission towers involves either directly burying high-voltage power lines in the ground or constructing underground tunnels, such as utility conduits, to accommodate the power lines, thereby improving urban aesthetics and preventing accidents that may occur due to natural disasters. In the vicinity of such underground power lines, electromagnetic fields that may affect the human body are generated, and aluminum has been used to shield these fields. Although aluminum materials are advantageous for long-term use due to their excellent corrosion resistance, the material must be applied in a relatively large thickness in order to achieve a sufficient shielding rate. Such thick aluminum materials make installation difficult and increase a cost of shielding underground power lines due to a large amount of material required.

20 **[0003]** To address the issues, it has been proposed to apply a steel material, which is relatively less expensive than aluminum. To secure excellent magnetic-field shielding performance in steel materials, the contents of interstitial elements and precipitate-forming elements are limited. This is because strain generated by interstitial elements and precipitates formed in the steel significantly reduce permeability, and therefore a method of limiting these elements has been proposed. In addition to limiting the compositional elements, a size of the precipitates is also restricted to obtain excellent magnetic flux density. However, in the case of shielding electromagnetic waves generated under low magnetic fields, excellent shielding performance may be secured only when both effects of compositional elements and grain-size control are simultaneously applied, and therefore additional microstructural control is required. In addition, because steel materials used for electromagnetic-wave shielding are often installed underground and thus exposed to soil-corrosion environments, and because electromagnetic shielding performance must be secured along the vicinity of transmission and distribution lines, high formability and installability of the material are required. Accordingly, for steel materials used for electromagnetic shielding, an excellent corrosion-resistant surface treatment is required in environments such as soil, and superior formability of the material is also necessary; however, shielding materials that satisfy these requirements are virtually unavailable.

35 **[Disclosure]****[Technical Problem]**

40 **[0004]** One embodiment of the present disclosure provides an electrical steel sheet for electromagnetic shielding and a method for manufacturing the same. Particularly, it provides an electrical steel sheet for electromagnetic shielding that exhibits excellent electromagnetic shielding performance and possesses insulation, oil resistance, and chemical resistance, as well as a method for manufacturing the same.

**[Technical Solution]**

45 **[0005]** An electrical steel sheet for electromagnetic shielding according to one embodiment of the present disclosure includes a steel-sheet substrate and a coating layer disposed on a surface of the steel sheet substrate, wherein among all grains present on a surface of the steel-sheet substrate, grains having a ratio ( $D2/D1$ ) of an inscribed-circle diameter ( $D2$ ) to a circumscribed-circle diameter ( $D1$ ) of 0.5 or greater occupy 70 area% or more, an average grain size in a surface region extending from the surface of the steel-sheet substrate to less than one-quarter of a thickness of the steel-sheet substrate is 80  $\mu\text{m}$  to 500  $\mu\text{m}$ , and the average grain size in a central region extending from one-quarter to one-half of the thickness of the steel sheet substrate is 50  $\mu\text{m}$  or less, and the coating layer includes 100 parts by weight of a metal phosphate containing one or more of Al, Mg, Co, Ca, Sr, Ba, Zn, and Mn, and 3 to 150 parts by weight, in total, of oxides containing two or more of Al, Si, Mg, and Fe.

55 **[0006]** A ratio of an area fraction of grains having a  $\langle 111 \rangle$  orientation within  $15^\circ$  of being parallel to a rolling direction of the steel sheet to an area fraction of grains having a  $\langle 110 \rangle$  orientation within  $15^\circ$  of being parallel to the rolling direction of the steel sheet may be 3 or greater.

**[0007]** A ratio of the average grain size in the surface region to the average grain size in the central region

(surface/center) may be 2.0 or greater.

**[0008]** The steel-sheet substrate may contain, in weight percent, Si: 0.3% to 7.0%, C: 0.15% or less (excluding 0%), and a balance is Fe and unavoidable impurities.

**[0009]** The steel-sheet substrate may further contain Mn: 0.1 wt% or less and S: 0.005 wt% or less.

**[0010]** The coating layer may further contain 50 to 250 parts by weight of silica.

**[0011]** The coating layer may further contain 2 to 10 parts by weight of chromium oxide.

**[0012]** A manufacturing method for an electrical steel sheet for electromagnetic shielding according to an embodiment of the present disclosure includes: hot-rolling a slab to produce a hot-rolled steel sheet; annealing the hot-rolled steel sheet; cold-rolling the annealed hot-rolled steel sheet; decarburization-annealing the cold-rolled steel sheet; and forming a coating layer by applying, to a surface of the decarburization-annealed steel sheet, a coating-forming composition containing, as solid content, 100 parts by weight of a metal phosphate including one or more of Al, Mg, Co, Ca, Sr, Ba, Zn, and Mn, and 3 to 150 parts by weight, in total, of oxides including two or more of Al, Si, Mg, and Fe.

**[0013]**  $\tau$  defined by Equation 1 below is 0.23 to 0.5.

[Equation 1]

$\tau$

$$= \left( \frac{\text{finishing rolling temperature} + 273}{\text{ROT cooling rate} \times \text{hot - band thickness} \times 10^4} \right) \cdot \left( \frac{2.54 \times (\text{dew point temperature} + 273) \times (\text{annealing temperature} + 273)}{\text{hot - band thickness} \times 10^4} \right)$$

(In Equation 1, a finishing rolling temperature refers to the finishing rolling temperature (°C) during hot rolling, an ROT cooling rate refers to the cooling rate (-°C/s) in an ROT section from completion of finishing rolling to before coiling, a hot-rolled sheet thickness refers to a thickness (mm) of the hot-rolled steel sheet, a dew-point temperature refers to a dew-point temperature (°C) of the atmosphere during the decarburization-annealing, an annealing temperature refers to an annealing temperature (°C) during the decarburization-annealing, and a cold-rolled sheet thickness refers to a thickness (mm) of the steel sheet after first cold rolling.)

**[0014]** The slab may contain, in weight percent, Si: 0.3% to 7.0%, C: 0.01% to 0.4%, and a balance is Fe and unavoidable impurities.

**[0015]** The slab may further contain, in weight percent, Mn: 0.1% or less and S: 0.005% or less.

**[0016]** The annealing of the hot-rolled steel sheet may include a decarburization process.

**[0017]** The annealing of the hot-rolled steel sheet may be performed at a temperature of 850°C to 1000°C and at a dew-point temperature of 70°C or lower.

**[0018]** The decarburization-annealing may be performed at a temperature of 600°C to 1000°C and at a dew-point temperature of 0°C to 70°C.

**[0019]** The coating-forming composition may further contain 50 to 250 parts by weight of silica

**[0020]** The coating-forming composition may further contain 2 to 10 parts by weight of chromium oxide.

[Advantageous Effects]

**[0021]** According to one embodiment of the present disclosure, both electromagnetic-wave shielding performance and corrosion resistance are excellent.

**[0022]** According to one embodiment of the present disclosure, an electrical steel sheet for electromagnetic shielding having excellent workability may be provided.

**[0023]** In addition, the steel sheet may be manufactured through a continuous process, whereby the manufacturing time may be relatively shortened and productivity may be improved.

[Description of the Drawings]

**[0024]**

FIG. 1 is a schematic diagram illustrating a cross-section of an electromagnetic-shielding steel sheet according to one embodiment of the present disclosure.

FIG. 2 is a schematic diagram illustrating one example of use of an electromagnetic-shielding steel sheet according to one embodiment of the present disclosure.

FIG. 3 is a photograph showing a surface of a substrate of the electromagnetic-shielding steel sheet manufactured in Example 1, as analyzed by EBSD.

FIG. 4 is a photograph showing a cross-section of the electromagnetic-shielding steel sheet manufactured in Example 1, as observed by SEM.

#### [Mode for Invention]

**[0025]** 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 component, constituent element, or section described below may be referred to as a second component, constituent element, or section, without departing from the range of the present disclosure

**[0026]** The terminologies used herein are used just to illustrate a specific exemplary embodiment, but are not intended to limit the present invention. It must be noted that, as used in the specification and the appended claims, singular forms used herein include plural forms unless the context clearly dictates the contrary. It will be further understood that the term "comprises" or "includes", used in this specification, specifies stated properties, regions, integers, steps, operations, elements, and/or components, but does not preclude the presence or addition of other properties, regions, integers, steps, operations, elements, components, and/or groups.

**[0027]** When referring to a part as being "on" or "above" another part, it may be positioned directly on or above the other part, or another part may be interposed therebetween. In contrast, when referring to a part being "directly above" another part, no other part is interposed therebetween.

**[0028]** Unless defined otherwise, all terms including technical and scientific terms used herein have the same meanings as those commonly understood by one of ordinary skill in the art to which the present invention belongs. Such terms as those defined in a generally used dictionary are to be interpreted to have the same meanings as 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.

**[0029]** In addition, unless otherwise specified, "%" refers to weight percent, and 1 ppm corresponds to 0.0001 wt%.

**[0030]** In one embodiment of the present disclosure, the expression that an additional element is further included means that an amount of the additional element replaces a corresponding amount of the balance iron (Fe).

**[0031]** The present disclosure will be described more fully hereinafter, in which an embodiment of the disclosure are shown. As those skilled in the art would realize, the described embodiments may be modified in various different ways, all without departing from the spirit or scope of the present disclosure.

**[0032]** FIG. 1 is a schematic diagram illustrating a cross-section of an electromagnetic-shielding electrical steel sheet according to one embodiment of the present disclosure.

**[0033]** As shown in FIG. 1, an electromagnetic-shielding electrical steel sheet 100 according to one embodiment of the present disclosure includes a steel-sheet substrate 10 and a coating layer 20 disposed on a surface of the substrate, wherein 70 area% or more of all grains present on the substrate surface have a ratio ( $D2/D1$ ) of a diameter  $D2$  of an inscribed circle to a diameter  $D1$  of a circumscribed circle of 0.5 or greater, an average grain size in a surface region 12 extending from the substrate surface to less than one-quarter of the substrate thickness is 80  $\mu\text{m}$  to 500  $\mu\text{m}$ , and the average grain size in a central region 11 extending from one-quarter to one-half of a substrate thickness is 50  $\mu\text{m}$  or less.

**[0034]** The coating layer 20 includes 100 parts by weight of a metal phosphate containing one or more selected from Al, Mg, Co, Ca, Sr, Ba, Zn, and Mn, and 3 to 150 parts by weight, in total, of oxides containing two or more selected from Al, Si, Mg, and Fe.

**[0035]** Hereinafter, each constituent of the electromagnetic-shielding electrical steel sheet according to one embodiment of the present disclosure will be described in detail.

**[0036]** First, the steel-sheet substrate 10 contains, in weight percent, 0.3% to 7.0% of Si, 0.15% or less of C (excluding 0%), and a balance Fe and unavoidable impurities.

Si: 0.3 to 7.0 wt%

**[0037]** Silicon (Si) improves electromagnetic-shielding performance of a material in a low magnetic-field region. If a Si content is too low, the material may have difficulty absorbing external magnetic fields in low magnetic-field regions. If the Si content is excessively high, an amount of impurities in the material may increase, which leads to a reduction in shielding performance due to a decrease in saturation magnetic flux density. More specifically, the Si content may be 0.5 to 4.0 wt%.

C: 0.15 wt% or less

**[0038]** Carbon (C) may be 0.010 to 0.400 wt%, because during intermediate decarburization annealing and final decarburization annealing, carbon in a central region must diffuse toward a surface region to allow Goss grains in a surface layer to grow and spread toward a center. More specifically, a C content in a slab may be 0.100 to 0.300 wt%. In addition, after completion of the decarburization-annealing, a carbon content in the steel sheet may be 0.150 wt% or less. More specifically, the carbon content may be 0.100 wt% or less. More specifically, it may be 0.050 wt% or less.

**[0039]** The steel-sheet substrate 10 may further contain 0.1 wt% or less of Mn and 0.005 wt% or less of S.

**[0040]** Mn and S form MnS precipitates, which hinder a growth of Goss grains diffusing toward the central region during the decarburization process. Accordingly, it is preferable that Mn and S are not added. However, in consideration of amounts unavoidably introduced during a steelmaking process, Mn and S contents in the slab and in the steel sheet after a non-oxidizing annealing operation may be controlled to 0.1 wt% or less of Mn and 0.005 wt% or less of S, respectively.

**[0041]** The balance includes Fe and unavoidable impurities. The unavoidable impurities are those introduced during a steelmaking operation and manufacturing processes of the electrical steel sheet, and since such impurities are well known in the art, a detailed description thereof is omitted. Specifically, elements such as Al, N, Ti, Mg, and Ca react with oxygen in the steel to form oxides, and thus it is necessary to strongly suppress their presence; accordingly, each of these elements may be controlled to 0.005 wt% or less. In an embodiment of the present disclosure, the addition of elements other than the above-described alloying components is not excluded, and various additional elements may be included insofar as they do not impair the technical spirit of the present disclosure. When additional elements are included, they replace a portion of the balance Fe.

**[0042]** On the surface of the steel-sheet substrate 10, grains having a ratio ( $D2/D1$ ) of 0.5 or more between the diameter ( $D1$ ) of the circumscribed circle and the diameter ( $D2$ ) of the inscribed circle among all grains may account for 70 area% or more. This is because, as will be described later in connection with the manufacturing process, the decarburization annealing was performed for a short duration. When batch annealing is performed for a prolonged period of 1 hour or more after the decarburization annealing, the diameter ( $D1$ ) of the circumscribed circle becomes significantly larger than the diameter ( $D2$ ) of the inscribed circle, and therefore the ratio ( $D2/D1$ ) may not reach 0.5 or more. Herein, the circumscribed circle refers to a smallest imaginary circle that encloses the grain, and the inscribed circle refers to a largest imaginary circle that is contained within the grain. More specifically, among all grains, those having a ratio ( $D2/D1$ ) of 0.5 or more between the diameter ( $D1$ ) of the circumscribed circle and the diameter ( $D2$ ) of the inscribed circle may account for 75 to 95 area%. More specifically, among all grains, those having a ratio ( $D2/D1$ ) of 0.5 or more between the diameter ( $D1$ ) of the circumscribed circle and the diameter ( $D2$ ) of the inscribed circle may account for 75% to 90 area%. Such grains respond to an external magnetic field, particularly in a low-field region, and contribute to electromagnetic shielding by functioning as sites that absorb the magnetic field. Grains having a ratio ( $D2/D1$ ) of 0.5 or more between the diameter ( $D1$ ) of the circumscribed circle and the diameter ( $D2$ ) of the inscribed circle among all grains may be analyzed by observing the surface (ND surface) of the steel-sheet substrate 10 with an optical microscope and then analyzing the obtained images using a computer program. When a coating layer 20 is present on the steel-sheet substrate 10, the coating layer 20 may be appropriately removed, and the surface of the steel-sheet substrate 10 may then be analyzed.

**[0043]** In an embodiment of the present disclosure, the average grain size in the surface region 12, which extends from the surface of the steel-sheet substrate 10 to less than one-quarter of the sheet thickness in the thickness direction, is 80  $\mu\text{m}$  to 500  $\mu\text{m}$ , and the average grain size in the central region 11, which extends from one-quarter to one-half of the sheet thickness, is 50  $\mu\text{m}$  or less. In this manner, by forming different grain sizes in the surface region 12 and the central region 11 of the steel-sheet substrate 10, the grains in the surface region may respond to and absorb an external magnetic field, thereby contributing to electromagnetic shielding. If the average grain size in the surface region 12 is too small, an ability of the material to absorb an external magnetic field may be reduced, which leads to a deterioration in electromagnetic-shielding performance. If the average grain size in the surface region 12 is excessively large, an interfacial contact area during coating may decrease, which results in reduced adhesion. If the average grain size in the central region 11 is excessively large, an ability of the material to respond to and absorb an external magnetic field may be reduced, which lead to a deterioration in electromagnetic-shielding performance. More specifically, an average grain size in the surface region 12 may be 10  $\mu\text{m}$  to 400  $\mu\text{m}$ , and an average crystal particle diameter in the central region 11 may be 15  $\mu\text{m}$  to 47  $\mu\text{m}$ . The average grain size may be determined by measuring a number of grains within a measurement area on a cross-section including a thickness direction of the steel sheet, and then dividing the measurement area by the number of grains to obtain an average grain area. The grain size may be determined as a diameter of a circle having the same area as the grain.

**[0044]** A ratio of the average grain size in the surface region to the average grain size in the central region (surface/center) may be 2.0 or greater. If this ratio is too small, the ability of the material to respond to an external magnetic field may be reduced, which results in inferior electromagnetic-shielding properties. More specifically, the

ratio of the average grain size in the surface region to the average grain size in the central region (surface/central) may be 3.0 to 20.0.

[0045] A ratio of the area fraction of grains having a <110> orientation parallel to the rolling direction of the steel sheet within 15° to the area fraction of grains having a <111> orientation parallel to the rolling direction within 15° (<110>//ND / <111>//ND) may be 3.0 or more. When this ratio is high, a permeability in the low magnetic-field region may be increased, thereby contributing to electromagnetic shielding. More specifically, the <110>//ND / <111>//ND ratio in the steel-sheet substrate may be 3.3 to 6.5. This may be measured using an electron backscatter diffraction (EBSD) analyzer.

[0046] Accordingly, by appropriately adjusting the steel composition of the steel-sheet substrate 10 and properly forming the texture, excellent electromagnetic-shielding performance may be achieved. Specifically, shielding effectiveness may be 50% or more under a 60 Hz, 100 mG magnetic field, and may be 65% or more under a 60 Hz, 1 G magnetic field. More specifically, the shielding effectiveness may be 50.0% to 75.0% under a 60 Hz, 100 mG magnetic field, and may be 70.0% to 85.0% under a 60 Hz, 1 G magnetic field.

[0047] In this case, the shielding effectiveness may be measured by generating a magnetic field of 1 G or less using a Helmholtz coil method and installing a pickup coil at the center of the generated magnetic field to measure the magnetic field. A shielding material may be used to shield the pickup coil, and the magnetic-field intensities measured before and after shielding are obtained, after which the shielding effectiveness is calculated as described below. The pickup coil may be shielded by wrapping the coil in a cylindrical form or by shielding four sides in a box-shaped structure.

$$\text{Shielding effectiveness (\%)} = (1 - B_{\text{shielded}} / B_{\text{unshielded}}) \times 100$$

[0048] The coating layer 20 includes 100 parts by weight of a metal phosphate containing one or more selected from Al, Mg, Co, Ca, Sr, Ba, Zn, and Mn, and 3 to 150 parts by weight, in total, of oxides containing two or more selected from Al, Si, Mg, and Fe.

[0049] Hereinafter, each component of the coating layer 20 will be described in detail. In one embodiment of the present disclosure, the parts by weight refer to relative weight ratios based on 100 parts by weight of a metal phosphate, and are defined on the basis of a solid content of each component. The term "solid content" refers to a weight of each component after being dried so that no solvent or other volatile matter remains. Specifically, assuming a heat-treatment process during formation of the coating layer 20, the solid content refers to the weight remaining after a heat treatment. When a coating-layer-forming composition is heat-treated, each component may remain in the coating layer 20 in proportion to its solid content within the composition.

[0050] A metal phosphate serves as a binder in the coating-layer-forming composition. If an appropriate amount of the metal phosphate is not included, adhesion of the coating layer 20 may be degraded, or sufficient corrosion resistance may not be obtained.

[0051] The metal phosphate may be produced through a manufacturing process in which a metal oxide is added to pure phosphoric acid ( $\text{H}_3\text{PO}_4$ ) and allowed to react. To improve the adhesion of the metal phosphate, boric acid may be additionally added during the reaction process and maintained for 3 hours or more to induce a condensation reaction between the metal phosphate and the boric acid, and a resulting condensation product may be used in place of the metal phosphate. In one embodiment of the present disclosure, the term "metal phosphate" includes not only the metal phosphate itself but also the condensation reaction product of the metal phosphate and boric acid. The metal phosphate thus produced exhibits strong acidity.

[0052] The metal phosphate may be added to the composition in the form of a solution having a solid content of 50 to 70 wt%. In this case, if the solid content in the solution is too low, an amount of free phosphoric acid in the metal phosphate may increase and may cause moisture absorption on the surface after the metal phosphate is produced, whereas if the solid content is too high, an excess of solids relative to pure phosphoric acid may result in poor reaction and precipitation.

[0053] The metal phosphate and the metal oxide may include various metals without limitation. Specifically, the metal of the metal phosphate and the metal oxide may include one or more selected from Al, Mg, Co, Ca, Sr, Ba, Zn, and Mn. More specifically, the metal phosphate may include one or more selected from magnesium dihydrogen phosphate ( $\text{Mg}(\text{H}_2\text{PO}_4)_2$ ) and aluminum dihydrogen phosphate ( $\text{Al}(\text{H}_2\text{PO}_4)_3$ ). More specifically, it may include magnesium dihydrogen phosphate ( $\text{Mg}(\text{H}_2\text{PO}_4)_2$ ) and aluminum dihydrogen phosphate ( $\text{Al}(\text{H}_2\text{PO}_4)_3$ ). In this case, the metal phosphate may include 10 to 40 parts by weight of aluminum dihydrogen phosphate and 60 to 90 parts by weight of magnesium dihydrogen phosphate, based on 100 parts by weight of the total metal phosphate in the coating layer 20. If an amount of aluminum dihydrogen phosphate is too low, a tensile-strength-enhancing effect provided by the addition of aluminum dihydrogen phosphate may be insufficient. If an excessive amount of aluminum dihydrogen phosphate is added, an Al component may increase the crystallization of silica, which causes cracking in the insulating

coating layer. Specifically, the metal phosphate may include, on a solids basis, 15 to 35 parts by weight of aluminum dihydrogen phosphate and 65 to 85 parts by weight of magnesium dihydrogen phosphate, based on 100 parts by weight of the total metal phosphate, and more specifically, may include 20 to 30 parts by weight of aluminum dihydrogen phosphate and 70 to 80 parts by weight of magnesium dihydrogen phosphate.

**[0054]** In one embodiment of the present disclosure, the coating layer 20 includes, relative to 100 parts by weight of the metal phosphate, 3 to 150 parts by weight of an oxide including two or more selected from Al, Si, Mg, and Fe. The oxide is added to improve electromagnetic shielding properties and corrosion resistance of the coating layer 20. If an amount of the oxide is too low, the electromagnetic shielding properties and corrosion resistance may be significantly degraded. If the amount of the oxide is excessively high, a solid fraction of the composition may increase, which may cause agglomeration and sedimentation among the oxides, and may also form voids at the oxide interfaces after film formation, thereby significantly deteriorating the insulating properties and corrosion resistance. Accordingly, specifically, 10 to 150 parts by weight of the oxide may be included relative to 100 parts by weight of the metal phosphate. More specifically, 15 to 80 parts by weight of the oxide may be included relative to 100 parts by weight of the metal phosphate.

**[0055]** An oxide including two or more selected from Al, Si, Mg, and Fe may include one or more selected from montmorillonite, kaolinite, illite, talc, and chlorite. More specifically, it may include montmorillonite ( $Mx(Al_{4-x}Mg_x)Si_8O_{20}(OH)_4$ ). The oxide including two or more selected from Al, Si, Mg, and Fe has an advantage in improving corrosion resistance compared to a single oxide (e.g.,  $Al_2O_3$ ).

**[0056]** The oxide including two or more selected from Al, Si, Mg, and Fe may have an average particle size of 102 nm to 105 nm. If an average particle size of the oxide is too small, it becomes difficult for the particles to be uniformly dispersed in the solution due to electrostatic attraction between the particles, and conversely, if the average particle size is too large, rapid sedimentation may occur in the solution, making it difficult for the composition to exhibit adequate performance. The average particle size may be measured by dispersing particles in a solution and using a laser scattering method.

**[0057]** The oxide in which two or more of Al, Si, Mg, and Fe are present in combination has an important compositional ratio, and, based on 100% by weight of the total amount of Al, Si, Mg, and Fe in the oxide particles, may include 15 to 45 wt% of Al, 40 to 70 wt% of Si, 0.1 to 5 wt% of Mg, and 1 to 10 wt% of Fe. A reason for limiting major components in the oxide as described above is that, if the amount of Al in the oxide particles is too low, the corrosion-resistance effect may not be achieved, whereas if the amount of Al is too high, the electrical conductivity increases, resulting in a decrease in insulating properties of the coating layer. If an amount of Si in the particles is too low, the corrosion-resistance effect may not be achieved, whereas if the amount of Si is too high, a hardness of the coating layer increases, which significantly deteriorates workability of the substrate. If an amount of Mg is too low, the affinity between water in the coating solution and the oxide decreases, resulting in poor dispersion of the oxide in the coating solution, and conversely, if the amount of Mg is too high, a corrosion-resistance effect may not be achieved. In addition, if an amount of Fe is too low, heat-resistance of the coating layer after coating-layer formation deteriorates, whereas if the amount of Fe is too high, specific gravity of the oxide increases, accelerating sedimentation of the oxide and thereby reducing corrosion resistance of the coating layer. More specifically, based on 100% by weight of the total amount of Al, Si, Mg, and Fe in the oxide particles, the oxide may include 20 to 40 wt% of Al, 45 to 65 wt% of Si, 0.5 to 3 wt% of Mg, and 3 to 7 wt% of Fe. The oxide may additionally include Ca and K.

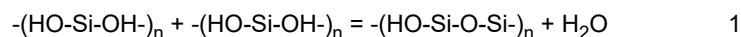
**[0058]** The coating layer 20 may further include 50 to 250 parts by weight of silica.

**[0059]** Silica increases strength and hardness of the coating layer during drying after coating through an internal molecular network reaction, and thereby further enhances the corrosion resistance provided by the coating layer 20. Various types of silica may be used without limitation, and commercially available colloidal silica may also be employed. More specifically, basic colloidal silica may be used.

**[0060]** Silica may be included in an amount of 50 to 250 parts by weight based on 100 parts by weight of the metal phosphate. If the amount of silica added is too low, corrosion-resistance improvement resulting from the addition of silica may not be sufficiently achieved. If too much silica is added, a relative amount of the metal phosphate may decrease, which degrades the adhesion of the insulating coating layer. Specifically, silica may be included in an amount of 100 to 200 parts by weight based on 100 parts by weight of the metal phosphate, and more specifically, may be included in an amount of 125 to 175 parts by weight based on 100 parts by weight of the metal phosphate. In this context, "parts by weight" refers to a relative weight based on the metal phosphate.

**[0061]** During a drying process of the coating layer, silica undergoes a condensation reaction through a chain reaction as shown in Reaction Scheme 1, thereby forming a network structure such as  $-(HO-Si-O-Si)-_n$ .

[Reaction Scheme 1]



**[0062]** However, when silica alone is used, an excessively uniform network structure is formed, which limits densifi-

cation of the coating layer. Accordingly, there are limitations in providing adhesion and corrosion resistance between the electrical steel substrate and the insulating coating layer, and to compensate for such insufficient properties, metal phosphate or a combination of metal phosphate and chromium oxide may be supplemented.

**[0063]** The silica may be colloidal silica having an average particle size in the range of 7 to 20 nm. The silica may be used in the form of a solution having a solid content of 25 to 35 wt% to prepare the composition. If the solid content is too low, a decrease in insulating performance may occur. If the solid content is too high, problems such as reduced miscibility of the coating composition may occur after preparation. More specifically, the solid content may be in the range of 28 to 32 wt%.

**[0064]** The silica may have a Na<sup>+</sup> content in the range of 0.1 to 1.0 wt%. If the Na<sup>+</sup> content is too low, problems such as reduced densification of the coating layer may occur. If the Na<sup>+</sup> content is too high, an increase in cations within the coating composition may hinder miscibility among the components. More specifically, the Na<sup>+</sup> content may be in the range of 0.3 to 0.7 wt%.

**[0065]** A silica-containing silica solution may have a pH in the range of 9.5 to 10.5. If the pH is too low or too high, a severe pH difference between silica and the other components in the coating composition may cause phase separation. More specifically, the pH may be in the range of 9.5 to 10.0.

**[0066]** The silica may have a viscosity in the range of 3.5 to 6.5 cp. If the viscosity is too low, problems may arise in coatability of the coating composition. If the viscosity is too high, thickening may occur during long-term use, leading to aging-related issues. More specifically, the viscosity may be in the range of 4 to 6 cp. The viscosity may be measured using a Brookfield viscometer at 20 °C based on a 30 wt% silica solution.

**[0067]** The silica may have a specific gravity in the range of 1.1 to 1.3. If the specific gravity is too low, it may become difficult to control a coating amount of the coating composition. If the specific gravity is too high, sedimentation issues may occur after preparation of the coating composition. More specifically, the specific gravity may be in the range of 1.15 to 1.25.

**[0068]** Chromium oxide may be additionally incorporated to enhance corrosion resistance of the coating layer. When chromium oxide is additionally included, it may be present in an amount of 2 to 10 parts by weight based on 100 parts by weight of the metal phosphate. If the amount of chromium oxide is too small, an effect of enhancing corrosion resistance may be insufficient, and it may also be difficult for the subsequently described silica to properly perform its neutralizing function. If an excessive amount of chromium oxide is included, viscosity of the coating composition may increase sharply, causing processing issues. Specifically, chromium oxide may be included in an amount of 2 to 8 parts by weight based on 100 parts by weight of the metal phosphate, and more specifically, chromium oxide may be included in an amount of 4 to 6 parts by weight based on 100 parts by weight of the metal phosphate.

**[0069]** Although the coating layer 20 does not contain a solvent because the solvent is removed during a coating-forming process, the coating-forming composition may further contain a solvent. The solvent serves to facilitate application of the composition and to uniformly disperse the components. An amount of the solvent is not particularly limited, but it may be included in an amount of 100 to 1000 parts by weight based on 100 parts by weight of the metal phosphate.

**[0070]** A thickness of the coating layer 20 may be in the range of 1 to 50 μm. If the thickness of the coating layer 20 is too small, it may be difficult to obtain sufficient corrosion resistance. Even if the thickness of the coating layer 20 is increased, corrosion resistance is not further enhanced, and excessive coating thickness may instead cause cracking of the coating layer. More specifically, the thickness of the coating film 20 may be 3 to 30 μm.

**[0071]** FIG. 2 illustrates one example of using an electrical steel sheet for electromagnetic shielding according to an embodiment of the present disclosure. As shown in FIG. 2, the electrical steel sheet 100 for electromagnetic shielding may be wound into a cylindrical or tubular shape and installed so as to surround a power transmission line 200. Alternatively, in an underground conduit that surrounds the power transmission line 200, the electrical steel sheet 100 for electromagnetic shielding may be inserted between the power transmission line 200 and the underground conduit, or the electrical steel sheet 100 may be installed so as to surround the underground conduit.

**[0072]** A manufacturing method for an electrical steel sheet for electromagnetic shielding according to an embodiment of the present disclosure includes: hot-rolling a slab to produce a hot-rolled steel sheet; annealing the hot-rolled steel sheet; cold-rolling the annealed hot-rolled steel sheet; decarburization-annealing the cold-rolled steel sheet; and forming a coating layer by applying, to a surface of the decarburization-annealed steel sheet, a coating-forming composition containing, as solid content, 100 parts by weight of a metal phosphate including one or more of Al, Mg, Co, Ca, Sr, Ba, Zn, and Mn, and 3 to 150 parts by weight, in total, of oxides including two or more of Al, Si, Mg, and Fe.

**[0073]** Hereinafter, each operation will be described in detail.

**[0074]** First, a slab is hot-rolled.

**[0075]** The slab may contain, in weight percent, Si: 0.3% to 7.0%, C: 0.01% to 0.4%, and a balance is Fe and unavoidable impurities.

**[0076]** The slab may further contain, in weight percent, Mn: 0.1% or less and S: 0.005% or less.

**[0077]** Since the description of the steel composition of the slab is the same as that of the electrical steel sheet for

electromagnetic shielding described above, so the redundant description is omitted. Except for C, the steel composition of the steel sheet may be substantially the same as the steel composition of the slab.

[0078] The slab may be heated before the slab is hot-rolled. A slab heating temperature may be in the range of 1050 °C to 1350 °C, which is higher than a conventional heating temperature. When the temperature is high during slab reheating, a hot-rolled microstructure may become coarsened, which adversely affects the magnetic properties. However, in the method for manufacturing an electrical steel sheet according to an embodiment of the present disclosure, the carbon content is higher than that of conventional steel, so the hot-rolled microstructure does not become coarsened even when the slab reheating temperature is high, and thus reheating at a temperature higher than in conventional processes is advantageous during hot rolling. However, when the reheating temperature is high, a solubility of precipitates such as TiN and AlN increases, and a large number of fine precipitates are formed during cooling, thereby inhibiting the growth of surface grains.

[0079] The hot rolling may produce a hot-rolled sheet having a thickness of 1.3 to 4.3 mm so that, by applying an appropriate reduction ratio in a final cold-rolling operation, the sheet may be manufactured to a final product thickness. More specifically, the hot-rolled sheet may be produced to have a thickness of 1.5 to 4.0 mm.

[0080] A finishing rolling temperature in the hot-rolling process may be in the range of 750 °C to 1050 °C. If the finishing rolling temperature in the hot-rolling process is excessively high, a surface defect may occur, thereby degrading product quality. In addition, if the finishing rolling temperature is too low, a rolling load increases, thereby reducing passability of the strip and lowering productivity. More specifically, it may be in the range of 800 to 1030 °C. In an embodiment of the present disclosure, a cooling rate in an ROT section after finishing rolling of the hot-rolling process and before the coil is wound may be controlled. More specifically, the cooling rate in the ROT section may be controlled to -50 to -5 °C/s. If the cooling rate is too high, growth of surface grains is suppressed, making it difficult to obtain coarse grains. More specifically, the cooling rate may be controlled to -30 to -7 °C/s.

[0081] After the hot rolling, the hot-rolled steel sheet is subjected to hot-band annealing. In this case, the hot-band annealing may include a decarburization process. Specifically, the hot-band annealing may be performed at a temperature of 850 to 1000 °C and at a dew point of 70 °C or lower. More specifically, the annealing may be performed at a dew point temperature of -70 to 70 °C. After the aforementioned annealing, additional annealing may be performed at a temperature of 1000 to 1200 °C and at a dew point of 0 °C or lower. After the hot-band annealing, pickling may be performed.

[0082] Next, cold rolling is performed to manufacture the cold-rolled steel sheet.

[0083] Accordingly, the cold rolling may be performed at a reduction ratio of 50% to 80%. More specifically, it may be 55% to 75%. Through this process, a cold-rolled steel sheet having a final thickness of 0.3 to 2.0 mm may be manufactured.

[0084] Next, the cold-rolled steel sheet is subjected to decarburization annealing. In this case, the decarburization annealing may be carried out in a region where an austenite single phase is present or in a region where a mixed phase of ferrite and austenite is present. Specifically, the annealing may be performed at a temperature of 800 to 970 °C and at a dew point temperature of 3 to 65 °C. In addition, the atmosphere may be a mixed gas atmosphere of hydrogen and nitrogen. In addition, after the decarburization annealing, the carbon content in the steel sheet may be 0.15 wt% or less.

[0085] In the method for manufacturing an electromagnetic-shielding electrical steel sheet according to an embodiment of the present disclosure,  $\tau$ , as defined by Equation 1 below, is in the range of 0.230 to 0.500.

[Equation 1]

$$\tau = \left( \frac{\text{finishing rolling temperature} + 273}{\text{ROT cooling rate} \times \text{hot - band thickness} \times 10^4} \right) \cdot \left( \frac{2.54 \times (\text{dew point temperature} + 273) \times (\text{annealing temperature} + 273)}{\text{hot - band thickness} \times 10^4} \right)$$

(In Equation 1, a finishing rolling temperature refers to the finishing rolling temperature (°C) during hot rolling, an ROT cooling rate refers to the cooling rate (-°C/s) in an ROT section from completion of finishing rolling to before coiling, a hot-rolled sheet thickness refers to a thickness (mm) of the hot-rolled steel sheet, a dew-point temperature refers to a dew-point temperature (°C) of the atmosphere during the decarburization-annealing, an annealing temperature refers to an annealing temperature (°C) during the decarburization-annealing, and a cold-rolled sheet thickness refers to a

thickness (mm) of the steel sheet after first cold rolling.)

[0086] If  $\tau$  is too small, grain growth in the surface region 12 may be insufficient. If  $\tau$  is too large, excessive grain growth may occur in the central region 11, which adversely affects the electromagnetic-shielding performance. More specifically,  $\tau$  may be in the range of 0.240 to 0.450.

[0087] Next, coating is formed by applying a coating-forming composition onto the surface of the decarburization-annealed steel sheet, the composition comprising, as solid content, 100 parts by weight of a metal phosphate containing one or more of Al, Mg, Co, Ca, Sr, Ba, Zn, and Mn, and 3 to 150 parts by weight, in total, of oxides containing two or more of Al, Si, Mg, and Fe. Since the coating-forming composition corresponds to the same components as those described above for the coating 20, a redundant description thereof will be omitted. In an embodiment of the present disclosure, a ratio of solid content in the coating-forming composition may be substantially the same as the ratio in the coating 20.

[0088] When applying the coating-forming composition, a coating amount may be in the range of 0.5 to 6.0 g/m<sup>2</sup>. If the coating amount is excessively high, the coating 20 may become too thick, and the adhesion to the steel sheet may be degraded. If the coating amount is too low, corrosion resistance may be insufficient. More specifically, the coating amount may be in the range of 1.0 to 5.0 g/m<sup>2</sup>.

[0089] After applying the coating-forming composition, the coating 20 may be formed by heating for 10 to 50 seconds at 550 to 900 °C to dry the coating.

[0090] Hereinafter, specific embodiments of the present disclosure will be described. However, the following examples merely illustrate specific embodiments of the present disclosure, and the present disclosure is not limited thereto.

## Examples

[0091] A slab containing, in weight percent, 2.0% Si and 0.101% C, with a balance being Fe and unavoidable impurities, is heated to 1270 °C and then subjected to hot rolling, hot-rolled sheet annealing, cold rolling, and decarburization annealing in this order under the manufacturing conditions shown in Table 1. After the decarburization annealing, a C content was 0.005 wt%.

[0092] For manufacturing condition 11, an additional operation of high-temperature annealing was performed at 1200 °C for 30 minutes under a dew point of -20 °C.

[0093] Subsequently, a coating composition containing the solid components summarized in Table 3, namely, a composite oxide of montmorillonite, 100 parts by weight of a metal phosphate, 150 parts by weight of silica, 5 parts by weight of chromium oxide, and 100 parts by weight of water, was applied in an amount of 4 g/m<sup>2</sup>, followed by drying at 850 °C for 30 seconds to form coating having a thickness of 3 μm.

[0094] Fabricated specimens were evaluated for an average grain size at surface and central regions, magnetic flux density, and electromagnetic shielding effectiveness, and results are shown in Tables 2 and 3.

[0095] The average grain size was measured using an optical microscope.

[0096] Grain morphology at the surface was measured using a backscattered electron diffraction (EBSD) analyzer.

[0097] <110>//ND and <111>//ND orientations were measured using the backscattered electron diffraction (EBSD) analyzer.

[0098] Magnetic flux density was measured using a single-strip magnetic field measurement method.

[0099] An electromagnetic shielding effectiveness was measured using a Helmholtz-coil method, in which a magnetic field of 1 G or less was generated and a cylindrical pickup coil capable of detecting an induced magnetic field was placed at a center of the generated field. The shielding effectiveness was calculated by shielding the pickup coil with the steel sheet, determining the magnetic field intensity measured before and after shielding, and calculating the shielding effectiveness as shown below.

$$\text{Shielding effectiveness (\%)} = (1 - B_{\text{shielded}} / B_{\text{unshielded}}) \times 100$$

[0100] An insulation property was measured by the Franklin insulation test, in which a current of 1.0 A at an input of 0.5 V was applied under a pressure of 300 PSI, and a resulting leakage current value was used as the measurement.

[0101] Salt-spray corrosion resistance was evaluated by a repeated test in which the specimens were exposed to a 5 wt% NaCl solution at 35 °C for 8 hours per cycle, and a cycle number at which rust initiation occurred was determined.

[0102] The soil-corrosion resistance was evaluated under test conditions of controlled salinity and pH in a 35 °C, 24-hour fog environment using a test solution composed of 1% NaCl, 0.01% Na<sub>2</sub>SO<sub>4</sub>, and 0.01% Na<sub>2</sub>CO<sub>3</sub>, wherein each specimen was buried to a depth of 10 cm with controlled moisture content and the time until rust initiation was measured.

(Table 1)

| Manuf<br>acturing<br>conditions | Hot rolling                              |                                |                   | Ho trolled sheet | Cold rolling          |                   | Decarbonization                  |                                  | Parameter<br>( $\tau$ ) |
|---------------------------------|------------------------------------------|--------------------------------|-------------------|------------------|-----------------------|-------------------|----------------------------------|----------------------------------|-------------------------|
|                                 | Finishing rolling<br>temperature<br>(°C) | ROT<br>cooling<br>rate (-°C/s) | Thickness<br>(mm) |                  | Reduction<br>rate (%) | Thickness<br>(mm) | Dew point<br>temperature<br>(°C) | Annealing<br>temperature<br>(°C) |                         |
| 1                               | 1002                                     | 8                              | 4.0               | 920              | 60                    | 1.60              | 60                               | 950                              | 0.258                   |
| 2                               | 975                                      | 10                             | 3.0               | 920              | 65                    | 1.05              | 43                               | 923                              | 0.380                   |
| 3                               | 950                                      | 13                             | 2.5               | 920              | 70                    | 0.75              | 23                               | 873                              | 0.432                   |
| 4                               | 925                                      | 25                             | 2.0               | 920              | 62                    | 0.76              | 5                                | 820                              | 0.243                   |
| 5                               | 900                                      | 28                             | 1.5               | 920              | 63                    | 0.56              | 10                               | 815                              | 0.390                   |
| 6                               | 880                                      | 32                             | 5.0               | 920              | 61                    | 1.95              | 15                               | 895                              | 0.032                   |
| 7                               | 911                                      | 55                             | 2.8               | 920              | 80                    | 0.56              | 0                                | 857                              | 0.108                   |
| 8                               | 843                                      | 35                             | 2.7               | 920              | 70                    | 0.81              | -20                              | 920                              | 0.112                   |
| 9                               | 863                                      | 30                             | 2.5               | 920              | 80                    | 0.50              | 7                                | 745                              | 0.219                   |
| 10                              | 965                                      | 32                             | 1.2               | 920              | 67                    | 0.40              | 55                               | 812                              | 0.729                   |
| 11                              | 780                                      | 20                             | 3.8               | 920              | 67                    | 1.25              | 60                               | 815                              | 0.102                   |

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(Table 2)

| Manufacturing conditions | Average grain size ( $\mu\text{m}$ ) |                | Fraction (area %) of D2/D1 $\geq 0.5$ | (Surface region / central region grain size) | <110>/ND / <111>/ND |
|--------------------------|--------------------------------------|----------------|---------------------------------------|----------------------------------------------|---------------------|
|                          | Surface region                       | Central region |                                       |                                              |                     |
| 1                        | 153                                  | 46             | 75                                    | 3.4                                          | 3.5                 |
| 2                        | 334                                  | 31             | 88                                    | 10.6                                         | 4.5                 |
| 3                        | 287                                  | 23             | 78                                    | 12.5                                         | 4.2                 |
| 4                        | 263                                  | 19             | 75                                    | 13.6                                         | 3.8                 |
| 5                        | 352                                  | 25             | 95                                    | 14.1                                         | 4.8                 |
| 6                        | 45                                   | 32             | 72                                    | 1.4                                          | 3.3                 |
| 7                        | 23                                   | 19             | 70                                    | 1.2                                          | 3.1                 |
| 8                        | 48                                   | 33             | 73                                    | 1.5                                          | 3.1                 |
| 9                        | 35                                   | 32             | 85                                    | 1.1                                          | 3.2                 |
| 10                       | 138                                  | 102            | 72                                    | 1.4                                          | 3.1                 |
| 11                       | 826                                  | 815            | 52                                    | 1.0                                          | 5.2                 |

(Table 3)

| Manufacturing conditions | B1 (T) | B50 (T) | Shielding effectiveness | Shielding effectiveness |
|--------------------------|--------|---------|-------------------------|-------------------------|
|                          |        |         | 100mG (%)               | 1G (%)                  |
| 1                        | 0.879  | 1.887   | 51.2                    | 72.8                    |
| 2                        | 1.345  | 1.853   | 66.5                    | 75.6                    |
| 3                        | 1.295  | 1.825   | 64.0                    | 74.4                    |
| 4                        | 1.270  | 1.781   | 61.4                    | 71.2                    |
| 5                        | 1.360  | 1.867   | 64.2                    | 75.1                    |
| 6                        | 0.555  | 1.835   | 30.5                    | 67.8                    |
| 7                        | 0.298  | 1.700   | 18.3                    | 61.8                    |
| 8                        | 0.605  | 1.846   | 31.8                    | 68.7                    |
| 9                        | 0.482  | 1.832   | 25.2                    | 67.5                    |
| 10                       | 0.921  | 1.702   | 60.2                    | 62.8                    |
| 11                       | 1.458  | 1.710   | 72.5                    | 63.5                    |

(Table 4)

| Manufacturing conditions | Coating composition       |                                             |                                   | Insulation (mA) | Corrosion resistance (salt-spray, cycles) | Corrosion resistance (soil corrosion, hr) | Division            |
|--------------------------|---------------------------|---------------------------------------------|-----------------------------------|-----------------|-------------------------------------------|-------------------------------------------|---------------------|
|                          | Types of metal phosphates | Content of complex oxides (parts by weight) | Average silica particle size (nm) |                 |                                           |                                           |                     |
| 1                        | Mg                        | 50                                          | 10                                | 20              | 6                                         | 1400                                      | Inventive Example 1 |
| 2                        | Mn                        | 50                                          | 8                                 | 15              | 6                                         | 1450                                      | Inventive Example 2 |

(continued)

|    | Manufacturing conditions | Coating composition       |                                             |                                   | Insulation (mA) | Corrosion resistance (salt-spray, cycles) | Corrosion resistance (soil corrosion, hr) | Division              |
|----|--------------------------|---------------------------|---------------------------------------------|-----------------------------------|-----------------|-------------------------------------------|-------------------------------------------|-----------------------|
|    |                          | Types of metal phosphates | Content of complex oxides (parts by weight) | Average silica particle size (nm) |                 |                                           |                                           |                       |
| 5  | 3                        | Al:Co=1 :1                | 50                                          | 8                                 | 12              | 6                                         | 1455                                      | Inventive Example 3   |
| 10 | 4                        | Al:Mg= 1:1                | 50                                          | 20                                | 8               | 6                                         | 1540                                      | Inventive Example 4   |
| 15 | 5                        | Al:Ca=1 :1                | 20                                          | 14                                | 75              | 4                                         | 800                                       | Inventive Example 5   |
|    | 6                        | Al:Mg= 1:1                | 20                                          | 19                                | 115             | 3                                         | 480                                       | Comparative Example 1 |
| 20 | 7                        | Al                        | 25                                          | 20                                | 100             | 3                                         | 570                                       | Comparative Example 2 |
|    | 8                        | Co                        | 25                                          | 14                                | 150             | 3                                         | 620                                       | Comparative Example 3 |
| 25 | 9                        | Mg                        | 25                                          | 7                                 | 120             | 3                                         | 650                                       | Comparative Example 4 |
|    | 10                       | Ca                        | 25                                          | 9                                 | 135             | 3                                         | 625                                       | Comparative Example 5 |
| 30 | 11                       | Al:Zn=1 :1                | 20                                          | 7                                 | 111             | 3                                         | 450                                       | Comparative Example 6 |
|    | 1                        | Al:Sr=1: 1                | 20                                          | 7                                 | 77              | 4                                         | 850                                       | Inventive Example 6   |
| 35 | 2                        | Sr                        | 35                                          | 13                                | 55              | 4                                         | 825                                       | Inventive Example 7   |
|    | 3                        | Zn                        | 35                                          | 14                                | 86              | 4                                         | 880                                       | Inventive Example 8   |
| 40 | 4                        | Al:Mg= 1:1                | -                                           | 12                                | 250             | 1                                         | 140                                       | Comparative Example 7 |

**[0103]** As shown in Tables 1 to 4, when the process conditions are appropriately controlled, a desirable crystallographic texture of the steel sheet substrate is formed, and excellent shielding effectiveness is clearly demonstrated. In addition, when a coating layer having an appropriate composition is employed, insulation and corrosion resistance are clearly demonstrated to be excellent.

**[0104]** In contrast, when the process conditions are not properly controlled, the crystallographic texture of the steel sheet substrate is not adequately formed, and the shielding effectiveness is clearly confirmed to be inferior.

**[0105]** Even when the steel sheet substrate is properly manufactured, if an appropriate complex oxide is not employed as the coating layer, the insulation and corrosion resistance are clearly confirmed to be inferior.

**[0106]** This disclosure is not limited to the above embodiments and/or examples but may be implemented in various other forms, and it will be understood by those skilled in the art that the disclosure may be practiced in other specific forms without departing from the technical spirit or essential characteristics thereof. Therefore, it is to be understood that the above implementation and/or embodiments are for illustrative purposes only, and the scope of the present invention is not limited thereto.

[Description of Symbols]

100: electrical steel sheet for electromagnetic shielding,

10: electrical steel sheet substrate,

(continued)

11: central region,  
20: coating,

12: surface region,  
200: transmission line

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**Claims**

1. An electrical steel sheet for electromagnetic shielding, comprising

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a steel-sheet substrate and a coating layer disposed on the surface of the steel sheet substrate, wherein, on a surface of the steel-sheet substrate, grains having a ratio ( $D2/D1$ ) of 0.5 or more between a diameter ( $D1$ ) of a circumscribed circle and a diameter ( $D2$ ) of an inscribed circle among all grains account for 70 area% or more,

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an average grain size in a surface region, which extends from the surface of the steel-sheet substrate to less than one-quarter of a sheet thickness in a thickness direction, is 80  $\mu\text{m}$  to 500  $\mu\text{m}$ , and an average grain size in a central region, which extends from one-quarter to one-half of the sheet thickness, is 50  $\mu\text{m}$  or less, and the coating layer includes 100 parts by weight of a metal phosphate containing one or more selected from Al, Mg, Co, Ca, Sr, Ba, Zn, and Mn, and 3 to 150 parts by weight, in total, of oxides containing two or more selected from Al, Si, Mg, and Fe.

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2. The electrical steel sheet of claim 1, wherein

a ratio of an area fraction of grains having a  $\langle 111 \rangle$  orientation within  $15^\circ$  of being parallel to a rolling direction of the steel sheet to an area fraction of grains having a  $\langle 110 \rangle$  orientation within  $15^\circ$  of being parallel to a rolling direction of the steel sheet is 3 or greater.

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3. The electrical steel sheet of claim 1, wherein

a ratio of the average grain size in the surface region to the average grain size in the central region is 2.0 or greater.

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4. The electrical steel sheet of claim 1, wherein

the steel-sheet substrate contains, in weight percent, Si: 0.3% to 7.0%, C: 0.15% or less (excluding 0%), and a balance is Fe and unavoidable impurities.

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5. The electrical steel sheet of claim 1, wherein

the steel-sheet substrate further contains Mn: 0.1 wt% or less and S: 0.005 wt% or less.

6. The electrical steel sheet of claim 1, wherein

the coating layer further contains 50 to 250 parts by weight of silica.

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7. The electrical steel sheet of claim 1, wherein

the coating layer further contains 2 to 10 parts by weight of chromium oxide.

8. A manufacturing method for an electrical steel sheet for electromagnetic shielding, the method comprising:

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producing a hot-rolled steel sheet by hot-rolling a slab;  
annealing the hot-rolled steel sheet;  
cold-rolling the hot-rolled steel sheet that has been annealed;  
decarburization-annealing the cold-rolled steel sheet; and

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forming coating by applying a coating-forming composition onto a surface of the decarburization-annealed steel sheet composition comprising, as solid content, 100 parts by weight of a metal phosphate containing one or more of Al, Mg, Co, Ca, Sr, Ba, Zn, and Mn, and 3 to 150 parts by weight, in total, of oxides containing two or more of Al, Si, Mg, and Fe,

wherein  $\tau$  defined by the following Equation 1 is in the range of 0.23 to 0.5:

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[Equation 1]

 $\tau$ 

$$= \left( \frac{\text{finishing rolling temperature} + 273}{\text{ROT cooling rate} \times \text{hot - band thickness} \times 10^4} \right) \cdot \left( \frac{2.54 \times (\text{dew point temperature} + 273) \times (\text{annealing temperature} + 273)}{\text{hot - band thickness} \times 10^4} \right)$$

(In Equation 1, a finishing rolling temperature refers to the finishing rolling temperature (°C) during hot rolling, an ROT cooling rate refers to the cooling rate (°C/s) in an ROT section from completion of finishing rolling to before coiling, a hot-rolled sheet thickness refers to a thickness (mm) of the hot-rolled steel sheet, a dew-point temperature refers to a dew-point temperature (°C) of the atmosphere during the decarburization-annealing, an annealing temperature refers to an annealing temperature (°C) during the decarburization-annealing, and a cold-rolled sheet thickness refers to a thickness (mm) of the steel sheet after the cold rolling.)

9. The manufacturing method of claim 8, wherein the slab contains, in weight percent, Si: 0.3% to 7.0%, C: 0.01% to 0.4%, and a balance is Fe and unavoidable impurities.
10. The manufacturing method of claim 9, wherein the slab further contains Mn: 0.1 wt% or less and S: 0.005 wt% or less.
11. The manufacturing method of claim 8, wherein the annealing of the hot-rolled steel sheet includes a decarburization process.
12. The manufacturing method of claim 8, wherein the annealing of the hot-rolled steel sheet is performed at a temperature of 850°C to 1000°C and at a dew-point temperature of 70°C or lower.
13. The manufacturing method of claim 8, wherein the decarburization-annealing is performed at a temperature of 600°C to 1000°C and at a dew-point temperature of 0°C to 70°C.
14. The manufacturing method of claim 8, wherein the coating-forming composition further contains 50 to 250 parts by weight of silica.
15. The manufacturing method of claim 8, wherein the coating-forming composition further contains 2 to 10 parts by weight of chromium oxide.

FIG. 1

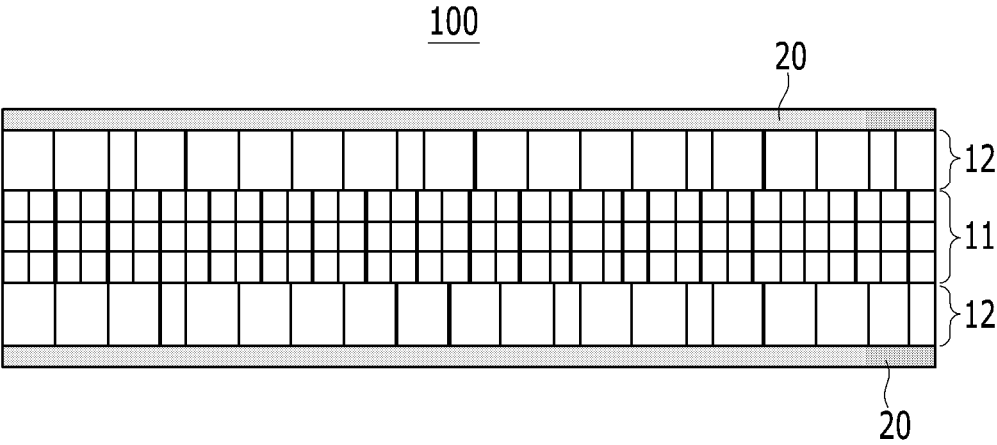


FIG. 2

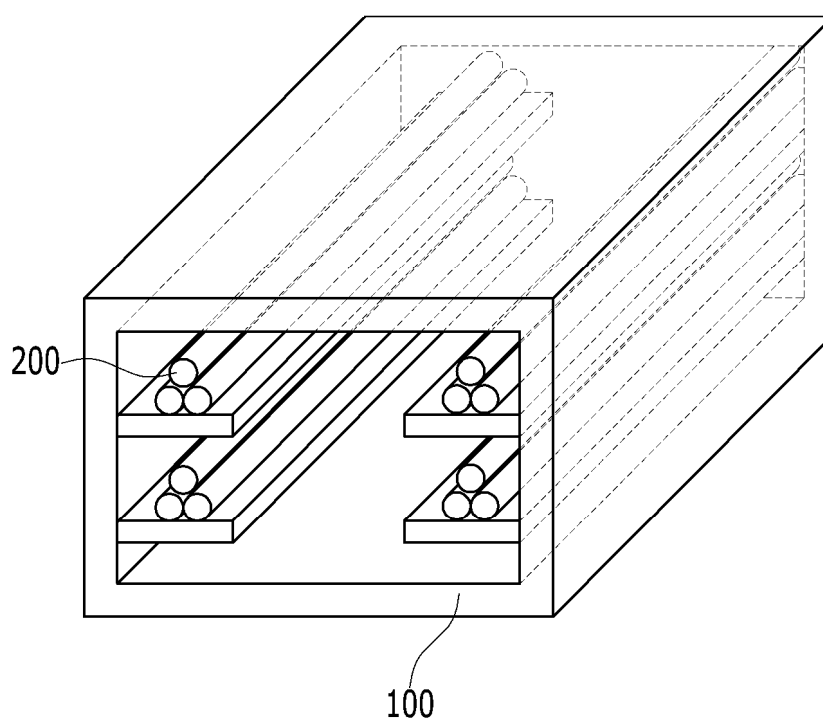


FIG. 3

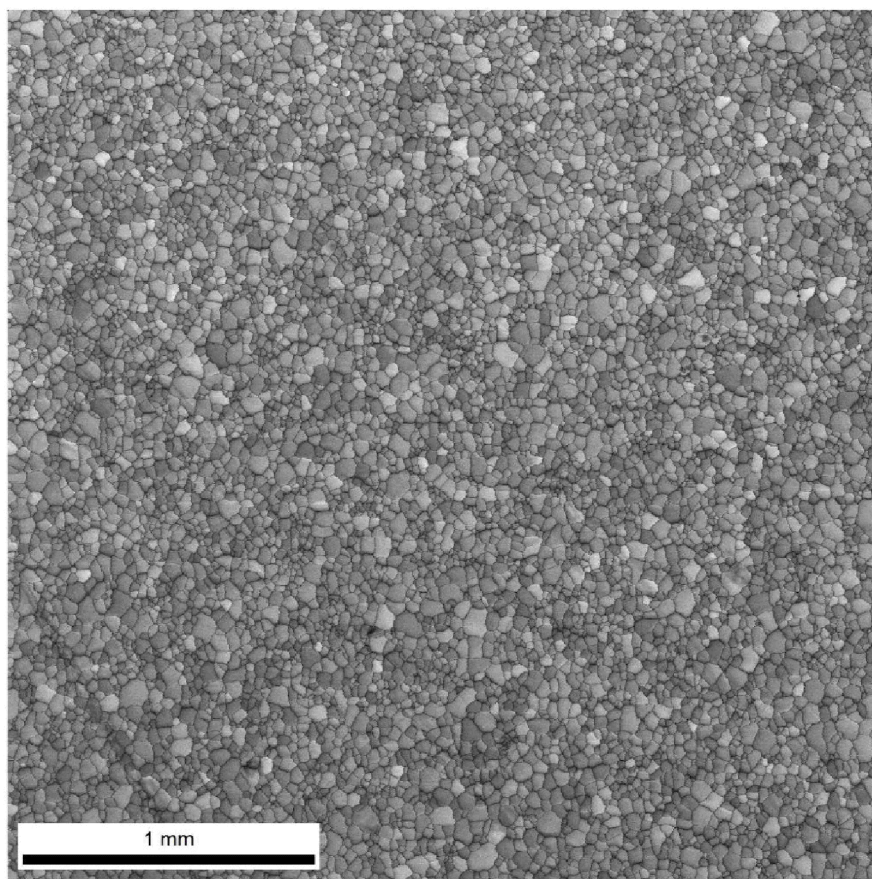
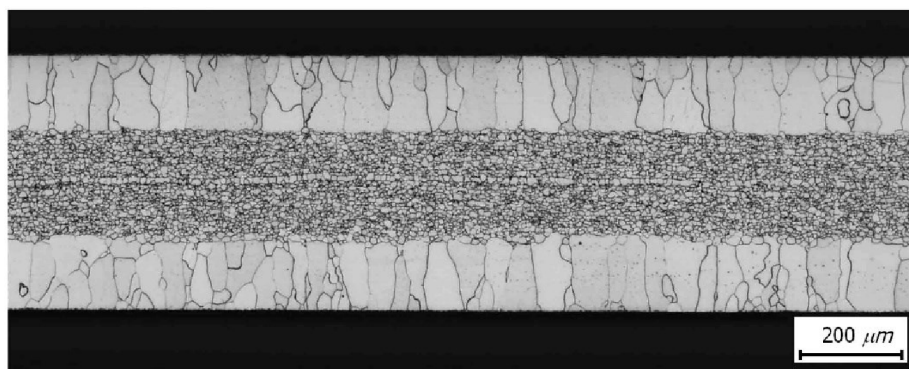


FIG. 4



## INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB2024/063305

## A. CLASSIFICATION OF SUBJECT MATTER

C22C 38/02(2006.01)i; C22C 38/04(2006.01)i; C23C 22/07(2006.01)i; C21D 8/12(2006.01)i; C21D 9/46(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)

C22C 38/02(2006.01); C21D 8/12(2006.01); C23C 22/00(2006.01); C23C 22/07(2006.01); C23C 22/18(2006.01);  
H01F 1/147(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: 전기강판(electrical steel sheet), 피막(film), 결정립(grain), 인산염  
(phosphate), 산화물(oxide), 규소(Si), 열간압연(hot rolling), 냉간압연(cold rolling), 소둔(annealing), 탈탄(decarburization)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                    | Relevant to claim No. |
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☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

\* Special categories of cited documents:

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

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

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

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

“&” document member of the same patent family

Date of the actual completion of the international search

15 April 2025

Date of mailing of the international search report

15 April 2025

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**INTERNATIONAL SEARCH REPORT**  
**Information on patent family members**

International application No.

**PCT/IB2024/063305**

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