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MAGNETIC BEHAVIOUR OF POLYMER BONDED Nd-Fe-B COMPOSITE MATERIALS

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ABSTRACT
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 Nd-Fe-B bonded magnets have been commonly used in various fields, such as electric appliances, automobile parts [1], sensing elements [2], electronic, communication and micro-electro-mechanical system (MEMS) applications [3,4]. Advantage of using bonded composite materials include their simple technology, possibility of forming their final properties, lowering manufacturing costs because of no costly finishing and lowering of material losses resulting from the possibility of forming any shape [5]. The quantity of Nd-Fe-B powder in the bonded magnet plays a crucial role in determining the magnetic properties. A higher content of Nd-Fe-B powder usually results in a higher remanence

magnetization (*Br*) and maximum energy product $(BH)_{max}$ and therefore it is desirable from the magnetic perspectives. However, the higher content of magnetic filler may change the rheology of polymer melt during process and, subsequently, impact the mechanical strength of bonded magnets [6]. The presented study is undertaken with intention to understand the effect of different content of filler on the magnetic properties of the Nd-Fe-B-type composite materials.

2. EXPERIMENTAL

The rapid quenched Nd-Fe-B magnetic powders enriched with neodymium ($Nd_{14}Fe_{79}B_7$) are employed as magnetic filler for polymer composite magnets manufacturing. Hybrid magnetic composites are produced by replacing the part of Nd-Fe-B particles with spherical barium ferrite ($BaFe_{12}O_{19}$) agglomerates. 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	$Nd_{14}Fe_{79}B_7$	6.0	5.1	13.3	7.5
Barium Ferrite	$BaFe_{12}O_{19}$	2.3	1.9	3.6	1.3

As a polymer matrix 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. 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 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

Uniform particle distribution and good adhesion between Nd-Fe-B particles and a polymer matrix are essential for the quality of composites, especially at temperatures above the glass transition temperature (*Tg*) of the polymer. 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 [7]. SEM micrographs of fracture surface morphology of Nd-Fe-B/epoxy composites are presented in Figure 1.

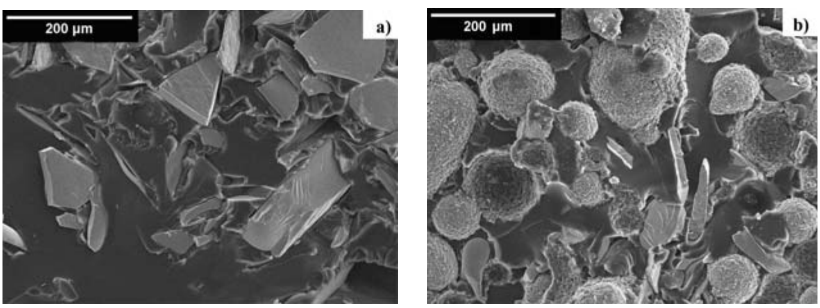

Figure 1. SEM micrographs of a) Nd-Fe-B/epoxy, and b) Nd-Fe-B/barium-ferrite/epoxy composites

The Nd–Fe–B particles are shown as light grey platelet shape, barium ferrite as spherical light grey, and the epoxy matrix is shown as dark. Although the magnetic particles are of variable size and shape, they seem to be attached rather well to the matrix.

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].

Characteristic of all magnetic materials is a manifestation of the hysteresis phenomena. The hard magnetic materials have the greater values of hysteresis [9]. A word of Greek derivation, hysteresis describes magnetic materials as highly nonlinear, meaning that their response to a stimulus lags behind in a repeatable manner. The stimulus in this case is an applied magnetic field and the material's response is the magnetization or induction [10]. 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 [8]. 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 [11]. 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.

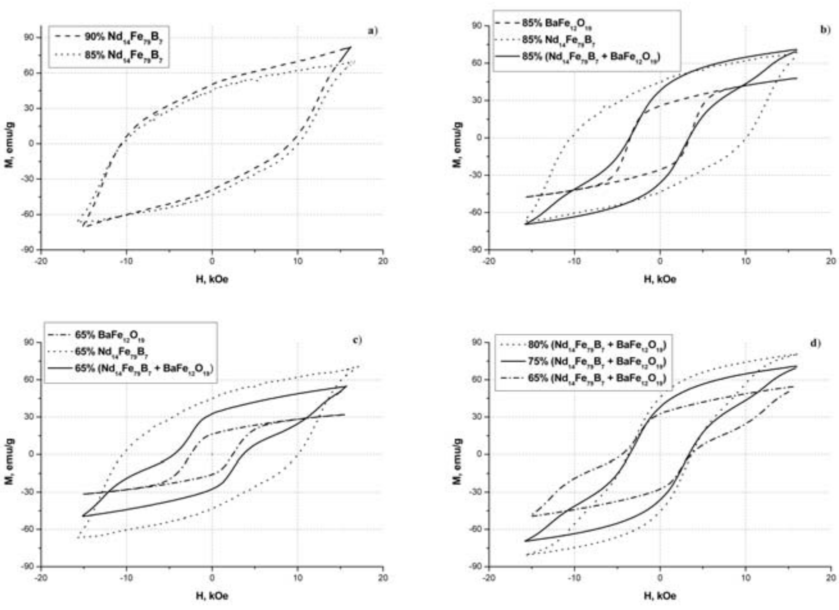

Figure 2. VSM hysteresis loops for different types of polymer bonded composites

Characteristic shape of hysteresis loops for Nd-Fe-B alloys enriched with Nd are presented in Figure 2.a. Magnetic properties are reduced due to presence of "only" 85 wt.% and 95 wt.% Nd-Fe-B in epoxy matrix. Compared to Nd-Fe-B bonded magnets and hybrid composites, magnetic properties of barium ferrite are reduced (Figure 2.b,c). 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 2.b,c,d). This shape of hysteresis practically represents a resultant of hysteresis loops of both, Nd-Fe-B and barium ferrite. 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.

5. ACKNOWLEDGEMENT

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6. REFERENCE

[1] Li J., Liu Y., Gao S.J., Li M., Wang Y.Q., Tu M.J., Journal of Magnetism and Magnetic Materials, 299 (1) (2006) 195-204

[2] Radojević V., Talijan N., Grujić A., Ćosović V., Aleksić R., Journal of Optoelectronics and Advanced Materials, 9 (8) (2007) 2424 -2429

[3] Chin T.S., Journal of Magnetism and Magnetic Materials, 209 (1-3) (2000) 75-79

[4] Hono K., Ping D.H., Materials Science and Engineering: A, 304-306 (2001) 81-87

[5] Dobrzanski L.A., Drak M., Journal of Alloys and Compounds, 449 (1-2) (2008) 88-92

[6] Grujić A., Talijan N., Stojanović D., Stajić-Trošić J., Burzić Z., Balanović Lj., Aleksić R., Journal of mining and metallurgy, Section B: Metallurgy, 46 (1) (2010b) 25-32

[7] Zhang X.H., Xiong W.H., Li Y.F., Song N., Materials and Design, 30 (4) (2009) 1386-1390

[8] Grujić A., Ćosović V., Stajić-Trošić J., Talijan N., Spasojević V., Lazić N., Aleksić R., Dynamic Mechanical Properties of Polymer Bonded Magnetic Materials with Different Nd-Fe-B Content, Proc. of the 21st Workshop on Rare-Earth Permanent Magnetis and their Applications, edited by Kobe S. and McGuiness P.J., 29.08.-02.09.2010., Bled, Slovenia, pp. 213-216

[9] Goll D., Kronmüller H., Naturwissenschaften, 87 (2002) 423-438

[10] Trout S. R., Understanding Permanent Magnet Materials; an Attempt at Universal Magnetic Literacy, Proceedings of EMCW 2000, Cincinnati, Ohio, October, 2000, http://spontaneousmaterials.com/Papers/CW2000.pdf

[11] Gutfleisch, O., Journal of Physics. D: Applied Physics, 33 (2000) R157–R172