Temperature Dependence of Magnetic Properties of a Polymer Bonded Magnetic Material

Wei-Tai Wu, Y.W. Wong and K.W. Eric Cheng

***Abstract*--Polymer bonded magnetic materials have recently attracted increasing attention from fundamental research to industrial applications in many electromagnetic devices. It is necessary to investigate the properties of these magnetic materials operated under different environmental conditions. In particular, in this work, we investigated the relationship between the temperature and the magnetic properties of a polymer bonded magnetic material, epoxy (EP) resin bonded Co-Ni magnetic material. Experimental results indicate that the coercivity, the remanence magnetic flux density and the saturation magnetic flux density decrease at the elevated temperature. It is envisioned that the present studies may offer guidance for the applications of the polymer bonded magnetic material.**

***Index Terms*—magnetic material; magnetic property; polymer bonded; temperature.**

I. INTRODUCTION

THE dynamic development in the technology and engineering domains gives the reason to increase the requirements posed to various desired materials. Recently, the polymer bonded magnetic materials has attracted a great deal of attention for the fundamental research in the fields of magneto-electrics, and magneto-optics, etc.[1]-[3] These magnetic materials have also emerged as a potential class of materials for such industrial applications as transformer cores, in which high saturation and low losses are desired, and electromagnetic interference (EMI) shielding—an application which becomes more and more important due to electromagnetic smog.[3]-[7]

Generally, the polymer bonded magnetic materials are mainly composed of polymer matrix and magnetic powder, and they can be prepared by two mixing methods namely "melt mixed method" and "cement mixed method".[3]-[16] There are many types of magnetic powder, including ferritic magnets (such as $BaO \bullet 6Fe_2O_3$, $SrO \bullet 6Fe_2O_3$, Mn-Zn ferrite, and Ni-Zn ferrite), iron alloys containing Co, Ni and other elements (such as FeNi alloy, and silicon steel sheet), and rare-earth magnets (such as $SmCo_3$, and Sm_2M_{17} (M = Co, Fe, Cu, Ni, Mn, etc.)), etc. And the polymer matrix can be thermoplastic, such as polyethylene (PE), polypropylene (PP) and polyamide (PA), or thermosetting resin like epoxy resin (EP) and phenolic resin (PF), etc. It is obvious that the polymer bonded magnetic materials have many advantages in respect to light weight, low cost, design flexibility, versatile electrical and microwave properties, compared with those magnets without polymer.[12]

The devices in which the polymer bonded magnetic materials are used work in various environmental conditions. Under these conditions, the factors, like temperature, change in a broad range and in short time, even stepwise often. Besides, a big problem in using the magnets in transformer cores is their significant calefaction because of the losses.[8]-[16] It is well known that carbon-based polymers typically suffer from a lack of stability when exposed to heat or other external factors, thus may causing more or less changes in the internal structure of the magnetic materials. Technological progress in electrical engineering (production, transport and use of electrical energy) is highly linked to studies made in material science. Therefore, in this work, the goal is to investigate the sensitivity of the magnetic properties of a polymer bonded magnetic material (EP resin bonded Co-Ni) to temperature. It is envisioned that the present studies may make some insight into the environmental effect on the material, which may be helpful for its applications.

II. EXPERIMENTAL

The magnetic material used in this investigation was prepared by a common mixing method namely "cement mixed method".[8][17] To obtain the composite materials the Co powder and Ni powder, the mass ratio of Co:Ni = 1:1, were mixed with the thermosetting EP resin powder. The mass ratio of EP resin was ~10% of the total mass of the mixture.

FTIR measurements were performed using a Nicolet Instrument Co. MAGNA-IR 750 FTIR spectrometer with KBr as background. SEM images were obtained on a JEOL JSM-6700F field emission scanning electron microanalyser using conventional sample preparation and imaging techniques. Differential scanning calorimetry

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(DSC) measurements of the sample were carried out with a Perkin-Elmer Pyris 7 at a heating rate of 10 °C/min over a temperature range of 30-300 °C.

The magnetic properties of the sample were measured by a microprocessor-controlled vibrating sample magnetometer (VSM). The specimen used in the measurements is about 1×2×3 mm of 0.041 g. In order to protect the sample against oxidation, the sample chamber was vacuumized for 15 min and then aerated with Ar gas to ambient pressure before measurements. Temperature dependence of the magnetic properties of the sample was measured at various temperatures from 300 K to 325 K. The saturation magnetic flux density (Bs), remanence magnetic flux density (Br), and coercivity (Hc) are derived from the hysteresis loop measurements.

III. RESULTS AND DISCUSSION

The sample was identified by examining FTIR spectrum (Fig. 1) recorded at room temperature. The evidence of characteristic absorptions located at ~2964.5 cm^{-1}, ~1250.4 cm^{-1} and ~910.2 cm^{-1} corresponding to the vibrancy models of the epoxy ring, and those located at ~1606.1 cm^{-1}, ~1508.7 cm^{-1} and ~828.6 cm^{-1} corresponding to the vibrancy models of the benzene ring observed in the FTIR spectrum confirm the successful attachment of EP resin to the surface of the magnetic powders.

SEM images in Fig. 2 show the microstructure of the as-prepared sample, revealing the well bonding of the magnetic powders by EP resin. A few crannies were also observed possibly due to the poor consistent between EP resin and the magnetic powders, resulting in phase separation to some extent. The DSC curve was also recorded as shown in Fig. 3, indicating the glass transition temperature (Tg) of the sample is about 104 °C.

The magnetic hysteresis loops of the sample are shown in Fig. 4. All curves exhibit the typical magnetic hysteresis, which indicates the ferromagnetic nature. The magnetic properties of the sample are measured from certain defined points and derivatives obtained from these hysteresis loops, delivering the saturation magnetic flux density Bs, the remanence Br, and the coercivity Hc, etc.

Fig. 5 shows the graphs of magnetic properties versus temperature. The magnetic properties of materials can be divided into two general categories: those that are structure sensitive and those that are structure insensitive. Structure-sensitive properties are those that are drastically affected by changes in materials processing (heat treatment or mechanical deformation) or by small changes in composition. Permeability, coercivity, hysteresis losses, remanence, and magnetic stability are all considered to be

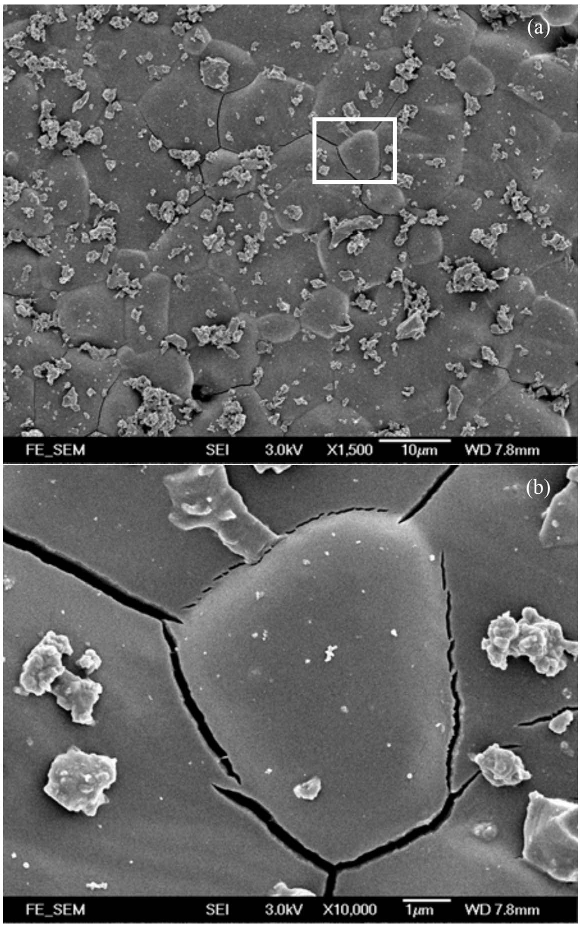

Fig. 2. Typical SEM images of the sample.

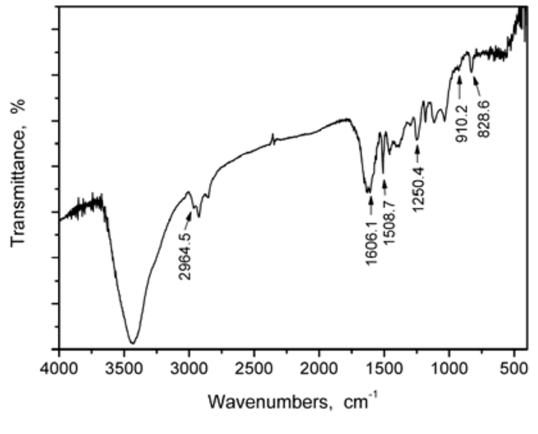

Fig. 1. FTIR spectrum of the sample recorded at room temperature.

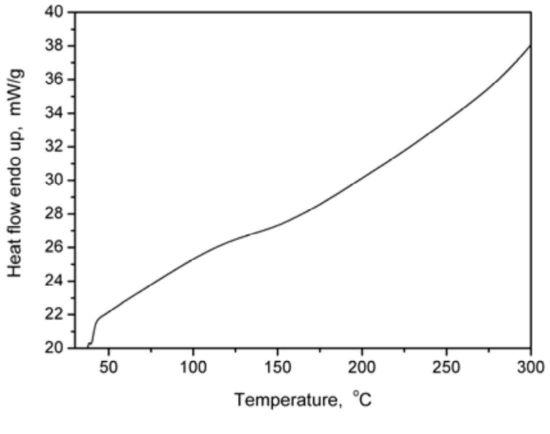

Fig. 3. DSC curve of the sample.

structure sensitive. The structure sensitive properties are controlled through processing of the material including mechanical and thermal treatments. It can be seen that the coercivity (Fig. 5a) and the remanence magnetic flux density (Fig. 5b) indeed decreases at the elevated temperature.

The hysteresis loss is the area enclosed by the hysteresis loop. It represents the energy expended per unit volume during one cycle of the hysteresis loop. The hysteresis loss increases as the maximum magnetic field reached during the cycle increases. This loss is closely related to the coercivity so that processing of materials to reduce coercivity also reduces the hysteresis loss. Reduce the remanence magnetic flux density could also reduce the hysteresis loss. Thus, from these points of view, it is envisioned that the available range of magnetic properties of the present material would not be restricted by the calefaction factor; on the contrary, it seems that it favors the application at the higher temperature.[3]

Moreover, the coercivity is the parameter which is used to distinguish hard and soft magnetic materials. Traditionally, a material with a coercivity of less than 1000 A/m (equals to 4π Oe) is considered magnetically "soft", and a material with a coercivity of greater than 10,000 A/m (equals to 40π Oe) is considered magnetically "hard".[3][18] According to the tendency shown in Fig. 5a, the coercivity (79.28 Oe) obtained at 325.02 K would further decrease to a much lower value, and the transition to magnetically "soft" may happen; however, we could not give further evidence due to the restriction of our experimental condition, and further studies are still needed to clarify this hypothesis.

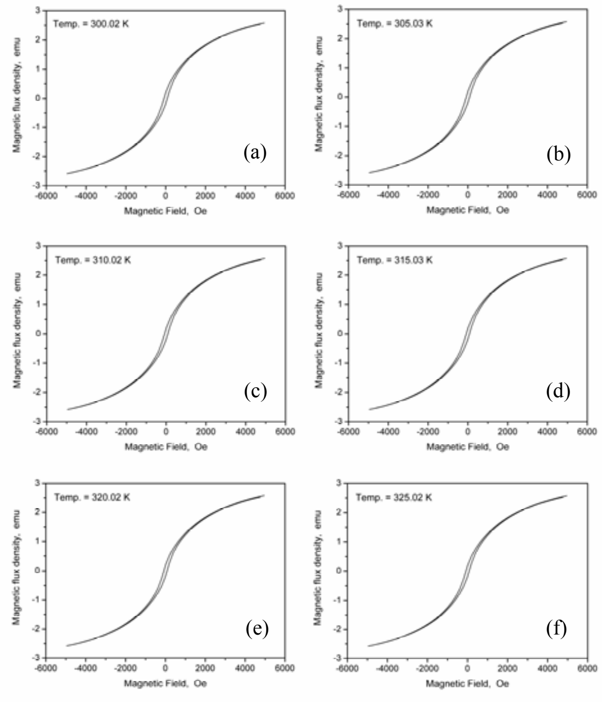

Fig. 4. Magnetic hysteresis loops of the sample measured at various temperatures: (a) 300.02 K, (b) 305.03 K, (c) 310.02 K, (d) 315.03 K, (e) 320.02 K, and (f) 325.02 K.

Structure insensitive refers to properties not markedly affected by changes in materials processing or composition. Structure-insensitive properties include the saturation magnetization and resistivity. These properties are largely dependent on the composition of the material and are not changed substantially in the processing. On the other hand, in the low temperature range (up to around 0.4-0.5 T_C) the temperature dependence of the magnetization M can be described by Bloch's law [19]:

$$M(T)=M(0)[1-BT^{3/2}]=M(0)[1-(\frac{T}{T_0})^{3/2}]$$

And

$$B=\mu_0(H+M)$$

Herein, μ_0 is the permeability of free space; H is the

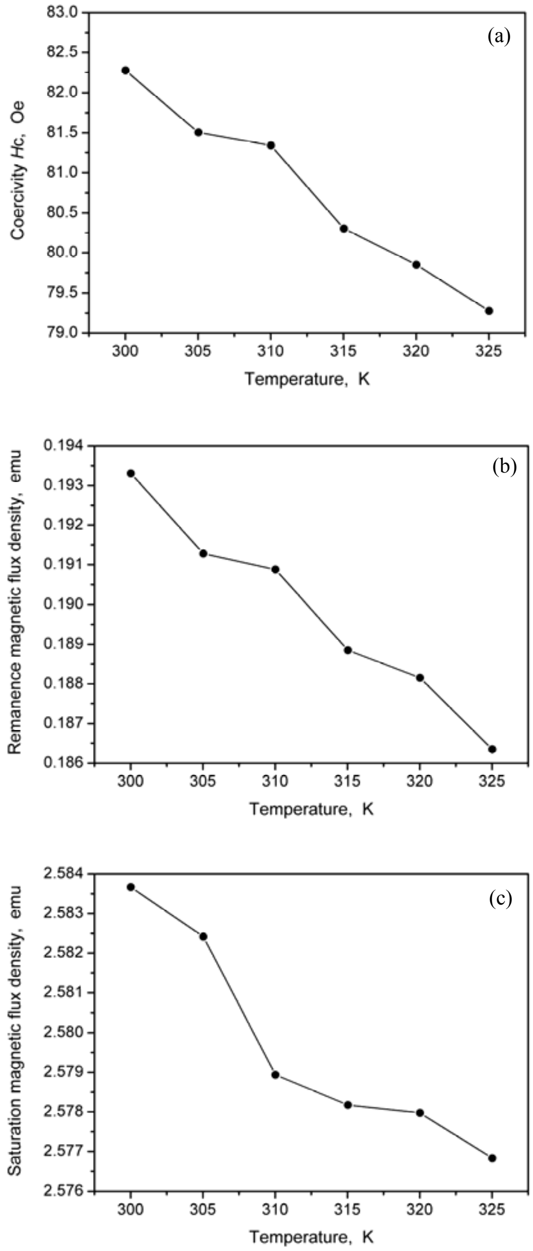

Fig. 5. Temperature dependent magnetic properties of the sample: (a) the coercivity, (b) the remanence magnetic flux density, and (c) the saturation magnetic flux density versus temperature.

strength of the external magnetic field. Fig. 5c shows the saturation magnetic flux density against the temperature, demonstrating that Bloch's law is well fulfilled in the present experimental temperature range that the saturation magnetic flux density decreases at the elevated temperature.

However, for transformer applications, not only low losses but also high saturation magnetic flux density is desired, since the higher saturation could improve the DC superposition property of permeability and favors the larger transmited power in a strong magnetic field. Under this considering, the relationship between the saturation magnetic flux density and the temperature may present as a shortcoming in the application of the present material as transformer cores.

IV. CONCLUSIONS

Polymer bonded magnetic materials have attracted increasing attention from fundamental research to industrial applications in many electromagnetic devices. The previous discussion underlines the need to investigate these magnetic materials under various environmental conditions. In particular, the aim of this paper was to investigate the relationship between the temperature and the magnetic properties of a polymer bonded magnetic material, EP resin bonded Co-Ni composite material. Experimental results indicate that the coercivity, the remanence magnetic flux density and the saturation magnetic flux density decrease at the elevated temperature. It is envisioned that the present studies may offer guidance for the applications of the polymer bonded magnetic material.

VI. ACKNOWLEDGMENT

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