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Modeling of magnetic properties of polymer bonded Nd–Fe–B magnets with surface modifications

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Abstract

The effects of surface modification on the magnetic properties of polymer-bonded Nd–Fe–B magnets have been studied. Two sets of Nd–Fe–B powders, coated and uncoated, were blended and compression molded with polyphenylene sulfide in isotropic form. Their magnetic properties were measured using a Helmholtz coil and a SQUID. The results showed that the effect of the coating significantly improved the irreversible loss in flux and energy product of the polymer-bonded magnets. The results have been interpreted using an isotropic model of hysteresis that takes into account energy losses. The modeling showed that the presence of soft magnetic materials in the Nd–Fe–B powders caused by oxidation reduces the interaction among magnetic particles, however, the coating treatment alters the magnetic properties by increasing the remanence of polymer-bonded magnets via increasing the interparticle coupling coefficient.

Introduction

Polymer-bonded magnets composed of polymer matrices and magnetic powders are produced by traditional polymer processing methods and the magnets offer significant advantages, in terms of shaping and cost, over their metallic or ceramic counterparts. Polymer-bonded magnets are typically obtained by mixing a magnetic powder with a binder such as a thermoplastic polymer at an appropriate mixing ratio in a mixer or extruder, and subjecting the extrudate in the form of pellets to injection molding or compression molding. They are thin-walled and permit close tolerances, which enables the formation of complex-shaped magnets [1], [2]. Polymer-bonded magnets have many advantages because of the presence of the polymer component. One of the most important advantages is the ease with which semi-assembled magnets can be obtained using one molding operation such as injection molding. Industry users of these parts can save on assembly line costs and quality control staff [3].

Magnetic rare-earth powders are readily oxidized in air, especially at elevated temperature. The poor thermal stability of rare-earth alloy powder reduces the processability of rare earth containing iron-base thermoplastics-bonded magnets because of the high injection molding temperature required by the high-performance thermoplastic polymers. In addition, the poor thermal stability of rare-earth powder limits their use in numerous potential applications such as components used in automobiles where the magnets are frequently subjected to elevated temperatures [4], [5], [6], [7], [8]. Furthermore, exposure to humid environments deteriorates the performance of polymer-bonded rare-earth magnets because the presence of water corrodes the material easily and quickly [9], [10]. In order to make bonded magnets with a high magnetic flux or energy product, attempts should be made to provide a bonded magnet composition wherein a magnetic powder can be processed and used in an aggressive environment.

Our previous papers studied the effect of coating treatment on the thermal stability and magneto-mechanical properties ([11] (see also Ref. [12]) [13], [14], [15], [16]). Application of an impervious high-temperature coating provides an oxidation and corrosion resistance to the magnetic powders, making the coated rare-earth powders thermally stable during injection molding of highly packed polymer-bonded rare-earth magnet. In addition, the coating imparts to the rare earth alloy resistance to mechanical shearing during the polymer and rare-earth alloy blending process as previously reported [11], [12]. However, it is still unclear how the coating treatment influences the magnetic properties. We have recently [17], [18] developed a theoretical model based on the energy balance during domain magnetization process to describe hysteresis in magnetic materials. The purpose of the present paper is to study the effect of coating treatment on the magnetic properties and apply the above model to polymer-bonded Nd–Fe–B magnets with and without coating treatment. The modeling may be able to provide a better understanding of the microstructural change that leads to the magnetic properties variation.

Section snippets

Experimental

Commercial Nd–Fe–B magnetic powder (MQP-O, Magnequench International, Inc.) was used for this study. The powder is a multimodal mixture of plate-like particles (Fig. 1). The surface modification of the Nd–Fe–B was performed following the method developed by Otaigbe and coworkers ([19] (see also Ref. [20]) and discussed in Refs. [11], [12], [13], [14], [15], [16]. An organometallic compound such as γ-aminopropyltriethoxysilane (hereinafter referred to as silane) was used as the coating agent in…

Results and discussion

It was reported previously that the silane coating on the magnetic fillers protects them from the moisture and oxygen (from air) attack at elevated temperature according to the chemical reaction mechanism reported in Refs. [14], [19], [20]. This corrosion and oxidation protection are expected to provide enhanced magnetic properties at high temperature. The results of short-term irreversible loss test (STILT) and a portion of the long-term irreversible loss test (LTILT) confirm the expectation…

Conclusions

Short-term irreversible loss test results of the polymer-bonded magnets containing silane coated Nd–Fe–B magnetic filler with high loading (about 62 vol%) showed zero irreversible loss in magnetic flux density after exposure to temperatures up to 180°C. The agreement between the modeled and measured data is satisfactory and the model was found to be useful for interpreting trends in the observed irreversible changes and interaction fields through the hysteresis loss model parameter *k* and changes …

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