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(54) **MAGNETIC CORE UNIT, CURRENT TRANSFORMER, AND METHOD FOR MANUFACTURING SAME**

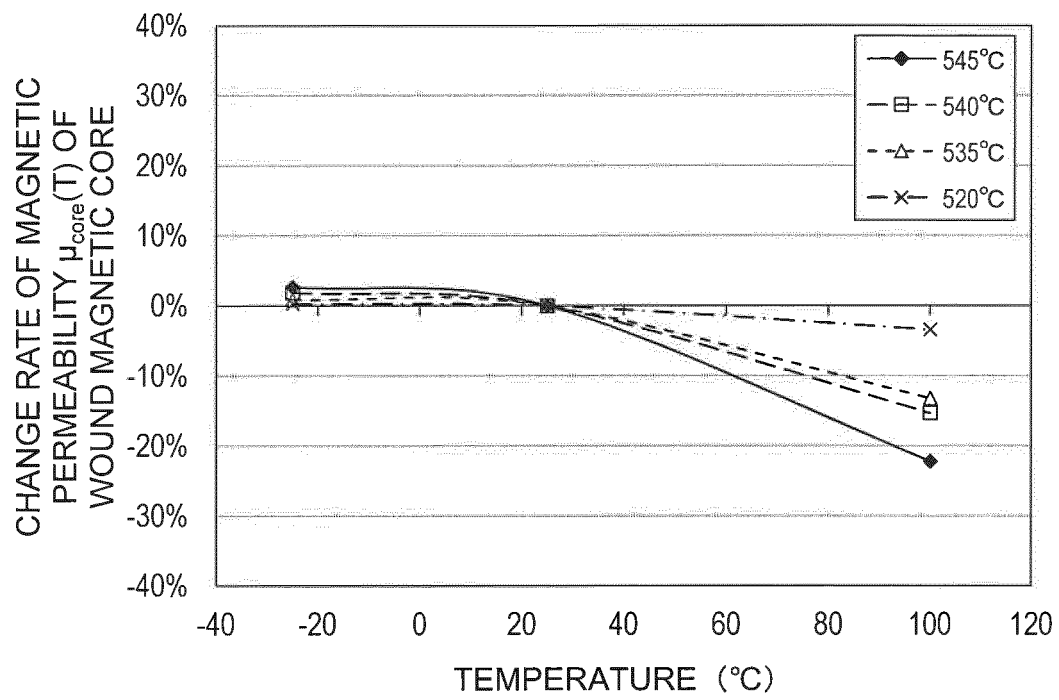
(57) A magnetic core unit includes: a wound magnetic core including a wound nanocrystalline alloy ribbon; a case having a space corresponding to an external shape of the wound magnetic core, the wound magnetic core being stored in the space; and an adhesive agent provided between a bottom surface of the space and a layered surface of the wound magnetic core for adhering the wound magnetic core to the bottom surface, wherein the nanocrystalline alloy ribbon has a saturated magnetostriction of greater than 1 ppm, and magnetic permeability $\mu_{\text{unit}}(25)$ is not less than 400000 and Formula 1 and Formula 2 are satisfied:

$$\text{(Formula 1)} \quad -0.28 \leq (\mu_{\text{unit}}(100) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0.1 \quad \text{(Formula 1)}$$

$$\text{(Formula 2)} \quad -0.28 \leq (\mu_{\text{unit}}(-25) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0 \quad \text{(Formula 2)}$$

where $\mu_{\text{unit}}(T)$ is a magnetic permeability measured at temperature $T^{\circ}\text{C}$ in the presence of an AC magnetic field of frequency $f=50$ Hz and amplitude $H=1.0$ ampere/meter (A/m) applied across the wound magnetic core adhered to the case.

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FIG. 1

Description**TECHNICAL FIELD**

5 **[0001]** The present disclosure relates to a magnetic core unit which includes a wound magnetic core formed by winding up a nanocrystalline alloy ribbon and a case for storing the wound magnetic core, a current transformer, and a manufacturing method thereof.

BACKGROUND ART

10 **[0002]** Soft magnetic alloy ribbons of an amorphous alloy, a nanocrystalline alloy, or the like, which are produced by a single-roll method have excellent soft magnetic characteristics and are therefore used for various magnetic parts. Particularly, the nanocrystalline alloy exhibits such excellent soft magnetic characteristics that it has a higher saturation magnetic flux density than Permalloy and Co-based amorphous alloys and has a higher magnetic permeability than Fe-based amorphous alloys. Thus, the nanocrystalline alloy has been used in magnetic cores of common mode choke coils, high frequency transformers, pulse transformers, current transformers, etc.

15 **[0003]** The magnetic characteristics of the nanocrystalline alloy magnetic core, such as magnetic permeability μ and squareness ratio, can be greatly changed by a temperature profile in a heat treatment or by applying a magnetic field in a specific direction in a heat treatment.

20 **[0004]** Patent Document No. 1 discloses, for example, carrying out a heat treatment in a magnetic field through three heating steps. Specifically, Patent Document No. 1 discloses that a heat treatment for nanocrystallization is carried out, and thereafter, a heat treatment is carried out at a temperature lower than the temperature of the heat treatment for nanocrystallization in the presence of a magnetic field applied in a longitudinal direction (direction of magnetic path), and thereafter, a heat treatment is carried out in the presence of a magnetic field applied in a transverse direction (direction perpendicular to magnetic path). Patent Document No. 1, the first paragraph of page 6, discloses that the heat treatment for nanocrystallization is preferably maintained at highest temperatures in the range of 540°C to 600°C for 1 hour to 3 hours.

25 **[0005]** Patent Document No. 2 and Patent Document No. 3 disclose that a first heat treatment for nanocrystallization is carried out in the absence of a magnetic field, and thereafter, a second heat treatment is carried out at a temperature lower than the temperature of the heat treatment for nanocrystallization in the presence of a magnetic field applied in a direction perpendicular to the magnetic path.

30 **[0006]** Other than the above-described techniques, the wound magnetic core of the nanocrystalline alloy is likely to have chips, and techniques for solving this problem are important. If a coil is directly wound around the wound magnetic core, chips are formed at the edge of the magnetic core because the wound magnetic core of the nanocrystalline alloy is brittle as compared with a magnetic core formed of an amorphous ribbon. Alloy dust separated from the magnetic core can enter electric circuits of the apparatus and cause unintended electrical conduction or cut circuit wires. A traditional solution for suppressing occurrence of this alloy dust is storing a wound magnetic core in a non-magnetic case which is made of a resin or the like and winding a coil outside the case. Patent Document No. 4 for example discloses that, on the supposition that a wound magnetic core of an amorphous magnetic alloy ribbon is stored in a case, production of noise can be suppressed when the relationship of $3 \times 10^6 \leq A \cdot E / (m \cdot d) \leq 1 \times 10^8$ is satisfied where m [kg] is the mass of the wound magnetic core, E [N/m²] is the Young's modulus of an adhesive agent after being cured, d [m] is the total thickness of the adhesive agent provided in a gap between the end face of the magnetic core and the case, and A [m²] is the total adhesion area of the adhesive agent between the end face of the magnetic core and the case.

40 **[0007]** Patent Document No. 4 considers anti-noise techniques for a case where an amorphous alloy whose magnetostriction exceeds 10 ppm is used.

CITATION LIST**PATENT LITERATURE**

50 **[0008]**

Patent Document No. 1: WO 2010/081993

Patent Document No. 2: Japanese Laid-Open Patent Publication No. 3-107417

55 Patent Document No. 3: Japanese Laid-Open Patent Publication No. 2000-328206

Patent Document No. 4: Japanese Laid-Open Patent Publication No. 9-69443

SUMMARY OF INVENTION**TECHNICAL PROBLEM**

[0009] Current transformers need to have a magnetic core unit whose magnetic permeability exhibits a small change with respect to the temperature. The present disclosure provides a magnetic core unit whose magnetic permeability exhibits a small change with respect to the temperature through a relatively simple heat treatment, a current transformer, and a manufacturing method thereof.

SOLUTION TO PROBLEM

[0010] A magnetic core unit of the present disclosure includes:

a wound magnetic core including a wound nanocrystalline alloy ribbon;
 a case having a space corresponding to an external shape of the wound magnetic core, the wound magnetic core being stored in the space; and
 an adhesive agent provided between a bottom surface of the space and a layered surface of the wound magnetic core for adhering the wound magnetic core to the bottom surface,
 wherein the nanocrystalline alloy ribbon has a saturated magnetostriction of greater than 1 ppm, and
 magnetic permeability $\mu_{\text{unit}}(25)$ is not less than 400000 and Formula 1 and Formula 2 are satisfied:

$$\text{(Formula 1)} \quad -0.28 \leq (\mu_{\text{unit}}(100) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0.1$$

$$\text{(Formula 2)} \quad -0.28 \leq (\mu_{\text{unit}}(-25) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

where $\mu_{\text{unit}}(T)$ is a magnetic permeability measured at temperature $T^{\circ}\text{C}$ in the presence of an AC magnetic field of frequency $f=50$ Hz and amplitude $H=1.0$ ampere/meter (A/m) applied across the wound magnetic core adhered to the case.

[0011] Preferably, the magnetic permeability $\mu_{\text{unit}}(T)$ satisfies Formula 1' and Formula 2':

$$\text{(Formula 1')} \quad -0.20 \leq (\mu_{\text{unit}}(100) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

$$\text{(Formula 2')} \quad -0.20 \leq (\mu_{\text{unit}}(-25) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0.$$

[0012] Preferably, a change rate $\Delta\mu$ between the magnetic permeability $\mu_{\text{unit}}(25)$ before the magnetic core unit is maintained at 100°C for 100 hours and the magnetic permeability $\mu_{\text{unit}}(25)$ after the magnetic core unit is maintained at 100°C for 100 hours is within $\pm 6\%$.

[0013] Preferably, the magnetic permeability $\mu_{\text{unit}}(25)$ is not more than 700000.

[0014] Preferably, the layered surface of the wound magnetic core is adhered to the case by the adhesive agent in a range of not less than 30% and not more than 50% with respect to an area of the layered surface of the wound magnetic core.

[0015] Preferably, the adhesive agent has a Shore A hardness of not less than 10 and less than 50.

[0016] Preferably, the nanocrystalline alloy ribbon is made of an alloy which has a composition represented by Formula: $(\text{Fe}_{1-a}\text{M}_a)_{100-x-y-z-\alpha-\beta-\gamma}\text{Si}_y\text{B}_z\text{M}'_{\alpha}\text{M}''_{\beta}\text{X}_{\gamma}$ (atomic %) (M is Co and/or Ni, M' is at least one element selected from the group consisting of Nb, Mo, Ta, Ti, Zr, Hf, V, Cr, Mn and W, M'' is at least one element selected from the group consisting of Al, platinum group elements, Sc, rare-earth elements, Zn, Sn and Re, X is at least one element selected from the group consisting of C, Ge, P, Ga, Sb, In, Be and As, a, x, y, z, α , β and γ satisfy $0 \leq a \leq 0.5$, $0.1 \leq x \leq 3$, $0 \leq y \leq 30$, $0 \leq z \leq 25$, $5 \leq y+z \leq 30$, $0 \leq \alpha \leq 20$, $0 \leq \beta \leq 20$ and $0 \leq \gamma \leq 20$, respectively).

[0017] A current transformer of the present disclosure includes the above-described magnetic core unit.

[0018] A method for manufacturing a magnetic core unit the present disclosure includes:

providing a magnetic core element formed by winding up an amorphous alloy ribbon, the magnetic core element having a composition represented by Formula: $(\text{Fe}_{1-a}\text{M}_a)_{100-x-y-z-\alpha-\beta-\gamma}\text{Cu}_x\text{Si}_y\text{B}_z\text{M}'_{\alpha}\text{M}''_{\beta}\text{X}_{\gamma}$ (atomic %) (M is Co and/or

Ni, M' is at least one element selected from the group consisting of Nb, Mo, Ta, Ti, Zr, Hf, V, Cr, Mn and W, M" is at least one element selected from the group consisting of Al, platinum group elements, Sc, rare-earth elements, Zn, Sn and Re, X is at least one element selected from the group consisting of C, Ge, P, Ga, Sb, In, Be and As, a, x, y, z, α , β and γ satisfy $0 \leq a \leq 0.5$, $0.1 \leq x \leq 3$, $0 \leq y \leq 30$, $0 \leq z \leq 25$, $5 \leq y+z \leq 30$, $0 \leq \alpha \leq 20$, $0 \leq \beta \leq 20$ and $0 \leq \gamma \leq 20$, respectively); producing a wound magnetic core by performing a first heat treatment and a second heat treatment on the magnetic core element, the first heat treatment including heating at a temperature equal to or higher than a crystallization initiating temperature in the absence of a magnetic field, the second heat treatment including heating at a temperature lower than the crystallization initiating temperature, the second heat treatment includes applying a magnetic field in a direction perpendicular to a magnetic path, the wound magnetic core having a saturated magnetostriction of greater than 1 ppm, magnetic permeability $\mu_{\text{core}}(25)$ being not less than 400000, and Formula 3 and Formula 4 being satisfied:

$$\text{(Formula 3)} \quad 0 < (\mu_{\text{core}}(-25) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$$

$$\text{(Formula 4)} \quad -0.25 \leq (\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25) < 0$$

where $\mu_{\text{unit}}(T)$ is a magnetic permeability measured at temperature $T^{\circ}\text{C}$ in the presence of an AC magnetic field of frequency $f=50$ Hz and amplitude $H=1.0$ ampere/meter (A/m) applied across the wound magnetic core; and providing an adhesive agent between a case and a layered surface of the wound magnetic core for adhering the wound magnetic core to the case, the case having a space which corresponds to an external shape of the wound magnetic core.

[0019] Preferably, a highest temperature of the first heat treatment is equal to or higher than 520°C and equal to or lower than 550°C .

[0020] Preferably, a highest temperature of the first heat treatment is equal to or higher than 530°C and lower than 545°C , and the magnetic permeability $\mu_{\text{core}}(T)$ satisfies Formula 4':

$$\text{(Formula 4')} \quad -0.20 \leq (\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25) < -0.05.$$

[0021] Preferably, a highest temperature of the second heat treatment is equal to or higher than 225°C and equal to or lower than 270°C .

[0022] Preferably, in the first heat treatment, a temperature rise rate at the crystallization initiating temperature is not more than $5^{\circ}\text{C}/\text{min}$.

[0023] Preferably, the adhesive agent is provided on the layered surface of the wound magnetic core in a range of not less than 30% and not more than 50% with respect to an area of the layered surface of the wound magnetic core for adhering the wound magnetic core to the case.

[0024] Preferably, the adhesive agent has a Shore A hardness of not less than 10 and less than 50.

[0025] A method for manufacturing a current transformer of the present invention includes:

manufacturing a magnetic core unit by the above-described magnetic core unit manufacturing method; and winding a wire around the magnetic core unit.

ADVANTAGEOUS EFFECTS OF INVENTION

[0026] According to the present disclosure, a magnetic core unit whose magnetic permeability μ exhibits a small change with respect to the temperature of a wound magnetic core even while the wound magnetic core is adhered to a case, a current transformer, and a manufacturing method thereof are realized.

BRIEF DESCRIPTION OF DRAWINGS

[0027]

FIG. 1 is a graph showing a temperature characteristic of a wound magnetic core (before being adhered) (the temperature and the change rate of the magnetic permeability relative to the magnetic permeability $\mu_{\text{core}}(25)$ of the wound magnetic core at 25°C).

FIG. 2 is a graph showing a temperature characteristic of a magnetic core unit on which a first heat treatment was performed at 520°C.

FIG. 3 is a graph showing a temperature characteristic of a magnetic core unit on which a first heat treatment was performed at 535°C.

FIG. 4 is a graph showing a temperature characteristic of a magnetic core unit on which a first heat treatment was performed at 540°C.

FIG. 5 is a graph showing a temperature characteristic of a magnetic core unit on which a first heat treatment was performed at 545°C.

FIG. 6 is a graph showing the relationship between the area ratio of the adhesive agent and the change rate of the magnetic permeability $\mu_{\text{unit}}(100)$ relative to the magnetic permeability $\mu_{\text{unit}}(25)$.

FIG. 7 is a graph showing the relationship between the area ratio of the adhesive agent and the change rate of the magnetic permeability $\mu_{\text{unit}}(-25)$ relative to the magnetic permeability $\mu_{\text{unit}}(25)$.

FIG. 8 is a graph showing the relationship between the area ratio of the adhesive agent and the high temperature temporal change rate $\Delta\mu$ (the change rate of $\mu_{\text{unit}}(25)$ between before and after the magnetic core unit is left at 100°C for 100 h).

FIG. 9 is a graph showing a temperature characteristic of a magnetic core unit when the area ratio of the adhesive agent was changed to 31.7%.

FIG. 10 is a graph showing a temperature characteristic of a magnetic core unit when the area ratio of the adhesive agent was changed to 39.8%.

FIG. 11 is a graph showing the relationship between the temperature of the second heat treatment and the magnetic permeability $\mu_{\text{core}}(25)$ of the wound magnetic core.

FIG. 12 is a graph showing the temperature pattern of the first heat treatment.

FIG. 13 is a graph showing the temperature of the second heat treatment and the pattern of magnetic field application.

FIG. 14 is a graph showing the relationship between the area ratio of the adhesive agent and the tensile strength of the case and the core.

FIG. 15(a) and FIG. 15(b) are an exploded perspective view and cross-sectional view showing a general configuration of a magnetic core unit. FIG. 15(c) is a schematic diagram showing an arrangement example of the adhesive agent.

FIG. 16 is a diagram for illustrating a measurement method of the magnetic permeability ($\mu_{\text{core}}(T)$, $\mu_{\text{unit}}(T)$).

FIG. 17 is a graph showing the relationship between the coercivity of the wound magnetic core and the temperature characteristic ($(\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$).

FIG. 18 is a graph showing the relationship between the temperature rise rate at the crystallization initiating temperature and the coercivity of the wound magnetic core.

DESCRIPTION OF EMBODIMENTS

[0028] The present inventor studied conventional techniques in detail. According to Patent Documents Nos. 1 to 3, the magnetic permeability and the squareness ratio Br/Bs of the nanocrystalline alloy ribbon can be adjusted by a heat treatment in a magnetic field. However, the nanocrystalline alloy ribbon sometimes need to have such a temperature characteristic that the variation of the magnetic permeability of the core is small within a use temperature range in order to comply with the temperature variation of the use environment. An example of a magnetic part which particularly need to have a temperature characteristic is a current transformer (CT). The current transformer is a current transforming device for use in measurement and is used in, for example, current meters and earth leakage circuit breakers. A wound magnetic core used in the current transformer is required to have a magnetic permeability whose change with respect to the temperature is small, such that a measurement error in the current value is small in any environment ranging from -25°C to 100°C.

[0029] For example, the heat treatment method disclosed in Patent Document No. 1, which is carried out in a magnetic field through three steps (the method of heat treatment in magnetic field, consisting of three steps: a heat treatment for nanocrystallization is carried out in the absence of a magnetic field; thereafter, a heat treatment is carried out at a temperature lower than the temperature of the heat treatment for nanocrystallization in the presence of a magnetic field applied in a longitudinal direction (direction of magnetic path); and thereafter, a heat treatment is carried out in the presence of a magnetic field applied in a transverse direction (direction perpendicular to magnetic path), hereinafter referred to as "three-step heat treatment") has such advantages that the magnetic permeability $\mu(25)$ and the squareness ratio Br/Bs of a wound magnetic core formed of a resultant nanocrystalline alloy can be easily adjusted within the aforementioned value ranges and the wound magnetic core has a stable temperature characteristic although, disadvantageously, the manufacturing cost is high due to a large number of heat treatment step. In the last heat treatment step of Patent Document No. 1 (a heat treatment carried out with a magnetic field applied in a direction perpendicular to the magnetic path), the magnetic permeability is likely to vary depending on the temperature of the heat treatment, and making the magnetic core have a constant magnetic permeability is difficult due to the variation of the temperature

among different places in a mass production furnace.

[0030] The heat treatment method such as disclosed in Patent Document No. 2 and Patent Document No. 3, which is carried out in a magnetic field through two steps (the method of heat treatment in magnetic field, consisting of two steps: a first heat treatment for nanocrystallization is carried out in the absence of a magnetic field; and thereafter, a second heat treatment is carried out at a temperature lower than the temperature of the heat treatment for nanocrystallization in the presence of a magnetic field applied in a transverse direction (a direction perpendicular to the magnetic path), hereinafter referred to as "two-step heat treatment") has such a merit that high magnetic permeability and stable temperature characteristic which are approximately at the same level as those of Patent Document No. 1 can be realized at a low cost.

[0031] However, on the other hand, when a magnetic core produced by the two-step heat treatment is used to form a magnetic core unit by adhering a wound magnetic core to a case using an adhesive agent, the magnetic core unit after being adhered to the case has deteriorated temperature characteristic even though the temperature characteristic of the wound magnetic core before being adhered to the case is excellent. When a wound magnetic core produced by the three-step heat treatment disclosed in Patent Document No. 1 is adhered to a case using an adhesive agent, resulting in a magnetic core unit, the temperature characteristic deteriorates, although the deterioration is less than that of the magnetic core unit produced by the two-step heat treatment. This is because, in my estimation, a magnetic core produced by the two-step heat treatment has large magnetostriction.

[0032] Patent Documents Nos. 2 and 3 do not have such a disclosure that the wound magnetic core before being adhered to the case and the magnetic core unit adhered to the case have varying temperature characteristics. In the examples of Patent Document No. 2, the highest temperature of the first heat treatment is 610°C, 620°C or 540°C. In the examples of Patent Document No. 3, the temperature of the nanocrystallization heat treatment is 520°C or 550°C. None of Patent Document No. 2 and Patent Document No. 3 discloses the relationship between the highest temperature of the first heat treatment and the temperature characteristic.

[0033] Based on the knowledge that the saturated magnetostriction of a nanocrystalline alloy ribbon produced by the two-step heat treatment is relatively large, e.g., greater than 1 ppm, and when a wound magnetic core formed of this nanocrystalline alloy ribbon is adhered to a case using an adhesive agent, whereby a magnetic core unit is formed, the temperature characteristic of the magnetic core unit deteriorates, the present inventor studied a magnetic core unit which has improved temperature characteristic after being adhered to the case although the saturated magnetostriction of the nanocrystalline alloy ribbon is greater than 1 ppm, and a manufacturing method thereof. As a result, the present inventor found that, in the temperature profile of the two-step heat treatment, the temperature characteristic of the wound magnetic core before being adhered to the case is maintained within a predetermined range, whereby the magnetic core unit of the present disclosure is realized. Further, the present inventor found that, as a specific manufacturing method, by setting the temperature in the first heat treatment within a predetermined range, a wound magnetic core which has a temperature characteristic within the above-described certain range is realized.

[0034] FIG. 15(a) is an exploded perspective view of one embodiment of a magnetic core unit of the present disclosure. FIG. 15(b) shows a cross section vertical to the circumferential direction of the magnetic core unit. The magnetic core unit 11 includes a wound magnetic core 13, a case 15, and an adhesive agent 16. The case 15 includes a body 14 and a lid 12. The body 14 of the case 15 has a space 14a corresponding to the external shape of the wound magnetic core 13. In the present embodiment, the wound magnetic core 13 has a ring shape, and accordingly, the space 14a also has a ring shape. In the drawings, 14b indicates the bottom surface of the space 14a of the body 14, and 12a indicates the ceiling surface of the lid 12.

[0035] The wound magnetic core 13 includes a wound nanocrystalline alloy ribbon. In the present embodiment, the nanocrystalline alloy ribbon is wound in the circumferential direction and layered (or stacked). The layered (or stacked) surfaces 13a, 13b are the top surface and the bottom surface. The wound magnetic core 13 is stored in the space 14a of the body 14 of the case 15. The lid 12 is provided over the opening of the space 14a of the body 14 so as to close the space 14a.

[0036] The nanocrystalline alloy ribbon has saturated magnetostriction which is greater than 1 ppm. The magnetic permeability $\mu_{\text{unit}}(25)$ is not less than 400000 and the following formulae, Formula 1 and Formula 2, are satisfied:

$$\text{(Formula 1)} \quad -0.28 \leq (\mu_{\text{unit}}(100) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0.1$$

$$\text{(Formula 2)} \quad -0.28 \leq (\mu_{\text{unit}}(-25) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

where $\mu_{\text{unit}}(T)$ is a magnetic permeability measured at temperature T°C in the presence of an AC magnetic field of frequency f=50 Hz and amplitude H=1.0 ampere/meter (A/m) applied to the wound magnetic core 13 adhered to the case 15.

[0037] Formula 1 shown above represents that the change rate of the magnetic permeability $\mu_{\text{unit}}(100)$ at 100°C of the magnetic core unit **11** from the magnetic permeability $\mu_{\text{unit}}(25)$ at 25°C is in the range from -28% to +10%. Formula 2 shown above represents that the magnetic permeability $\mu_{\text{unit}}(-25)$ at -25°C of the magnetic core unit **11** is not greater than magnetic permeability $\mu_{\text{unit}}(25)$ at 25°C but is in the range of not less than -28%.

[0038] Preferably, magnetic permeability $\mu_{\text{unit}}(T)$ satisfies the following formulae, Formula 1' and Formula 2'.

$$\text{(Formula 1')} \quad -0.20 \leq (\mu_{\text{unit}}(100) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

$$\text{(Formula 2')} \quad -0.20 \leq (\mu_{\text{unit}}(-25) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

[0039] The change rate $\Delta\mu$ between the magnetic permeability $\mu_{\text{unit}}(25)$ before the magnetic core unit **11** is maintained at 100°C for 100 hours and the magnetic permeability $\mu_{\text{unit}}(25)$ after the magnetic core unit **11** is maintained at 100°C for 100 hours is preferably within $\pm 6\%$. In this case, the magnetic core unit **11** can have excellent heat resistance. More preferably, the change rate $\Delta\mu$ is within $\pm 5\%$.

[0040] The magnetic permeability $\mu_{\text{unit}}(25)$ is preferably not more than 700000.

[0041] The nanocrystalline alloy ribbon is preferably made of an alloy which has a composition represented by Formula: $(\text{Fe}_{1-a}\text{M}_a)_{100-x-y-z-\alpha-\beta-\gamma}\text{Cu}_x\text{Si}_y\text{B}_z\text{M}'_\alpha\text{M}''_\beta\text{X}_\gamma$ (atomic %) (M is Co and/or Ni, M' is at least one element selected from the group consisting of Nb, Mo, Ta, Ti, Zr, Hf, V, Cr, Mn and W, M'' is at least one element selected from the group consisting of Al, platinum group elements, Sc, rare-earth elements, Zn, Sn and Re, X is at least one element selected from the group consisting of C, Ge, P, Ga, Sb, In, Be and As, and a, x, y, z, α , β and γ satisfy $0 \leq a \leq 0.5$, $0.1 \leq x \leq 3$, $0 \leq y \leq 30$, $0 \leq z \leq 25$, $5 \leq y+z \leq 30$, $0 \leq \alpha \leq 20$, $0 \leq \beta \leq 20$ and $0 \leq \gamma \leq 20$, respectively).

[0042] The adhesive agent **16** is provided between the bottom surface **14b** of the space of the body **14** of the case **15** and the layered surface **13b** of the wound magnetic core **13** and partially adheres the wound magnetic core **13** to the bottom surface **14b**. Preferably, the adhesive agent **16** does not cover the entirety of the layered surface **13b**. Since the layered surface **13b** is partially adhered to the bottom surface **14b** of the case **15** by the adhesive agent **16**, expansion and shrinkage of the nanocrystalline alloy ribbon at the layered surface is allowed even if the case or the adhesive agent expands or shrinks, and occurrence of stress in the nanocrystalline alloy ribbon is suppressed. Therefore, variation of the temperature characteristic due to the stress is suppressed. The site at which the wound magnetic core **13** is partially adhered to the case can be on the ceiling surface **12a** of the lid **12**.

[0043] Preferably, the layered surface **13b** of the wound magnetic core **13** is adhered to the case **15** by the adhesive agent **16** in a range of not less than 30% and not more than 50% with respect to the area of the layered surface **13b** of the wound magnetic core **13**. In this case, occurrence of stress due to the above-described magnetostriction is further suppressed. The adhesive agent **16** preferably has a Shore A hardness of not less than 10 and less than 50. When the Shore A hardness is in this range, the adhesive agent **16** is relatively soft. Therefore, expansion and shrinkage of the nanocrystalline alloy ribbon due to the magnetostriction is allowed, and stress due to the magnetostriction can be reduced.

[0044] Such a magnetic core unit can be manufactured, for example, by the following method.

[0045] First, a magnetic core element formed by winding up an amorphous alloy ribbon is provided, the magnetic core element having a composition represented by Formula: $(\text{Fe}_{1-a}\text{M}_a)_{100-x-y-z-\alpha-\beta-\gamma}\text{Cu}_x\text{Si}_y\text{B}_z\text{M}'_\alpha\text{M}''_\beta\text{X}_\gamma$ (atomic %) (M is Co and/or Ni, M' is at least one element selected from the group consisting of Nb, Mo, Ta, Ti, Zr, Hf, V, Cr, Mn and W, M'' is at least one element selected from the group consisting of Al, platinum group elements, Sc, rare-earth elements, Zn, Sn and Re, X is at least one element selected from the group consisting of C, Ge, P, Ga, Sb, In, Be and As, and a, x, y, z, α , β and γ satisfy $0 \leq a \leq 0.5$, $0.1 \leq x \leq 3$, $0 \leq y \leq 30$, $0 \leq z \leq 25$, $5 \leq y+z \leq 30$, $0 \leq \alpha \leq 20$, $0 \leq \beta \leq 20$ and $0 \leq \gamma \leq 20$, respectively).

[0046] Then, the first heat treatment and the second heat treatment are performed on the magnetic core element. The first heat treatment includes heating the magnetic core element at a temperature equal to or higher than the crystallization initiating temperature in the absence of a magnetic field. The second heat treatment includes heating the magnetic core element at a temperature lower than the crystallization initiating temperature. In the second heat treatment, a magnetic field is applied in a direction perpendicular to the magnetic path. As a result, a wound magnetic core **13** is produced whose saturated magnetostriction is greater than 1 ppm, whose magnetic permeability $\mu_{\text{core}}(25)$ is not less than 400000, and which satisfies the following formulae, Formula 3 and Formula 4:

$$\text{(Formula 3)} \quad 0 < (\mu_{\text{core}}(-25) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$$

$$\text{(Formula 4)} \quad -0.25 \leq (\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25) < 0$$

where $\mu_{\text{core}}(T)$ is the magnetic permeability measured at $T^{\circ}\text{C}$ in the presence of an AC magnetic field of frequency $f=50$ Hz and amplitude $H=1.0$ ampere/meter (A/m) applied to the wound magnetic core **13**.

[0047] Due to the first heat treatment and the second heat treatment, a nanocrystalline alloy ribbon can be realized whose saturated magnetostriction is greater than 1 ppm. However, by adjusting the magnetic permeability $\mu_{\text{core}}(T)$ so as to satisfy Formula 3 and Formula 4, a magnetic core unit **11** which includes a wound magnetic core of excellent temperature characteristic can be realized even if the magnetic core unit **11** is produced by adhering the wound magnetic core **13** to the case **15**.

[0048] Specifically, the highest temperature of the first heat treatment is preferably equal to or higher than 520°C and equal to or lower than 550°C . More preferably, the highest temperature of the first heat treatment is equal to or higher than 530°C and lower than 545°C . A magnetic core unit **11** whose magnetic permeability $\mu_{\text{core}}(T)$ satisfies Formula 4' is preferably realized.

$$(\text{Formula } 4') \quad -0.20 \leq (\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25) \leq -0.05$$

[0049] The highest temperature of the second heat treatment is preferably equal to or higher than 225°C and equal to or lower than 270°C .

[0050] The temperature rise rate at the crystallization initiating temperature is preferably not more than $5^{\circ}\text{C}/\text{min}$.

[0051] After the wound magnetic core **13** that has the above-described characteristics is produced, the adhesive agent **16** is partially provided between the case **15** that has the space **14a** corresponding to the external shape of the wound magnetic core **13** and the layered surface **13b** or the layered surface **13a** of the wound magnetic core **13**, whereby the wound magnetic core **13** is adhered to the case **15**. Thereby, the magnetic core unit is completed. The site in the case at which the adhesive agent **16** is to be provided can be on the bottom surface **14b** of the space **14a** or on the ceiling surface **12a** of the lid **12**.

[0052] Next, the composition of a used amorphous alloy ribbon which is capable of nanocrystallization is described in detail.

[0053] As previously described, an example of an amorphous alloy which is capable of nanocrystallization is an alloy which has a composition represented by Formula: $(\text{Fe}_{1-a}\text{M}_a)_{100-x-y-z-\alpha-\beta-\gamma}\text{Cu}_x\text{Si}_y\text{B}_z\text{M}'_{\alpha}\text{M}''_{\beta}\text{X}_{\gamma}$ (atomic %) (M is Co and/or Ni, M' is at least one element selected from the group consisting of Nb, Mo, Ta, Ti, Zr, Hf, V, Cr, Mn and W, M'' is at least one element selected from the group consisting of Al, platinum group elements, Sc, rare-earth elements, Zn, Sn and Re, X is at least one element selected from the group consisting of C, Ge, P, Ga, Sb, In, Be and As, and a, x, y, z, α , β and γ satisfy $0 \leq a \leq 0.5$, $0.1 \leq x \leq 3$, $0 \leq y \leq 30$, $0 \leq z \leq 25$, $5 \leq y+z \leq 30$, $0 \leq \alpha \leq 20$, $0 \leq \beta \leq 20$ and $0 \leq \gamma \leq 20$, respectively). Preferably, in the above formula, a, x, y, z, α , β and γ satisfy $0 \leq a \leq 0.1$, $0.7 \leq x \leq 1.3$, $12 \leq y \leq 17$, $5 \leq z \leq 10$, $0.1 \leq \alpha \leq 5$, $0 \leq \beta \leq 1$ and $0 \leq \gamma \leq 1$, respectively. More preferably, the composition satisfies $a=0$, $0.8 \leq x \leq 1.2$, $13 \leq y \leq 16.5$, $6 \leq z \leq 9$, $1.0 \leq \alpha \leq 4$, $\beta=0$ and $\gamma=0$, respectively. With an alloy of such a composition, a magnetic core unit is easily realized whose magnetic permeability $\mu_{\text{core}}(25)$ is not less than 400000 and not more than 700000 and which has the characteristics of Formula 1 and Formula 2.

[0054] An alloy which has the above-described composition is melted to a temperature equal to or higher than the melting point and then quenched and solidified by a single-roll method or the like, resulting in a lengthy amorphous alloy ribbon.

[0055] The amorphous alloy ribbon is wound up into a magnetic core element which has a ring shape. A small gap or any other substance may be present between layers of the amorphous alloy ribbon. The volume occupancy of the amorphous alloy ribbon in the magnetic core element is, for example, about 70% to 90%.

[0056] The first heat treatment is performed on the amorphous alloy ribbon such that the amorphous alloy ribbon is heated to a temperature equal to or higher than the crystallization initiating temperature, whereby nanocrystallization of the ribbon is carried out. The highest temperature of the first heat treatment is equal to or higher than 520°C and equal to or lower than 550°C . If it is equal to or higher than 520°C , the magnetic permeability $\mu_{\text{unit}}(100)$ at 100°C of the magnetic core unit is prevented from being greater by more than 10% than the magnetic permeability $\mu_{\text{unit}}(25)$ at room temperature and is prevented from being smaller than -28%. If it is equal to or lower than 550°C , the magnetic permeability $\mu_{\text{unit}}(-25)$ at -25°C of the magnetic core unit is prevented from being greater than the magnetic permeability $\mu_{\text{unit}}(25)$ at room temperature and is prevented from being smaller than -28%, although the saturated magnetostriction is greater than 1 ppm.

[0057] In the manufacturing method, if the highest temperature of the first heat treatment is equal to or higher than 520°C , the magnetic permeability $\mu_{\text{core}}(-25)$ at -25°C of the wound magnetic core before being adhered to the case can be controlled so as to be greater than the magnetic permeability $\mu_{\text{core}}(25)$ at room temperature. If the highest temperature of the first heat treatment is equal to or lower than 550°C , the magnetic permeability $\mu_{\text{core}}(100)$ at 100°C of the wound magnetic core is prevented from being greater than the magnetic permeability $\mu_{\text{core}}(25)$ at room temperature and is prevented from being smaller than -25%, although the saturated magnetostriction is greater than 1 ppm.

[0058] In the present application, the crystallization initiating temperature is defined as a temperature at which an

exothermic reaction by initiation of nanocrystallization where the measurement condition of Differential Scanning Calorimetry (DSC) is the temperature rise rate of 10°C/min is detected.

[0059] The highest temperature of the first heat treatment is preferably equal to or higher than 530°C and lower than 545°C. When the first heat treatment is performed in this temperature range, a wound magnetic core is realized whose magnetic permeability $\mu_{\text{core}}(T)$ satisfies Formula 4':

$$\text{(Formula 4')} \quad -0.20 \leq (\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25) < -0.05.$$

[0060] A magnetic core unit formed by adhering this wound magnetic core to the case using a resin has magnetic permeability $\mu_{\text{unit}}(T)$ which satisfies Formula 1' and Formula 2' shown below, i.e., has further improved temperature characteristic.

$$\text{(Formula 1')} \quad -0.20 \leq (\mu_{\text{unit}}(100) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

$$\text{(Formula 2')} \quad -0.20 \leq (\mu_{\text{unit}}(-25) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

[0061] A magnetic core unit for a current transformer is, in some cases, required to have such a characteristic that the change rate of magnetic permeability $\mu_{\text{unit}}(25)$ after being maintained at 100°C for 100 hours (hereinafter, also referred to as "high temperature temporal change rate $\Delta\mu$ " or simply " $\Delta\mu$ ") is small. As will be described later, the high temperature temporal change rate $\Delta\mu$ is likely to decrease as the highest temperature of the first heat treatment increases. Thus, when a magnetic core unit whose high temperature temporal change rate $\Delta\mu$ is, for example, within the range of $\pm 6\%$ is produced, the highest temperature of the first heat treatment is preferably equal to or higher than 530°C. That is, when the high temperature temporal change rate $\Delta\mu$ is required to be within $\pm 6\%$ in addition to the temperature characteristics of Formula 1 and Formula 2 shown above, the highest temperature of the first heat treatment is preferably equal to or higher than 530°C and lower than 545°C.

[0062] In the first heat treatment, the temperature does not necessarily need to be maintained at the highest temperature. Although nanocrystallization can be realized even if the temperature is maintained at the highest temperature for 0 minutes (no maintenance duration), the temperature is preferably maintained at the highest temperature for a duration in the range of not less than 5 minutes and not more than 24 hours. If the maintenance duration at the highest temperature is not less than 5 minutes, the entirety of the alloy that forms the core is likely to have a uniform temperature and is therefore likely to have uniform magnetic characteristics. On the other hand, if the maintenance duration at the highest temperature is longer than 24 hours, the productivity deteriorates, and furthermore, the magnetic characteristics are likely to deteriorate due to excessively growth of crystal grains or production of crystal grains in a nonuniform form.

[0063] In the first heat treatment, the temperature rises from a temperature lower than the crystallization initiating temperature to a temperature higher than the crystallization initiating temperature. The temperature rise rate at the crystallization initiating temperature (the average temperature rise rate between a temperature lower than the crystallization initiating temperature by 5°C and a temperature higher than the crystallization initiating temperature by 5°C) is preferably moderate. Stable nanocrystallization can be realized.

[0064] The upper limit of the temperature rise rate is preferably 5°C/min. The coercivity H_c can be decreased, and the value of $(\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$ of the wound magnetic core can be easily set in the range of $-0.25 \leq (\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25) < 0$. The temperature rise rate is preferably not more than 3°C/min, more preferably not more than 2°C/min, still more preferably not more than 1.5°C, still more preferably not more than 1.4°C, and still more preferably not more than 1.2°C. The lower limit of the temperature rise rate is not particularly limited. However, when the temperature rise rate is not less than 0.2°C/min, stable nanocrystallization can be realized. Further, the duration of the first heat treatment can be reduced. When the temperature rise rate is not less than 0.375°C/min, the coercivity H_c of the wound magnetic core can be decreased, and the duration of the first heat treatment can be further reduced. Details will be described later with examples.

[0065] The saturated magnetostriction of the nanocrystallized alloy ribbon is greater than 1 ppm but can be smaller than that of an amorphous alloy ribbon, and therefore, a magnetic core unit of excellent temperature characteristic can be realized. To a temperature lower than the crystallization initiating temperature by 20°C, the temperature can be relatively rapidly increased at a temperature rise rate of, for example, 3-5°C/min.

[0066] Cooling down from the highest reached temperature is preferably carried out at a cooling rate of 1-5°C/min. The alloy ribbon may be cooled to room temperature or may be cooled to the temperature of the second heat treatment, which will be described later, before being subjected to the second heat treatment at that temperature.

[0067] At least 50 volume%, or 80 volume%, of the nanocrystallized alloy ribbon is occupied by minute crystal grains

whose average grain diameter measured at the maximum dimension is not more than 100 nm. The other part of the alloy than the minute crystal grains is mainly amorphous. The proportion of the minute crystal grains may be substantially 100 volume%.

[0068] Next, the second heat treatment is described.

[0069] After the first heat treatment is performed on the magnetic core element, the second heat treatment is performed by heating at a temperature lower than the crystallization initiating temperature. The step of this second heat treatment includes the step of applying a magnetic field in a direction perpendicular to the magnetic path. Thereby, the magnetic core element is changed into a wound magnetic core.

[0070] The direction of an applied magnetic field is perpendicular to the direction of the magnetic path. In the wound magnetic core, the magnetic field can be applied in the vertical direction of the magnetic core. Application of the magnetic field may be realized by either of a DC magnetic field, an AC magnetic field or a pulsed magnetic field.

[0071] The second heat treatment is performed separately from the first heat treatment, and only the step of the second heat treatment includes the step of applying a magnetic field, so that a soft magnetic characteristic of high linearity can be achieved. This heat treatment in a magnetic field contributes to decreasing the residual magnetic flux density B_r although the magnetic permeability decreases, and the squareness ratio B_r/B_m can be decreased to the range of, for example, $0.50 \leq B_r/B_m \leq 0.85$, resulting in a magnetic core in which magnetic bias is unlikely to occur. These magnetic characteristics are suitable to current transformers. In the present application, the saturation magnetic flux density B_m is defined as the magnetic flux density $B(80)$ with magnetic field $H=80\text{A/m}$.

[0072] The highest temperature of the second heat treatment is preferably equal to or higher than 225°C and equal to or lower than 270°C . In this temperature range, the magnetic permeability $\mu_{\text{unit}}(25)$ of the magnetic core unit can easily be set in the range of not less than 400000 and not more than 700000. A more preferred lower limit of the highest temperature of the second heat treatment is 230°C . A more preferred upper limit of the highest temperature of the second heat treatment is 265°C .

[0073] In the second heat treatment, the temperature does not necessarily need to be maintained at the highest temperature. The second heat treatment can be performed without maintenance duration. The maintenance duration is preferably set in the range of not less than 5 minutes and not more than 24 hours. If the maintenance duration is not less than 5 minutes, the entirety of the alloy that forms the core is likely to have a uniform temperature and is therefore likely to have uniform magnetic characteristics. On the other hand, if the maintenance duration is longer than 24 hours, the productivity deteriorates, and furthermore, the magnetic characteristics are likely to deteriorate due to excessively growth of crystal grains or production of crystal grains in a nonuniform form. The magnetic field can be applied while the temperature is maintained at the highest temperature. Alternatively, the temperature can be increased to a predetermined temperature in the absence of a magnetic field, and thereafter, the magnetic field can be applied while the temperature is decreased. Still alternatively, the temperature can be increased to a predetermined temperature and maintained for a predetermined time period in the absence of a magnetic field, and thereafter, the magnetic field can be applied while the temperature is decreased. When the temperature is decreased in the first heat treatment, the temperature can be decreased to the maintained temperature of the second heat treatment so that the second heat treatment can be performed without intermission.

[0074] The magnetic field applied in the second heat treatment is preferably applied at a magnetic field intensity of not less than 50 kA/m. If the applied magnetic field is excessively weak, provision of induced magnetic anisotropy under actual operative conditions is difficult. A more preferred range is not less than 60 kA/m. A still more preferred range is not less than 100 kA/m.

[0075] Although the upper limit of the magnetic field intensity is not particularly limited, the magnetic field intensity is preferably not more than 400 kA/m because the induced magnetic anisotropy is not further provided even if the magnetic field intensity is more than 400 kA/m.

[0076] For example, when a wound magnetic core or magnetic core unit has a squareness ratio B_r/B_m in the range of $0.50 \leq B_r/B_m \leq 0.85$, it is preferred that in the second heat treatment a magnetic field is applied at a magnetic field intensity of not less than 50 kA/m in a temperature range of at least equal to or higher than 225°C and equal to or lower than 270°C . The duration for which the magnetic field is applied is preferably not less than 10 minutes and not more than 10 hours.

[0077] When the magnetic field is applied while the temperature is decreased, the temperature decrease rate and the magnetic field application duration are preferably adjusted such that the magnetic field is applied at a magnetic field intensity of not less than 50 kA/m in a temperature range of equal to or higher than 225°C and equal to or lower than 270°C . The duration for which the magnetic field is applied is preferably not less than 10 minutes and not more than 10 hours likewise as in the above-described example.

[0078] The first heat treatment and the second heat treatment are preferably performed in a non-reactive atmosphere gas. When the heat treatment is carried out in a nitrogen gas, sufficient magnetic permeability is achieved, and the nitrogen gas can be substantially used as a non-reactive gas. As the non-reactive gas, an inert gas can also be used. The first heat treatment and the second heat treatment may be carried out in vacuum. Specifically, it is preferred that

the first heat treatment and the second heat treatment are performed in an atmosphere whose oxygen concentration is not more than 10 ppm because the coercivity can be further reduced.

[0079] The case is used for the purpose of protecting the wound magnetic core and ensuring insulation. So long as such purposes are achieved, the material of the case is not particularly limited. For example, resins such as polyamide (PA), typically PA6 and PA66, polyethylene terephthalate (PET), polybutylene terephthalate (PBT), polyphenylene sulfide (PPS), etc., can be used.

[0080] In the present disclosure, measurement of the saturated magnetostriction was carried out by a method which will be described below.

[0081] A nanocrystalline alloy ribbon is cut out from the wound magnetic core or magnetic core unit so as to have a length of 5 cm in the magnetic path direction. A strain gauge is adhered to the resultant nanocrystalline alloy ribbon via an adhesive agent. This nanocrystalline alloy ribbon with the adhered strain gauge is inserted into the inside diameter side of a solenoid coil, and the magnetostriction is measured while a sufficiently saturated magnetic field is applied.

[0082] In the present disclosure, the strain gauge used was a strain gauge manufactured by KYOWA ELECTRONIC INSTRUMENTS CO., LTD. (Product No.: KFN-2-350-C9-11). The adhesive agent used was a cement adhesive agent manufactured by KYOWA ELECTRONIC INSTRUMENTS CO., LTD. (Product No.: CC-33A). The device used for measuring the magnetostriction was a static strain measurement device manufactured by KYOWA ELECTRONIC INSTRUMENTS CO., LTD. (Product No.: SMD-10A). The magnetic field applied in the measurement was 15.6 kA/m.

[0083] In the present application, the term "magnetic permeability" refers to an amplitude magnetic permeability measured at temperature T (°C) in the presence of an AC magnetic field of frequency f=50 Hz and amplitude H=1.0 ampere/meter (A/m) applied.

[0084] The magnetic permeability of a single wound magnetic core measured under the above-described conditions is represented as "magnetic permeability $\mu_{\text{core}}(T)$ " or simply " $\mu_{\text{core}}(T)$ ". The magnetic permeability of a wound magnetic core which was measured while the wound magnetic core is adhered to the case is represented as "magnetic permeability $\mu_{\text{unit}}(T)$ " or simply " $\mu_{\text{unit}}(T)$ ".

[0085] FIG. 16 is a diagram for illustrating the configuration of a measurement system used in measuring the magnetic permeability $\mu(T)$ of a wound magnetic core or magnetic core unit for use in a current transformer or the like. In the illustrated configuration, the primary side conductor 18 of an object of measurement (wound magnetic core or magnetic core unit) is coupled with a function generator 54 which can generate an AC voltage signal having an arbitrary frequency and waveform, via a digital multimeter (DMM) 52 which can measure a DC voltage, direct current, AC voltage, and electrical resistance over wide ranges and a resistor R. On the other hand, the secondary side conductor 17 of the current transformer is coupled with another digital multimeter (DMM) 56 which is different from the digital multimeter 52 on the primary side conductor 18 side. In the measurement in the present application, the resistance value was set to 47 ohm, and digital multimeter 34401A manufactured by Agilent Technologies was used as the digital multimeters 52 and 56. As the function generator 54, multifunction generator WF1973 manufactured by NF CORPORATION was used, and an AC voltage signal was generated by the multifunction generator.

[0086] The magnetic permeability $\mu_r(T)$ is determined by Formula 5:

$$\mu_r(T) = \frac{V_o}{4.44 \times f \times A_e \times H \times \mu_0}$$

where $V_o(V)$ is the voltage value measured by the digital multimeter (DMM) 56, $A_e(m^2)$ is the effective cross-sectional area of the core, μ_0 is the magnetic permeability in vacuum, $f(Hz)$ is the frequency, and $H(A/m)$ is the intensity of the AC magnetic field applied by the primary side conductor 18.

[0087] Next, adhesion between the wound magnetic core and the case is described in detail.

[0088] For example, an adhesive agent is applied to only one of the layered surfaces (surfaces perpendicular to the roll axis) of the wound magnetic core. Examples of the adhesive agent which can be suitably used include resin adhesive agents, thermosetting adhesive agents, silicone adhesive agents, instantaneous adhesive agents, and varnish materials.

[0089] The adhesive agent may be applied to the entirety of the layered surface. However, if the adhesion area between the case and the wound magnetic core is large, the temperature characteristic of the magnetic core unit after being adhered is likely to deteriorate due to the effects of magnetostriction. Thus, it is preferred that the wound magnetic core is adhered to the case by an adhesive agent in a range of not less than 30% and not more than 50% with respect to the area of the layered surface (only one of the layered surfaces) of the wound magnetic core. Hereinafter, the ratio of the area of the adhesive agent to the area of this layered surface is referred to as "the area ratio of the adhesive agent" or simply "the area ratio".

[0090] When the area ratio of the adhesive agent is not less than 30%, the adhesion strength between the wound magnetic core and the case can be sufficiently secured, and separation of the wound magnetic core and the case can

be suppressed. When the area ratio is not more than 50%, as will be described later, the temperature characteristic of the magnetic permeability μ_{unit} of the wound magnetic core after being adhered to the case can be improved. Further, a magnetic core unit whose high temperature temporal change rate $\Delta\mu$ is not more than $\pm 6\%$ can be easily realized.

[0091] The adhesive agent preferably has a Shore A hardness of not less than 10 and less than 50. The change of the magnetic permeability between before and after the wound magnetic core is adhered to the case can be reduced.

[0092] When the Shore A hardness is not less than 50 and less than 10, the aforementioned voltage value V_0 (voltage value V_0 in FIG. 16) is likely to greatly change between before and after the wound magnetic core is adhered to the case. Since the magnetic permeability $\mu_r(T)$ is proportional to the voltage value V_0 as represented by Formula 5, the change rate of the magnetic permeability $\mu_r(T)$ is also large when the change rate of the voltage value V_0 is large. So long as the Shore A hardness is not less than 10 and less than 50, the change of the voltage value V_0 can be suppressed to 10% or smaller. The lower limit of the Shore A hardness is more preferably 15%, still more preferably 18%. The upper limit of the Shore A hardness is more preferably 48%.

[0093] When the Shore A hardness is not less than 20 and not more than 45, the change of the voltage value V_0 can be suppressed to 8% or smaller. Details will be described later with examples.

[0094] The measurement method of the Shore A hardness is compliant with JIS2246.

[0095] As described above, the magnetic core unit of the present embodiment is suitably used in, for example, current transformers.

[0096] For example, a current transformer of the present embodiment includes a magnetic core unit of the present embodiment and a coil. A magnetic core unit is produced by the above-described magnetic core unit manufacturing method, and a wire is wound around the magnetic core unit, whereby a coil is formed around the magnetic core unit. Thereby, the current transformer is completed.

[0097] Hereinafter, the present disclosure is described with examples, although the magnetic core unit of the present disclosure is not limited to the examples.

(Example 1)

[0098] A molten alloy consisting of Cu: 1%, Nb: 3%, Si: 15%, B: 7%, and the remainder including Fe and unavoidable impurities (atomic %) was quenched by a single-roll method, resulting in a Fe-based amorphous alloy ribbon which had a width of 50 mm and a thickness of 18 μm . The crystallization initiating temperature of this alloy measured by differential scanning calorimetry (DSC) was 500°C. This Fe-based amorphous alloy ribbon was slit (cut) so as to have a width of 10 mm and thereafter wound up into a magnetic core element which had an outside diameter of 17 mm and an inside diameter of 12 mm (and a height of 10 mm).

[0099] The first heat treatment was performed on the produced magnetic core element in a temperature pattern shown in FIG. 12.

[0100] The first heat treatment was performed in the absence of a magnetic field. Firstly, the temperature was increased to 450°C in 30 minutes, maintained at 450°C for 30 minutes, and then increased to the highest temperature in 240 minutes. This process was carried out for each of the highest temperatures of 520°C, 535°C, 540°C and 545°C. Thereafter, the temperature was maintained at the highest temperature for 60 minutes and then decreased to 350°C in 90 minutes. Thereafter, the magnetic core element was held in the furnace without being heated till it reached the room temperature. Thereby, a wound magnetic core of the nanocrystalline alloy was produced. This first heat treatment was performed in an atmosphere in which the oxygen concentration was not more than 10 ppm (2 ppm).

[0101] Thereafter, the second heat treatment was performed in a temperature pattern and a magnetic field application pattern shown in FIG. 13. First, the temperature was increased to 240°C in 60 minutes and maintained at 240°C for 30 minutes. The process until this point in time was carried out in the absence of a magnetic field. Thereafter, the temperature was decreased to 120°C in 60 minutes. A magnetic field of 159.5 kA/m was applied for 30 minutes since the decrease of the temperature was started. The direction of application of the magnetic field was the width direction of the alloy ribbon, i.e., the vertical direction of the core. Thereafter, the magnetic core was held in the furnace without being heated in the absence of a magnetic field till it reached the room temperature. This second heat treatment was also performed in an atmosphere in which the oxygen concentration was not more than 10 ppm (2 ppm).

[0102] In a resultant wound magnetic core on which the first heat treatment was performed at 520°C, the magnetic permeability $\mu_{\text{core}}(25)$ was 500, 000, the squareness ratio Br/B_m was 39.6%, and the saturated magnetostriction was 3 ppm. In a resultant wound magnetic core on which the first heat treatment was performed at 535°C, the magnetic permeability $\mu_{\text{core}}(25)$ was 500,000, the squareness ratio Br/B_m was 46.9%, and the saturated magnetostriction was 2 ppm. In a resultant wound magnetic core on which the first heat treatment was performed at 540°C, the magnetic permeability $\mu_{\text{core}}(25)$ was 668,000, the squareness ratio Br/B_m was 47.8%, and the saturated magnetostriction was 2 ppm. In a resultant wound magnetic core on which the first heat treatment was performed at 545°C, the magnetic permeability $\mu_{\text{core}}(25)$ was 662, 000, the squareness ratio Br/B_m was 49.9%, and the saturated magnetostriction was 2 ppm.

[0103] FIG. 1 shows the magnetic permeability $\mu_{\text{core}}(-25)$, $\mu_{\text{core}}(25)$, $\mu_{\text{core}}(100)$ of the wound magnetic core measured at -25°C , 25°C , 100°C as the change rate relative to $\mu_{\text{core}}(25)$.

[0104] Each of the wound magnetic cores for which the highest temperature of the first heat treatment was 520°C , 535°C , 540°C , and 545°C satisfies Formula 3 and Formula 4:

$$\text{(Formula 3)} \quad 0 < (\mu_{\text{core}}(-25) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$$

$$\text{(Formula 4)} \quad -0.25 \leq (\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25) < 0$$

where $\mu_{\text{core}}(T)$ is the magnetic permeability measured at temperature $T^{\circ}\text{C}$ in the presence of an AC magnetic field of frequency $f=50$ Hz and amplitude $H=1.0$ ampere/meter (A/m).

[0105] The change rate of the magnetic permeability of FIG. 1 is shown in TABLE 1.

[TABLE 1]

FIRST HEAT TREATMENT TEMPERATURE	$(\mu_{\text{core}}(-25) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$	$(\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$
520°C	0.3%	-3.4%
535°C	0.9%	-13.2%
540°C	1.9%	-15.3%
545°C	2.7%	-22.2%

[0106] Next, 0.04 g, 0.05 g, or 0.06 g drops of an adhesive agent (SE9168RTV manufactured by TORAY-DOW CORNING (R), Shore A hardness: 44) were applied to the layered surface (area: 132 mm^2) of the wound magnetic core, at 2, 3 or 4 positions separated at equal angular intervals.

[0107] Thereafter, as shown in FIG. 15, the wound magnetic core 13 was adhered to the body 14 of the case via the adhesive agent 16, and thereafter, the lid 12 was adhered to the body 14, resulting in a magnetic core unit 11.

[0108] The body 14 has the shape of an annular space 14a (trench) whose outside diameter is 25 mm, whose inside diameter is 8 mm, and whose height is 13 mm (each of them is an inner dimension). The lid 12 is formed by a doughnut-like plate so as to close the opening of the body 14. Both the body 14 and the lid 12 are made of polyamide 66 (PA66).

[0109] In the magnetic core units to which 0.05 g drops of the adhesive agent were applied, the wound magnetic core was separated from the case after the adhesion. In the magnetic core unit to which the adhesive agent was applied at two positions, the area in which the adhesive agent was applied was 48 mm^2 . In the magnetic core unit to which the adhesive agent was applied at three positions, the area in which the adhesive agent was applied was 77 mm^2 . In the magnetic core unit to which the adhesive agent was applied at four positions, the area in which the adhesive agent was applied was 86 mm^2 . In these cases, the area ratios of the adhesive agent are 36.4%, 58.3% and 65.2%.

[0110] FIG. 2 to FIG. 5 show the change rate of $\mu_{\text{unit}}(-25)$ and $\mu_{\text{unit}}(100)$ relative to the magnetic permeability $\mu_{\text{unit}}(25)$. FIG. 2 shows the measurements in a magnetic core unit including a wound magnetic core which underwent the first heat treatment at 520°C . FIG. 3 shows the measurements in a magnetic core unit including a wound magnetic core which underwent the first heat treatment at 535°C . FIG. 4 shows the measurements in a magnetic core unit including a wound magnetic core which underwent the first heat treatment at 540°C . FIG. 5 shows the measurements in a magnetic core unit including a wound magnetic core which underwent the first heat treatment at 545°C .

[0111] Each of the magnetic core units has excellent temperature characteristic so that the magnetic permeability $\mu_{\text{unit}}(T)$ satisfies Formula 1 and Formula 2.

$$\text{(Formula 1)} \quad -0.28 \leq (\mu_{\text{unit}}(100) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0.1$$

$$\text{(Formula 2)} \quad -0.28 \leq (\mu_{\text{unit}}(-25) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

[0112] The change rate of the magnetic permeability of FIG. 2 to FIG. 5 is shown in TABLE 2.

[TABLE 2]

	FIRST HEAT TREATMENT TEMPERATURE	ADHESIVE AGENT AMOUNT	AREA RATIO	$(\mu_{\text{unit}}(-25) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25)$	$(\mu_{\text{unit}}(100) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25)$
5	520°C	Applied at 2 positions, 0.05 g at each position	36.4%	-15.7%	3.0%
	520°C	Applied at 4 positions, 0.05 g at each position	65.2%	-23.3%	5.7%
10	535°C	Applied at 2 positions, 0.05 g at each position	36.4%	-10.2%	-7.8%
	535°C	Applied at 4 positions, 0.05 g at each position	65.2%	-16.8%	-1.6%
15	540°C	Applied at 2 positions, 0.05 g at each position	36.4%	-13.7%	-16.4%
	540°C	Applied at 4 positions, 0.05 g at each position	65.2%	-18.0%	-8.5%
20	545°C	Applied at 2 positions, 0.05 g at each position	36.4%	-10.5%	-25.1%
	545°C	Applied at 3 positions, 0.05 g at each position	58.5%	-26.4%	-12.0%
25	545°C	Applied at 4 positions, 0.05 g at each position	65.2	-27.1	-15.0

[0113] FIG. 6 is a graph where the change rate of the magnetic permeability $\mu_{\text{unit}}(100)$ on the high temperature side (100°C) relative to $\mu_{\text{unit}}(25)$ was plotted over the area ratio of the adhesive agent (horizontal axis) for respective temperatures of the first heat treatment. As the temperature of the first heat treatment increases, the magnetic permeability $\mu_{\text{unit}}(100)$ decreases. For the magnetic core unit treated at 545°C, the decrease rate of the magnetic permeability of $\mu_{\text{unit}}(-25)$ relative to $\mu_{\text{unit}}(25)$ is -25.1% but does not exceed -28%.

[0114] As clearly seen from FIG. 2, for a magnetic core unit treated at 520°C in the first heat treatment, $\mu_{\text{unit}}(-25)$ decreases relative to $\mu_{\text{unit}}(25)$ while $\mu_{\text{unit}}(100)$ increases. In the range of -25°C to 100°C, the maximum difference in magnetic permeability is the sum of the decrease of $\mu_{\text{unit}}(-25)$ relative to $\mu_{\text{unit}}(25)$ and the increase of $\mu_{\text{unit}}(100)$. Therefore, this magnetic core unit is likely to have a large maximum difference in magnetic permeability. However, such a difference is allowable in consideration of the temperature characteristic required of a magnetic core unit for use in a current transformer.

[0115] FIG. 7 is a graph where the change rate of the magnetic permeability $\mu_{\text{unit}}(-25)$ on the low temperature side (-25°C) relative to $\mu_{\text{unit}}(25)$ was plotted over the area ratio of the adhesive agent (horizontal axis) for respective temperatures of the first heat treatment. In a wound magnetic core in which the area ratio of the adhesive agent on the layered surface of the wound magnetic core is not more than 50%, the change rate of the magnetic permeability of $\mu_{\text{unit}}(-25)$ is smaller than in a wound magnetic core in which the area ratio is more than 50%.

[0116] In the magnetic core unit treated at 520°C, the change rate of the magnetic permeability $\mu_{\text{unit}}(25)$ after the magnetic core unit is maintained at 100°C for 100 hours is more than $\pm 6\%$ as will be described later. Therefore, if the magnetic core unit is required to undergo a small temporal change at high temperatures, it is preferred that the temperature of the first heat treatment is a still higher temperature.

[0117] As seen from FIG. 3 and FIG. 4, the magnetic core units which include the wound magnetic cores on which the first heat treatment was performed at 535°C and 540°C have more excellent temperature characteristics, and the magnetic permeability $\mu_{\text{unit}}(T)$ satisfies Formula 1' and Formula 2'.

$$\text{(Formula 1')} \quad -0.20 \leq (\mu_{\text{unit}}(100) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

$$\text{(Formula 2')} \quad -0.20 \leq (\mu_{\text{unit}}(-25) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

[0118] That is, both the change rates of $\mu_{\text{unit}}(-25)$ and $\mu_{\text{unit}}(100)$ relative to $\mu_{\text{unit}}(25)$ are suppressed to 20% or lower.

[0119] As seen from FIG. 5, in the magnetic core unit which includes the wound magnetic core treated at 545°C in the first heat treatment, the change rate of at least one of $\mu_{\text{unit}}(-25)$ and $\mu_{\text{unit}}(100)$ relative to $\mu_{\text{unit}}(25)$ is greater than in the magnetic core units treated at 535°C and 540°C, although its decrease rate is suppressed to 28% or lower.

(Example 2)

[0120] The first heat treatment in which the highest temperature was 540°C was performed on a magnetic core element. Thereafter, in the same way as in Example 1, the second heat treatment was performed in the temperature pattern and the magnetic field application pattern shown in FIG. 13. To one of the layered surfaces of this wound magnetic core, an adhesive agent (SE9168RTV manufactured by TORAY-DOW CORNING (R), Shore A hardness: 44) was applied at 2, 3 or 4 positions separated at equal angular intervals. The amount of the adhesive agent at each position was varied among 0.02 g, 0.03 g, 0.04 g, 0.05 g, and 0.06 g, and the adhesive agent was applied in 15 patterns in total. This wound magnetic core was adhered to a case, resulting in a magnetic core unit shown in FIG. 15. The present inventor examined the relationship between the area ratio of the applied adhesive agent and the adhesion strength (tensile strength) between the wound magnetic core and the case and found such a tendency that the adhesion strength improves as the area ratio of the adhesive agent increases as shown in FIG. 14.

(Example 3)

[0121] The first heat treatment in which the highest temperature was 520°C, 535°C, 540°C or 545°C was performed on the magnetic core element. Thereafter, the second heat treatment was performed in the temperature pattern and the magnetic field application pattern shown in FIG. 13 in the same way as in Example 1. To one of the layered surfaces of this wound magnetic core, an adhesive agent was applied at 2 positions separated at equal angular intervals, and the amount of the adhesive agent at each position was varied between 0.02 g and 0.06 g. In these samples, the change rate of $\mu_{\text{unit}}(-25)$ and $\mu_{\text{unit}}(100)$ relative to $\mu_{\text{unit}}(25)$ of the magnetic core unit was examined.

[0122] After the measurement, the case and the wound magnetic core were separated from the magnetic core unit, and the area ratio of the adhesive agent was measured. In a magnetic core unit in which the amount of the adhesive agent at each position was 0.02 g, the area ratio of the adhesive agent was 31.7%. In a magnetic core unit in which the amount of the adhesive agent at each position was 0.06 g, the area ratio of the adhesive agent was 39.8%.

[0123] The measurement results are shown in FIG. 9 and FIG. 10. In both the magnetic core units in which the area ratio of the adhesive agent was 31.7% and 39.8%, the saturated magnetostriction was greater than 1 ppm. However, the change rates of $\mu_{\text{unit}}(-25)$ and $\mu_{\text{unit}}(100)$ relative to $\mu_{\text{unit}}(25)$ of the magnetic core units satisfy Formula 1 and Formula 2 shown below, i.e., the magnetic core units have excellent temperature characteristics.

$$\text{(Formula 1)} \quad -0.28 \leq (\mu_{\text{unit}}(100) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0.1$$

$$\text{(Formula 2)} \quad -0.28 \leq (\mu_{\text{unit}}(-25) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

(Example 4)

[0124] FIG. 8 is a graph where the change rate of the magnetic permeability $\mu_{\text{unit}}(25)$ after the magnetic core unit was maintained at 100°C for 100 hours (hereinafter, referred to as "high temperature temporal change rate $\Delta\mu$ ") was plotted for respective temperatures of the first heat treatment. The horizontal axis represents the area ratio of the adhesive agent. The vertical axis represents the high temperature temporal change rate $\Delta\mu$.

[0125] In the measured magnetic core units, the area ratio of the adhesive agent (SE9168RTV manufactured by TORAY-DOW CORNING (R), Shore A hardness: 44) on the layered surface of the wound magnetic core was 31.6%, 36.4%, 58.5% or 65.2%. TABLE 3 shows the numerical values of the points plotted in FIG. 8. When the area ratio of the adhesive agent is more than 50%, the high temperature temporal change rate $\Delta\mu$ is more than $\pm 6\%$ in some of the magnetic core units.

[TABLE 3]

AREA RATIO OF ADHESIVE AGENT	CHANGE RATE $\Delta\mu$ OF MAGNETIC PERMEABILITY $\mu_{\text{unit}}(-25)$ AFTER MAGNETIC CORE UNIT WAS MAINTAINED AT 100°C FOR 100 HOURS			
	545°C	540°C	535°C	520°C
31.6%	-1.5	-2.6	-4.9	-1.9
36.4%	0	-1.3	--	-5.5
58.5%	--	-1.3	-5.5	-12.1
65.2%	--	-1.3	-0.8	-6.6

[0126] On the other hand, in the magnetic core units for which the highest temperature of the first heat treatment was 545°C, 540°C or 530°C, the high temperature temporal change rate $\Delta\mu$ was not more than 6%.

[0127] Concluding from the foregoing, in order to manufacture a magnetic core unit in which the high temperature temporal change rate $\Delta\mu$ is within 6%, such a manufacturing method is preferred that (1) the area ratio of the adhesive agent is not more than 50%, or (2) the highest temperature of the first heat treatment is equal to or higher than 530°C (535°C, 540°C, 545°C). Considering the variation in characteristics due to mass production, it can be said that the manufacturing method preferably meet both of the conditions (1) and (2).

(Example 5)

[0128] FIG. 11 is a graph showing the relationship between the highest temperature in the second heat treatment in the presence of an applied magnetic field (in FIG. 13, a temperature at which application of the magnetic field is started during decrease of the temperature) (horizontal axis) and the magnetic permeability $\mu_{\text{core}}(25)$ of the wound magnetic core after the second heat treatment (vertical axis).

[0129] As the highest temperature increases, the achieved magnetic permeability is likely to decrease. The highest temperature and the achieved magnetic permeability are in a generally proportional relationship. From the measurement results, it is understood that the magnetic permeability $\mu_{\text{unit}}(25)$ of not less than 400000 and not more than 700000 can be achieved by setting the highest temperature of the second heat treatment in the presence of an applied magnetic field to a temperature in the range of not less than 225°C and not more than 270°C. When the lower limit of this highest temperature is 230°C, a wound magnetic core whose magnetic permeability $\mu_{\text{unit}}(25)$ is not less than 400000 is easily realized. When the upper limit is 265°C, a wound magnetic core whose magnetic permeability $\mu_{\text{unit}}(25)$ is not more than 700000 is easily realized.

(Example 6)

[0130] The effects of the Shore A hardness of the adhesive agent on the temperature characteristic were studied.

[0131] The Fe-based amorphous alloy ribbon used was the same as that of Example 1 (alloy composition consisting of Cu: 1%, Nb: 3%, Si: 15%, B: 7%, and the remainder including Fe and unavoidable impurities (atomic %), width: 50 mm, thickness: 18 μm).

[0132] This Fe-based amorphous alloy ribbon was slit (cut) so as to have a width of 6 mm and thereafter wound up into a magnetic core element which had an outside diameter of 20 mm and an inside diameter of 10 mm (and a height of 10 mm).

[0133] The first heat treatment was performed on the produced magnetic core element. The first heat treatment was performed in the absence of a magnetic field. Firstly, the temperature was increased to 450°C in 30 minutes, maintained at 450°C for 30 minutes, and then increased to 530°C in 240 minutes, which was the highest temperature. Thereafter, the magnetic core element was maintained at the highest temperature for 60 minutes and then cooled to the room temperature.

[0134] Thereafter, the second heat treatment was performed. First, the temperature was increased to 250°C in 60 minutes and maintained at 250°C for 30 minutes. The process until this point in time was carried out in the absence of a magnetic field. Thereafter, the temperature was decreased to 150°C in 60 minutes. A magnetic field of 159.5 kA/m was applied for 30 minutes since the decrease of the temperature was started. The direction of application of the magnetic field was the width direction of the alloy ribbon, i.e., the vertical direction of the core. Thereafter, the magnetic core element was held in the furnace without being heated in the absence of a magnetic field till it reached the room temperature. This second heat treatment was performed in an atmosphere in which the oxygen concentration was not more than 10 ppm (2 ppm). Thereby, a wound magnetic core of the nanocrystalline alloy was produced.

[0135] To one of the layered surfaces of this wound magnetic core, an adhesive agent was applied at 4 positions separated at equal angular intervals. The amount of the adhesive agent at each position was 0.02 g.

[0136] The adhesive agents used had Shore A hardness of 20, 44, 50 and 70 (Samples A to D). The adhesive agent of Sample B was used for preparing three magnetic core units. Each of the other adhesive agent samples was used for preparing two magnetic core units.

[0137] Before and after the wound magnetic core is adhered to the case, the voltage value $V_o(V)$ was measured by the digital multimeter (DMM) **56** in the measurement system of FIG. **16**, and the change rate of the voltage value $V_o(V)$ was calculated. The measurement results are shown in TABLE 4.

[TABLE 4]

ADHESIVE AGENT	SHORE A HARDNESS	VOLTAGE VALUE V_o		CHANGE RATE
		BEFORE ADHERED	AFTER ADHERED	
SAMPLE A1	20	3.39	3.53	4%
SAMPLE A2	20	3.43	3.63	6%
SAMPLE B1	44	3.23	3.06	-5%
SAMPLE B2	44	3.07	2.87	-7%
SAMPLE B3	44	3.18	2.92	-8%
SAMPLE C1	50	3.6	2.8	-22%
SAMPLE C2	50	3.82	2.89	-24%
SAMPLE D1	70	3.6	2.22	-38%
SAMPLE D2	70	3.5	2.31	-34%

[0138] When Sample C was used whose Shore A hardness was 50, the change rate of the voltage value V_o was more than 20%. When Sample B was used whose Shore A hardness was 44, the change rate of the voltage value V_o was not more than 10%. When Sample A was used whose Shore A hardness was 20, the change rate of the voltage value V_o was not more than 10%. In the magnetic core units in which Sample A or Sample B was used, the change rate of V_o was 8% at the maximum.

[0139] In the magnetic core units in which Sample A was used whose Shore A hardness was 20, the change of V_o between before and after the wound magnetic core was adhered to the case was an increasing change. On the other hand, in the magnetic core units in which Sample B was used whose Shore A hardness was 44, V_o exhibited a decreasing change. As estimated from this comparison, the Shore A hardness is at the midpoint between Sample A and Sample B when the change rate of V_o is not more than 8%, and when these adhesive agents are used, the temperature characteristic of the wound magnetic core can be further improved.

(Example 7)

[0140] In a wound magnetic core produced by the two-step heat treatment, as will be described later, the temperature characteristic improves when the coercivity is small. In view of such, the present inventor examined whether or not the coercivity H_c can be reduced by changing the temperature rise rate in a temperature range at which nanocrystallization begins.

[0141] In the temperature pattern of the first heat treatment which is similar to that of Example 6, the temperature rise rate from 450°C to 530°C that was the highest temperature was 0.375°C/min, 0.5°C/min, 0.75°C/min, 1°C/min, 1.5°C/min, 2°C/min or 3°C/min. The other conditions were the same as those of Example 6 in manufacturing a magnetic core unit. The coercivity H_c of the resultant magnetic core unit was measured.

[0142] As previously described, it was confirmed that a wound magnetic core produced by the two-step heat treatment has improved temperature characteristic when the coercivity is small. FIG. **17** shows the results of measurement of $(\mu_{core}(100) - \mu_{core}(25)) / \mu_{core}(25)$ of the wound magnetic core in varying temperature patterns of the first heat treatment and the second heat treatment. It was confirmed that, in a wound magnetic core produced by the two-step heat treatment, the temperature characteristic represented by $(\mu_{core}(100) - \mu_{core}(25)) / \mu_{core}(25)$ is likely to decrease as the coercivity decreases.

[0143] As previously described, setting the range of $(\mu_{core}(100) - \mu_{core}(25)) / \mu_{core}(25)$ of the wound magnetic core to $-0.25 \leq (\mu_{core}(100) - \mu_{core}(25)) / \mu_{core}(25) < 0$ leads to improvement of the temperature characteristic after the magnetic core

unit is produced. A preferred range is, as previously described, $-0.20 \leq (\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25) \leq 0.05$.

[0144] As seen from FIG. 17, $(\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$ of the wound magnetic core can be set to the range of not less than -25% and less than 0% by setting the coercivity H_c in the range of not less than 0.4 A/m and not more than 0.75 A/m. It is also seen that $(\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$ of the wound magnetic core can be set in a more preferred range of not less than -20% and not more than -5% by setting the coercivity H_c in the range of not less than 0.5 A/m and not more than 0.65 A/m.

[0145] FIG. 18 is a graph showing the relationship between the temperature rise rate and the coercivity of the wound magnetic core.

[0146] Throughout the range of the temperature rise rate from 0.375°C/min to 3/min, the coercivity H_c of the wound magnetic core is not less than 0.4 A/m and not more than 0.75 A/m. In this range of the temperature rise rate, the range of $(\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$ of the wound magnetic core can be easily set to $-0.25 \leq (\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25) < 0$.

[0147] When the temperature rise rate is not more than 2°C/min, the coercivity H_c of the wound magnetic core is not less than 0.4 A/m and not more than 0.65 A/m. In this range of the temperature rise rate, the range of $(\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$ of the wound magnetic core can be easily set to $-0.20 \leq (\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25) \leq -0.05$.

[0148] In FIG. 18, when the temperature rise rate is not more than 1.5°C/min, the coercivity H_c further decreases to a level not more than 0.61 A/m, and the coercivity H_c is not less than 0.55 A/m even if the temperature rise rate is 0.375°C/min. Thus, it is estimated that the range of $(\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$ of the wound magnetic core can be further narrowed.

[0149] As seen from the approximate curve (third order polynomial approximate curve) of the measurements in FIG. 18, when the temperature rise rate is not more than 1.2°C/min, the coercivity H_c is generally equal to the value achieved at 0.375°C/min, and when the temperature rise rate is in the range of not less than 0.375°C/min and not more than 1.2°C/min, the coercivity H_c reaches a minimum value. Thus, it is estimated that the wound magnetic core can be stably manufactured in a further narrowed range of $(\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$ of the wound magnetic core. If the upper limit of the temperature rise rate is 1.0°C/min, the coercivity H_c can be further reduced.

INDUSTRIAL APPLICABILITY

[0150] A magnetic core unit of the present disclosure is suitably usable for a magnetic core of common mode choke coils, high frequency transformers, pulse transformers, current transformers, etc., and can be suitably used in, for example, a current transformer.

REFERENCE SIGNS LIST

[0151]

- 11 magnetic core unit
- 12 lid
- 12a ceiling surface
- 13 wound magnetic core
- 13a, 13b layered surface
- 14 body
- 14a space
- 14b bottom surface
- 15 case
- 16 adhesive agent

Claims

1. A magnetic core unit comprising:

- a wound magnetic core including a wound nanocrystalline alloy ribbon;
 - a case having a space corresponding to an external shape of the wound magnetic core, the wound magnetic core being stored in the space; and
 - an adhesive agent provided between a bottom surface of the space and a layered surface of the wound magnetic core, the adhesive agent adhering the wound magnetic core to the bottom surface,
- wherein the nanocrystalline alloy ribbon has a saturated magnetostriction of greater than 1 ppm, and

magnetic permeability $\mu_{\text{unit}}(25)$ is not less than 400000 and Formula 1 and Formula 2 are satisfied:

$$\text{(Formula 1)} \quad -0.28 \leq (\mu_{\text{unit}}(100) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0.1$$

$$\text{(Formula 2)} \quad -0.28 \leq (\mu_{\text{unit}}(-25) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

where $\mu_{\text{unit}}(T)$ is a magnetic permeability measured at temperature $T^{\circ}\text{C}$ in the presence of an AC magnetic field of frequency $f=50$ Hz and amplitude $H=1.0$ ampere/meter (A/m) applied across the wound magnetic core adhered to the case.

2. The magnetic core unit of claim 1, wherein the magnetic permeability $\mu_{\text{unit}}(T)$ satisfies Formula 1' and Formula 2':

$$\text{(Formula 1')} \quad -0.20 \leq (\mu_{\text{unit}}(100) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0$$

$$\text{(Formula 2')} \quad -0.20 \leq (\mu_{\text{unit}}(-25) - \mu_{\text{unit}}(25)) / \mu_{\text{unit}}(25) \leq 0.$$

3. The magnetic core unit of claim 1 or 2, wherein a change rate $\Delta\mu$ between the magnetic permeability $\mu_{\text{unit}}(25)$ before the magnetic core unit is maintained at 100°C for 100 hours and the magnetic permeability $\mu_{\text{unit}}(25)$ after the magnetic core unit is maintained at 100°C for 100 hours is within $\pm 6\%$.

4. The magnetic core unit of any of claims 1 to 3, wherein the magnetic permeability $\mu_{\text{unit}}(25)$ is not more than 700000.

5. The magnetic core unit of any of claims 1 to 4, wherein the layered surface of the wound magnetic core is adhered to the case by the adhesive agent in a range of not less than 30% and not more than 50% with respect to an area of the layered surface of the wound magnetic core.

6. The magnetic core unit of any of claims 1 to 5, wherein the adhesive agent has a Shore A hardness of not less than 10 and less than 50.

7. The magnetic core unit of any of claims 1 to 6, wherein the nanocrystalline alloy ribbon is made of an alloy which has a composition represented by Formula: $(\text{Fe}_{1-a}\text{M}_a)_{100-x-y-z-\alpha-\beta-\gamma}\text{Cu}_x\text{Si}_y\text{B}_z\text{M}'_{\alpha}\text{M}''_{\beta}\text{X}_{\gamma}$ (atomic %) (M is Co and/or Ni, M' is at least one element selected from the group consisting of Nb, Mo, Ta, Ti, Zr, Hf, V, Cr, Mn and W, M'' is at least one element selected from the group consisting of Al, platinum group elements, Sc, rare-earth elements, Zn, Sn and Re, X is at least one element selected from the group consisting of C, Ge, P, Ga, Sb, In, Be and As, a, x, y, z, α , β and γ satisfy $0 \leq a \leq 0.5$, $0.1 \leq x \leq 3$, $0 \leq y \leq 30$, $0 \leq z \leq 25$, $5 \leq y+z \leq 30$, $0 \leq \alpha \leq 20$, $0 \leq \beta \leq 20$ and $0 \leq \gamma \leq 20$, respectively).

8. A current transformer comprising the magnetic core unit as set forth in any of claims 1 to 7.

9. A method for manufacturing a magnetic core unit, comprising:

providing a magnetic core element formed by winding up an amorphous alloy ribbon, the magnetic core element having a composition represented by Formula: $(\text{Fe}_{1-a}\text{M}_a)_{100-x-y-z-\alpha-\beta-\gamma}\text{Cu}_x\text{Si}_y\text{B}_z\text{M}'_{\alpha}\text{M}''_{\beta}\text{X}_{\gamma}$ (atomic %) (M is Co and/or Ni, M' is at least one element selected from the group consisting of Nb, Mo, Ta, Ti, Zr, Hf, V, Cr, Mn and W, M'' is at least one element selected from the group consisting of Al, platinum group elements, Sc, rare-earth elements, Zn, Sn and Re, X is at least one element selected from the group consisting of C, Ge, P, Ga, Sb, In, Be and As, a, x, y, z, α , β and γ satisfy $0 \leq a \leq 0.5$, $0.1 \leq x \leq 3$, $0 \leq y \leq 30$, $0 \leq z \leq 25$, $5 \leq y+z \leq 30$, $0 \leq \alpha \leq 20$, $0 \leq \beta \leq 20$ and $0 \leq \gamma \leq 20$, respectively);

producing a wound magnetic core by performing a first heat treatment and a second heat treatment on the magnetic core element, the first heat treatment including heating at a temperature equal to or higher than a crystallization initiating temperature in the absence of a magnetic field, the second heat treatment including heating at a temperature lower than the crystallization initiating temperature, the second heat treatment includes applying a magnetic field in a direction perpendicular to a magnetic path, the wound magnetic core having a saturated magnetostriction of greater than 1 ppm, magnetic permeability $\mu_{\text{core}}(25)$ being not less than 400000, and Formula 3 and Formula 4 being satisfied:

$$\text{(Formula 3)} \quad 0 < (\mu_{\text{core}}(-25) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25)$$

$$\text{(Formula 4)} \quad -0.25 \leq (\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25) < 0$$

where $\mu_{\text{unit}}(T)$ is a magnetic permeability measured at temperature $T^{\circ}\text{C}$ in the presence of an AC magnetic field of frequency $f=50$ Hz and amplitude $H=1.0$ ampere/meter (A/m) applied across the wound magnetic core; and providing an adhesive agent between a case and a layered surface of the wound magnetic core for adhering the wound magnetic core to the case, the case having a space which corresponds to an external shape of the wound magnetic core.

10. The method of claim 9, wherein a highest temperature of the first heat treatment is equal to or higher than 520°C and equal to or lower than 550°C .

11. The method of claim 9, wherein a highest temperature of the first heat treatment is equal to or higher than 530°C and lower than 545°C , and the magnetic permeability $\mu_{\text{core}}(T)$ satisfies Formula 4':

$$\text{(Formula 4')} \quad -0.20 \leq (\mu_{\text{core}}(100) - \mu_{\text{core}}(25)) / \mu_{\text{core}}(25) < -0.05.$$

12. The method of any of claims 9 to 11, wherein a highest temperature of the second heat treatment is equal to or higher than 225°C and equal to or lower than 270°C .

13. The method of any of claims 9 to 12 wherein, in the first heat treatment, a temperature rise rate at the crystallization initiating temperature is not more than $5^{\circ}\text{C}/\text{min}$.

14. The method of any of claims 9 to 13, wherein the adhesive agent is provided on the layered surface of the wound magnetic core in a range of not less than 30% and not more than 50% with respect to an area of the layered surface of the wound magnetic core for adhering the wound magnetic core to the case.

15. The method of any of claims 9 to 14, wherein the adhesive agent has a Shore A hardness of not less than 10 and less than 50.

16. A method for manufacturing a current transformer, comprising:

manufacturing a magnetic core unit by the magnetic core unit manufacturing method as set forth in any of claims 9 to 15; and

winding a wire around the magnetic core unit.

FIG. 1

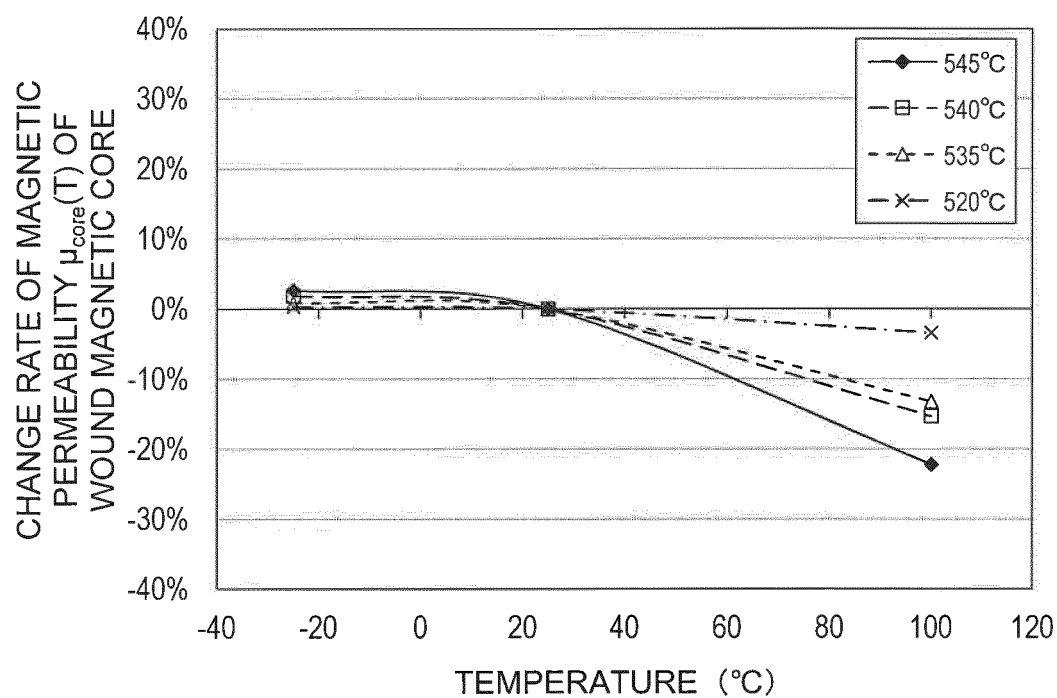


FIG. 2

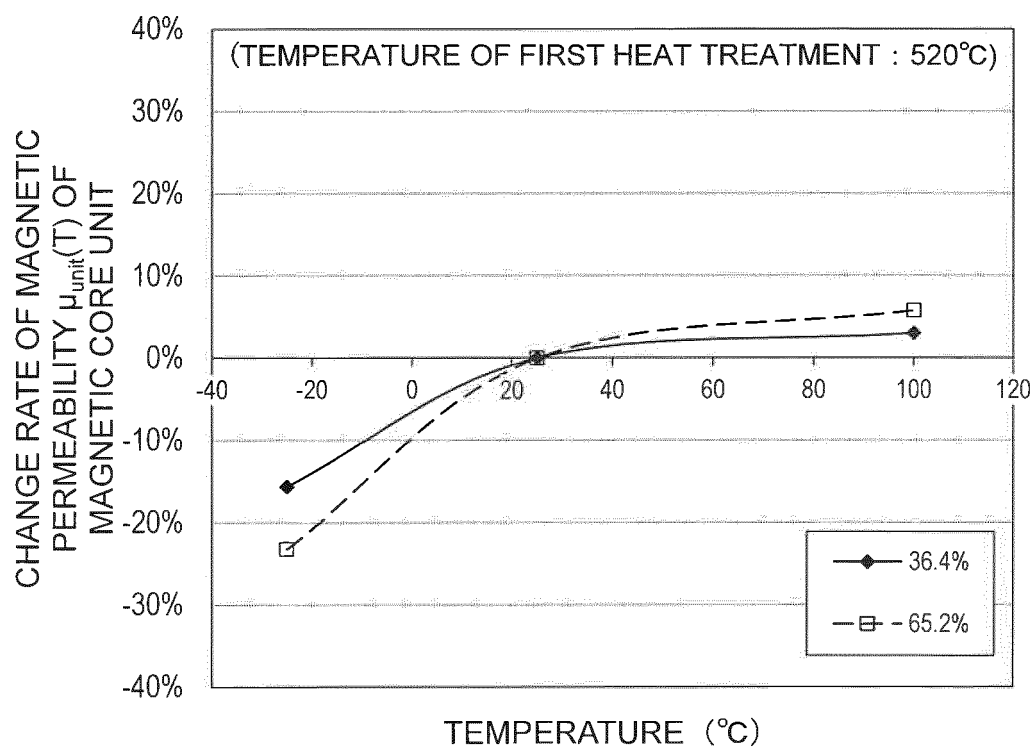


FIG.3

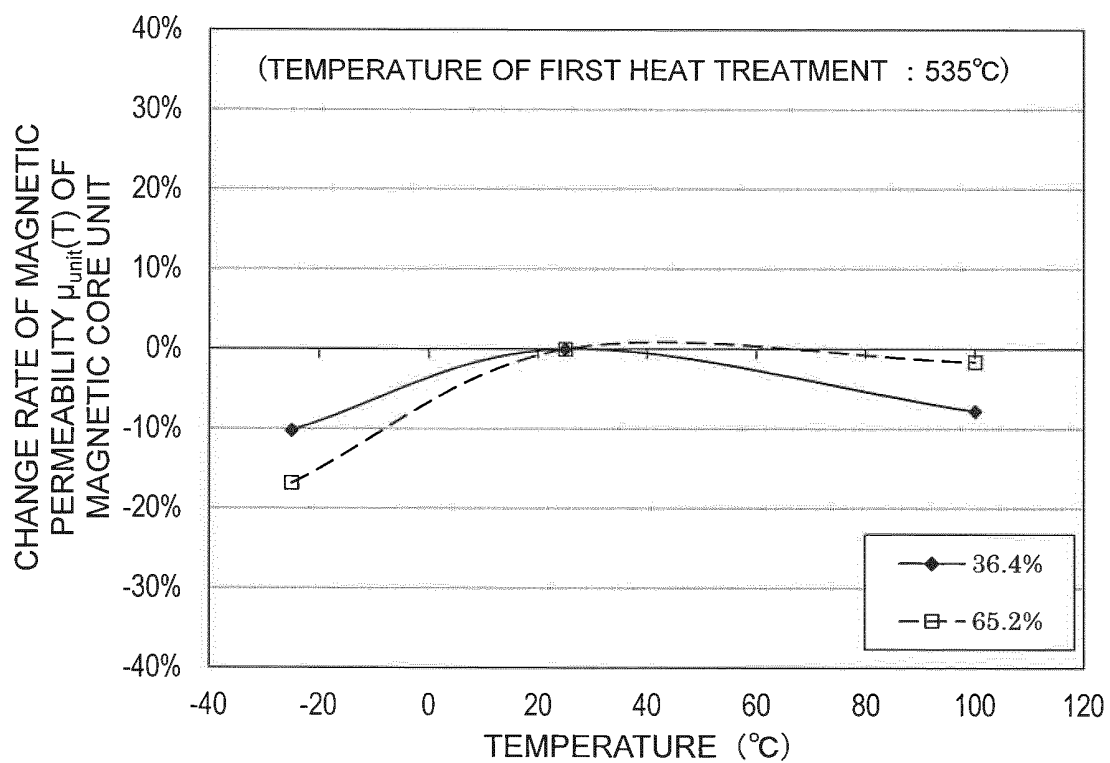


FIG.4

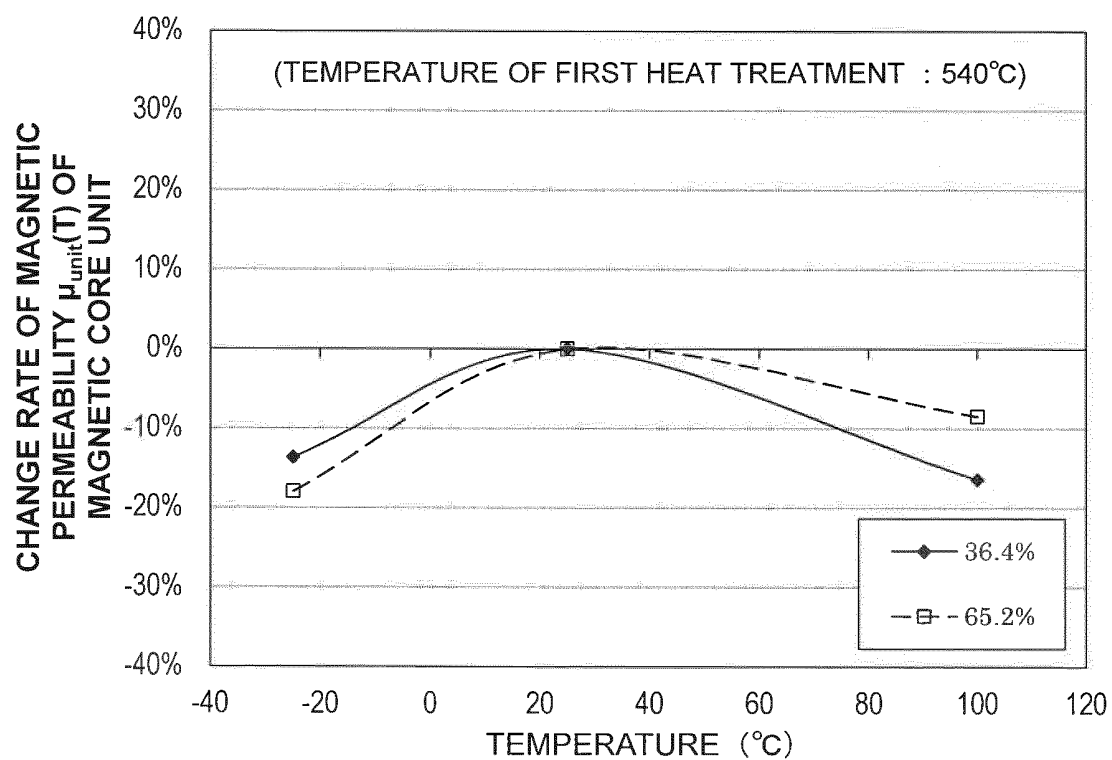


FIG. 5

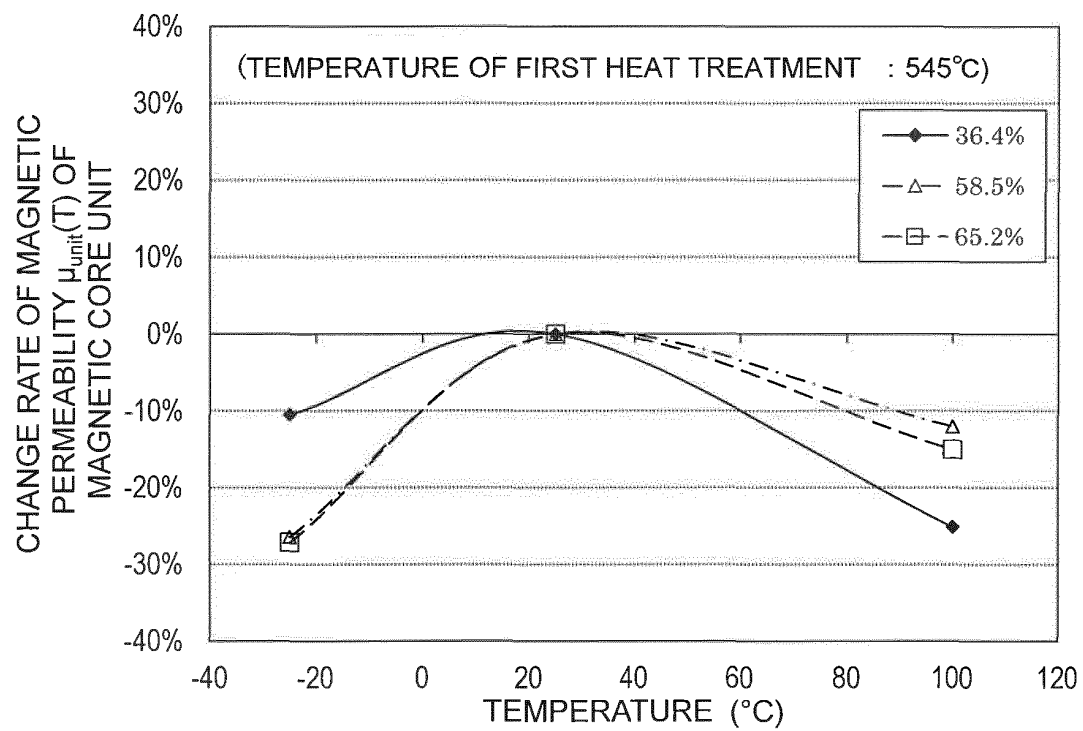


FIG. 6

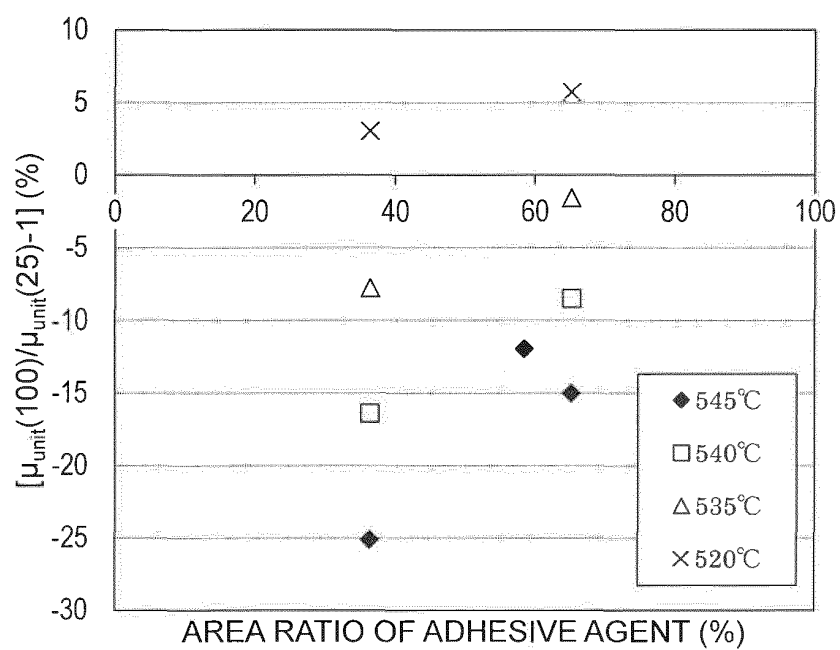


FIG. 7

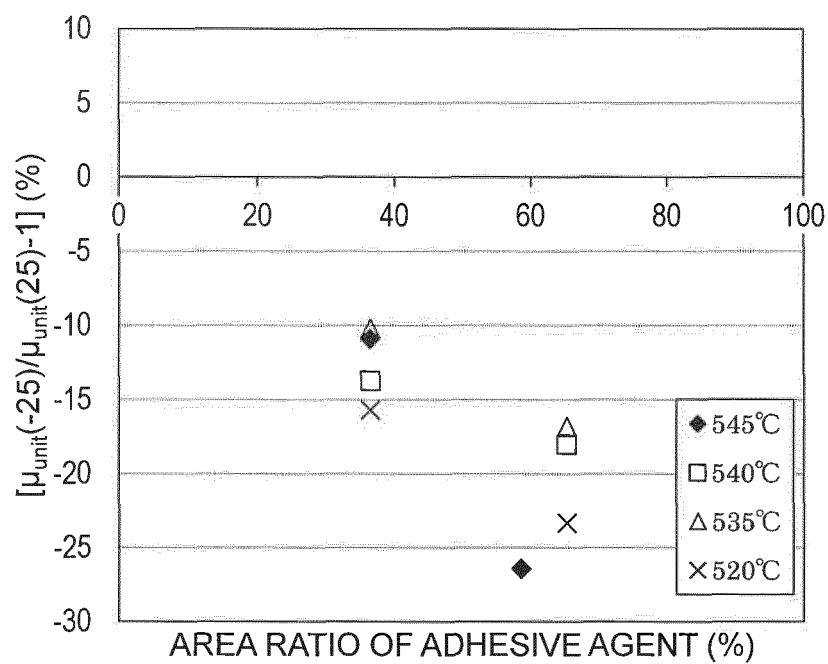


FIG. 8

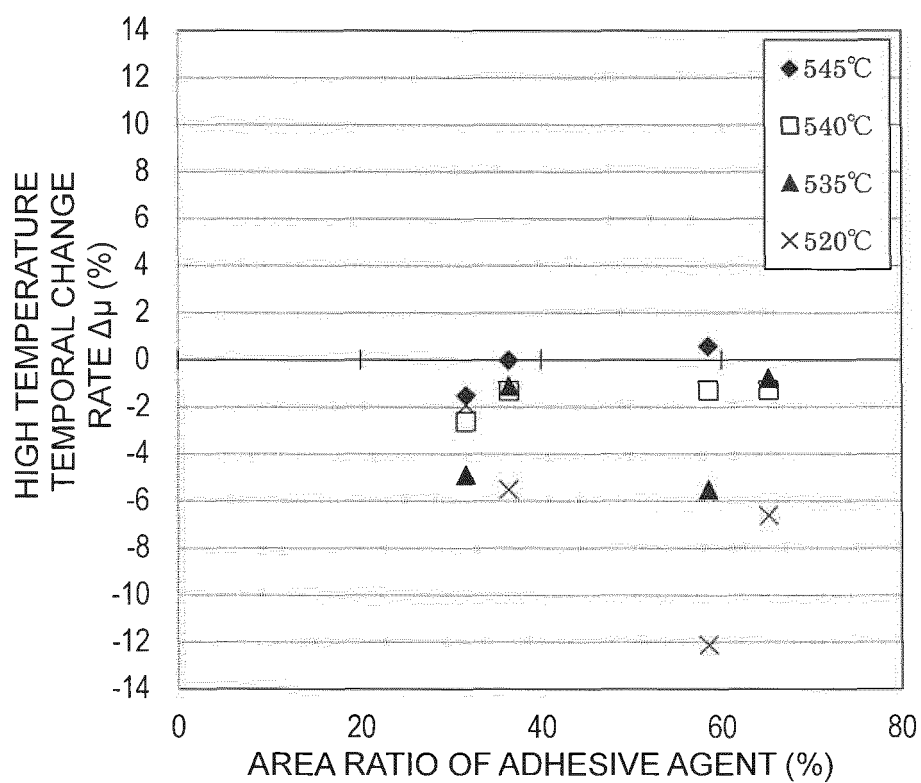


FIG. 9

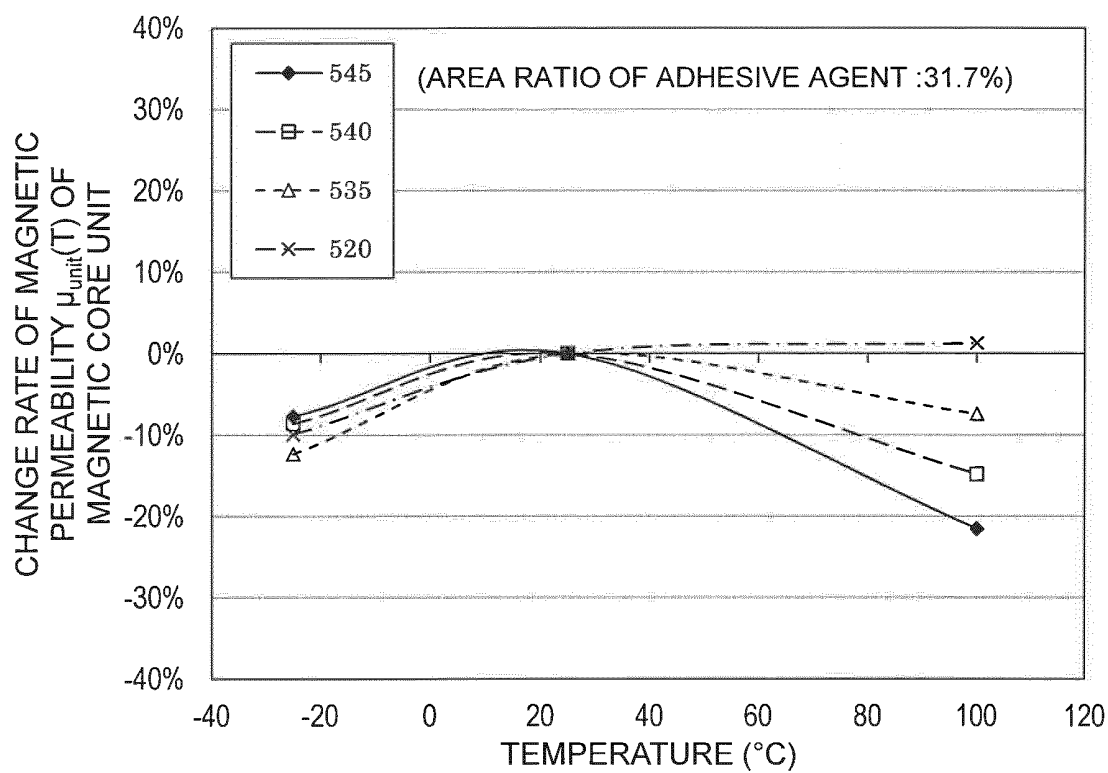


FIG. 10

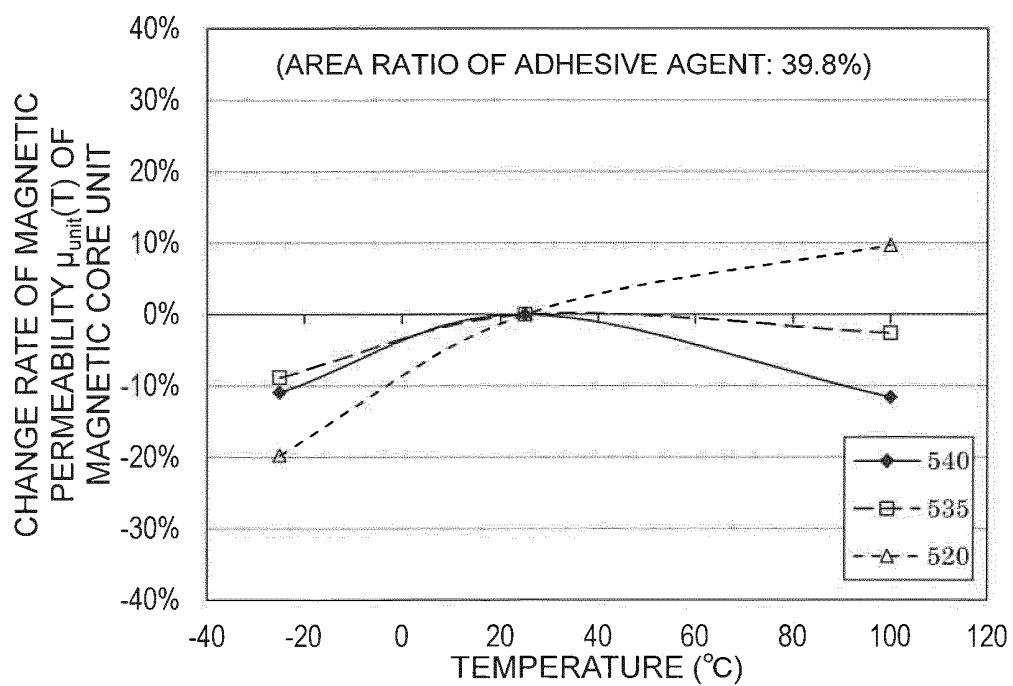


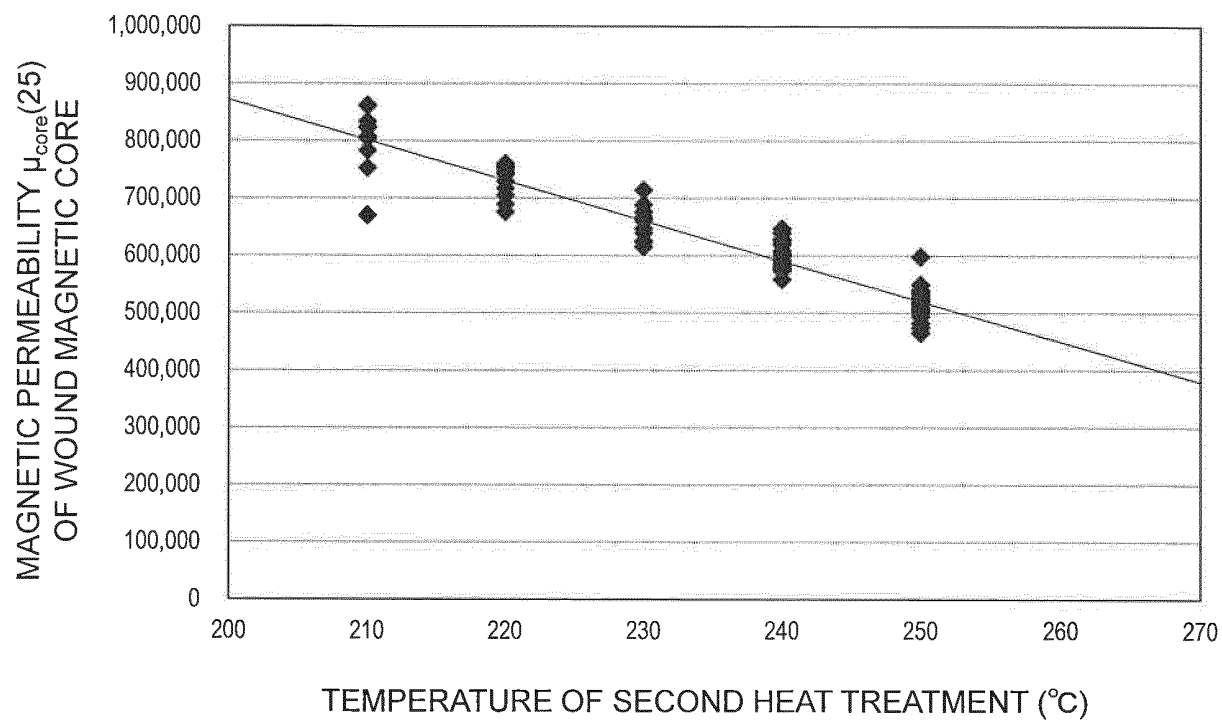
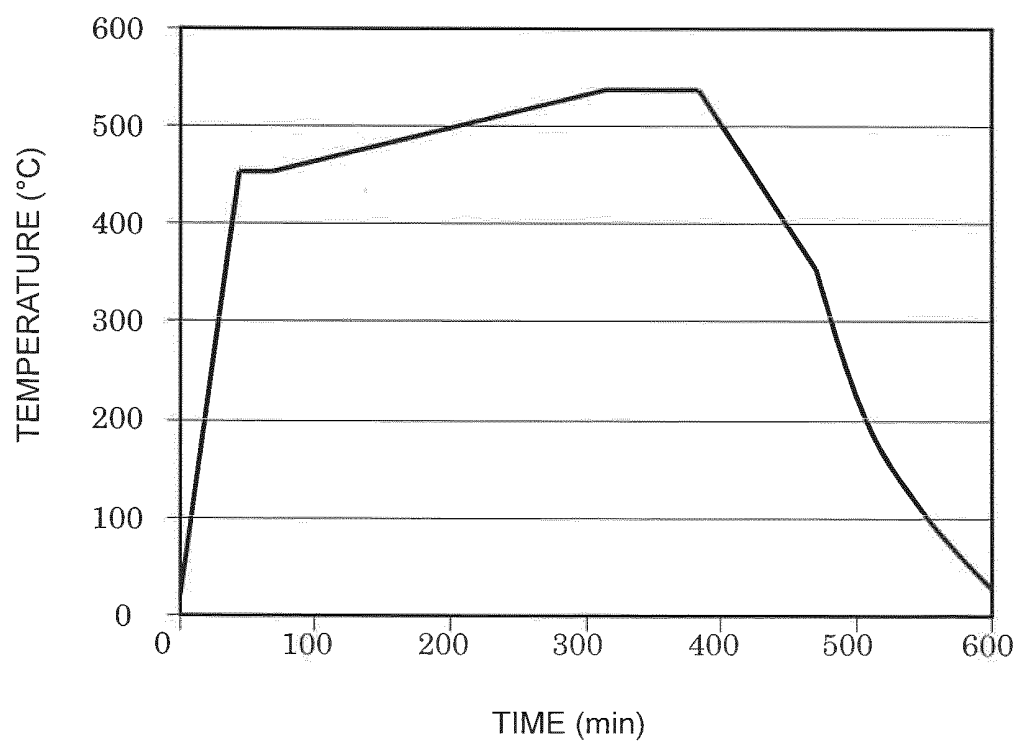
FIG. 11*FIG. 12*

FIG. 13

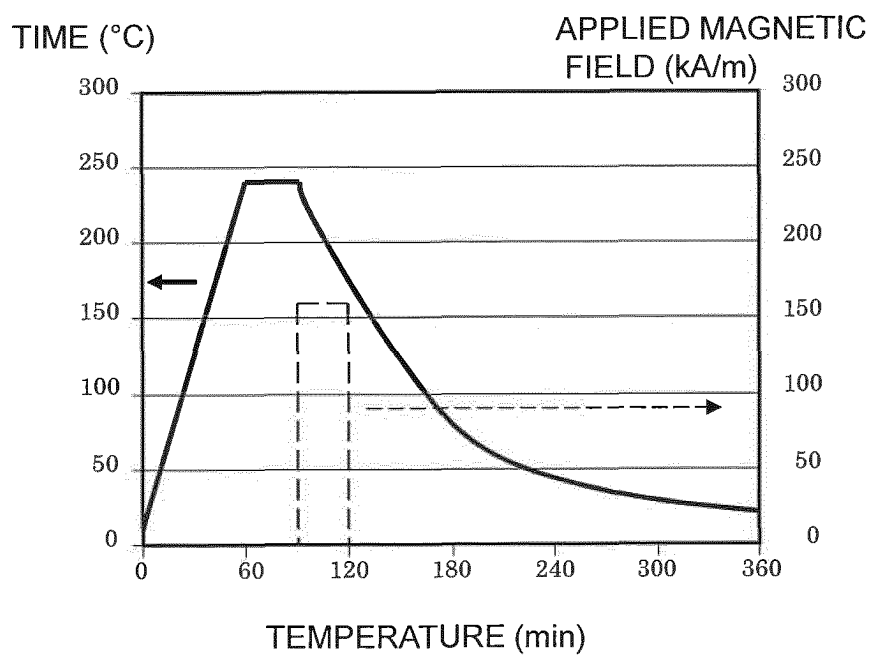


FIG. 14

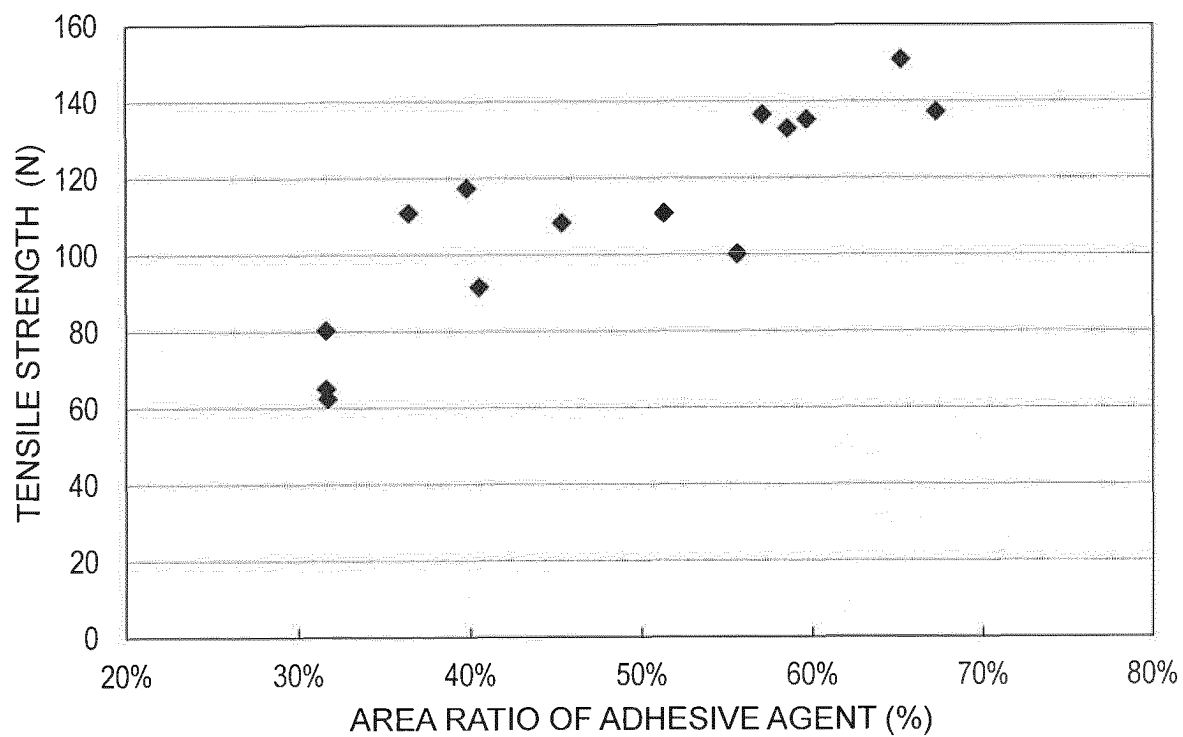


FIG. 15

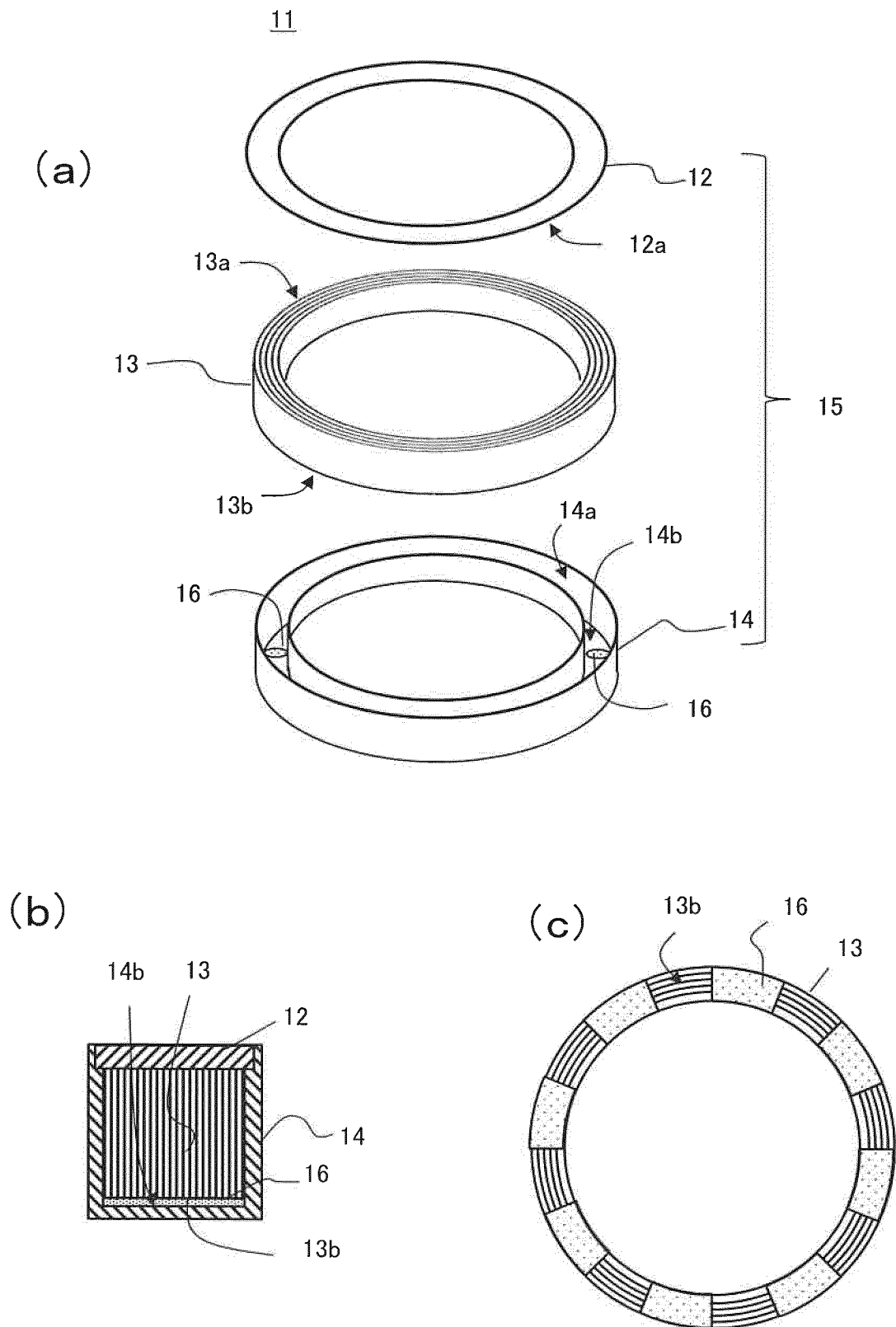


FIG. 16

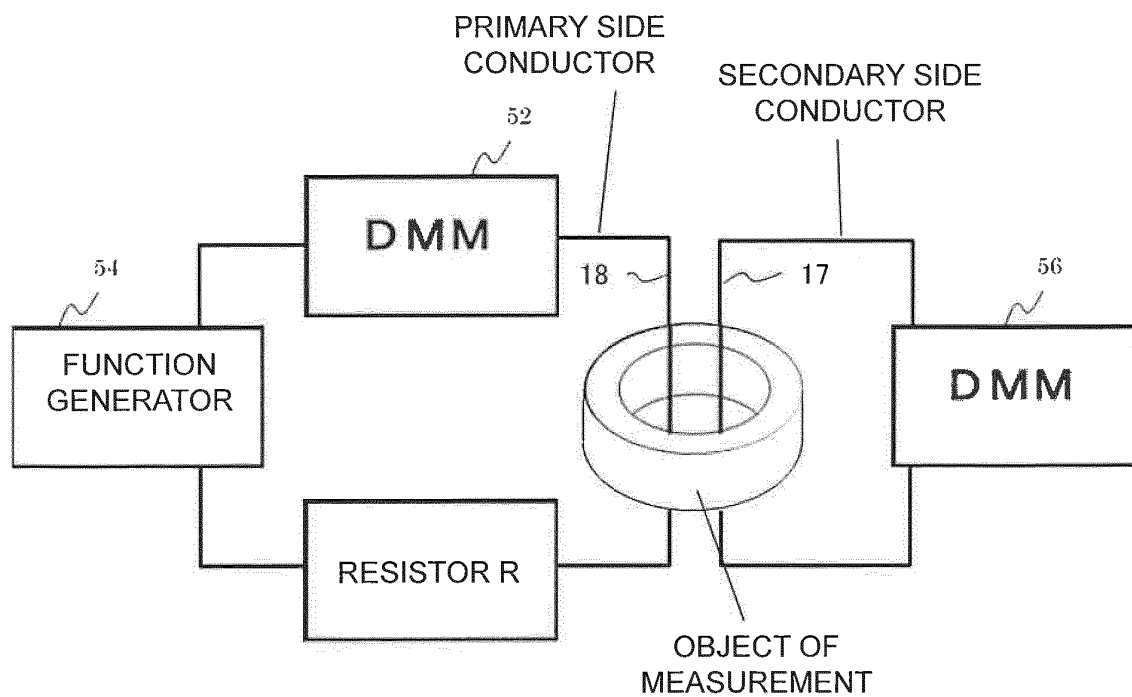


FIG. 17

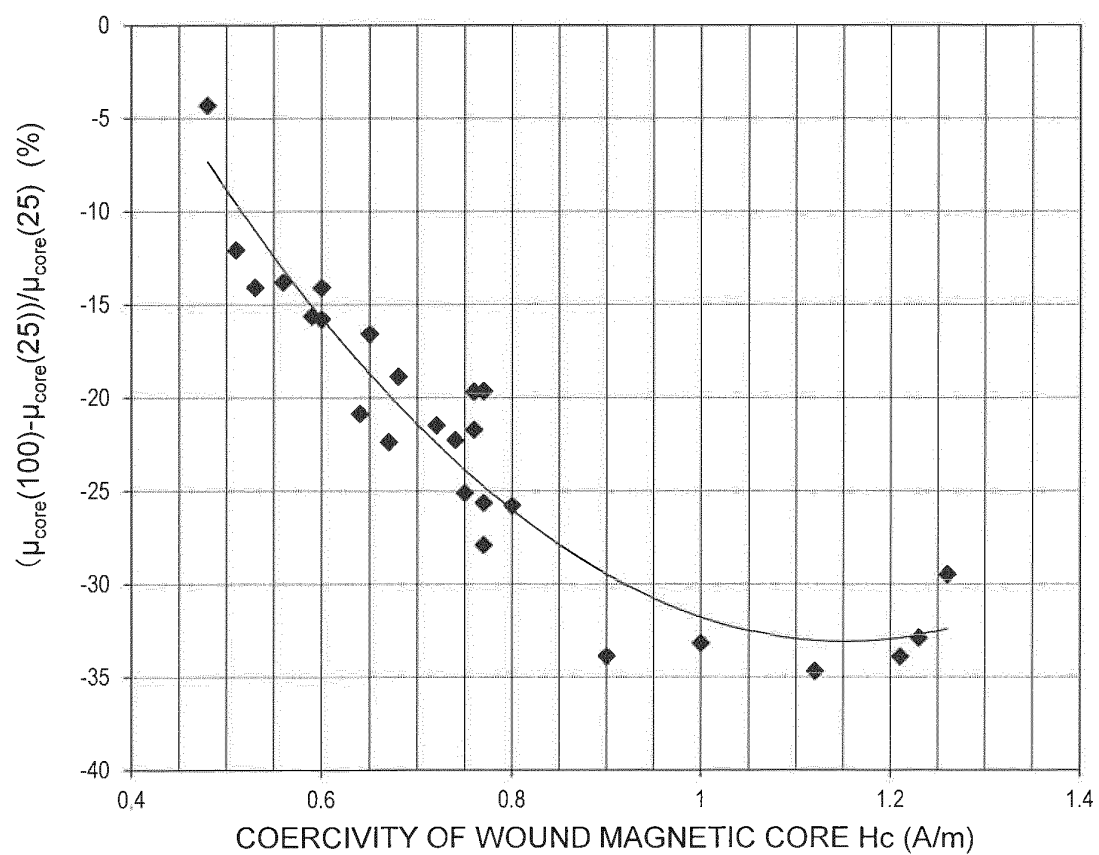
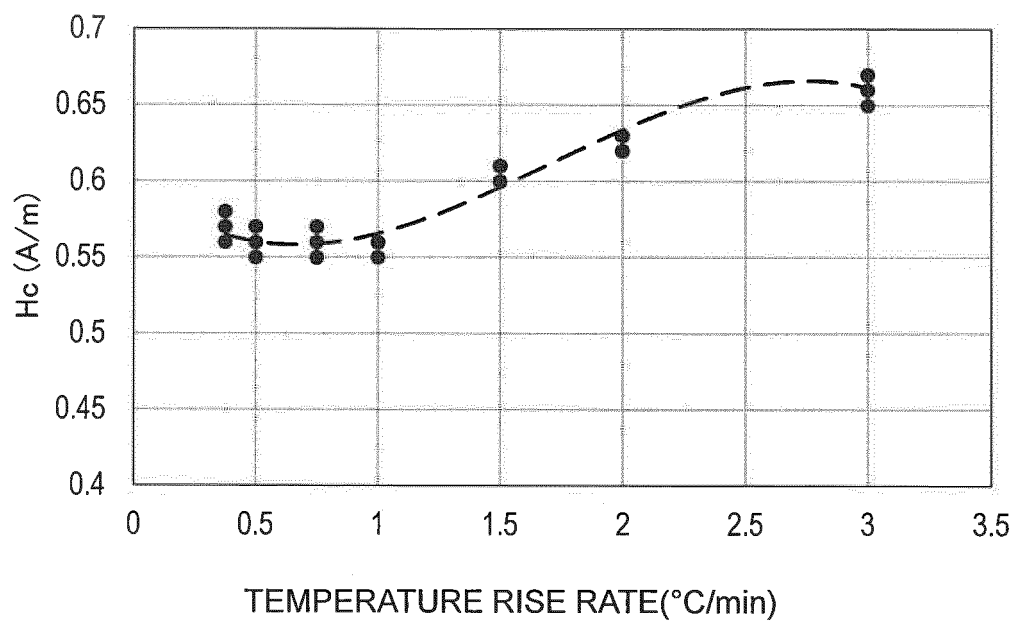


FIG.18

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2018/006308

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H01F1/153(2006.01)i, C21D6/00(2006.01)i, C22C1/00(2006.01)i,
C22C38/00(2006.01)i, C22C45/02(2006.01)i, H01F27/24(2006.01)i,
H01F41/02(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)

Int.Cl. H01F1/153, C21D6/00, C22C1/00, C22C38/00, C22C45/02, H01F27/24,
H01F41/02

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2018
Registered utility model specifications of Japan	1996-2018
Published registered utility model applications of Japan	1994-2018

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 08-085821 A (HITACHI METALS LTD.) 02 April 1996, paragraphs [0001], [0019], [0040]-[0042], fig. 6 & US 5611871 A, column 1, lines 8-11, column 5, lines 39-51, column 11, line 25 to column 12, line 26, fig. 7	1, 3-10, 12-16 2, 11
Y A	CD-ROM of the specification and drawings annexed to the request of Japanese Utility Model Application No. 050995/1993 (Laid-open No. 029814/1995) (MATSUSHITA ELECTRIC WORKS LTD.) 02 June 1995, paragraphs [0002]-[0007], [0017]-[0020], fig. 1-3 (Family: none)	1, 3-10, 12-16 2, 11



Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search
16.04.2018

Date of mailing of the international search report
01.05.2018

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Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2018/006308

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 08-339932 A (MITSUI PETROCHEMICAL INDUSTRIES) 24 December 1996, paragraphs [0001]-[0005], [0011]-[0031], fig. 1-3 (Family: none)	1, 3-10, 12-16 2, 11
Y A	JP 2004-327779 A (TORAY INDUSTRIES) 18 November 2004, paragraph [0059] (Family: none)	6, 8, 15, 16 2, 11
A	JP 03-107417 A (HITACHI METALS LTD.) 07 May 1991, page 3, lower left column, line 20 to page 4, upper left column, table 1, fig. 2(b) (Family: none)	1-16

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2010081993 A [0008]
- JP 3107417 A [0008]
- JP 2000328206 A [0008]
- JP 9069443 A [0008]