ABSTRACT

A non-directional electrical steel sheet according to an embodiment of the present disclosure includes, in wt %, 2.5 to 3.3 wt % of Si, 0.05 to 1 wt % of Al, 0.05 to 1 wt % of Mn, 0.01 wt % or less of (not including 0 wt %) S, 0.005 wt % or less of (not including 0 wt %) N, 0.005 wt % or less of (not including 0 wt %) C, 0.005 wt % or less of (not including 0 wt %) Ti, 0.005 wt % or less of (not including 0 wt %) P, 0.001 to 0.1 wt % of P, 0.001 to 0.1 wt % of Sn, and 0.001 to 0.1 wt % of Sb, with the remainder being Fe and unavoidable impurities, and satisfies Formulas 1 to 3 below.

\[ 1.74\% \text{Si} + (\%\text{Al}) + (\%\text{Mn}) \leq 2.9 \]  
\[ 50 \times 10^{-3} \times (\%\text{Si}) + (\%\text{Al}) + (\%\text{Mn}) \leq 0.05 \]  
\[ 0.025 \times (\%\text{P}) + (\%\text{Sn}) + (\%\text{Sb}) \leq 0.15 \] 

(In Formulas 1 to 3, [Si], [Al], [Mn], [P], [Sn], and [Sb] represent the content (in wt %) of Si, Al, Mn, P, Sn, and Sb, respectively.)
NON-Oriented Electrical steel Sheet and Method for Manufacturing the Same

Technical Field

[0001] The present disclosure relates to a non-directional electrical steel sheet and a method for manufacturing the same.

Background Art

[0002] A non-directional electrical steel sheet is mainly used in a device to convert electrical energy into mechanical energy, and it requires excellent magnetic properties in order to achieve high efficiency in this process. The magnetic properties include core loss and flux density. Accordingly, when the core loss is low, the energy loss in the energy conversion process can be reduced, and when the flux density is high, greater power can be generated with the same electric energy. Therefore, energy efficiency of the motor can be increased when the non-directional electrical steel sheet has a lower core loss and a higher flux density. Generally, elements that increase specific resistivity are added or steel sheet is rolled to a thin thickness to reduce the core loss of a non-directional electrical steel sheet.

[0003] The typical method of increasing the magnetic properties of non-directional electrical steel sheet is to add Si as an alloy element. While the addition of Si increases the specific resistivity of the steel, and thus provides an advantage of reduced high-frequency core loss, this also results in inferior flux density and deteriorated machinability. That is, addition of too much Si can hinder cold rolling. In particular, the electrical steel sheet for high frequency applications can have less core loss when it is made with thinner thickness, but the deteriorated machinability due to the addition of Si can serve as a fatal problem for the rolling of a thin film. Other specific-resistivity-increasing elements such as Al and Mn may be added to overcome the machinability degradation due to Si addition.

[0004] The addition of these elements may reduce the core loss, but there is a disadvantage that the flux density is deteriorated due to increased total alloy amount, and that the increased hardness of the material and deterioration of machinability also hinder cold rolling. In addition, Al and Mn can combine with impurities unavoidably present in the steel sheet to minutely precipitate nitrides, sulfides, etc., in which case core loss can be further increased. For this reason, a method is used, which controls impurities at a very low level in the steelmaking step of the non-directional electrical steel sheet to suppress the generation of fine precipitates that impede the movement of the magnetic wall, thereby lowering the core loss. However, the method for improving the core loss by way of high cleanliness of steel has the drawback that it is not effective in improving the flux density, and it serves as a factor that rather lowers the steel workability and increases the cost.

[0005] In order to improve the magnetic properties of non-directional electrical steel sheet, various methods have been proposed, such as thinning the product thickness, adding special elements to improve magnetic properties, or optimizing the grain size and texture. Some methods have been proposed, examples of which include a method of improving the magnetic properties of non-directional electrical steel sheet by adding REM, a method of making large grain size after annealing the hot rolled sheet and performing cold rolling and recrystallization annealing, a method of improving the magnetic properties by retaining the [001]//ND orientation from the columnar grains using the slab having a thickness of 50 mm or less, and the like. However, there is a problem in that when these methods are applied to the actual production process, the cost increases sharply, or the production using the existing facilities is impossible, or the productivity drops considerably.

Disclosure

Technical Problem

[0006] The present invention has been made in an effort to provide a non-directional electrical steel sheet with excellent magnetic properties as well as high productivity, by precisely controlling the contents of Si, Al and Mn among the additive components of steel.

[0007] Another embodiment of the present disclosure is to provide a method for manufacturing a non-directional electrical steel sheet.

Technical Solution

[0008] A non-directional electrical steel sheet according to an embodiment of the present disclosure includes, in wt %, 2.5 to 3.3 wt % of Si, 0.05 to 1 wt % of Al, 0.05 to 1 wt % of Mn, 0.01 wt % or less of (not including 0 wt %) S, 0.005 wt % or less of (not including 0 wt %) N, 0.005 wt % or less of (not including 0 wt %) C, 0.005 wt % or less of (not including 0 wt %) Ti, 0.005 wt % or less of (not including 0 wt %) Nb, 0.001 to 0.1 wt % of P, 0.001 to 0.1 wt % of Sn, 0.001 to 0.1 wt % of Sb, with the remainder being Fe and unavoidable impurities, and satisfies Formulas 1 to 3 below.

\[1.76\times[\text{Si}]+[\text{Al}]+[\text{Mn}]\leq 2.9 \quad \text{(Formula 1)}\]

\[5\leq 13.35\times[\text{Si}]+[\text{Al}]+[\text{Mn}]\leq 60 \quad \text{(Formula 2)}\]

\[0.025\times[\text{P}]+[\text{Sn}]+[\text{Sb}]\leq 0.15 \quad \text{(Formula 3)}\]

[0009] (In Formulas 1 to 3, [Si], [Al], [Mn], [P], [Sn], and [Sb] represent the content (in wt %) of Si, Al, Mn, P, Sn, and Sb, respectively).

[0010] The non-directional electrical steel sheet may further include 0.001 wt % or less of (not including 0 wt %) B, 0.005 wt % or less of (not including 0 wt %) Mg, Zr and V and 0.025 wt % or less of (not including 0 wt %) Cu.

[0011] The density calculated by Formula 4 below may be 7.57 to 7.67 g/cm³.

\[7.865\times[\text{Si}]+0.016\times[\text{Al}]+0.00589\times[\text{Mn}]\] \quad \text{(Formula 4)}

[0012] (In Formula 4, [Si], [Al] and [Mn] represent the contents (in wt %) of Si, Al and Mn, respectively.)

[0013] Tensile test elongation may be 2% or higher.

[0014] The thickness may be 0.10 to 0.35 mm.

[0015] A method for manufacturing a non-directional electrical steel sheet according to an embodiment of the present disclosure includes steps of: heating a slab including, in wt %, 2.5 to 3.3 wt % of Si, 0.05 to 1 wt % of Al, 0.05 to 1 wt % of Mn, 0.01 wt % or less of (not including 0 wt %) S, 0.005 wt % or less of (not including 0 wt %) N, 0.005 wt % or less of (not including 0 wt %) C, 0.005 wt % or less of (not including 0 wt %) Ti, 0.005 wt % or less of (not including 0 wt %) Nb, 0.001 to 0.1 wt % of P, 0.001 to 0.1
wt % of Sn, and 0.001 to 0.1 wt % of Sb, with the remainder being Fe and unavoidable impurities, and satisfying Formulas 1 to 3 below and then hot rolling the slab to manufacture a hot rolled sheet; cold rolling the hot rolled sheet to manufacture a cold rolled sheet; and recrystallization annealing the cold rolled sheet.

\[ 1.78[Si][Al]+[Mn]/2=2.9 \]  
\[ 50\times 13.25+11.3\times [Si]+[Al]+[Mn]/2=60 \]  

[Formula 1]  
[Formula 2]

[0016] In Formulas 1 and 2, [Si], [Al], and [Mn] represent the contents (in wt %) of Si, Al, and Mn, respectively.

[0017] The step of manufacturing the hot rolled sheet may include heating the slab to 1100 to 1200°C.

[0018] The step of manufacturing the hot rolled sheet may include hot rolling at a finishing temperature of 800 to 1000°C.

[0019] After the step of manufacturing the hot rolled sheet, the method may further include a step of annealing at a temperature of 850 to 1150°C.

[0020] The slab may further include 0.001 wt % or less of (not including 0 wt %) B, 0.005 wt % or less of (not including 0 wt %) Mg, Zr, V and 0.025 wt % or less of (not including 0 wt %) Cu.

[0021] The density of the manufactured steel sheet calculated by Formula 4 may be 7.57 to 7.67 g/cm³.

\[ 7.654+(-0.0651\times [Si]-0.0127\times [Al]+0.00589\times [Mn]) \]  

[Formula 4]

[0022] In Formula 4, [Si], [Al] and [Mn] represent the contents (in wt %) of Si, Al and Mn, respectively.

[0023] The manufactured steel sheet may have a tensile test elongation of 24% or more.

[0024] The step of manufacturing the cold rolled sheet may include cold rolling to a thickness of 0.10 to 0.35 mm.

Advantageous Effects

[0025] The non-directional electrical steel sheet according to an embodiment of the present disclosure has excellent magnetic properties as well as superior productivity.

MODE FOR INVENTION

[0026] The terms “first,” “second” and “third” as used herein are intended to describe various parts, components, regions, layers and/or sections, but not construed as limiting. These terms are merely used to distinguish any parts, components, regions, layers and/or sections from another parts, components, regions, layers and/or sections. Accordingly, a first part, component, region, layer or section to be described below may be referred to as a second part, component, region, layer or section without departing from the scope of the present disclosure.

[0027] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to limit the present disclosure. The singular forms used herein include plural forms as long as the phrases do not expressly mean to the contrary. As used herein, the meaning of “comprising” specifies specific features, regions, integers, steps, operations, elements and/or components, and does not exclude the presence or the addition of other features, regions, integers, steps, operations, elements and/or components.

[0028] When a portion is referred to as being “above” or “on” another portion, it may be directly on another portion or may be accompanied by yet another portion disposed in between. In contrast, when a portion is referred to as being “directly above” another portion, no other portion is interposed in between.

[0029] Unless otherwise defined, all terms including technical and scientific terms used herein have the same meaning as commonly understood by those with ordinary knowledge in the art to which this invention belongs. Terms defined in the generally available dictionaries have a meaning corresponding to a related technology document and presently disclosed contents and are not analyzed as an ideal or very official meaning unless stated otherwise.

[0030] In addition, unless otherwise stated, % means wt %, and 1 ppm is 0.0001 wt %.

[0031] Hereinafter, preferred embodiments of the present disclosure will be described in detail to help those with ordinary knowledge in the art easily achieve the present disclosure. 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 invention.

[0032] A non-directional electrical steel sheet according to an embodiment of the present disclosure includes, in wt %, 2.5 to 3.3 wt % of Si, 0.05 to 1 wt % of Al, 0.05 to 1 wt % of Mn, 0.01 wt % or less of (not including 0 wt %) S, 0.005 wt % or less of (not including 0 wt %) N, 0.005 wt % or less of (not including 0 wt %) Ti, 0.005 wt % or less of (not including 0 wt %) Nb, 0.001 to 0.1 wt % of P, 0.001 to 0.1 wt % of Sn, and 0.001 to 0.1 wt % of Sb, with the remainder being Fe and unavoidable impurities.

[0033] First, the reason for limiting the components of non-directional electrical steel sheet is explained.

[0034] Si: 2.5 to 3.3 wt %

[0035] Silicon (Si) plays a role of increasing the specific resistivity of the material to decrease the core loss. Addition of Si in an insufficient amount can result in less than desired improvement of the high-frequency core loss. On the contrary, addition of too much Si can cause increased brittleness of the material, resulting in drastically deteriorated rolling productivity. Accordingly, Si may be added in the range described above.

[0036] Al: 0.05 to 1 wt %

[0037] Likewise Mn, aluminum (Al) plays a role of increasing the specific resistivity to lower the core loss. The specific resistivity increase by Al is lower than that of Si, but when added in the proper amount, Al can increase the specific resistivity while maintaining the rolling properties. Addition of Al in an insufficient amount considerably reduces the effect of improving the high-frequency core loss, and also causes formation of fine nitride and sulfide, which results in deteriorated magnetic properties. On the contrary, addition of too much Al can drastically deteriorate the magnetic properties or rolling properties. Accordingly, Al may be added in the range described above.

[0038] Mn: 0.05 to 1 wt %

[0039] Likewise Al, Manganese (Mn) plays a role of increasing the specific resistivity to decrease the core loss. Addition of Mn in an insufficient amount considerably reduces the effect of improving the high-frequency core loss, and also causes formation of fine nitride and sulfide, which results in deteriorated magnetic properties. On the contrary, addition of too much Mn can drastically deteriorate the
magnetic properties or rolling properties. Accordingly, Mn may be added in the range described above.

[0040] S: 0.01 wt % or less

[0041] Sulfur (S) is an element unavoidably present in the steel to form fine precipitates such as MnS, CuS, and like to deteriorate the magnetic properties. It is thus desired to limit S to 0.01 wt % or less or more specifically, to 0.005 wt % or less.

[0042] N: 0.005 wt % or less

[0043] Nitrogen (N) not only forms fine and long AlN precipitates in the base material, but also combines with other impurities to form fine nitride that suppresses the grain growth and exacerbates the core loss. It is thus desirable to limit N to 0.005 wt % or less, or more specifically, to 0.003 wt % or less.

[0044] C: 0.005 wt % or less

[0045] Carbon (C) causes self-ageing and combines with other impurity elements to produce carbide, thus deteriorating the magnetic properties. It is thus desirable to limit C to 0.005 wt % or less, or more specifically, to 0.003 wt % or less.

[0046] Ti: 0.005 wt % or less, Nb: 0.005 wt % or less

[0047] Titanium (Ti) and Niobium (Nb) form carbides or nitrides to deteriorate core loss and promote development of {111} texture detrimental to the magnetic properties. It is thus desirable to limit Ti and Nb to 0.005 wt % or less, or more specifically, to 0.003 wt % or less.

[0048] P: 0.001 to 0.1 wt %, Sn: 0.001 to 0.1 wt %, Sb: 0.001 to 0.1 wt %

[0049] Phosphorus (P), tin (Sn), and antimony (Sb) are segregated on the surfaces and the grain boundaries of the steel sheet, playing a role of inhibiting the surface oxidation and inhibiting recrystallization of the {111}/ND orientation in the annealing process, thus improving the texture. If any of these elements is added in an insufficient amount, effect thereof is considerably deteriorated, and if the elements are added more than necessary, an increase in the amount of grain boundary segregation suppresses grain growth, thus deteriorating core loss and lowering the toughness of steel, and deteriorating productivity, which is not desirable. In particular, when the sum of P, Sn, and Sb is limited to 0.025 to 0.15 wt %, the surface oxidation inhibition and texture improvement effect are maximized and the magnetic properties are remarkably improved.

[0050] Other Impurities

[0051] In addition to the elements described above, unavoidable impurities, such as B, Mg, Zr, V, and Cu may be incorporated. Although these elements are in trace amounts, they may still cause deterioration of magnetic properties through formation of dross in the steel, and so on, and accordingly, the elements are managed to satisfy the following conditions: B: 0.001 wt % or less, Mg, Zr, V: 0.005 wt % or less, and Cu: 0.025 wt % or less.

[0052] The non-directional electrical steel sheet according to an embodiment of the present disclosure satisfies Formulas 1 to 3 below.

\[ 1.74[Si]+[Al]+[Mn] = 2.9 \]  \hspace{1cm} \text{[Formula 1]}

\[ 50[Si]+13.25+[Al]+[Mn] = 60 \]  \hspace{1cm} \text{[Formula 2]}

\[ 0.025[Si]+[Sn]+[Sb] = 0.15 \]  \hspace{1cm} \text{[Formula 3]}

[0053] In Formulas 1 to 3, [Si], [Al], [Mn], [P], [Sn], and [Sb] represent the content (in wt %) of Si, Al, Mn, P, Sn, and Sb, respectively.

[0054] When Formulas 1 to 3 are satisfied, both excellent magnetic properties and excellent rolling properties are provided, but outside this range, the magnetic properties or the rolling properties may deteriorate rapidly.

[0055] The non-directional electrical steel sheet according to an embodiment of the present disclosure may have a density of 7.57 to 7.67 g/cm^3, as calculated by Formula 4 below. When the density is less than 7.57g/cm^3, the flux density may be deteriorated or the rolling properties may be decreased rapidly. When the density exceeds 7.67 g/cm^3, the core loss may be deteriorated and especially the high-frequency core loss may be seriously deteriorated. Accordingly, the density may be regulated to the range described above.

[0056] The non-directional electrical steel sheet according to an embodiment of the present disclosure may have a tensile test elongation of 24% or higher. When the elongation is less than 24%, the rolling property is deteriorated and results in deteriorated productivity. More specifically, the elongation may be 28 to 34%.

[0057] A method for manufacturing a non-directional electrical steel sheet according to an embodiment of the present disclosure includes steps of: heating a slab including, in wt %, 2.5 to 3.3 wt % of Si, 0.05 to 1 wt % of Al, 0.05 to 1 wt % of Mn, 0.01 wt % or less of (not including 0 wt %) S, 0.005 wt % or less of (not including 0 wt %) C, 0.005 wt % or less of (not including 0 wt %) Ti, 0.005 wt % or less of (not including 0 wt %) Nb, 0.001 to 0.1 wt % of P, and 0.001 to 0.1 wt % of Sn, and 0.001 to 0.1 wt % of Sb, with the remainder being Fe and unavoidable impurities, and satisfying Formulas 1 to 3 below and then hot rolling the slab to manufacture a hot rolled sheet; cold rolling the hot rolled sheet to manufacture a cold rolled sheet; and recrystallization annealing the cold rolled sheet.

\[ 1.74[Si]+[Al]+[Mn] = 2.9 \]  \hspace{1cm} \text{[Formula 1]}

\[ 50[Si]+13.25+[Al]+[Mn] = 60 \]  \hspace{1cm} \text{[Formula 2]}

\[ 0.025[Si]+[Sn]+[Sb] = 0.15 \]  \hspace{1cm} \text{[Formula 3]}

[0058] In Formulas 1 to 3, [Si], [Al], [Mn], [P], [Sn], and [Sb] represent the content (in wt %) of Si, Al, Mn, P, Sn, and Sb, respectively.

[0059] First, the slab is heated and then hot rolled to a slab temperature. The reason for limiting the addition ratio of each composition is the same as the reason for limiting the composition of the non-directional electrical steel sheet described above. Since the composition of the slab does not substantially change during hot rolling, hot rolled sheet annealing, cold rolling, and recrystallization annealing, and the like, will be described below, the composition of the slab remains substantially the same as that of the non-directional electrical steel sheet.

[0060] The slab is charged into a furnace and then heated to 1100 to 1200°C.

[0061] The heated slab is hot rolled to 2 to 2.3 mm to manufacture a hot rolled sheet. The finish temperature at the step of manufacturing the hot rolled sheet may be 800 to 1000°C.

[0062] The hot rolled sheet is subjected to hot rolled sheet annealing at a temperature of 850 to 1150°C.
C. When the hot rolled sheet annealing temperature is lower than 850°C, the structure does not grow or grows too minimally to increase the flux density, and when the annealing temperature is higher than 1150°C, the magnetic properties are rather deteriorated and the rolling workability may deteriorate due to the deformation of the sheet shape. Accordingly, the temperature range is limited to 850 to 1150°C. More preferably, the annealing temperature of the hot rolled sheet may be 950 to 1150°C. The hot rolled sheet annealing may be performed as necessary, to increase the orientation favorable to the magnetic property, or may be omitted. The average grain diameter after the hot rolled sheet annealing may preferably be 120 μm or higher.

**0064** After the hot rolled sheet annealing, the hot rolled sheet is pickled and cold rolled to a predetermined thickness. While different thicknesses may be applied depending on the thickness of the hot rolled sheet, the hot rolled sheet may be cold rolled to a final thickness of 0.10 to 0.35 mm by applying a reduction ratio of about 70 to 95%.

**0065** The cold rolled sheet after final cold rolling is then subjected to final recrystallization annealing. When the final recrystallization annealing temperature is too low, sufficient recrystallization does not occur, and when the final recrystallization annealing temperature is too high, rapid grain growth occurs and, resulting in deteriorated flux density and high-frequency core loss. Accordingly, it is desirable to perform the final recrystallization annealing at a temperature of 850 to 1150°C.

**0066** The recrystallization annealing sheet is treated with an insulating coating and shipped to the customer. The insulating coating may include an organic, inorganic or organic-inorganic composite coating, and other coatings having insulating property may be used. The customer may use the steel sheet as it is, or may use it after performing stress relieving annealing, if necessary.

**0067** Hereinafter, the present disclosure is explained in more detail with reference to Examples. However, the Examples are described merely to illustrate the present disclosure, and the present disclosure is not limited thereto.

**EXAMPLE 1**

The slab composed as shown in Table 1 was heated at 1100°C and hot rolled at a finish temperature of 870°C to prepare a hot rolled sheet having a thickness of 2.3 mm. The hot rolled sheet was annealed at 1000°C for 100 seconds, pickled, cold rolled to 0.35 mm thickness, and then subjected to final recrystallization annealing at 1000°C for 110 seconds. Values of [Si]/([Al]+[Mn]), 13.25±11.3*(Si)+[Al]+[Mn]/2, and P+[Sn]+[Sb], density, flux density (B50), core loss (W15/50), high-frequency core loss (W10/400), and the bend test results and elongation with respect to the respective specimens are summarized in Table 2 below.

**0069** The density was expressed by the value calculated by the formula 7.865*(1-0.611*([Si]-0.102*[Al]+0.005891*[Mn])). For magnetic properties such as flux density, core loss and high-frequency core loss, at least three specimen sheets in 60mm*60mm size were cut for each specimen, and then the magnetic properties in the vertical direction and the rolling direction were measured with a single sheet tester. The averages of the measurements obtained in the two directions are listed. In this case, ‘B50’ refers to the flux density induced in the magnetic field of 5000 A/m, ‘W15/50’ is the core loss when the 1.5-T flux density is induced at the frequency of 50 Hz, and ‘W10/400’ refers to the core loss when the flux density of 1.0 T is induced at the frequency of 400 Hz. The bend test was carried out to predict the rolling productivity. After the hot rolled sheet annealing, 2.3 mm-thick specimen was cut into 300 mm*35 mm size, and subjected to the adhesion bend test at room temperature. The result was marked ‘poor’ when there occurred fracture such as crack at the outer bent surfaces and edges, or marked ‘good’ when there was no crack. The elongation was expressed by the value obtained by tensile test according to JIS-S specification.

**TABLE 1**

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<th>Specimen No.</th>
<th>Si (%)</th>
<th>Al (%)</th>
<th>Mn (%)</th>
<th>P (%)</th>
<th>S (%)</th>
<th>Sb (%)</th>
<th>C (%)</th>
<th>S (%)</th>
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<th>Ti (%)</th>
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<td>0.0011</td>
<td>0.0023</td>
<td>0.0014</td>
<td>0.0017</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE 2**

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Formula Value</th>
<th>Formula Value</th>
<th>Formula Value</th>
<th>Density [k2/m2]</th>
<th>B50 (T)</th>
<th>W15/50 (W/kg)</th>
<th>W10/400 (W/kg)</th>
<th>Bend test</th>
<th>Elongation Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>2.19</td>
<td>1.93</td>
<td>0.087</td>
<td>7.563</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Poor</td>
<td>X Comp. Ex.</td>
</tr>
<tr>
<td>A2</td>
<td>2.75</td>
<td>1.71</td>
<td>0.096</td>
<td>7.584</td>
<td>1.44</td>
<td>2.13</td>
<td>1.62</td>
<td>Poor</td>
<td>13.7 Comp. Ex.</td>
</tr>
<tr>
<td>A3</td>
<td>3.67</td>
<td>2.02</td>
<td>0.059</td>
<td>7.064</td>
<td>1.65</td>
<td>2.16</td>
<td>16.8</td>
<td>Poor</td>
<td>14.4 Comp. Ex.</td>
</tr>
<tr>
<td>A4</td>
<td>2.86</td>
<td>1.72</td>
<td>0.096</td>
<td>7.607</td>
<td>1.68</td>
<td>2.03</td>
<td>15.7</td>
<td>Good</td>
<td>29.0 Ex.</td>
</tr>
</tbody>
</table>
As shown in Table 1 and Table 2, Examples A4, A5, A7, A8, A10, A11, and A12 satisfying the conditions of the present disclosure exhibited excellent magnetic properties, and both good bend test results and good elongation. On the other hand, Examples A3 and A6 having [Si][Al][Mn] above the range of the present disclosure exhibited inferior magnetic properties or poor bend test results and elongation, and Examples A9 and A13 having [Si][Al][Mn] below the range of the present invention also exhibited inferior magnetic properties or poor bend test results and elongation. Examples A2 and A14 having 13.25+11.3*([Si][Al][Mn][2]) above or below the range of the present disclosure also exhibited inferior magnetic properties or poor bend test results and elongation.

EXAMPLE 2

The slab composed according to Tables 3 and 4 were heated at 1130℃ and hot rolled at a finish temperature of 870℃ to prepare a 2.0 mm-thick hot rolled sheet. The hot rolled sheet was annealed at 1030℃ for 100 seconds, pickled, and then cold rolled to 0.35 mm thickness, and subjected to final recrystallization annealing at 990℃ for 110 seconds. Values of [Si][Al] and [Mn], 13.25+11.3*([Si][Al][Mn][2]), and [P][Sn][Sb], flux density (B50), high-frequency core loss (W10/400), and the bend test results and elongation with respect to the respective specimens are summarized in Table 5 below.
TABLE 5

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Formula 1 Value</th>
<th>Formula 2 Value</th>
<th>Formula 3 Value</th>
<th>BS(T)</th>
<th>W15/50 (W/kg)</th>
<th>W10/400 (W/kg)</th>
<th>Bending test</th>
<th>Elongation</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>2.64</td>
<td>56.76</td>
<td>0.104</td>
<td>1.70</td>
<td>1.98</td>
<td>15.3</td>
<td>Good</td>
<td>29.7</td>
<td>Ex.</td>
</tr>
<tr>
<td>B2</td>
<td>2.64</td>
<td>56.76</td>
<td>0.076</td>
<td>1.70</td>
<td>2.02</td>
<td>15.4</td>
<td>Good</td>
<td>30.2</td>
<td>Ex.</td>
</tr>
<tr>
<td>B3</td>
<td>2.64</td>
<td>56.76</td>
<td>0.032</td>
<td>1.70</td>
<td>1.99</td>
<td>15.2</td>
<td>Good</td>
<td>29.9</td>
<td>Ex.</td>
</tr>
<tr>
<td>B4</td>
<td>2.64</td>
<td>56.76</td>
<td>0.065</td>
<td>1.66</td>
<td>2.14</td>
<td>16.9</td>
<td>Good</td>
<td>28.9</td>
<td>Comp. Ex.</td>
</tr>
<tr>
<td>B5</td>
<td>2.64</td>
<td>56.76</td>
<td>0.073</td>
<td>1.67</td>
<td>2.20</td>
<td>17.1</td>
<td>Good</td>
<td>30.7</td>
<td>Comp. Ex.</td>
</tr>
<tr>
<td>B6</td>
<td>2.64</td>
<td>56.76</td>
<td>0.089</td>
<td>1.67</td>
<td>2.15</td>
<td>17.0</td>
<td>Good</td>
<td>30.2</td>
<td>Comp. Ex.</td>
</tr>
<tr>
<td>B7</td>
<td>2.64</td>
<td>56.76</td>
<td>0.018</td>
<td>1.66</td>
<td>2.14</td>
<td>17.4</td>
<td>Good</td>
<td>31.1</td>
<td>Comp. Ex.</td>
</tr>
<tr>
<td>C1</td>
<td>2.16</td>
<td>53.37</td>
<td>0.105</td>
<td>1.71</td>
<td>2.03</td>
<td>15.9</td>
<td>Good</td>
<td>31.2</td>
<td>Ex.</td>
</tr>
<tr>
<td>C2</td>
<td>2.16</td>
<td>53.37</td>
<td>0.067</td>
<td>1.71</td>
<td>2.01</td>
<td>15.6</td>
<td>Good</td>
<td>30.1</td>
<td>Ex.</td>
</tr>
<tr>
<td>C3</td>
<td>2.16</td>
<td>53.37</td>
<td>0.076</td>
<td>1.71</td>
<td>2.01</td>
<td>15.7</td>
<td>Good</td>
<td>30.2</td>
<td>Ex.</td>
</tr>
<tr>
<td>C4</td>
<td>2.16</td>
<td>53.37</td>
<td>0.103</td>
<td>1.67</td>
<td>2.19</td>
<td>17.9</td>
<td>Good</td>
<td>30.9</td>
<td>Comp. Ex.</td>
</tr>
<tr>
<td>C5</td>
<td>2.16</td>
<td>53.37</td>
<td>0.084</td>
<td>1.68</td>
<td>2.18</td>
<td>17.7</td>
<td>Good</td>
<td>29.8</td>
<td>Comp. Ex.</td>
</tr>
<tr>
<td>C6</td>
<td>2.16</td>
<td>53.37</td>
<td>0.137</td>
<td>1.68</td>
<td>2.24</td>
<td>18.1</td>
<td>Good</td>
<td>31.3</td>
<td>Comp. Ex.</td>
</tr>
<tr>
<td>C7</td>
<td>2.16</td>
<td>53.37</td>
<td>0.172</td>
<td>1.67</td>
<td>2.19</td>
<td>18.0</td>
<td>Poor</td>
<td>17.2</td>
<td>Comp. Ex.</td>
</tr>
</tbody>
</table>

[0072] As shown in Table 5, Examples B1, B2, B3, C1, C2, and C3, which correspond to the range of the present disclosure, exhibited both excellent magnetic properties and good bend test results. On the other hand, Examples B4, B5, B6, C4, C5, and C6 having a content of one or more of B, Mg, Zr, V, and Cu above the range of the present disclosure exhibited inferior magnetic properties. Example B7 having the sum of P, Sn, and Sb below the range of the present disclosure exhibited inferior magnetic properties, and Example C7 having the Mg content and also the sum of Sn, and Sb contents exceeding the range of the present disclosure also exhibited inferior magnetic properties as well as poor bend test results and elongation.

[0073] It will be understood that the present disclosure is not limited to the above embodiments but may be embodied in many different forms from each other and those of ordinary skill in the art to which the present disclosure pertains can implement the invention in other specific forms without changing the technical idea or essential features of the present disclosure. Accordingly, it will be understood that the exemplary embodiments described above are only illustrative, and should not be construed as limiting.

1. A non-directional electrical steel sheet, comprising, in wt %, 2.5 to 3.3 wt % of Si, 0.05 to 1 wt % of Al, 0.05 to 1 wt % of Mn, 0.01 wt % or less of (not including 0 wt %) S, 0.005 wt % or less of (not including 0 wt %) N, 0.005 wt % or less of (not including 0 wt %) C, 0.005 wt % or less of (not including 0 wt %) Ti, 0.005 wt % or less of (not including 0 wt %) Nb, 0.001 to 0.1 wt % of P, 0.001 to 0.1 wt % of Sn, and 0.001 to 0.1 wt % of Sb, with the remainder being Fe and unavoidable impurities, and satisfying Formulas 1 to 3 below.

$$\frac{1.74[Si][Al][Mn]}{2+2.9}$$  \[Formula 1\]

$$50[13.25+11.35[Si]+[Al]+[Mn]/2]+60$$  \[Formula 2\]

$$0.025[S][P]+[Sn]+[Sb]+0.15$$  \[Formula 3\]

(\text{In Formulas 1 to 3, [Si], [Al], [Mn], [P], [Sn], and [Sb] represent the content (in wt %) of Si, Al, Mn, P, Sn, and Sb, respectively.})

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

0.001 wt % or less of (not including 0 wt %) B, 0.005 wt % or less of (not including 0 wt %) Mg, Zr and V and 0.025 wt % or less of (not including 0 wt %) Cu.

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

density of 7.57 to 7.67 g/cm³ is calculated by Formula 4 below.

$$7.655+0.0061[Si]-0.102[Al]+0.00599[Sn]$$  \[Formula 4\]

(In Formulas 4, [Si], [Al], and [Mn] represent the contents (in wt %) of Si, Al and Mn, respectively.)

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

tensile test elongation is 24% or higher.

5. The non-directional electrical steel sheet of claim 1, wherein

a thickness is 0.10 to 0.35 mm.

6. A method for manufacturing a non-directional electrical steel sheet, comprising steps of heating a slab comprising, in wt %, 2.5 to 3.3 wt % of Si, 0.05 to 1 wt % of Al, 0.05 to 1 wt % of Mn, 0.01 wt % or less of (not including 0 wt %) S, 0.005 wt % or less of (not including 0 wt %) N, 0.005 wt % or less of (not including 0 wt %) C, 0.005 wt % or less of (not including 0 wt %) Ti, 0.005 wt % or less of (not including 0 wt %) Nb, 0.001 to 0.1 wt % of P, 0.001 to 0.1 wt % of Sn, and 0.001 to 0.1 wt % of Sb, with the remainder being Fe and unavoidable impurities, and satisfying Formulas 1 to 3 below and then hot rolling the slab to manufacture a hot rolled sheet;

cold rolling the hot rolled sheet to manufacture a cold rolled sheet; and

recrystallization annealing the cold rolled sheet.

$$1.74[Si][Al][Mn]/2+2.9$$  \[Formula 1\]

$$50[13.25+11.35[Si]+[Al]+[Mn]/2]+60$$  \[Formula 2\]

$$0.025[S][P]+[Sn]+[Sb]+0.15$$  \[Formula 3\]

(\text{In Formulas 1 to 3, [Si], [Al], [Mn], [P], [Sn], and [Sb] represent the content (in wt %) of Si, Al, Mn, P, Sn, and Sb, respectively.})

7. The method of claim 6, wherein

the step of manufacturing the hot rolled sheet comprises heating the slab at 1100 to 1200°C.

8. The method of claim 6, wherein

the step of manufacturing the hot rolled sheet comprises hot rolling at a finish temperature of 800 to 1000°C.
9. The method of claim 6, after the step of manufacturing the hot rolled sheet, further comprising a step of annealing the hot rolled sheet at a temperature of 850 to 1150°C.

10. The method of claim 6, wherein the slab further includes 0.001 wt % or less of (not including 0 wt %) B, 0.005 wt % or less of (not including 0 wt %) Mg, Zr and V and 0.025 wt % or less of (not including 0 wt %) Cu.

11. The method of claim 6, wherein the manufactured steel sheet has a density of 7.57 to 7.67 g/cm³ as calculated by Formula 4 below.

\[
7.856 + (-0.0611 \times [\text{Si}]) - 0.12 \times [\text{Al}] + 0.00589 \times [\text{Mn}])
\]  
[Formula 4]

(In Formula 4, [Si], [Al] and [Mn] represent the contents (in wt %) of Si, Al and Mn, respectively.)

12. The method of claim 6, wherein the manufactured steel sheet has a tensile test elongation of 24% or higher.

13. The method of claim 6, wherein the step of manufacturing the cold rolled sheet comprises cold rolling at a thickness of 0.10 to 0.35 mm.

* * * * *