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Effect of viscosity on the magnetic permeability of Sendust-filled polymer composites

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ABSTRACT

A flake-shaped Sendust/acryl suspension is tape cast and the effect of the viscosity of the suspension on the magnetic permeability of the resulting composite is investigated. The real part of the permeability of the composite is inversely proportional to the viscosity of the suspension, indicating that the lower the viscosity of the suspension, the higher the permeability of the composite. The viscosity of the suspension is controlled by adding a small amount of surfactant; an anionic surfactant is most effective for lowering the viscosity at a given concentration range. It is thought that using a suspension with a relatively low viscosity improves the permeability of the resulting composite due to the easy alignment of the flake-shaped filler with the plain direction of the sheet.

1. Introduction

Since polymer-based composites have the advantage of easy processibility, low density, flexibility and tunable properties, they have attracted much attention for the applications to the electromagnetic components such as electromagnetic wave absorber, noise suppressor and inductor [1–4]. Ferrite, Fe-based powders, dielectrics and conductive materials are generally filled in the matrix polymers to render the polymer composites the effective electromagnetic properties.

As the shape of filler is general random with the exception of cylinder shape [5] and flake [2], most filler can be easily compounded with the polymer matrix by using two roll mixer and extruder, and the mixture of filler and polymer are fabricated to a desired shape of application via injection molding, pressing, and so on. For obtaining the sheet or film tape casting method is extraordinary effective and facilitates the control of film thickness.

In general, the improvement of the magnetic properties of the composites can be achieved by increasing the content of the filler, magnetic permeability of the filler itself and particle size [4]. However, we found that the viscosity of the suspension composed of the flake-shaped magnetic filler, polymer and solvent can also affect the magnetic permeability of the composite fabricated from the suspension via tape casting method.

The present study focused on the influence of the viscosity of acryl/flake-shaped Sendust suspension on the magnetic properties of the composites fabricated from the suspension by tape casting method. First, the Sendust is rolling-treated in ethanol by using an attrition milling machine to obtain the flake-shaped Sendust. The flake-shaped Sendust/acryl suspensions are prepared for tape casting and their viscosity is controlled by applying the various types of surfactant. We report the change in the viscosity of the suspension with the content of surfactant and the complex permeability of the acryl/Sendust composites according to the change of the viscosity of the suspensions.

2. Experimental procedures

Sendust (Dongbu Co., Korea) composed of Fe:Al:Si = 70:17:13 was used as a soft magnetic material. In order to improve the magnetic properties, this random-shaped Sendust was

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rolling-treated in an ethanol solution by using an attrition milling machine at room temperature for 12 h, dried at 100 °C for 24 h, and then heat-treated at 800 °C for 2 h. The obtained disc-shaped powder has an average diameter of 47.5 μm. The ethanol solution contained a small amount of thickener and lubricant. The steel balls of ϕ 3 were used as a media for the attrition in the ethanol vessel. Acryl copolymer with weight average molecular weight of 16,000 g/mol was used as matrix. Triton X-100 (Ducksan Chemicals Co., Korea), sodium dodecyl sulfate (SDS, Sigma-Aldrich, Korea) and benzalkonium chloride (BKC, Junsei Chemical Co., Japan) were used as non-ionic, anionic and cationic surfactant, respectively, for the comparison of surfactant effect. Toluene was organic solvent for the preparation of acryl/Sendust suspension.

The Sendust was first suspended in toluene/surfactant solution in an ultrasonic bath at room temperature for 1 h, where the surfactant content was varied in the range from 0.6 to 1.5 wt% as the ratio to the amount of the Sendust. The 20 wt% of acryl/toluene solution was poured into the Sendust suspension, and the mixture was again mechanically homogenized for 30 min. The solid content of the mixture solution was 54.5 wt% (26.5 vol%).

The acryl/Sendust solution was tape cast with Tape Casting Machine (Sung An Machinery Co., Ltd., Korea). The cast solution passed through the drying zone heated at 100 °C at the speed of 0.5 m/min to obtain the composite film with the thickness of about 75 μm. After the complete evaporation of the solvent, the films were laminated to a desired thickness and pressed at 150 °C for 1 h under the pressure of 40 kg/cm^2 to finally obtain the sheet of acryl/Sendust composite. The specimens for measuring the permeability were precisely machined to become the coaxial shape with the inner and outer diameter of 3.0 and 7.0 mm, respectively, and the thickness of 2.0–2.5 mm.

Brookfield viscometer (LVDV-II+Pro, Brookfield Engineering Laboratory, Inc., USA) was used for measuring the viscosity change of the acryl/Sendust suspension with the type and content of surfactant. The polished cross-section of the composites was observed by field emission scanning electron microscope (FESEM, S-2700, Hitachi Co., Japan). The permeability in the frequency range from 200 MHz to 2.0 GHz was measured by using a network analyzer (Agilent N5230A, USA) and coaxial airline (HP 85053–60005). The coaxial S-parameter method was adopted for obtaining the complex permeability and permittivity. Calibration was conducted with Teflon standard sample prior to every measurement.

3. Results and discussion

Since the appropriate rolling and heating treatment of Fe/Si alloy are known to increase the number of dipole grain as well as to align unidirectionally the direction of dipole moment [6], the flake-shaped Sendust is expected to have increased permeability and smaller hysteresis losses compared with the random-shaped Sendust. Fig. 1 shows the effect of the shape of Sendust on the complex permeability and permittivity of acryl composites at the frequency range from 200 MHz to 2 GHz, where the content of Sendust is 40 vol%. The rolling treatment of Sendust particles enables both the permeability and permittivity of the composites to be remarkably increased in the given frequency range. Both real and imaginary permeability of the flake-type Sendust-filled acryl composites show more than 3 times values compared to the as-received Sendust composites, while the permittivity is incredibly increased.

It is known that the permittivity of composite system depends mainly on the orientation polarization by polymer elements and interface or space charge polarization between the filler and matrix [7,8]. The Sendust is soft magnetic material, but it also shows the dielectric property. If it is covered with insulation materials like polymer, however, the permittivity is significantly increased due to the interfacial polarization, which can be strengthened with increasing the interfacial surface area or the number of interface between the Sendust and matrix. Since the rolling treatment increased the specific surface area of the Sendust, the composite filled with the flake-type Sendust enhanced the complex permittivity. The specific surface area measured by Surface Area & Porosimetry Analyzer (ASAP 2020 Analyser, Micromeritics, USA) was enlarged from 796 to 7310 cm^2/g by the rolling treatment of the Sendust.

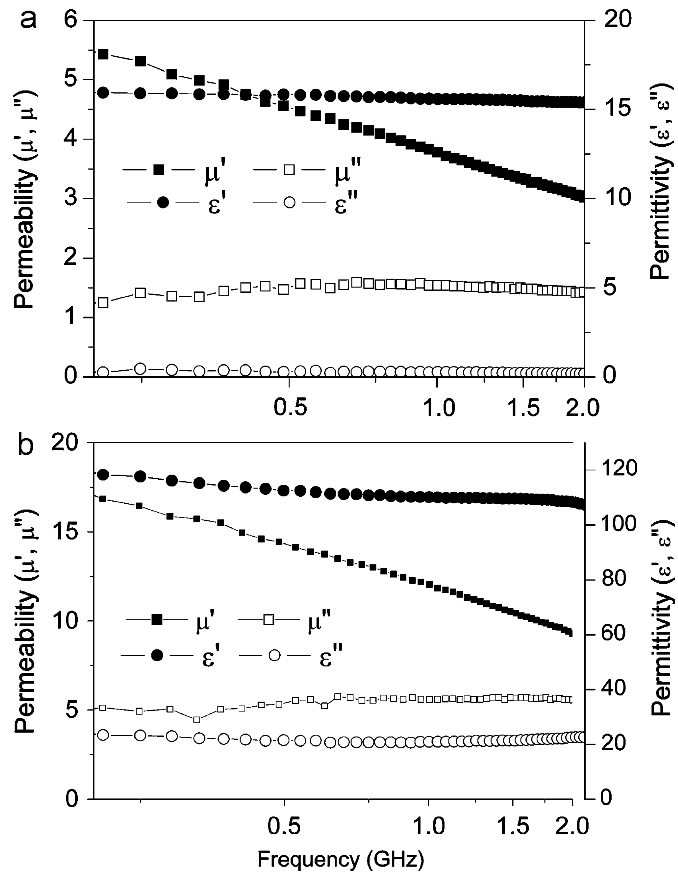

Fig. 1. Permeability and permittivity of acryl composite filled with 40 vol% of (a) as-received and (b) rolling-treated Sendust.

For the application of Sendust composite as the noise suppressor, imaginary part, i.e. magnetic loss rather than real part of the complex permeability is more important. This is why the magnetic field is separated from the electromagnetic field in the inductive (near) field region of wave impedance, and thus the material property of magnetic loss should be required to suppress the magnetic field. In order to have the high value of imaginary permeability the high value of real permeability is also needed. The complex permeability exhibited a typical frequency dispersion behavior as shown in Fig. 2. The real part linearly decreased with increasing frequency, while imaginary part showed a broad peak with a maximum value at around 500 MHz for the random-shaped Sendust-filled composite and an almost constant value for the flake-shaped Sendust-filled composite. The imaginary value of permeability of the latter was also increased by up to around 3 times the former.

Frequency dependence of complex permeability is shown in Fig. 2 with the content of flake-shaped Sendust. The real permeability is linearly decreased and the difference in the values