Properties of Soft Magnetic Composite with Evaporated MgO Insulation Coating for Low Iron Loss

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Abstract

Innovative SMC with low iron loss was made from iron powders with evaporated MgO insulation coating. The coating had greater heat-resistance than conventional phosphatic insulation coating, which enabled stress relieving annealing at higher temperature.Magnetic properties of toroidal samples (OD35mm,ID25mm, t5) were examined. The iron loss at 50Hz for Bm = 1.5T was lower 50% of conventional SMC and was almost the same with silicon iron laminations(t0.35). It became clear that MgO insulation coating has enough heat resistance and adhesiveness to powdersurface to obtain innovative SMC with low iron loss.

Keywords : soft magnetic composite core, iron loss, MgO, insulation coating, magnetic properties

1. Introduction

Recently soft magnetic material with low iron loss comes into request for high-efficiency motor and actuator to realize energy-saving electrically operated machine. Soft magnetic composite (SMC) comes to the fore for the following advantages; (a) Low iron loss at the high frequencies due to low eddy current loss. (b) 3-D capability of SMC concerning magnetic flux and shape due to its isotropic nature and powder. However the SMC has following challenges; (c) Lower magnetic induction compared to the laminated steel plate. (d) Considerable iron loss at the low frequencies due to large hysteresis loss. Stress relieving annealing at high temperature is an effective measure to decrease the hysteresis loss [1-5], however annealing temperature is restricted to the heat resistance of insulation coating on the surface of iron powder.

The phosphate insulation coating is commonly applied for conventional SMC due to their good manufacturability and firm adhesiveness to iron powder [6]. There have been many studies on the coating to improve heat resistance [1-5], and reported that maximum annealing temperature is 500C-550C [1,2,4] to obtain SMC having electrical resistivity larger than 10μΩm.

In this study, we successfully developed innovative insulation coating, which had greater heat-resistance than phosphate insulation coating, and obtained SMC with low iron loss. We evaporated MgO insulation coating on the surface of iron powder, which enabled stress relieving annealing at higher temperature (600C).

2. Experimental and Results

Water-atomized powder was used as starting material. At first, oxide layer was formed on the surface of the iron powder. Mg powder of 0.2 mass% was added, and the mixture was heated at 650C in vacuum. The Mg evaporated powders with/without silicon resin (0.15mass%) and glass binder (0.5 mass%) were compacted at 780MPa-1180MPa with a die press. The specimens were in the toroidal shape (OD 35 mm x ID 25 mm x H 5 mm) for examination of magnetic properties and in the rectangular shape (55 mm x 10mm x 5mm) for electrical resistivity. These specimens were annealed in the range from 400C to 1000C. DC magnetic properties and AC magnetic properties were measured with B-H loop tracer and B-H analyzer respectively. Electrical resistivity was measured with four-point probe method. The structure of Mg evaporated coating was examined with SEM, TEM, XPS, AES. Iron powder with phosphate insulation coating (Somaloy500) and non-coated powder were also used for comparison. Laminated steel plate in the troidal shape (OD 40 mm x ID 37 mm x H 5 mm) was also examined for comparison.

The green density of Mg evaporated powder was almost the same with that of non-coated powder. Fig. 1 shows the dependence of electrical resistivity of SMC on annealing temperature. The density of all SMC was within 7.60 -7.67Mg/m3. As general trend, the electrical resistivity decreases with the increases in the annealing temperature. The electrical resistivity of SMC with phosphate insulation coating dropped to less than 1μΩm at 600C. However, the resistivity of SMC with Mg evaporated coating was kept

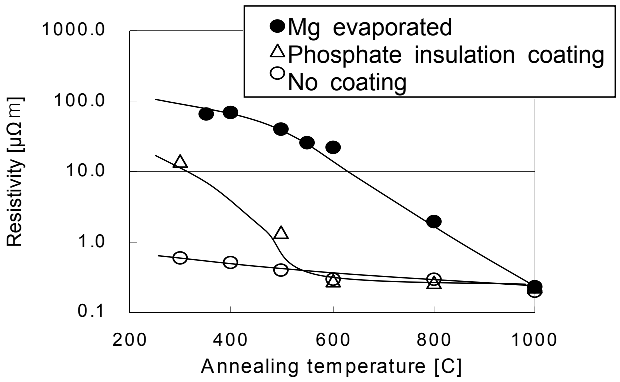

Fig. 1 Dependence of resistivity of SMC on annealing temperature.

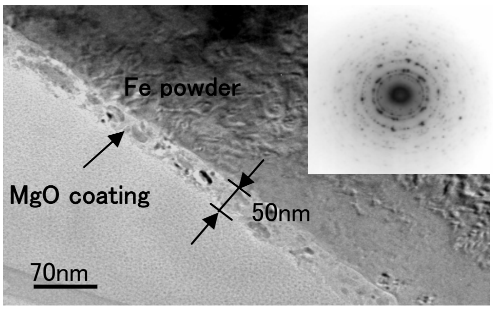

Fig. 2 Typical TEM image and diffraction pattern of MgO coated powder.

larger than 10μΩm at 600C. This result shows that heat resistance of Mg evaporated coating is superior to that of phosphate insulation coating.

Structure and composition of Mg evaporated coating on the iron powder are examined to understand its superior heat resistance. Fig. 2 shows typical TEM image and diffraction pattern of the coating. Homogeneous and continuous coating with thickness of ca. 50nm was observed on the surface of iron powder. The diffraction pattern shows that the coating is crystalline material. The coating was analyzed with XPS, and found that the coating has MgO composition. The cross section of SMC annealed at 600C was observed with AES analysis. It was found that Mg and O are distributed along the grain boundary homogeneously, which indicate that continuous MgO insulation coating with thickness of ca. 100nm is formed along the grain boundary.

These experimental results revealed that continuous MgO insulation coating is preserved in the SMC after annealing at 600C. On the contrary, it is reported that the phosphate insulation coating is noncrystalline material and it is broken due to crystallization when it is annealed at 500C-550C [1,2,4]. These facts indicate that MgO insulation coating has two excellent features as follows; (1) The coating is not vulnerable and its structural continuity is preserved through compaction process, which is similar to phosphate insulation coating. (2) The coating has superior heat resistance to phosphate insulation coating because it is crystalline material, and its structural continuity is preserved even if SMC is annealed at 600C.

Phosphorous oxide layer was prepared on the surface of iron powder to improve the heat resistance of MgO insulation coating. SMC (annealed at 650C) was fabricated with improved MgO coated powder, silicon resin and glass binder. The constituent of silicon resin was also optimized to be better suited for MgO insulation coating [7]. The density of all cores was within 7.58-7.73 Mg/m3. Although, the electrical resistivity of SMC with conventional MgO coating was dropped to less than 10Ωμm at 700C, the resistivity of SMC with improved MgO coating was kept larger than 10μΩm. Iron loss of SMC with improved MgO coating is at the same level with that of 0.35mm laminated steel plate, and is 40% of SMC with phosphate coating.

3. Summary

MgO insulation coating with superior heat resistance to conventional coating (phosphate insulation) was deposited by Mg evaporation on the iron powder. Continuous MgO insulation coating was preserved inside SMC through compaction and annealing process, and the iron loss of SMC was at the same level with that of 0.35mm laminated steel plate.

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