In the name of

god

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FABRICATION OF POLYMERIC-BASED SOFT MAGNETIC COMPOSITES AND MEASUREMENT OF THE MAGNETIC PROPERTIES

By
HOOMAN SHOKROLLAHI

Supervised by
KAMAL JANGHORBAN

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THESIS

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EVALUATED AND APPROVED BY THE THESIS COMMITTEE AS: EXCELLENT

K. JANGHORBAN, PROFESSOR OF MATERIALS SCIENCE AND ENGINEERING (CHAIRMAN)

M.J. HADIANFARD, ASSOCIATE PROF. OF MATERIALS SCIENCE AND ENGINEERING

S. JAVADPOUR, ASSISTANT PROF. OF MATERIALS SCIENCE AND ENGINEERING

M.H. PAYDAR, ASSISTANT PROF. OF MATERIALS SCIENCE AND ENGINEERING

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Abstract

FABRICATION OF POLYMERIC-BASED SOFT MAGNETIC COMPOSITES AND MEASUREMENT OF THE MAGNETIC PROPERTIES

By:

Hooman Shokrollahi

Iron powder with high purity was covered by a polyepoxy, DDS and DGEBA (4,4'-Diaminodiphenyl Sulfone, C12H12N2O2S, and Diglycidyl Ether of Bis Phenol A) and effect of amount of resin, different curing treatments and compaction pressure on the magnetic properties, residual stresses, densification and microstructure were examined. Results showed that the samples with double insulation layers of phosphate and polyepoxy had minimum power loss. Also, the sample with 3wt% polyepoxy compacted at 800MPa had an acceptable real part of permeability and minimum imaginary part of permeability in comparison with other samples. Partial curing treatment reduced the imaginary part of permeability; and annealing treatment reduced this part of permeability and increased the real part of permeability. The permeability of small-size particles, 30 μm, was lower than that of large-size particles, 100μm and 50μm, at low frequencies (<200 Hz) and was higher than that of large-size particles at high frequencies (>200 Hz). The permeability value for the sample with a diameter about 30μm was higher than (35%) that of the sample with 100μm diameter. Compaction experiments showed that increasing the pressure and applying warm compaction and two-step compaction methods for iron powders increased the magnetic induction and density and decreased the core loss. Different annealing (two steps annealing and magnetic annealing) treatments were applied to some samples. It was found that at low frequencies (<10kHz) the magnetic loss in the high-temperature magnetic annealed state (280°C/0.5T) was smaller than that in the low-temperature magnetic annealed (180°C/0.5T) and without annealing state. On the contrary, the magnetic loss in the high-temperature magnetic annealed state was larger at high frequencies (>10kHz) than the others. The results showed that magnetic loss of annealed powder was smaller than that of unannealed powder after 100 hours milling process. By loss separation technique ($P/f=C_0+C_1f+C_2f^{1/2}$), different magnetic losses and the related coefficients for two different composites including single insulation layer (iron phosphate) and double insulation layer (iron phosphate+polyepoxy) were calculated. The results showed that the sample with double layer coating had lower bulk eddy currents.

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List of Symbols

Symbols	Designation
I	Current
Q	Quality factor
f	Frequency
P_t	Total power loss
P_h	Hysteresis loss
P_e	Eddy current loss
L	Self inductance
μ_0	Absolute permeability
μ_i	Initial permeability
μ_e	Effective permeability
μ_m	Maximum permeability
μ_c	Complex permeability
μ_r	Relative permeability
μ_s	Saturation permeability
μ_{app}	Apparent permeability
M	Saturation magnetization
R	Resistivity
ρ	Resistivity of core material
B	Flux density
B_r	Remanent flux density
B_e	Effective flux density
B_s	Saturation flux density

H	Magnetic field strength
H_C	Coercive magnetic field strength
H_i	Internal magnetic strength
γ	Gyromagnetic ratio
α	Magnetostriction coefficient
λ	Magnetocrystalline coefficient
T	Temperature
T_C	Curie temperature
T_N	Neel temperature
k	Susceptibility
l	Length
K_B	Boltzmann's constant
$\tan\delta$	Loss factor
K_1	Magneto-crystalline anisotropy
a	Lattice parameter
γ_w	Wall energy

Chapter 1
Introduction

During the last several years, interest in the study of Soft Magnetic Composites (SMCs) has been increasing at an accelerating rate, stimulated by recent advances in materials synthesis and characterization techniques and the realization that these materials exhibit many unique and interesting physical and chemical properties with a number of potential technological applications. These composite materials offer several advantages over traditional laminated steel cores in most applications. The unique properties include three–dimensional (3D) isotropic ferromagnetic behavior, very low eddy current loss, relatively low total core loss at medium and high frequencies, possibilities for improved thermal characteristics, flexible machine design and assembly and a prospect for greatly reduced weight and production costs. Figure 1.1 shows the applicable regions for several soft magnetic materials used in AC magnetic fields. Soft ferrite has low core loss in the high frequency region, but due to its low magnetic flux density, it has the drawback of requiring a large core. Electrical steel sheets have high flux density, but electrical sheets cannot be used in the high frequency region due to the excessive core loss. Powder cores are magnetic materials which cover the region where the former two magnetic materials cannot be used.

SMCs, which are used in electromagnetic applications, can be described as ferromagnetic powder particles or soft magnetic powders surrounded by an electrical insulating film (Fig. 1.2). This insulating film can reduce the eddy currents at relatively high frequencies. Figure 1.3 shows the ring shaped component with coated iron powder exhibits lower power loss. The magnetically soft powders must combine as many as possible of the following characteristics at moderate cost: (1) low hysteresis losses, (2) low eddy current losses, (3) high permeability at low field strength, (4) high saturation value, (5) no aging effects and (6) uniform magnetic characteristics.

Insulation materials used for SMCs can be divided into two categories: organic and inorganic materials. Inorganic coatings can be subdivided into several categories; metallic oxide coatings (such as, Fe_2O_3), phosphate coatings (zinc phosphate, iron phosphate and manganese phosphate), and sulfate coatings. Organic coatings can be subdivided into three categories, thermoplastic coatings, elastomers and thermosetting coatings. Thermoset resins have several advantages over thermoplastic and elastomeric materials. The selection of a thermoset instead of a thermoplastic is done to minimize the effect of the temperature variations on the magnetic and mechanical properties of the composites. Some of the thermosets which are used for coating are listed in table 1.1.

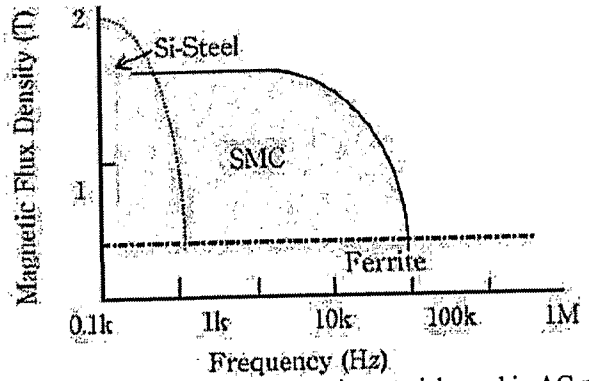

Fig. 1.1. The applicable regions for soft magnetic materials used in AC magnetic fields.

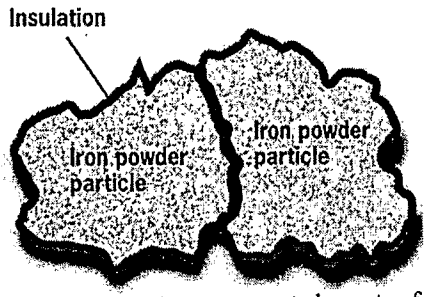

Fig. 1.2. A schematic diagram of the component elements of a powder core [65].

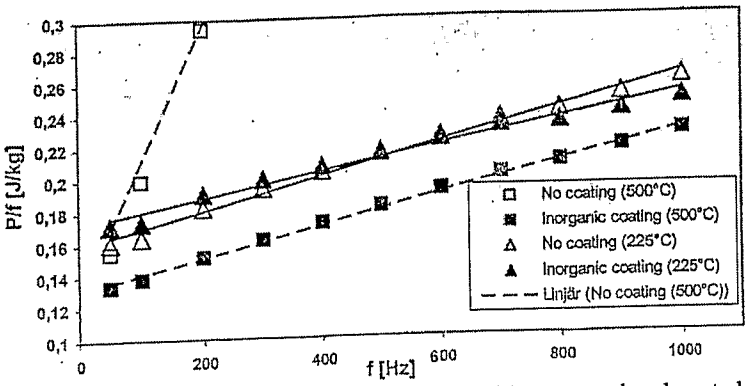

Fig. 1.3. The total losses for ring shaped components with un-coated and coated iron powder particles.