MAGNETIC BEHAVIOUR OF HYBRID MAGNETIC COMPOSITE MATERIALS

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Abstract

Polymer bonded magnets are contemporary materials with a very large range of applications. The objective of this study is to assess how different content of Nd-Fe-B and/or barium ferrite particles affect on magnetic and morphological properties of bonded composite materials. Interactions between employed magnetic powders and interactions between magnetic powders and polymer binder are considered. For examination of the magnetic behavior Vibrating Sample Magnetometer (VSM) is used. Different shape and size of obtained hysteresis loops are used for comparison and prediction of polymer bonded materials properties.

Keywords: bonded magnets, Nd-Fe-B, composite materials, VSM

1. Introduction

The hard magnetic alloys such as Nd-Fe-B and barium ferrite are identified as suitable for research and further development of magnetic composite materials with polymer matrix, so called bonded magnets [1]. Contemporary research in the field of magnetic composite materials on the basis of Nd–Fe–B alloys are directed to reduction of the subtle rare earth content (Nd), targeting towards decreasing the price of the final magnetic material while keeping high values of the maximum magnetic energy. Application of various process techniques in the production process of bonded magnets gives the possibility for utilization of various magnetic powders in combination with different polymeric materials as binding agent [2–4]. Advantages of the using bonded composite materials include their simple technology, possibility of tuning their final properties, low manufacturing costs (as no costly finishing is necessary), and low material losses (due to a simple forming of any shape).

The strong influence the both of applied magnetic filler particles on the magnetic properties of composites have significantly contributed to increased use of polymer materials in many commercial applications. The presented study is undertaken with intention to investigate the effect of different filler content on the structural and magnetic properties of the Nd–Fe–B/barium ferrite hybrid composite materials.

2. Experimental

The thermosetting epoxy system that is a combination of liquid mixture of Bisphenol A and Bisphenol F resins and cross linking agent (hardener) which cures fully at room temperature is used as a polymer matrix. The epoxy resin has following properties: tensile strength ~ 58 MPa, elongation ~ 2.8%, compression strength ~ 96 MPa, flexural strength ~ 78 MPa and density ~ 1.2 g/cm^3, is selected.

The rapid quenched plate-like Nd-Fe-B magnetic powders with stoichiometric Nd content neodymium ($Nd_{11.7}(Fe,Co)_{80}B_{8.3}$) and spherical barium ferrite ($BaFe_{12}O_{19}$) agglomerates are employed as magnetic filler for polymer composite magnets manufacturing. The magnetic properties of started magnetic materials are presented in Table 1.

Table 1. Magnetic properties of started magnetic materials

Material	Chemical Formula	B_r [kG]	H_{cb} [kOe]	H_{cj} [kOe]	$(BH)_{max}$ [MGOe]
Neodymium Iron Boron	$Nd_{11.7}(Fe,Co)_{80}B_{8.3}$	8.2	6.0	8.7	13.1
Barium Ferrite	$BaFe_{12}O_{19}$	2.3	1.9	3.6	1.3

The structure and morphology of fracture surfaces of synthesized composite materials are observed by JEOL JSM-5800 Scanning Electron Microscope (SEM), with an accelerating voltage of 20 kV. After tensile tests at room temperature fracture sample surfaces are sputtered with gold using a POLARON SC 502 sputter coater for enhanced conductivity.
The examination of magnetic properties is tested using Vibrating Sample Magnetometer (VSM) EG&G Princeton Applied Research type at ambient temperature (300 K). Disc shape samples with 5 mm radius and 3 mm thickness are placed parallel to vector of magnetic field. Maximal magnetic field strength and time of exposure were 2.4 T and 10 s, respectively.

3. Results and discussion

The particle size of magnetic powder plays an important role in determination of powder to binder ratio, degree of particle alignment and magnetic and mechanical properties. Generally speaking, the plate–like particles would result in higher packing density under the optimal compression conditions [5]. SEM micrographs of fracture surface morphology of Nd-Fe-B/barium ferrite hybrid composites in epoxy matrix are presented in Figure 1.
The synthesized hybrid magnetic composite materials correspond to a mixture of Nd-Fe-B and barium ferrite in different ratio. For better insight into the influence of added barium ferrite to the final characteristics of hybrid composite materials are examined for a constant quantity of the polymer matrix. Since the crumbled ferrite agglomerates are incorporated between bigger particles of ferrite and Nd-Fe-B they contribute to the improved dynamic mechanical properties of composite [8]. However, spherical barium ferrite agglomerates contribute to the higher values of storage modulus i.e. higher stiffness of materials [6, 7].

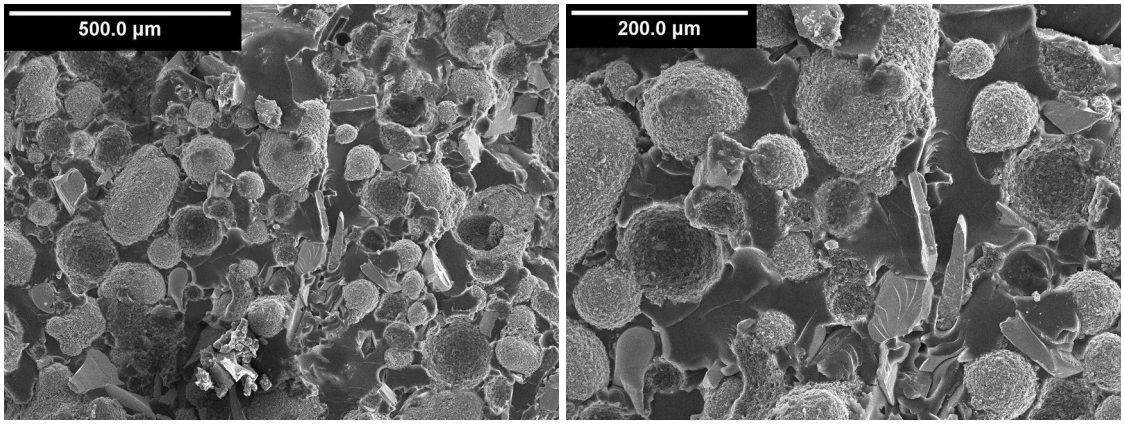

Figure 1. SEM micrographs of Nd-Fe-B/barium-ferrite/epoxy composites

Characteristic of all magnetic materials is a manifestation of the hysteresis phenomena. The hard magnetic materials have the greater values of hysteresis [8]. Magnetic properties of magnetic composite materials (bonded magnets) are affected by the magnetic properties of the magnetic powder and weight (volume) ratio of the powder. It is known that bonded magnets have inferior magnetic characteristics compared to magnetic material obtained by convectional methods (sintering for example), because in bonded technology maximal density of magnetic powder can not be achieved [6]. One of the most important characteristics of the used type of Nd-Fe-B rare-

earth magnetic material is high values of remanence and coercivity, which have a direct influence on high values of maximal energy product [9]. The results of magnetic measurements for bonded Nd-Fe-B/epoxy composites are presented in Figure 2. It is obvious that higher content of magnetic particles in polymer matrix has direct influence on the magnetic properties of polymer bonded composites.

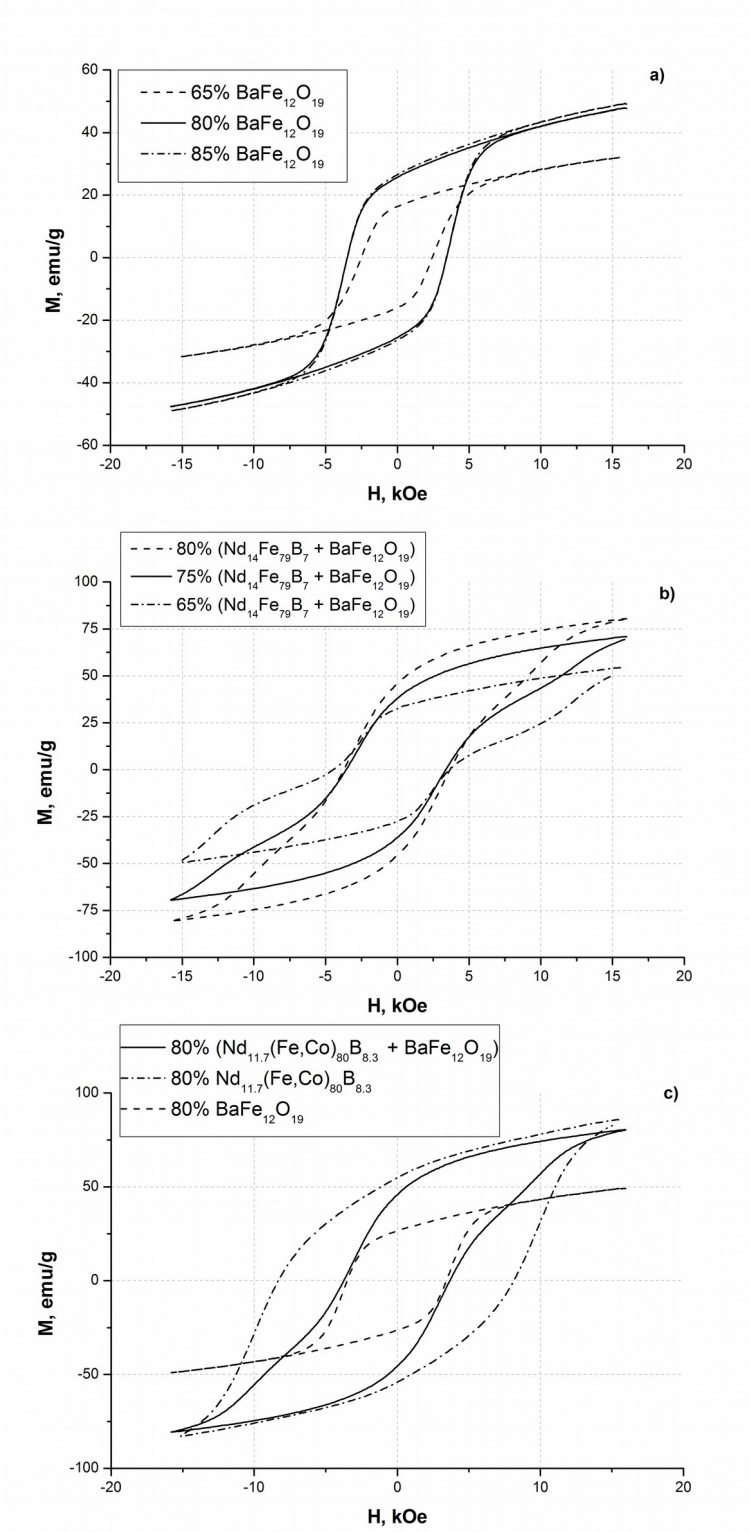

Figure 2. VSM hysteresis loops for different types of polymer bonded composites

Characteristic shapes of hysteresis loops for Nd–Fe–B alloys with stoichiometric Nd content, barium ferrite and hybrid composites (Nd–Fe–B/barium ferrite) are presented in Figures 2a–2c. Characteristic shape of hysteresis loops for barium ferrite a are presented in Figure 2a.

Magnetic properties are reduced due to presence of "only" 65 wt.% and 85 wt.% barium ferrite in epoxy matrix. Hysteresis loops show stepped transition for all investigated hybrid magnetic composites as a consequence of magnetic response of Nd-Fe-B and barium ferrite mixture (Figure 2b,c). This shape of hysteresis practically represents a resultant of hysteresis loops of both, Nd-Fe-B and barium ferrite. Compared to barium ferrite bonded magnets and hybrid composites, magnetic properties of Nd-Fe-B are more pronounced (Figure 2c). In the region of high magnetic field strength, hysteresis curves of barium ferrite show constant increase of magnetization with a tendency to achieve saturation.
The values presented on Figure 2. should be taken as approximate because the field strength of VSM (2.4 T) is not sufficient for full saturation of Nd-Fe-B powders. It can be seen in the first quadrant, the horizontal end of the hysteresis loop of barium ferrite indicates that this magnetic powder achieves a complete saturation, as opposed to Nd-Fe-B alloy.

4. Conclusion

As expected, magnetic properties are drastically improved with higher quantity of Nd-Fe-B magnetic powder, especially for highly filled composites. These results provide information about the Nd-Fe-B/epoxy composites which could be of importance in cases where the relatively brittle metallic permanent magnets are not useable.
Hybrid materials development and utilization are economically motivated, due to fact that these materials can be produced at low cost. For example, replacing one fraction of Nd-Fe-B with less expensive barium ferrite creates the new hybrid composite. This hybrid composite shows lower intensity of magnetic property comparing with original composite, but they are still applicable for wide range of usage. It could be concluded that hybrid materials impose themselves as the contemporary materials with tendency of replacing existing composite materials in numerous applications. Also, it should be notice that further investigations in hybrid magnetic composite materials area are directed to the improvement of dynamic mechanical, thermal and electrical properties, as well as corrosion resistance.

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MAGNETNO PONAŠANJE HIBRIDNIH MAGNETNIH KOMPOZITNIH MATERIJALA

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Polimerom vezani magneti predstavljaju savremene materijale sa veoma širokim spektrom primene. Cilj ovog rada je da se analizira i prikaže kako različiti udeli čestica Nd-Fe-B i/ili barijum ferita utiču na magnetna i morfološka svojstva bonded kompozitnih materijala. Razmatrane su interakcije između primenjenih magnetnih prahova različitog tipa i interakcije između magnetnih prahova i polimerne matrice. Za merenje magnetnih svojstava kompozita korišćen je vibracioni magnetometar (VSM). Različiti oblici i veličine dobijenih histerezisnih petlji su poređeni i analizirani u cilju predviđanja magnetnog ponašanja kompozita.

Ključne reči: Bonded magneti, Nd-Fe-B, Kompozitni materijali, VSM

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