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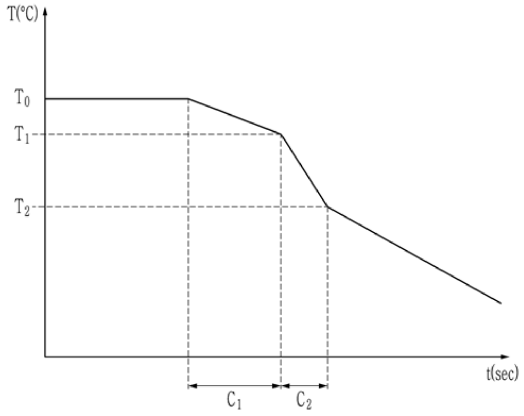
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(54) NON-ORIENTED ELECTRICAL STEEL SHEET AND MANUFACTURING METHOD THEREFOR

(57) A non-oriented electrical steel sheet according to an embodiment of the present invention comprises, in weight %, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, and at least one of Mo, V, and Nb: 0.002 to 0.03%, with the balance Fe and inevitable impurities, wherein a number ratio of carbides having a particle diameter of 20 nm or more and comprising at least one of Mo, V, and Nb in an amount of 5 weight % or more with respect to the total number of carbides in the steel sheet is 0.2 or more.

FIG. 1



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Description

[Technical Field]

[0001] An embodiment of the present invention relates to a non-oriented electrical steel sheet and a method of manufacturing the same. Specifically, an embodiment of the present invention relates to a non-oriented electrical steel sheet and a method of manufacturing the same, wherein magnetic properties are improved by appropriately controlling a thermal history during cooling of the steel sheet in an annealing process before cold rolling, thereby appropriately forming Mo, Nb, and V carbides in the steel sheet.

[Background Art]

[0002] A non-oriented electrical steel sheet is mainly used for motors that convert electrical energy into mechanical energy, and excellent magnetic properties of the non-oriented electrical steel sheet are required to exhibit high efficiency in the process. In particular, as eco-friendly vehicles driven by motors instead of internal combustion engines have recently attracted attention, the demand for non-oriented electrical steel sheets used as driving motor core materials is increasing, and for this, a non-oriented electrical steel sheet having excellent magnetic properties and strength at the same time is required.

[0003] The magnetic properties of a non-oriented electrical steel sheet are mainly evaluated by iron loss and magnetic flux density. Iron loss refers to energy loss occurring at a specific magnetic flux density and frequency, and magnetic flux density refers to the degree of magnetization obtained under a specific magnetic field. The lower the iron loss, the higher the energy efficiency a motor may achieve under the same conditions, and the higher the magnetic flux density, the more the motor may be downsized or copper loss may be reduced. Therefore, a driving motor having excellent efficiency and torque may be made by using a non-oriented electrical steel sheet having low iron loss and high magnetic flux density, through which the driving range and output of eco-friendly vehicles may be improved.

[0004] The characteristics of a non-oriented electrical steel sheet to be considered also vary depending on the operating conditions of a motor. As a general criterion for evaluating the characteristics of a non-oriented electrical steel sheet used for a motor, $W_{15/50}$, which is an iron loss when a 1.5 T magnetic field is applied at a commercial frequency of 50 Hz, is widely used. However, for non-oriented electrical steel sheets with a thickness of 0.35 mm or less used in eco-friendly vehicle driving motors, magnetic properties are often important at a low magnetic field of 1.0 T or less and at a high frequency of 400 Hz or higher; therefore, the characteristics of the non-oriented electrical steel sheet are often evaluated using $W_{10/400}$ iron loss.

[0005] A method commonly used to improve the magnetic properties of a non-oriented electrical steel sheet is to add alloying elements such as Si, Al, and Mn. If the electrical resistivity of the steel increases through the addition of these alloying elements, eddy current loss decreases, and thus the total iron loss may be lowered. In addition, alloying elements are dissolved in iron as substitutional elements to cause a strengthening effect, thereby increasing strength. On the other hand, there are disadvantages in that as the amount of alloying elements such as Si, Al, and Mn added increases, magnetic flux density becomes inferior and brittleness increases, and if added beyond a certain amount, cold rolling becomes impossible, making commercial production impossible. In particular, the thinner the thickness of the electrical steel sheet, the better the high-frequency core loss, but a decrease in rollability due to brittleness becomes a critical problem. The maximum value of the total content of Si, Al, and Mn that allows for commercial production is known to be about 4.5 weight %, and in addition, a top-grade non-oriented electrical steel sheet having excellent magnetic properties and strength may be produced by optimizing the content of trace elements.

[0006] However, when a large amount of high-resistivity alloying elements such as Si, Al, Mn, and Cr is added, a problem occurs in that the magnetic flux density may be lowered. In particular, for applications where materials are continuously required to be lightweight, such as eco-friendly electric vehicle driving motors, the use of a material having a high magnetic flux density is essential.

[0007] To this end, a method of improving characteristics by thin gauging a hot-rolled sheet has been proposed, and a method of improving magnetic properties by including high Al and performing two-stage annealing and two-stage rolling has been proposed. In addition, a method of performing thin gauging of a hot-rolled sheet through a thin slab manufacturing method has been proposed.

[0008] However, the method of reducing the hot-rolled sheet thickness is difficult to implement in mass production due to an increase in rolling load during a general hot rolling process. While the high Al addition, the two-stage annealing, and the two-stage rolling process are confirmed to partially improve magnetic properties, the {110}<001> Goss texture also develops, which leads to a deterioration in the circumferential property of the motor, and surface defects increase significantly due to the high Al addition.

[Disclosure]

[Technical Problem]

[0009] An embodiment of the present invention provides a non-oriented electrical steel sheet and a manufacturing method thereof. Specifically, an embodiment of the present invention provides a non-oriented electrical steel sheet and a manufacturing method thereof, wherein magnetic properties are improved by appropriately controlling a thermal history during cooling of the steel sheet in an annealing process before cold rolling to appropriately form Mo, Nb, and V carbides in the steel sheet.

[Technical Solution]

[0010] A non-oriented electrical steel sheet according to an embodiment of the present invention comprises, in weight %, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, and at least one of Mo, V, and Nb: 0.002 to 0.03%, with the balance Fe and inevitable impurities, wherein a number ratio of carbides having a particle diameter of 20 nm or more and comprising at least one of Mo, V, and Nb in an amount of 5 weight % or more with respect to the total number of carbides in the steel sheet is 0.2 or more.

[0011] A non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise at least one of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

[0012] A non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise one or two or more elements of Sn, Sb, Bi, Pb, Ge, and As in an amount of 0.005 to 0.200 weight % each or in total.

[0013] A non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise at least one of Cu: 0.005 to 0.2 wt %, Cr: 0.01 to 0.5 wt %, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

[0014] A non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise at least one of B: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Zr: 0.005 weight % or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

[0015] A method for manufacturing a non-oriented electrical steel sheet according to an embodiment of the present invention comprises the steps of: hot rolling a slab comprising, in weight %, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, and at least one of Mo, V, and Nb: 0.002 to 0.03%, with the balance Fe and inevitable impurities, to manufacture a hot-rolled steel sheet; annealing before cold rolling for annealing the steel sheet; cold rolling the annealed steel sheet to manufacture a cold-rolled sheet; and cold-rolled sheet annealing for annealing the cold-rolled sheet.

[0016] The annealing before cold rolling comprises soaking of the steel sheet; first cooling of cooling the steel sheet to a first cooling temperature at a first cooling rate; and second cooling of cooling the steel sheet to a second cooling temperature at a second cooling rate that is 3 to 17°C/sec higher than the first cooling rate.

[0017] The slab may further comprise at least one of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

[0018] The slab may further comprise one or two or more of Sn, Sb, Bi, Pb, Ge, and As in an amount of 0.005 to 0.200 weight % for each or for the total amount thereof.

[0019] The slab may further comprise at least one of Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt %, Ni: 0.05 wt% or less (excluding 0%), and Zn: 0.01 wt% or less (excluding 0%).

[0020] The slab may further comprise at least one of B: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), Co: 0.05 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

[0021] After manufacturing the hot-rolled steel sheet, subsequent steps may be performed in a state where scale existing on the hot-rolled steel sheet remains.

[0022] The method may further comprise preliminary cold rolling on the hot-rolled sheet before the annealing before cold rolling.

[0023] In the preliminary cold rolling, the reduction ratio may be 65 to 80%.

[0024] A soaking temperature of the annealing before cold rolling may be 800 to 1200°C.

[0025] The first cooling temperature may be 580 to 770°C.

[0026] The second cooling temperature may be 280 to 370°C.

[0027] The first cooling rate may be 5 to 20°C/sec, and the second cooling rate may be 10 to 30°C/sec.

[Advantageous Effects]

[0028] A non-oriented electrical steel sheet according to an embodiment of the present invention exhibits excellent

magnetic flux density and low iron loss.

[0029] A non-oriented electrical steel sheet according to an embodiment of the present invention has improved cold rollability, whereby productivity is improved.

[0030] Ultimately, a non-oriented electrical steel sheet according to an embodiment of the present invention contributes to the manufacture of motors for eco-friendly vehicles, motors for high-efficiency home appliances, and super premium grade motor cores.

[Brief Description of the Drawings]

[0031] FIG. 1 is a diagram schematically illustrating a cooling pattern in annealing before cold rolling.

[Mode for Invention]

[0032] Terms such as first, second, and third are used to describe various parts, components, regions, layers, and/or sections, but are not limited thereto. These terms are used only to distinguish any part, component, region, layer, or section from another part, component, region, layer, or section. Therefore, a first part, component, region, layer, or section described below may be referred to as a second part, component, region, layer, or section without departing from the scope of the present invention.

[0033] The terminology used herein is for the purpose of referring to specific examples only and is not intended to limit the present invention. As used herein, singular forms also include plural forms unless the phrases clearly indicate the opposite. The meaning of "comprising" as used in the specification specifies a specific characteristic, region, integer, step, operation, element, and/or component, and does not exclude the presence or addition of other characteristics, regions, integers, steps, operations, elements, and/or components.

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

[0035] In addition, unless otherwise specified, % means weight %, and 1 ppm is 0.0001 weight %.

[0036] In an embodiment of the present invention, further comprising an additional element means that the additional element is included in an amount that replaces a corresponding amount of the balance iron (Fe).

[0037] Unless defined otherwise, all terms, including technical and scientific terms, used herein have the same meaning as commonly understood by a person skilled in the art to which the present invention belongs. Terms defined in commonly used dictionaries shall be interpreted as having meanings consistent with the relevant technical literature and the content of the present disclosure, and shall not be interpreted in an ideal or overly formal sense unless explicitly defined otherwise.

[0038] Hereinafter, embodiments of the present invention will be described in detail such that a person skilled in the art to which the present invention pertains may easily carry out the present invention. However, the present invention may be implemented in many different forms and is not limited to the embodiments described herein.

[0039] A non-oriented electrical steel sheet according to an embodiment of the present invention comprises, in weight %, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, and at least one of Mo, V, and Nb: 0.002 to 0.03%, with the balance Fe and inevitable impurities.

[0040] Hereinafter, the reasons for the limitations on the components of the non-oriented electrical steel sheet will be described.

Si: 1.5 to 4.5 wt%

[0041] Silicon (Si) serves to lower iron loss by increasing the electrical resistivity of the material and to increase strength through solid solution strengthening. If Si is added in an excessively small amount, the effect of improving iron loss and strength may be insufficient. If Si is added in an excessive amount, the brittleness of the material increases, which may sharply decrease rolling productivity and form a surface oxide layer and oxides harmful to magnetic properties. Therefore, the material may comprise Si in an amount of 1.5 to 4.5 weight %. More specifically, it may comprise 2.0 to 4.3 weight %. More specifically, it may comprise 2.5 to 4.0 weight %.

Al: 0.1 to 2.0 wt%

[0042] Aluminum (Al) serves to lower iron loss by increasing the electrical resistivity of the material and to increase strength through solid solution strengthening. If Al is added in too small an amount, fine nitrides may be formed, making it difficult to obtain a magnetic property improvement effect. If Al is added too much, nitrides are excessively formed to deteriorate magnetic properties, and problems may occur in all processes such as steelmaking and contin-

uous casting, which may significantly reduce productivity. Therefore, Al may be contained in an amount of 0.1 to 2.0 weight %. More specifically, it may be contained in an amount of 0.2 to 1.7 weight %. More specifically, it may be contained in an amount of 0.5 to 1.6 weight %.

Mn: 0.1 to 2.0 wt%

[0043] Manganese (Mn) serves to improve iron loss by increasing the electrical resistivity of the material and to form sulfides. If Mn is added in too small an amount, sulfides are finely formed to cause deterioration of magnetic properties, and if Mn is added too much, fine MnS is excessively precipitated, and the formation of {111} texture, which is unfavorable to magnetic properties, is promoted, so that the magnetic flux density is sharply reduced. Therefore, Mn may be contained in an amount of 0.1 to 2.0 weight %. More specifically, it may be contained in an amount of 0.3 to 1.8 weight %. More specifically, it may be contained in an amount of 0.5 to 1.6 weight %.

At least one of Mo, V, and Nb: 0.002 to 0.03 wt%

[0044] When molybdenum (Mo), vanadium (V), and niobium (Nb) are additionally added, they form carbides and undergo complex precipitation with TiC or the like, which results in coarsening of precipitates and improvement in magnetic flux density by reducing the number of fine carbides. If they are appropriately added, the above-mentioned effects may be additionally obtained; however, if they are contained in an excessive amount, a large amount of segregation occurs, which inhibits grain growth, and consequently, magnetic flux density and iron loss may rather become inferior. More specifically, at least one of Mo, V, and Nb may be contained in an amount of 0.005 to 0.015 weight %. When Mo, V, and Nb are contained individually or two or more thereof are contained, the total amount thereof may be within the above-mentioned range. More specifically, two or more of Mo, V, and Nb may be contained in the above-mentioned range as a total amount. More specifically, Mo, V, and Nb may be contained in the above-mentioned range as a total amount. More specifically, Mo, V, and Nb may each be contained in an amount of 0.001 to 0.02 weight %.

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

P: 0.1 wt% or less

[0046] Phosphorus (P) is a grain boundary segregation element and may improve magnetic flux density, but if it is added in an excessive amount, it increases the brittleness of a steel sheet, resulting in inferior weldability. More specifically, P may be contained in an amount of 0.0001 to 0.0500 weight %.

C: 0.005 wt% or less

[0047] Carbon (C) causes magnetic aging and may combine with other impurity elements to generate carbides, thereby hindering the grain boundary or magnetic domain wall movement to deteriorate magnetic properties. More specifically, C may be contained in an amount of 0.0001 to 0.003 weight %.

S: 0.005 wt% or less

[0048] Sulfur (S) forms MnS and CuS, which are fine precipitates, and may deteriorate magnetic properties and worsen hot workability. More specifically, S may be contained in an amount of 0.0001 to 0.0030 weight %.

Ti: 0.005 wt% or less

[0049] Titanium (Ti) forms carbonitride and hinders magnetic domain movement; therefore, its content may be limited. More specifically, Ti may be present in an amount ranging from 0.0001 to 0.005 weight %. Even more specifically, Ti may be present in an amount ranging from 0.0001 to 0.003 weight %.

N: 0.005 wt% or less

[0050] Nitrogen (N) not only forms fine AlN precipitates inside the base material but also combines with other impurities to form fine precipitates, which may inhibit grain growth and domain wall movement, thereby potentially worsening iron loss. More specifically, N may be contained in an amount of 0.0001 to 0.0030 weight %.

[0051] A non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise one or two or more elements of Sn, Sb, Bi, Pb, Ge, and As in an amount of 0.005 to 0.200 weight % each or in total.

Sn and Sb

[0052] Tin (Sn) and antimony (Sb) segregate at the grain boundaries at the initial stage of final recrystallization annealing and serve to suppress the development of {111} orientation, which deteriorates magnetic properties. If Sn and Sb are added in excessive amounts, they hinder the recovery and growth of coarse elongated band structures and may deteriorate surface quality. Therefore, one or more selected from the group consisting of Sn and Sb may be further added within the aforementioned range. More specifically, Sn may be contained in an amount of 0.005 to 0.200 weight %, or Sb may be contained in an amount of 0.005 to 0.200 weight %.

Bi, Pb, Ge and As

[0053] When bismuth (Bi), lead (Pb), germanium (Ge), and arsenic (As) are additionally added, they segregate at the grain boundaries and alleviate stress concentration at the grain boundaries during cold rolling, thereby improving magnetic flux density by suppressing recrystallization of <111>//ND oriented grains in the subsequent recrystallization annealing process. If they are added in appropriate amounts, the above-mentioned effects may be additionally obtained, but if they are contained in an excessive amount, a large amount of segregation occurs, inhibiting grain growth, and magnetic flux density and iron loss may rather become inferior.

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

Cu: 0.005 to 0.200 wt%

[0055] Copper (Cu) serves to form sulfides together with Mn. When Cu is further added, if it is added in too small an amount, (Cu · Mn)S is finely precipitated, which may deteriorate magnetic properties. If Cu is added too much, high temperature brittleness occurs, which may form cracks during continuous casting or hot rolling. More specifically, Cu may be contained in an amount of 0.01 to 0.10 weight %.

Cr: 0.01 to 0.50 wt%

[0056] Chromium (Cr) serves to improve iron loss by increasing electrical resistivity. If Cr is added in too small an amount, the effect of increasing electrical resistivity may not be sufficient. If Cr is contained in too large an amount, magnetic flux density may decrease. More specifically, Cr may be contained in an amount of 0.050 to 0.20 weight %.

Ni: 0.05 wt% or less

[0057] Nickel (Ni) reacts with impurity elements to form fine sulfides, carbides, and nitrides, which may have a harmful effect on magnetic properties. More specifically, Ni may be contained in an amount of 0.001 to 0.03 weight %.

Zn: 0.01wt% or less

[0058] When the content of zinc (Zn) is excessive, it acts as an impurity and may deteriorate magnetic properties. Therefore, Zn may be further added within the above-mentioned range. More specifically, Zn may be contained in an amount of 0.001 to 0.005 weight %.

Co: 0.05 wt% or less

[0059] Cobalt (Co) does not form fine sized precipitates that deteriorate the magnetic properties of a steel sheet, but it may increase high temperature strength and make the shape of the coil poor after hot rolling.

[0060] A non-oriented electrical steel sheet according to an embodiment of the present invention may further comprise at least one of B: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Zr: 0.0050 wt% or less (excluding 0%), Te: 0.0100 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

B: 0.0050 wt% or less

[0061] If boron (B) is added in an excessive amount, it may cause deterioration of magnetic properties through the formation of inclusions or the like in the steel. Therefore, B may be contained in an amount of 0.005 wt% or less. The lower limit is not particularly limited, but it may be 0.0001 weight % due to steelmaking cost. More specifically, B may be contained in an amount of 0.0001 to 0.0030 weight %.

Ca: 0.0050 wt% or less

[0062] Calcium (Ca) has a very strong tendency toward the formation of precipitates in the steel, and it deteriorates iron loss by forming fine sulfides inside the base material, thereby suppressing grain growth and domain wall movement.

Zr: 0.0050 wt% or less

[0063] If zirconium (Zr) is added in an excessive amount, it may cause deterioration of magnetic properties through the formation of inclusions or the like in the steel. Therefore, Zr may be contained in an amount of 0.005 wt% or less. The lower limit is not particularly limited, but it may be 0.0001 weight % due to steelmaking cost. That is, Zr may be contained in an amount of 0.0001 to 0.0050 weight %. More specifically, it may be contained in an amount of 0.0005 to 0.0030 weight %.

Te: 0.0100 wt% or less

[0064] Tellurium (Te) diffuses into an oxide layer on the surface of a hot-rolled coil and may be added to increase a friction coefficient between the oxide layer and a rolling work roll while being concentrated under the oxide layer to improve hardness, thereby allowing the oxide layer crushed during rolling to be removed instead of being pressed into the base material. If the amount of Te added is too small, the effect may be insignificant. If an excessive amount of Te is added, the oxide layer is easily removed and the base material directly contacts the work roll, reducing the effect; furthermore, deformation bands are excessively generated in the steel sheet during cold rolling, so that a {111}//ND texture unfavorable to magnetic properties may develop. More specifically, tellurium may be contained in an amount of 0.0001 to 0.007 weight %.

Mg: 0.0050 wt% or less

[0065] Magnesium (Mg) is an element that mainly combines with S to form sulfides, and may affect the surface oxidation layer of the base steel. Therefore, Mg may be contained in an amount of 0.0050 wt% or less. The lower limit is not particularly limited, but it may be 0.0001 weight % due to steelmaking cost. That is, Mg may be contained in an amount of 0.0001 to 0.0050 weight %. More specifically, it may be contained in an amount of 0.0005 to 0.0030 weight %.

[0066] The balance comprises Fe and inevitable impurities. Inevitable impurities are impurities incorporated during the steelmaking step and the manufacturing process of the non-oriented electrical steel sheet; as these are well known in the art, detailed descriptions thereof are omitted. In an embodiment of the present invention, the addition of elements other than the aforementioned alloy composition is not excluded, and such elements may be included in various ways within a range that does not depart from the technical concept of the present invention. When an additional element is further included, it replaces the balance Fe.

[0067] As described above, in an embodiment of the present invention, by containing appropriate amounts of Mo, V, and Nb, carbides are formed and undergo complex precipitation with TiC or the like, thereby causing coarsening of precipitates and improving magnetic flux density by reducing the number of fine carbides. In an embodiment of the present invention, the number ratio of carbides having a particle diameter of 20 nm or more and comprising at least one of Mo, V, and Nb in an amount of 5 weight % or more, with respect to the total number of carbides in the steel sheet, is 0.2 or more.

[0068] Carbide refers to the aggregation of carbon components in the steel sheet into a particle form. Specifically, it refers to a portion where carbon is contained in an amount greater than the base content of the steel sheet. In an embodiment of the present invention, a carbide is determined to be a particle containing a carbon component and having a carbon-aggregated particle diameter of at least 1 nm when measured by TEM (Transmission Electron Microscopy) and EDS (Energy Dispersive Spectroscopy). The cross-section for the carbide measurement standard is not particularly limited, but may be a plane normal to the transverse direction (TD direction) of the steel sheet (TD plane). The particle diameter of a carbide refers to the diameter of a virtual circle having an area equal to the area

occupied by the carbide.

[0069] In an embodiment of the present invention, a number ratio of carbides having a particle diameter of 20 nm or more and comprising at least one of Mo, V, and Nb in an amount of 5 weight % or more with respect to the total number of carbides in the steel sheet is 0.2 or more. When the particle diameter is too small or many carbides such as TiC containing a small amount of Mo, V, and Nb exist, the movement of magnetic domains may become difficult, and iron loss may increase. When two or more of Mo, V, and Nb are included, it means including them in an amount of 5 weight % or more as a total amount. More specifically, a number ratio of carbides having a particle diameter of 20 nm or more and comprising at least one of Mo, V, and Nb in an amount of 5 weight % or more with respect to the total number of carbides in the steel sheet is 0.2 to 0.5. More specifically, it is 0.21 to 0.35. The carbide ratio may be analyzed by analyzing an image obtained through TEM or SEM and EDS using an image analysis program. In order to reduce deviation according to the measurement position, three or more non-overlapping positions for a specimen of 20 μm x 20 μm or more may be measured, and the ratio may be obtained as the average value thereof.

[0070] In an embodiment of the present invention, the density of carbides may be 2.5/μm^2 or less. If the density of carbides is high, even if the carbide ratio is large, the absolute number of fine carbides increases, which may adversely affect iron loss. More specifically, the density of carbides may be 0.1 to 2.5/μm^2. Even more specifically, it may be 2.00 to 2.45/μm^2. The density of carbides may be obtained in the same manner as the above-described ratio of carbides.

[0071] The size distribution and density of carbides may be controlled by a cooling pattern during annealing before cold rolling, and specific details will be described in relation to a method for manufacturing a non-oriented electrical steel sheet.

[0072] The carbide may comprise at least one of Ti, S, Cr, N, O, and Fe in addition to C.

[0073] In an embodiment of the present invention, the magnetic flux density in the rolling direction and the high-frequency core loss are excellent.

[0074] Specifically, the non-oriented electrical steel sheet according to an embodiment of the present invention may satisfy Equation 1 below.

[Equation 1]

$$(B50_L + B50_C) / 2 \geq 1.60$$

[0075] (In Equation 1, $B50_L$ represents magnetic flux density measured in the rolling direction (B50, Tesla), and $B50_C$ represents magnetic flux density measured in the transverse direction (B50, Tesla).)

[0076] B50 means induced magnetic flux density in a magnetic field of 5000 A/m.

[0077] Equation 1 is basically a general method for evaluating the magnetic flux density of a non-oriented electrical steel sheet, and represents the average value of the magnetic flux densities (B50) in the rolling direction (L) and the transverse direction (C). More specifically, the value of Equation 1 may be in the range of 1.60 to 1.65.

[0078] In addition, the non-oriented electrical steel sheet according to an embodiment of the present invention may satisfy Equation 2 below.

[Equation 2]

$$(W10/400_L + W10/400_C) / 2 \leq 6.885 \times e^{(2.99 \times t)}$$

[0079] (In Equation 2, $W10/400_L$ represents iron loss measured in the rolling direction (W10/400, W/kg), $W10/400_C$ represents iron loss measured in the transverse direction (W10/400, W/kg), e represents a natural constant, and t represents a thickness of the electrical steel sheet (mm).)

[0080] W10/400 is iron loss when a magnetic flux density of 1.0 T is induced at a frequency of 400 Hz.

[0081] Equation 2 achieves a significant reduction in iron loss as a result of securing excellent magnetic flux density according to Equation 1, thereby enabling an increase in motor efficiency. Such iron loss characteristics are influenced by magnetic flux density characteristics, but they are also significantly affected by the thickness of the steel sheet. Accordingly, the iron loss refers to the iron loss that may be secured in a steel sheet exhibiting excellent magnetic flux density in all directions of the steel sheet as in the present invention, depending on the thickness of the steel sheet. More specifically, W10/400 may be 13.5 W/kg or less. Even more specifically, it may be 12.5 to 13.4 W/kg. In this case, the thickness may be 0.25 mm.

[0082] A manufacturing method of a non-oriented electrical steel sheet according to an embodiment of the present invention comprises the steps of: hot rolling a slab to manufacture a hot-rolled steel sheet; annealing before cold

rolling for annealing the steel sheet; cold rolling the annealed steel sheet to manufacture a cold-rolled sheet; and cold-rolled sheet annealing for annealing the cold-rolled sheet.

[0083] Hereinafter, each step will be described in detail.

[0084] First, a slab is hot rolled.

[0085] Since the alloy composition of the slab has been described in relation to the alloy composition of the above-described non-oriented electrical steel sheet, overlapping descriptions will be omitted. Since the alloy composition does not substantially change during the manufacturing process of the non-oriented electrical steel sheet, the alloy composition of the non-oriented electrical steel sheet and that of the slab are substantially the same.

[0086] Specifically, the slab comprises, in weight %, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, and at least one of Mo, V, and Nb: 0.002 to 0.03%, with the balance Fe and inevitable impurities.

[0087] Since other additional elements have been described in the alloy composition of the non-oriented electrical steel sheet, overlapping descriptions will be omitted.

[0088] The slab may be heated before hot rolling. The heating temperature of the slab is not limited, but the slab may be heated to 1200°C or less. If the slab heating temperature is too high, precipitates, such as AlN and MnS, present in the slab may be re-dissolved and then finely re-precipitated during hot rolling and annealing, which may inhibit grain growth and decrease magnetic properties.

[0089] Next, the slab is hot rolled to manufacture a hot-rolled sheet. The thickness of the hot-rolled sheet may be 1.0 to 4.5 mm. In an embodiment of the present invention, preliminary cold rolling before cold rolling may be further included, so that even if the thickness of the hot-rolled sheet is relatively thick, a non-oriented electrical steel sheet of an appropriate thickness may be manufactured. More specifically, the thickness of the hot-rolled sheet may be 1.5 to 3.5 mm.

[0090] The step of hot rolling may comprise finish rolling at a temperature of 850°C or higher.

[0091] If the finishing rolling temperature of hot rolling is too low, the rolling load increases, resulting in decreased hot rolling workability. Furthermore, a large amount of a deformed structure remains in the hot-rolled steel sheet, which may cause an increase in the rolling load during the subsequent process of preliminary cold rolling. In addition, during intermediate annealing, recrystallization of <111>//ND oriented grains from the deformed structure is promoted, thereby causing the magnetic flux density to be inferior. Therefore, a higher hot rolling finish temperature is better, and more specifically, it is preferable to perform finish rolling at a temperature of 860 to 1000°C.

[0092] The step of hot rolling may comprise a step of water cooling after a lapse of 0.1 seconds or more after finish rolling.

[0093] After finish rolling, cooling is performed for coiling. In performing water cooling, if water cooling is performed immediately after finish rolling (i.e., less than 0.1 seconds), the steel sheet is rapidly cooled, which may cause deformation and residual stress in the steel sheet, making coiling difficult. In addition, in terms of microstructure, the deformation stress after finish rolling remains unrelieved, which may cause an increase in rolling load in a subsequent cold rolling step and the formation of fine <111>//ND oriented recrystallized grains. Therefore, maintaining the steel sheet for 0.1 seconds or more so that recovery and recrystallization of the hot rolling deformed structure may occur immediately after hot rolling finish rolling reduces rolling load during subsequent preliminary cold rolling and suppresses the generation of <111>//ND oriented recrystallized grains. More specifically, water cooling may be performed after 0.3 to 5.0 seconds, and even more specifically, water cooling may be performed after 0.5 to 3.0 seconds.

[0094] The step of hot rolling may comprise coiling at a temperature of 600 to 800°C. The method may further comprise a step of rough rolling before the step of finish rolling.

[0095] If the temperature in the coiling step is maintained at an excessively low level, recovery and recrystallization of the hot-rolling deformed structure may not occur sufficiently, the cooling load may increase to rapidly cool the steel sheet to a low temperature, and difficulties may arise in coiling an overcooled coil. Conversely, if the temperature is excessively high, although recovery and recrystallization may be promoted, additional oxidation by atmospheric oxygen may occur during coiling, resulting in the formation of a thicker scale and a potential problem of grain boundary oxidation. Grain boundary oxidation of a hot-rolled sheet is highly likely to promote grain boundary corrosion in a subsequent pickling process, which may cause surface stripe defects, and a rolling roll may be severely worn. Therefore, it is preferable that the coiling process be performed at a temperature of 600 to 800°C, and more specifically, the coiling may be performed at 600 to 750°C.

[0096] After manufacturing the hot-rolled steel sheet, subsequent steps may be performed in a state where scale existing on the hot-rolled steel sheet remains. That is, after hot rolling, scale removal such as pickling, shot blasting, or surface grinding may be omitted, and subsequent steps may be performed. By performing cold rolling in a state where the pickling process is omitted, friction between a rolling work roll and the steel sheet increases, so that a specific orientation develops during recrystallization annealing as shear deformation is applied simultaneously with plane strain deformation during rolling. In an embodiment of the present invention, scale refers to a portion where elements such as Fe, Al, and Si on the surface of the steel sheet combine with oxygen to form a phase different from that of the base material. The expression that scale remains means that scale having a thickness of at least 1 μm remains on the

hot-rolled sheet. In this case, the scale thickness refers to the sum of the scale thicknesses formed on both surfaces of the steel sheet. If the remaining scale thickness is too thin, the effect of the remaining scale may not be sufficiently exhibited. Even if the scale thickness is greater, the effect is not improved, and there is a problem that the yield of the steel sheet decreases. More specifically, scale having a thickness of 0.1 to 1 μm may remain.

[0097] In an embodiment of the present invention, after manufacturing a hot-rolled steel sheet, annealing before cold rolling may be performed by immediately annealing the hot-rolled steel sheet. Alternatively, after performing preliminary cold rolling on the hot-rolled steel sheet, annealing before cold rolling may be performed by annealing the preliminary cold-rolled sheet.

[0098] The preliminary cold rolling is distinguished from the cold rolling described later, in that the preliminary cold rolling is a primary rolling step of a process comprising rolling to an intermediate thickness, instead of the final product thickness, followed by performing intermediate annealing and cold rolling to the final product thickness.

[0099] The preliminary cold rolling may be performed at a reduction ratio in the range of 65 to 80% to improve final cold rolling productivity and grain in a final product plate. In addition, when rolling productivity is not a factor, the preliminary cold rolling may be performed in a reverse rolling mill in the present invention. The preliminary cold-rolled sheet may have a thickness of 0.3 to 1.5 mm. More specifically, the reduction ratio may be 68 to 78% and the thickness may be 0.6 to 1.3 mm.

[0100] The preliminary cold reduction ratio may be obtained as (thickness of steel sheet before rolling - thickness of steel sheet after rolling) / thickness of steel sheet before rolling. If the reduction ratio is too low in the preliminary cold rolling step, the rolling load increases during final cold rolling, thereby decreasing productivity, and a problem of promoting fine <111>//ND orientation recrystallization may occur as the final reduction ratio increases. Conversely, if the reduction ratio is too high, the cold rolling load increases and the possibility of strip breakage also increases.

[0101] The preliminary cold rolling step may be performed at a temperature of 60 to 300°C. This temperature may be reached by an increase in the temperature of the steel sheet due to friction between the steel sheet and the rolling roll, or by applying heat from an external source. If the temperature is too low, the rolling load may increase significantly, and the steel sheet may slip between the rolling rolls instead of being rolled, causing problems such as kinking. If the temperature is too high, a thick oxide layer may be generated on the surface of the steel sheet, magnetic properties may be deteriorated, and problems such as ignition of the rolling oil may occur. More specifically, the step is preferably performed at a temperature of 70 to 250°C. The above-described temperature refers to the temperature of the steel sheet.

[0102] As described above, the preliminary cold rolling step may be omitted as needed.

[0103] Next, in annealing before cold rolling, the hot-rolled steel sheet or preliminary cold-rolled sheet is annealed.

[0104] A soaking temperature in annealing before cold rolling may be 800 to 1200°C. If the annealing temperature is too low, a recrystallized structure is not formed or grows finely, so that the effect of increasing magnetic flux density is small, and if the annealing temperature is too high, magnetic properties are rather lowered, and rolling workability may be worsened due to deformation of a sheet shape. More specifically, the temperature range may be 830 to 1170°C. The soaking time may be 15 to 180 seconds.

[0105] In an embodiment of the present invention, the size distribution of carbides and the density thereof may be controlled by controlling the cooling pattern in annealing before cold rolling.

[0106] In FIG. 1, a cooling pattern in annealing before cold rolling is schematically shown.

[0107] As shown in FIG. 1, annealing before cold rolling comprises: soaking of the steel sheet; first cooling (C_1) of cooling the steel sheet to a first cooling temperature (T_1) at a first cooling rate; and second cooling (C_2) of cooling the steel sheet to a second cooling temperature at a second cooling rate that is 3 to 17°C/sec higher than the first cooling rate.

[0108] In the first cooling step (C_1), the steel sheet is cooled from a soaking temperature (T_0) to a first cooling temperature (T_1) at a first cooling rate. In an embodiment of the present invention, the cooling temperature in the cooling step refers to an average cooling temperature over the entire duration of the cooling step. Although FIG. 1 illustrates the cooling rate as being uniform, the cooling rate may vary over time without affecting the scope of the invention.

[0109] The first cooling temperature (T_1) may be 580 to 770°C. If the first cooling temperature (T_1) is too low, it means that the material has been cooled for a long time at the first cooling rate, and in this case, deformation of the material due to thermal shock, as well as deterioration of magnetic flux density and iron loss due to resultant residual stress, may occur. If the first cooling temperature (T_1) is too high, the first cooling step (C_1) ends prematurely, and fine carbides may be formed, which may cause problems in terms of magnetic flux density and iron loss. In one embodiment of the present invention, the cooling temperature is based on the sheet surface temperature. More specifically, the first cooling temperature (T_1) may be 600 to 750°C.

[0110] The first cooling rate may be 5 to 20°C/sec. If the first cooling rate is too slow, carbides coarsen, which may cause problems in terms of inhibition of grain growth and deterioration of magnetic properties. If the first cooling rate is too fast, a problem may occur in terms of residual stress due to thermal shock. More specifically, the first cooling rate

may be 10 to 15°C/sec.

[0111] Next, in the second cooling step (C_2), the steel sheet is cooled from the first cooling temperature (T_1) to the second cooling temperature (T_2) at a second cooling rate. At this time, the second cooling rate is 3 to 17°C/sec higher than the first cooling rate. When the difference between the second cooling rate and the first cooling rate is small, a problem may occur in that the total annealing time increases and carbide growth is promoted. When the difference between the second cooling rate and the first cooling rate is too large, a problem may occur in that magnetic properties are deteriorated due to residual stress formed by rapid cooling. More specifically, the second cooling rate may be 5 to 15°C/sec higher than the first cooling rate.

[0112] The second cooling temperature (T_2) may be 280 to 370°C. If the second cooling temperature (T_2) is too low, it means that it has been cooled for a long time at the second cooling rate, which may cause a problem in terms of increasing the amount of carbide precipitation. If the second cooling temperature (T_2) is too high, the second cooling step (C_2) ends early, which may cause a problem in that time required for growth of fine carbides is insufficient. More specifically, the second cooling temperature (T_2) may be 300 to 350°C.

[0113] The second cooling rate may be 10 to 30°C/sec. If the second cooling rate is too slow, carbide precipitation may significantly increase. If the second cooling rate is too fast, residual stress due to rapid cooling may increase. More specifically, the second cooling rate may be 15 to 25°C/sec.

[0114] After the second cooling step, it may be cooled to room temperature, but additional cooling and heat insulation may be performed to prevent strip breakage due to material deviation in the width direction and longitudinal direction and shape failure when cooling to room temperature.

[0115] The above-described annealing before cold rolling may be performed in vertical continuous annealing equipment or horizontal continuous annealing equipment. In performing the annealing, a pickling process for removing an oxide layer that may exist on the steel sheet before annealing using sulfuric acid, hydrochloric acid, or nitric acid may be performed; or, alternatively, it is possible to remove an oxide layer remaining on the surface by performing pickling after the annealing.

[0116] Returning to the description of the method for manufacturing a non-oriented electrical steel sheet, the annealed steel sheet is cold-rolled to manufacture a cold-rolled sheet. At this time, the steel sheet may be cold-rolled at a reduction ratio of 30 to 80%. If the reduction ratio is too low, the strain energy accumulated in the rolled steel sheet is small, making it difficult to recrystallize in a subsequent annealing process, such that a rolled structure remains, which may cause a problem in improving the magnetic flux density and iron loss. Conversely, if the reduction ratio is too high, recrystallization of <111>//ND oriented grains is promoted in a subsequent annealing process and the grains also become fine, so that the magnetic flux density is inferior and the iron loss increases. More specifically, the reduction ratio may be 40 to 70%. The thickness may be 0.1 mm to 0.5 mm. More specifically, it may be 0.15 to 0.35 mm. In the cold rolling step, a tandem cold rolling mill that continuously cold-rolls the steel sheet using a plurality of rolling stands or a reverse rolling mill that discontinuously cold-rolls the steel sheet using 12 or more rolling rolls may be used.

[0117] Next, the step of annealing the cold-rolled sheet may be performed in a temperature range of 600 to 1200°C. If the annealing temperature is too low, recrystallization of <111>//ND oriented grains is promoted, and grains also become fine, so that excellent magnetic flux density characteristics may not be secured. If the annealing temperature is too high, grains grow coarsely, so that iron loss increases, and an oxide layer or a nitride layer is generated on the surface of the steel sheet from an annealing atmosphere gas, which may also cause a problem of increasing iron loss. More specifically, the cold-rolled sheet may be annealed at 750 to 1100°C.

[0118] After cold-rolled sheet annealing, a step of forming an insulating coating to secure insulation and corrosion resistance in the steel sheet may be further included. Since the insulating coating is widely known, a specific description thereof will be omitted.

[0119] The present invention will be described in more detail below with reference to examples. However, these examples are provided only for the purpose of illustrating the present invention, and the present invention is not limited thereto.

Example 1

[0120] Slabs having the compositions as shown in Table 1 below were manufactured. The balance is Fe. The slab was heated to 1150°C, hot finish rolled at 920°C, and coiled at 650°C to manufacture a hot-rolled sheet having a thickness of 2.3 mm. Subsequently, the hot-rolled sheet was preliminarily cold rolled to a thickness of 1.5 mm. Subsequently, the sheet was soaked at 1100°C for 30 seconds, subjected to first cooling to 600°C at a cooling rate of 10°C/sec, subjected to second cooling to 350°C at a cooling rate of 15°C/sec, and air-cooled to room temperature. Subsequently, final cold rolling was performed to a thickness of 0.25 mm using a reversing rolling mill, followed by annealing at 900°C for 100 seconds and an insulation coating treatment. Carbides in the steel sheet were measured by TEM and EDS, and the results are summarized in Table 2 below.

[0121] The magnetic properties were measured with an Epstein tester after preparing Epstein specimens for each angle, and the results are summarized in Table 2 below.

[0122] The magnetic flux density and iron loss are expressed as the average values of the rolling direction and the transverse direction.

[Table 1]

No.	Si (wt%)	Al(wt%)	Mn(wt %)	C(ppm)	S(ppm)	N(ppm)	Ti(ppm)	Mo(pp m)	V(ppm)	Nb(pp m)
A1	2.70	1.6	0.7	70	14	16	16	15	50	12
A2	2.70	1.6	0.7	32	15	55	15	20	12	15
A3	2.70	1.6	0.7	28	20	21	20	15	351	35
A4	2.70	1.6	0.7	16	62	32	29	40	125	50
A5	2.70	1.6	0.7	20	23	26	31	50	107	20
A6	2.70	1.6	0.7	25	10	17	24	30	154	15
B1	3.45	0.7	1.2	56	16	32	58	85	-	-
B2	3.45	0.7	1.2	28	22	28	26	-	-	70
B3	3.45	0.7	1.2	26	16	23	14	-	125	-
B4	3.45	0.7	1.2	20	15	27	22	-	100	40
B5	3.45	0.7	1.2	30	23	26	23	10	-	80
B6	3.45	0.7	1.2	45	15	20	32	70	20	-
B7	3.45	0.7	1.2	45	15	20	32	5	5	5

[Table 2]

No.	Carbide density (number/μm^2)	Ratio of Mo, V, Nb carbides of 20 nm or more	B50(T)	W10/400(W/kg)	Remarks
A1	3.25	0.15	1.58	13.6	Comparative Example
A2	2.42	0.10	1.59	13.7	Comparative Example
A3	3.70	0.35	1.57	13.9	Comparative Example
A4	2.80	0.16	1.58	13.8	Comparative Example
A5	2.31	0.24	1.63	12.9	Example
A6	2.45	0.23	1.62	13.4	Example
B1	2.61	0.18	1.57	14.1	Comparative Example
B2	2.83	0.13	1.58	13.9	Comparative Example
B3	2.72	0.15	1.58	14.0	Comparative Example
B4	2.43	0.27	1.61	13.2	Example
B5	2.35	0.26	1.61	13.3	Example
B6	2.38	0.24	1.62	13.0	Example
B7	2.62	0.09	1.59	13.9	Comparative Example

[0123] As shown in Table 1 and Table 2, it may be confirmed that examples, in which the steel composition is appropriately controlled, the process conditions are appropriately controlled, and carbides are appropriately formed, exhibit excellent iron loss and magnetic flux density.

[0124] On the other hand, when the steel composition is not appropriately controlled, carbides may not be appropriately formed, and it can be confirmed that iron loss and magnetic flux density are inferior.

Example 2

[0125] A slab comprising, in weight %, Si: 3.5%, Al: 0.8%, Mn: 1.8%, C: 0.0025%, S: 0.0020%, N: 0.002%, Ti: 0.003%, Mo: 0.007%, V: 0.003%, Nb: 0.004%, and the balance being Fe was heated to 1100°C and then hot-rolled to a thickness of 1.5 mmt. The hot-rolled sheet was annealed under the conditions shown in Table 3 below, and then final cold rolling was performed to a thickness of 0.20 mmt using a tandem rolling mill having a plurality of rolling stands, followed by maintaining the sheet at a temperature of 950°C for 100 seconds, cooling, and performing an insulation coating treatment.

[0126] The magnetic properties and carbide analysis of the final product were performed in the same manner as in Example 1 and are shown in Table 3 and Table 4.

[Table 3]

No.	Soaking temperature(° C)	First cooling rate(°C/s)	First cooling temperature(°C)	Second cooling rate(°C s)	Second cooling temperature(° C)
C1	1000	10	600	15	350
C2	1000	25	600	15	350
C3	900	10	550	15	350
C4	1000	10	800	15	320
C5	900	10	600	15	320
C6	1000	15	600	15	320
C7	850	5	650	15	300
C8	900	10	700	20	320
C9	950	15	750	25	350
C10	1000	5	650	15	300
C11	1050	10	700	20	320
C12	850	10	750	30	350
C13	900	20	650	22	300

[Table 4]

No.	Carbide density (number/μm^2)	Ratio of Mo, V, Nb carbides of 20 nm or more	B50(T)	W10/400(W/kg)	Remarks
C1	2.40	0.21	1.61	13.2	Example
C2	2.83	0.13	1.58	13.8	Comparative Example
C3	2.72	0.15	1.58	13.9	Comparative Example
C4	2.43	0.18	1.58	13.8	Comparative Example
C5	2.35	0.26	1.61	13.1	Example
C6	2.38	0.19	1.59	13.7	Comparative Example
C7	2.31	0.23	1.63	13.0	Example
C8	2.40	0.21	1.62	13.2	Example
C9	2.42	0.22	1.61	13.3	Example
C10	2.34	0.25	1.62	13.2	Example
C11	2.38	0.23	1.62	13.2	Example
C12	2.43	0.16	1.58	13.9	Comparative Example
C13	2.60	0.21	1.59	14.0	Comparative Example

[0127] As shown in Table 3 and Table 4, when the cooling pattern is appropriately controlled during annealing before cold rolling, the carbide properties may be appropriately controlled, resulting in excellent magnetic properties. On the other hand, when the cooling pattern is not appropriately controlled, many carbides or many fine carbides may be generated, resulting in inferior magnetic properties.

[0128] The present invention is not limited to the examples but may be manufactured in various different forms, and a person skilled in the art to which the present invention belongs will understand that the present invention may be carried out in other specific forms without changing the technical idea or essential features of the present invention. Therefore, it should be understood that the examples described above are illustrative in all respects and not restrictive.

Claims

1. A non-oriented electrical steel sheet comprising, in weight %, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, and at least one of Mo, V, and Nb: 0.002 to 0.03%, with the balance Fe and inevitable impurities,
wherein a number ratio of carbides having a particle diameter of 20 nm or more and comprising at least one of Mo, V, and Nb in an amount of 5 weight % or more with respect to the total number of carbides in the steel sheet is 0.2 or more.

2. The non-oriented electrical steel sheet of claim 1,
wherein density of the carbides is $2.5/\mu m^2$ or less.

3. The non-oriented electrical steel sheet of claim 1,
further comprising at least one of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

4. The non-oriented electrical steel sheet of claim 1,
further comprising one or more elements of Sn, Sb, Bi, Pb, Ge, and As in an amount of 0.005 to 0.200 weight % each or in total.

5. The non-oriented electrical steel sheet of claim 1,
further comprising at least one of Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

6. The non-oriented electrical steel sheet of claim 1,
further comprising at least one of B: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

7. A method for manufacturing a non-oriented electrical steel sheet comprising steps of:

   hot rolling a slab comprising, in weight %, Si: 1.5 to 4.5%, Al: 0.1 to 2.0%, Mn: 0.1 to 2.0%, and at least one of Mo, V, and Nb: 0.002 to 0.03%, with the balance Fe and inevitable impurities, to manufacture a hot-rolled steel sheet;
   annealing before cold rolling for annealing the steel sheet;
   cold rolling the annealed steel sheet to manufacture a cold-rolled sheet; and
   cold-rolled sheet annealing for annealing the cold-rolled sheet,
   wherein the annealing before cold rolling comprises soaking of the steel sheet;
   first cooling of cooling the steel sheet to a first cooling temperature at a first cooling rate; and
   second cooling of cooling the steel sheet to a second cooling temperature at a second cooling rate that is 3 to 17°C/sec higher than the first cooling rate.

8. The method for manufacturing a non-oriented electrical steel sheet of claim 7,
wherein the slab further comprises at least one of P: 0.1 wt% or less (excluding 0%), C: 0.005 wt% or less (excluding 0%), S: 0.005 wt% or less (excluding 0%), Ti: 0.005 wt% or less (excluding 0%), and N: 0.005 wt% or less (excluding 0%).

9. The method for manufacturing a non-oriented electrical steel sheet of claim 7,
wherein the slab further comprise one or two or more of Sn, Sb, Bi, Pb, Ge, and As in an amount of 0.005 to 0.200

weight % for each or for the total amount thereof.

10. The method for manufacturing a non-oriented electrical steel sheet of claim 7, wherein the slab further comprises at least one of Cu: 0.005 to 0.2 wt%, Cr: 0.01 to 0.5 wt%, Ni: 0.05 wt% or less (excluding 0%), Zn: 0.01 wt% or less (excluding 0%), and Co: 0.05 wt% or less (excluding 0%).

11. The method for manufacturing a non-oriented electrical steel sheet of claim 7, wherein the slab further comprises at least one of B: 0.0050 wt% or less (excluding 0%), Ca: 0.0050 wt% or less (excluding 0%), Zr: 0.005 wt% or less (excluding 0%), Te: 0.01 wt% or less (excluding 0%), and Mg: 0.0050 wt% or less (excluding 0%).

12. The method for manufacturing a non-oriented electrical steel sheet of claim 7, wherein, the hot rolling to manufacture the hot-rolled steel sheet, subsequent steps are performed in a state where scale existing on the hot-rolled steel sheet remains.

13. The method for manufacturing a non-oriented electrical steel sheet of claim 7, further comprising preliminary cold rolling on the hot-rolled sheet before the annealing before cold rolling.

14. The method for manufacturing a non-oriented electrical steel sheet of claim 13, wherein reduction ratio in the preliminary cold rolling is 65% to 80%.

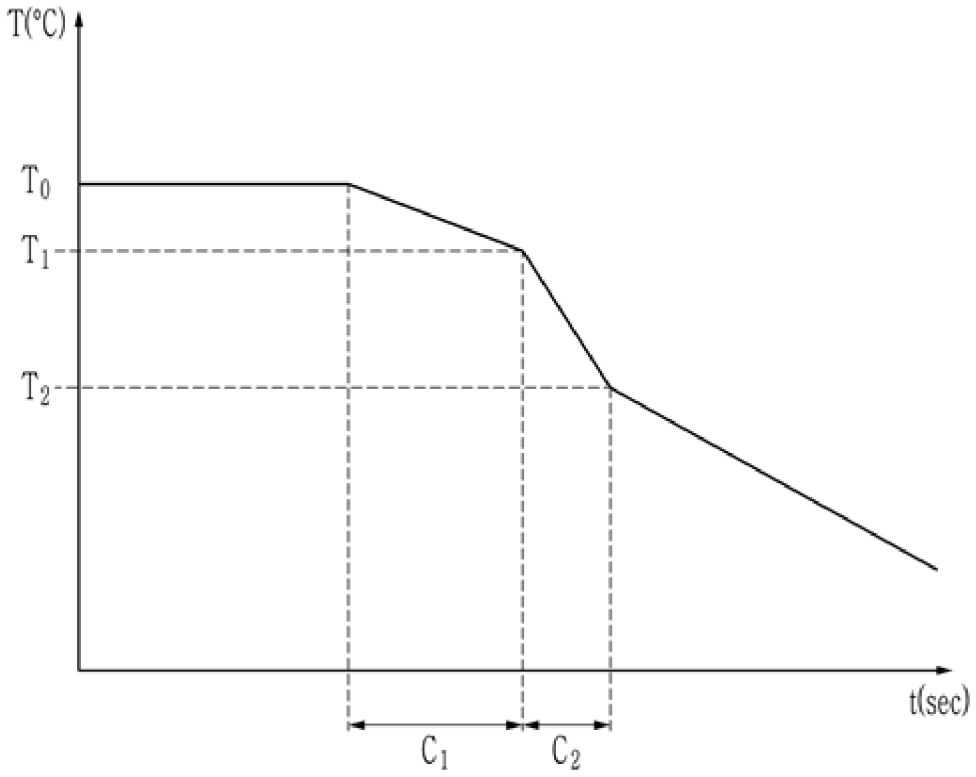
15. The method for manufacturing a non-oriented electrical steel sheet of claim 7, wherein the soaking temperature of the annealing before cold rolling is 800 to 1200°C.

16. The method for manufacturing a non-oriented electrical steel sheet of claim 7, wherein the first cooling temperature is 580 to 770°C.

17. The method for manufacturing a non-oriented electrical steel sheet of claim 7, wherein the second cooling temperature is 280 to 370°C.

18. The method for manufacturing a non-oriented electrical steel sheet of claim 7, wherein the first cooling rate is 5 to 20°C/sec, and the second cooling rate is 10 to 30°C/sec.

FIG. 1



INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2024/063285

A. CLASSIFICATION OF SUBJECT MATTER

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

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C22C 38/02(2006.01); C09D 7/61(2018.01); C21D 8/12(2006.01); C22C 38/00(2006.01); C22C 38/60(2006.01); H01F 1/16(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: 탄화물(carbide), 열연판 소둔(hot rolled plate annealing), 균열(crack), 냉각(cooling), 무방향성(non-oriented)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 6341281 B2 (NIPPON STEEL & SUMITOMO METAL CORPORATION) 13 June 2018 (2018-06-13) See paragraph [0052] and claims 1 and 3-4.	1-18
Y	JP 2002-356718 A (NIPPON STEEL CORP.) 13 December 2002 (2002-12-13) See paragraph [0032] and table 2.	1-18
Y	KR 10-2020-0066492 A (POSCO) 10 June 2020 (2020-06-10) See claim 3.	2
Y	KR 10-2020-0066510 A (POSCO) 10 June 2020 (2020-06-10) See claim 6.	12
Y	KR 10-2015-0073787 A (POSCO) 01 July 2015 (2015-07-01) See claim 1.	13-14

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

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Date of the actual completion of the international search	Date of mailing of the international search report
15 April 2025	**15 April 2025**
Name and mailing address of the ISA/KR **Korean Intellectual Property Office** **Government Complex-Daejeon Building 4, 189 Cheongsa-ro, Seo-gu, Daejeon 35208** Facsimile No. **+82-42-481-8578**	Authorized officer Telephone No.

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB2024/063285

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