Development of Powdered Soft Magnetic Material Suitable for Electric Devices Operating at High Frequencies

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Abstract

Recently, there has been a growing demand for soft magnetic materials with high conversion characteristics, due to the trend of electric devices to higher-frequency range. For ruduceing core loss in the high-frequency range, using finely grained and high-resistivity Fe-based alloy powder is most efficient methods. But, conventionally, there's been a compressibility problem for such powder. In this work, Fe-based alloy powder that offers both high resistivity and high compressibility was developed by studyuing composition of the powder, and reduction of core loss of P/M soft magnetic materials in the high frequency range was achieved.

Keywords : soft magnetic material, core loss, high-frequency characteristics

1. Introduction

P/M soft magnetic materials made by compacting soft magnetic powders coated with an insulating film have attracted great attention in recent years due to their flexibility in the design of magnetic circuits, and because they also enable three-dimensional near-net shaping. Furthermore, P/M soft magnetic materials are more advantageous than laminated steel in the high-frequency range, and can be applied in the frequency range beyond 10 kHz, to which general-purpose laminated steel is poorly suited for. However, the need for low core loss in P/M soft magnetic materials still remains.

A crucial prerequisite for reducing high-frequency core loss is the reduction of eddy-current loss. Two techniques widely known for reducing eddy-current loss are using finely grained powders and alloying to increase electrical resistivity. However, the properties of finely grained powders lead to greater loss of coercivity and of hysteresis, as well as inferior moldability and poor yields, which are unacceptable for mass-production of P/M soft magnetic materials. Consequently, there are limitations to using smaller grain sizes to reduce core loss. In this work, we report about P/M soft magnetic materials that consist of Fe-based alloy powders.

Silicon and aluminum are effective alloying elements for P/M soft magnetic materials. It enables high flux density that only small amounts of these elements increase electrical resistivity. And, both Fe–Si and Fe–Al are known as high-magnetic-permeability alloys and offer low coercivity. However, plastic deformability of the powder gets poor drastically with increase of electrical resistivity. That presents a problem of forming compacts with low density. Therefore, compositions of Fe-Si or Fe-Al powders with both high electrical resistivity and high deformability suitable for P/M soft magentic material was studied. And using these powders, P/M soft magnetic materials was developed with insulating films that we previously reported, which offer excellent deformability, lubricity and heat resistivity[1].

2. Experimental and Results

Determining the Alloy Composition

Ingot of pure Fe, Fe–xAl (where x = 2, 4, or 6 mass%), and Fe–ySi (where y = 1, 2, or 3 mass%) were prerpared, using a high-frequency induction furnace with an argon atmosphere. These were then homogenized in a 1,473K argon atmosphere, then annealed at 1123K. The hardness was verified by means of a micro-Vickers hardness tester.

Fabrication of P/M soft magnetic materials

Water atomized Fe-1Si and Fe-2Al powders no larger than 75 μm in size were prepared. The powders were annealed in a hydrogen atmosphere to eliminate the effects of atomization strain and microcrystallization on magnetic properties. Next, a phosphate insulation coating and a silicone-resin binder coating was applied. The amount of resin added was 0.2wt%. To facilitate comparison with a conventional material, a pure iron powder (Somaloy 500, made by Höganäs AB) coated with insulating film was similarly sieved to a size of 75 μm or smaller, then mixed with 0.2wt% binder resin. Both powders were compressed at pressure of 1,274 MPa into ring shapes measuring ø34 × ø20 × 5 mm thick, which were then heat-treated in a nitrogen atmosphere. An AC/DC B–H analyzer and a LCR meter were used for measurements of magnetic property. From the frequency dependence of the core loss (50 - 10 kHz), the hysteresis loss coefficient kh, and eddy-current loss coefficient ke are calculated with equation (1) using a least square method.

$$W_{B/f} = kh \times f + ke \times f^2 \quad (1)$$

Fig.1 shows the correlation between the hardness and electrical resistivity of the fabricated ingots. While hardness tends to increase linearly with electrical resistivity for both Fe-Si and Fe-Al, Fe-Al offers higher deformability than that of Fe-Si, comparing at same resistivity. Considering these results, we decided to create powders composed of Fe–1Si and Fe–2Al and use them to make P/M soft magnetic materials.

Table.1 shows the magnetic properties of P/M soft magnetic materials in this work. Both alloy samples show higher relative density than that of conventional material (i.e.,Fe), indicating the effectiveness of the high-deformability composition and insulating film developed. Comparing between Fe–2Al and Fe-1Si, Fe-2Al show an even higher density than Fe–1Si, which confirms that aluminum is superior to silicon in that it enables high-density compaction in the ingots. With regard to core loss properties, the alloys exhibited a great reduction in eddy-current loss over the conventional material.

Fig.2 is a comparison of core loss in each P/M soft magnetic material at 10 and 50 kHz. Core loss remains nearly unchanged at 10 kHz, but at 50 kHz eddy-current loss accounts for a larger portion of core loss, indicating the low-iron-loss effect of alloying. The results show that both the 2Al and 1Si compositions reduce core loss by more than 20% over the conventional material.

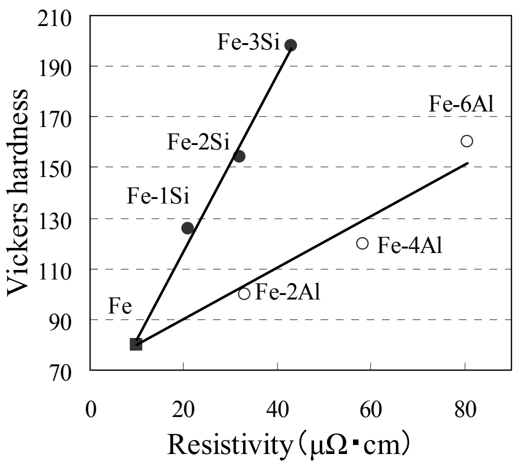

Fig. 1. Relationship between Hardness and resistivity.

Table 1. Magnetic property of the fabricated materials

Powder	Relative Density [%]	Hc [Oe]	B_{100} [kG]	Kh Bm=0.1T [mWs/kg]	Ke Bm=0.1T [mWs^2/kg]
Fe-2Al	95.7	4.16	12.7	9.1	1.1×10^{-4}
Fe-1Si	94.8	3.75	11.5	8.4	1.2×10^{-4}
Fe	94.0	3.74	13.8	7.9	2.2×10^{-4}

Hc and B_{100} : Applied magnetic field is 100Oe

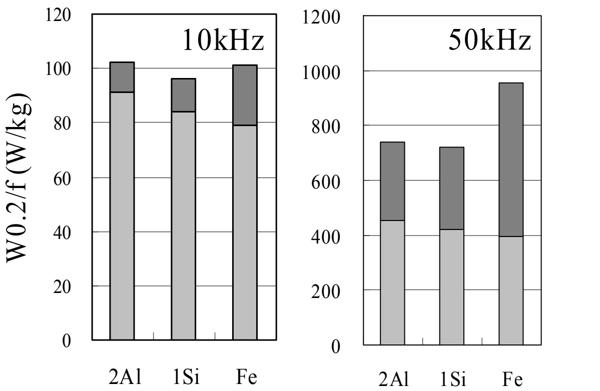

Fig. 2. Iron loss of each P/M soft magnetic material at high frequencies.
■: Eddy-current loss ■: Hysteresis loss

3. Summary

P/M soft magentic materials were developed using powdered Fe–Si and Fe–Al alloys to produce suitable for the high-frequency range. The Fe–Al composition achieved greater electrical resistivity and deformability than the Fe–Si. Using the Fe–2Al and Fe–1Si powders resulted in less eddy-current loss than with pure iron. As a result, core loss at 50 kHz was reduced by more than 20% over conventional materials.

4. References

1. T. Maeda et al., Proc. PM2TEC2005 part 9, p.121 (2005).