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NEW FABRICATION METHOD SUGGESTION OF THE MOTOR CORE WITH DISSIMILAR METAL BONDING METHOD

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ABSTRACT

An iron loss increases by the fixation method of a stator core such as swaging, welding and the thermal insert, etc. They make a residual stress in the motor core. It leads to increase a building factor and an iron loss of the motor. Therefore, the residual stress must be removed or reduced to decrease the iron loss of the rotating machines. It needs to remove or reduce the fixation method of a stator core for the motor. In this paper, a possibility of the new Fe-Al bonding method using the barrel nitride method for motor core was investigated. AlN and Fe-Al intermetallic compounds were appeared between the pure Al and the silicon steel sheet. And the insulating layer was appeared between the pure Al and the silicon steel sheet. The Fe-Al bonding material is possible to be a motor core. But it needs thinner AlN and FexAly layers. Moreover, a measurement method of the thin layer resistance should be established.

KEYWORDS: Motor Core, Fe-Al Bonding, Residual Stress, Dissimilar Metal Bonding, Iron Loss

Note: There should no nonstandard abbreviations, acknowledgments of support, references or footnotes in in the abstract.

INTRODUCTION

Modern society needs huge amount of energy. Especially, the electric energy is clean and highly adaptable. Most large electricity usage in the modern society is a rotating machine which shows over more than 57.3% of the electricity usage rate [1], [2]. The rotating machines are used in many fields such as an industry, commerce and a household, because those have high efficiency and handiness. Therefore, an increasing of the rotating machine efficiency leads to save the huge amount of the electrical energy. It is the realizable way of the Negawatt [3].

Usually, the rotating machines are controlled by an inverter because of its available method to control their speed and torque. However, it increases an iron loss of the rotating machines by making a lot of minor loops and a large major loop of the magnetic hysteresis curve in a stator and rotor of the motor. Moreover, magnetic hysteresis curves are affected by the residual stress (mainly compressive stress).

The motor core is including a rotor core and a stator core. And the cores of the rotor and the stator are made from electrical steel sheets. An iron loss increases by the fixation method of a stator core such as swaging, welding and the thermal insert, etc. They make a residual stress in the motor core. It leads to increase a building factor and the iron loss of the motor. To get a high efficiency motor, a residual stress of the motor core must be removed or reduced. Therefore, to get a high efficiency motor, it needs to remove the process of the swaging, welding or the thermal insert of the core of the motor.

The Fe-Al bonding method with AlN (aluminum nitride) layer using a barrel nitriding method is reported recently [4]. In this report, used Fe material was a stainless steel. If it is possible to bond between the silicon steel with an AlN bonding layer using the thin aluminum film, new fabrication method of the motor core without caulking and welding will be realized.

In this paper, a possibility of the new bonding method is investigated in the materials of the motor core.

EXPERIMENTAL PROCEDURE

Specimen Preparation

Silicon steel sheet (35A300, 0.35 mm thickness) without insulating layers are used as a substrate material. JIS-A1050 commercial grade pure aluminum plates (1 mm and 0.1 mm thickness) are prepared to bond silicon steel sheets. A size of prepared materials is 20 mm width × 50 mm length. The specific chemical compositions of the aluminum are measured by a spectrometer (Ametek., Spectrolab) as shown in Table 1.

Table 1: Chemical Composition

Component / Material	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
A1050	0.0951	0.318	0.014	0.0028	0.0041	0.0038	0.0138	Bal.

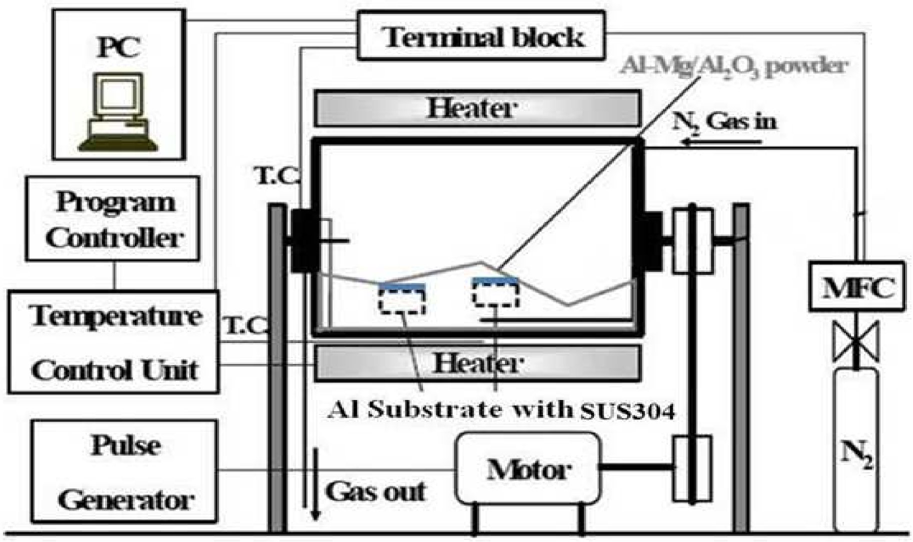

Figure 1: A Schematic Diagram of the Barrel Nitriding Process

Barrel Nitriding

Al2O3 particles (average diameter 0.1 mm) and Al 50 wt.% Mg alloy powders (average diameter 0.2 mm) were prepared as filler for the inside of the barrel chamber. The furnace was evacuated by a rotary pump and the vacuum rate was maintained at 7.5×10^{-1} torr before the treatment; after that, the atmosphere was substituted by N2. The N2 gas flow rate was adjusted with a program control unit and a mass flow controller when the nitrogen gas (N2) was introduced into the barrel. The furnace temperature was adjusted with a temperature control unit. A schematic diagram of the barrel nitriding furnace used for the experiment is shown in Figure 1 [5], [6].

After the introduction of N2, barrel nitriding was carried out with the oscillation of the barrel chamber at the temperature of 640 ºC for 10hrs. After a holding time, the specimen was cooled in the barrel. The temperature inside of the powder was measured by a thermocouple; the temperature and the N2 gas flow-rate were both monitored with a data processor.

Microstructure Observation

The optical microscopy (OM) and scanning electron microscopy (SEM-EDS) (HITACHI, SU6600) were used to observe the micro-structure and morphology after grinding and polishing on the cross-sectional region of the specimen. The structures of the AlN and Fe-Al intermetallic compound layers were identified by an X-ray diffractometer (RIGAKU, UltraX 18 TTR) using monochromatic Cu-Kα radiation. The X-ray diffraction (XRD) measurements were performed using a goniometer at a scanning range of $30° \leq 2\theta \leq 80°$ at 40kV and 200mA with a step-size of 0.02°. The Al substrate was mechanically polished to the AlN and Fe-Al intermetallic compound layer in regular increments in order to measure the XRD for each layer.

Measurement of Hardness

The micro hardness of the AlN and Fe-Al intermetallic compound layer was measured by using a Vickers micro hardness tester (Akashi, HM-125). The hardness measurements were performed from the Al substrate to the 35A300 silicon steel with the AlN and Fe-Al intermetallic compound layer under a load of 100 g for 10 sec on the cross-sectional region.

Continuity Test

It is difficult to get a resistance value of each layer between the A1050 plate and the 35A300 plate. The resistance value is investigated from the surface to the opposite side surface of the Fe-Al bonding material using a digital multimeter (Hioki, 3541).

RESULTS AND DISCUSSIONS

As shown in Figure 2, the multilayer are formed between A1050 and 35A300 at 640 ºC for 10hrs. The thicknesses of each multilayer are around 200 μm and 90 μm with the 1 mm and 0.1 mm Al plate, respectively. Moreover, the multilayer is different with the thickness of Al plate. Al plate is still left around the part A. However, Al plate disappeared around the part C. It means that the thickness of the Al plate is important to decide the amount of the Al remains.

Enlarged SEM image of the circled part A is shown in Figure 3. From the shape of the AlN layer, AlN growths from Al plate to the silicon steel. In other word, Al and N diffuse from Al plate to the silicon steel. A width of the AlN layer is around 40 μm. Table II shows the chemical component of the point a and b using SEM-EDS. 3 components such Al, N and Mg appear at the point a. The Al component is detected twice as large as the component N, and the Mg component remains nothing much. From the point b, Fe, Al and Si components are detected. The Al component is detected 2.7 times as large as the Fe component. It means that the intermetallic compounds of Fe2Al5.4 appear between the silicon steel sheet and Al plate.

To clearly demonstrate which phases appear at the multilayer between the aluminum substrate and the 35A300 substrate, XRD measurements were performed, as shown in Figure 4 and 5. Figure 4 shows the XRD result of the nitride layer (point a) and Figure 5 shows the XRD result of the FexAly layer

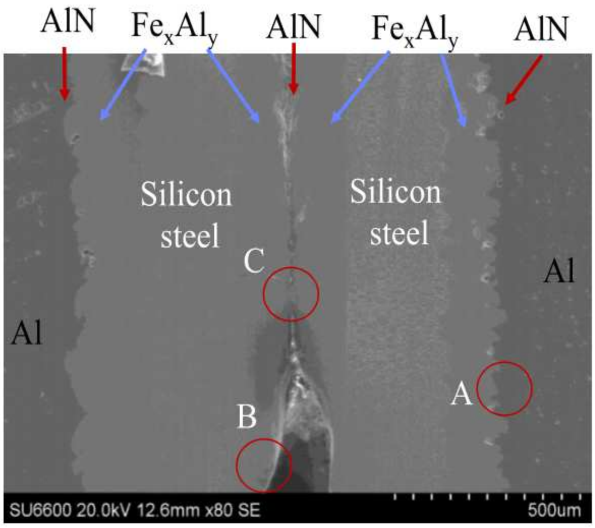

Figure 2: SEM Image of the Silicon Steel-Al Plate Multilayer

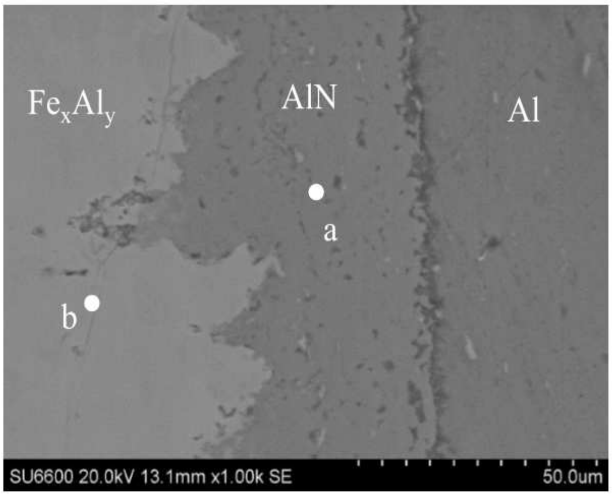

Figure 3: Enlarged image of the part A of Figure 2

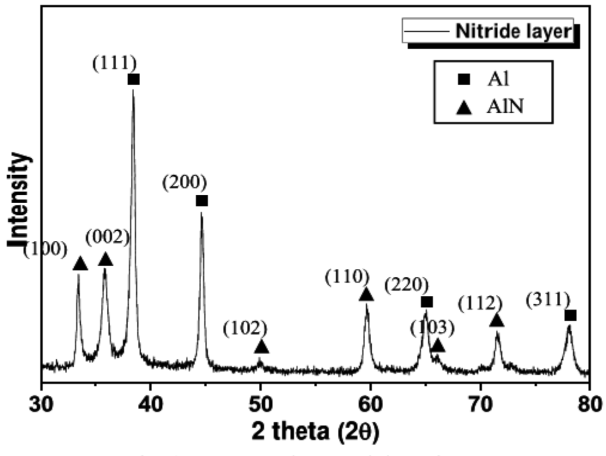

Figure 4: XRD Result Around the Point a

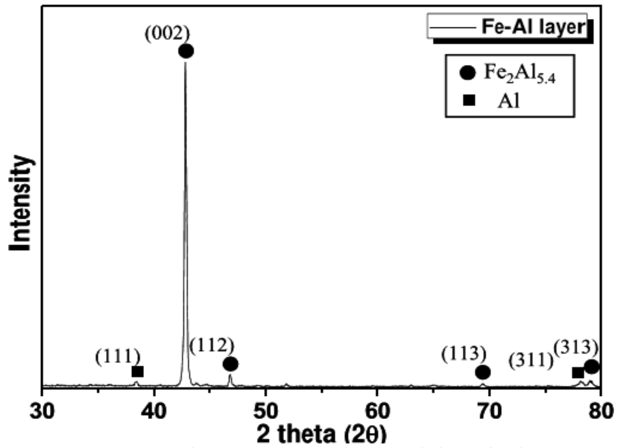

Figure 5: XRD Result Around the Point a

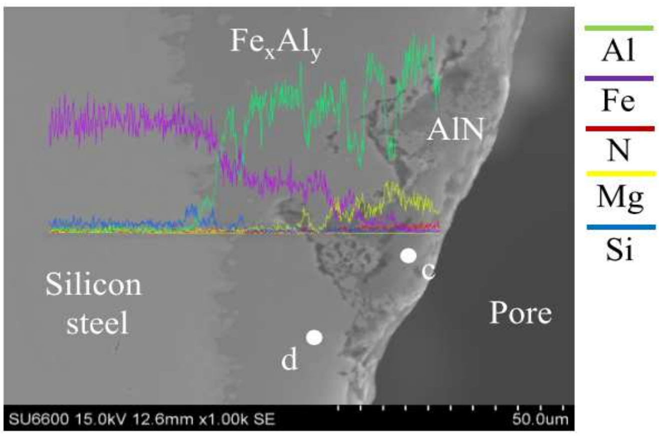

Figure 6: Enlarged Image and EDS Result of the Part B of Figure 2

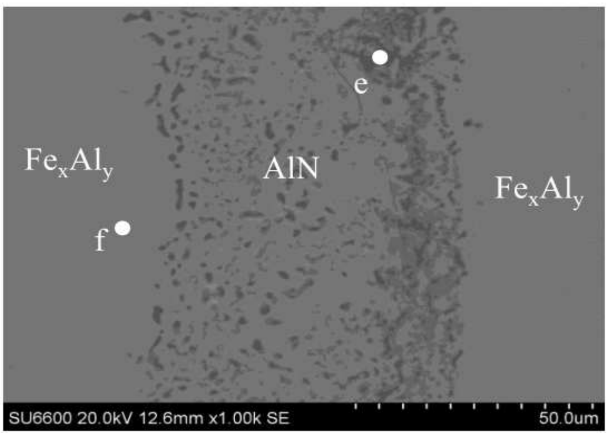

Figure 7: Enlarged Image of the Part C of Figure 2

(point b). In the case of the nitride layer, AlN peaks were detected with Al peaks. Al peaks appear stronger than the AlN peaks. It means that the nitride layer has many Al components. It is possible to reduce the insulation strength of the nitride layer. It must be improved to use the motor core. In the FexAly layer, an intense peak is exhibited which is attributable to Fe2Al5.4 (221) with other low intensity peaks attributed to other Fe compounds. As mentioned above, the nitride layer shows Al rich. It will be explained later with Figure 8.

Enlarged SEM image and EDS result of the circled part B is shown in Figure 6. From the line scanning result using SEM-EDS, Al and N components decrease from the pore side to the silicon steel side. It means that Al and N is diffused

Table 2: Element of Each Point

Component [at%] / Point	Fe	Al	Mg	N	O	Si
a	-	65.98	0.52	33.5	-	-
b	27.00	72.67	-	-	-	0.33
c	0.80	39.58	6.17	53.45	-	-
d	28.38	70.74	-	0.21	-	0.67
e	4.21	24.68	14.52	4.89	51.00	0.70
f	27.70	71.37	-	-	-	0.92

from Al plate to the silicon steel. The chemical component of the point c and d is shown in table II. The chemical component of the point c is different to that of the point a. Though an amount of the AlN is less, N component is 1.5 times larger than Al component. However, it is not clear why this kind of a big pore appears and the thickness of nitride layer and Fe-Al layer is thin. One of the possible reason is that Al plate near pore is absorbed by above and below the area of the silicon steel sheet. Another possible reason is that the space between Al plate and the silicon steel sheet partially. It should be figured out to make a homogeneous Fe-Al and AlN layers.

Figure 7 shows enlarged SEM image of the circled part C. Ceramic particles are scattered in the middle of Fe-Al layer. It means that Al plate is absorbed completely to the silicon steel sheet. Inhomogeneous AlN layer, however, is possible to reduce the insulation strength. Therefore, it must be improved.

AlN is possible to exist with aluminum below 660 ºC, as shown in Figure 8. And MgN is also possible to exist with magnesium below 660 ºC. It means that Al-Mg liquid is possible to absorb N2 gas around 640 ºC. And then, the liquid with N2 gas permeates between the silicon steel sheet and the aluminum plate in capillarity. This is the possible reason of the aluminum nitriding between the silicon steel sheets.

Figure 9 is the Fe-Al phase diagram [7] which shows five types of Fe-Al intermetallic compounds. It has been known that the FeAl2, Fe2Al5 and FeAl3 compounds which have a high aluminum composition have high hardness values with brittleness. In addition, Fe3Al and FeAl compounds also have good mechanical properties in the aspects of wear resistance, oxidation resistance, corrosion resistance and specific strength properties [8]. In this work, as there are different diffusion rates of aluminum into the surface of the 35A300, it can be expected that an intermetallic Fe-Al compound layer will be formed with a nitride layer between the pure aluminum and 35A300 silicon steel sheet using the barrel nitriding.

The Vickers hardness was investigated on a cross-section of the multilayer after the barrel nitriding at 640 ºC for

10 hrs. In general, the area is divided into four types: pure Al, AlN, Fe-Al, and silicon steel. The hardness of the pure Al and silicon steel is found to be about 30 HV and 200 HV, respectively. In addition, the maximum hardness of the aluminum nitride layer is found to be 377 HV, and the Fe-Al

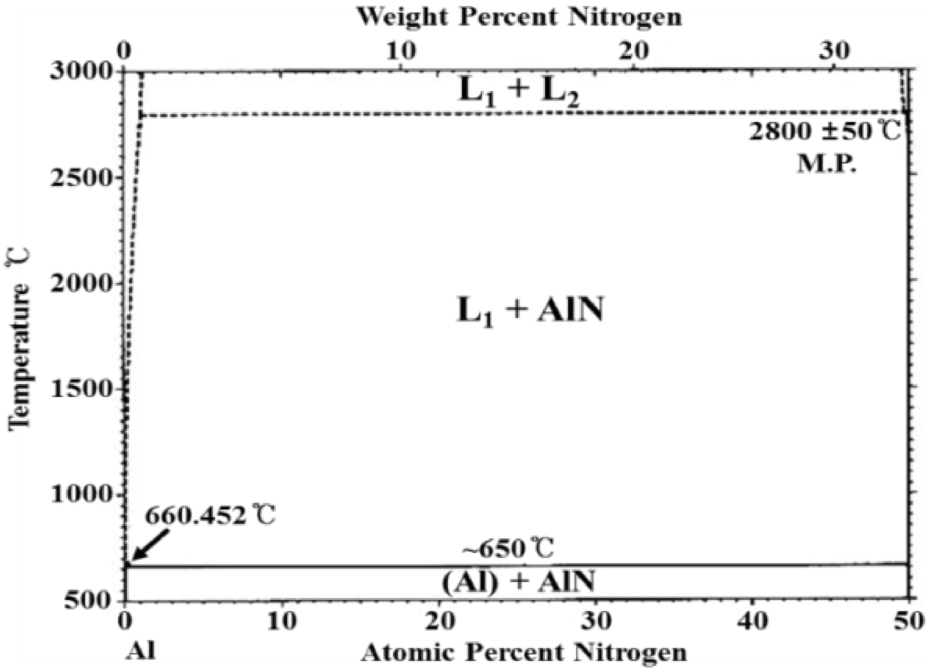

Figure 8: Binary Phase diagrams of Al-N

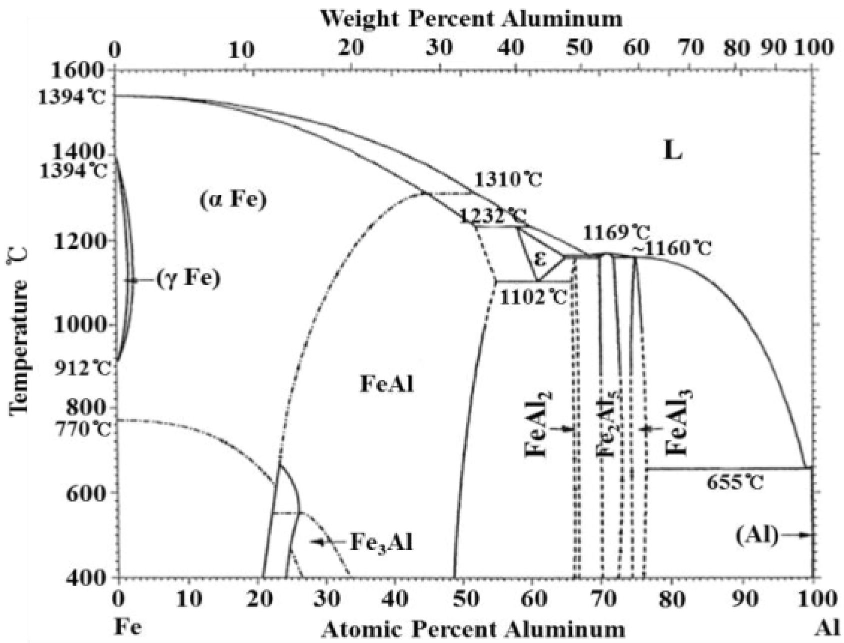

Figure 9: Binary Phase diagrams of Fe-Al

compound layer is found to have a maximum hardness of 910 HV, after barrel nitriding.

The conduction state of the Fe-Al bonding material with AlN layer was investigated. As a result, the resistance value of Fe-Al bonding material shows infinite value. It means that the layer between the A1050 plate and the 35A300 is insulated. But it is difficult to specify which layer has the insulating property. Moreover, the resistance value of each layer is not measured. Therefore, it needs to find a measurement method of the thin layer resistance.

From the result, the Fe-Al bonding material is possible to be a motor core. But it needs thinner AlN and FexAly layers. Moreover, a measurement method of the thin layer resistance should be established.

CONCLUSIONS

A possibility of the new Fe-Al bonding method using the barrel nitride method for motor core was investigated.

AlN and Fe-Al intermetallic compounds were appeared between the pure Al and the silicon steel sheet. And the insulating layer was appeared between the pure Al and the silicon steel sheet.

The Fe-Al bonding material is possible to be a motor core.

But it needs thinner AlN and FexAly layers. Moreover, a measurement method of the thin layer resistance should be established.

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