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New possibilities of composite materials application—Materials of specific magnetic properties

L.A. Dobrzański *, M. Drak, B. Ziębowicz

Institute of Engineering Materials and Biomaterials, Silesian University of Technology, 44-100 Gliwice, Poland

Abstract

This paper presents the material and technological solution which makes it possible obtaining of soft and hard magnetic composite materials: nanocrystalline material–polymer. For fabrication of composite materials the following powders were used: soft magnetic material ($Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$) and hard magnetic material ($Nd_{14.8}Fe_{76}Co_{4.95}B_{4.25}$). Polymer was used as the matrix (2.5 wt.%). Advanced composite materials were compacted by the one-sided uniaxial pressing. The complex relationships among the manufacturing technology of these materials, their microstructure, as well as their mechanical and physical properties were evaluated. Materialographic examination of powders morphology and the structure of composite materials were made. Composite materials show regular distribution of magnetic powder in polymer matrix. Examination of mechanical properties shows that these materials have satisfactory compression strength. Composite materials show lower magnetic properties in comparison with magnetic powder but their geometrical form allows extending their applications. The paper shows also the possibilities of these magnetic materials application. The advantage of the bonded composite materials is their simple technology, possibility of forming their properties, lowering manufacturing costs because of no costly finishing and lowering of material losses resulting from the possibility of forming any shape. The manufacturing of composite materials greatly expand the applicable possibilities of nanocrystalline powders of magnetically hard and soft materials.

Keywords: Magnetic materials; Nd–Fe–B; FINEMET; Composite materials

1. Introduction

The dynamical development of the technical civilisation depends to a greater and greater extent on development of the materials engineering which still searches for the non-conventional materials with the unique mechanical and physical properties. It is connected, among others, with the development of the contemporary electrotechnical and electronic industry employing the modern magnetic materials [1].

The search for the new magnetic materials has lead, among others, to development of research on the Fe based metallic materials with the nanocrystalline structure, having the great soft magnetic properties and the intermetallic phases based on the rare earth metals and transition metals Nd–Fe–B nanocrystalline structure showing excellent hard magnetic properties [2,6–8].

Bonding of Nd–Fe–B and FINEMET powders with the polymer, chemically setting, thermosetting and thermoplastic materials, low-melting glasses or metals makes it possible to obtain the composite materials. These magnetic materials may be made also by sintering, injection moulding, hot compacting, upseting, casting and explosive consolidation but they can more affect the nanocrystalline structure of magnetic component [6–10,12–14].

The mechanical properties of the composite magnets depend mostly on the magnetic powder and binding agent types and on the technology employed. The portion of the polymer matrix affects the mechanical and magnetic properties of the manufactured composite materials. The mechanical properties increase along with the increasing portion of resin in the matrix but this increase has a negative effect on the magnetic properties. Usually the 2.5–3.0% mass portion is assumed, i.e., 15–20% volume portion, and compacting pressure is 350–900 MPa [4,11].

Magnetic composite materials are characteristic of various magnetic, mechanical, and physical properties depending on the powder manufacturing and compacting technology. This makes it possible to obtain materials for various applications, according to the particular requirements [3,5,9].

The advantage of the bonded composite materials is their simple technology, possibility of forming their properties, lowering manufacturing costs because of no costly finishing and lowering

* Corresponding author.
E-mail address: leszek.dobrzanski@polsl.pl (L.A. Dobrzański).

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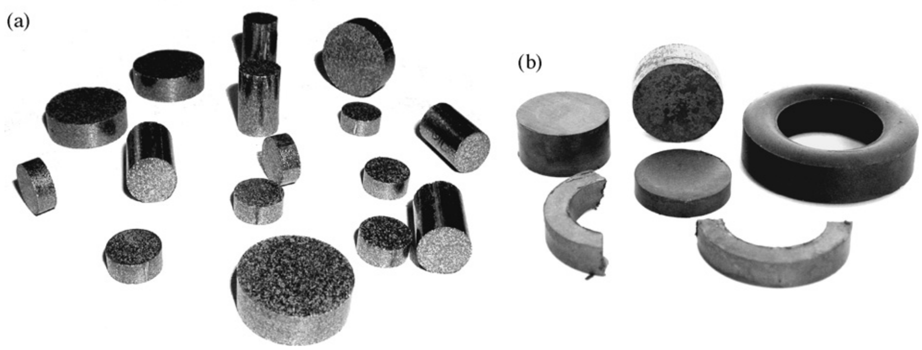

Fig. 1. Composite materials: (a) Nd–Fe–B–EP and (b) FINEMET–PEHD.

of material losses resulting from the possibility of forming any shape.

The goal of the work is to investigate the structure, magnetic and mechanical properties of chosen magnetic composite materials with polymer matrix reinforced with Nd–Fe–B or FINEMET particles manufactured by one-sided uniaxial pressing. The paper shows also the possibilities of these magnetic materials application.

2. Experimental

The experiments were made with the polymer matrix magnetic composite materials reinforced with particles of the powdered rapid quenched Nd–Fe–B ($Nd_{14.8}Fe_{76}Co_{4.95}B_{4.25}$) strip bonded with thermosetting epoxy resin (EP) and FINEMET ($Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$) strip bonded with the high density pressureless polyethylene (PEHD). The amount of polymer matrix was 2.5 wt.%. Advanced composite materials were compacted by the one-sided uniaxial pressing.

The following compacting process parameters were used:

- Nd–Fe–B–EP, room temperature; pressure, 900 MPa; curing of the polymer matrix, 180 °C for 2 h after compacting.
- FINEMET–PEHD, 170 °C; pressure 350 MPa; pressing time 0.25 h.

Fig. 1 shows examples of manufactured magnetic composite materials.

Metallographic examinations were made on the LEICA MEF4A light microscope equipped with the computer image analysis system. The powder grains size measurements were carried out on the light microscope of the magnetic materials powders. Test results were analysed statistically using the Leica-Qwin and Microcal Origin 6.0 programs. Observations of morphology of powders used were made on the DSM 940 OPTON scanning electron microscope at the maximum magnification of 400× using the secondary electron detection at the 20 kV accelerating voltage.

The density of the composite materials was evaluated by determining the test piece mass using the analytical balance with the accuracy of $\pm 10^{-4}$ g and its volume basing on the apparent mass loss by immersing in water.

Examination of magnetic properties of Nd–Fe–B–EP composite materials was carried out on the MCS type device designed for examining permanent magnets in the magnetic circuit with the air-gap. The examination method is based on the measurement of the magnetic induction B_0 in the gap between the electromagnet pole and the test piece face using the Hall generator, and on the measurement of the external magnetizing field H_0 generated by the electromagnet. The test pieces were magnetized in the field magnet before the measurement and further the demagnetization curve was recorded as well as remanence B_r, coercive force H_{cB} and maximum energy product BH_{max}. These quantities were determined based on the measured magnetic induction B_0 and the external magnetizing field intensity H_0. The FINEMET–PEHD composite materials were examined on the Lake Shore Cryotronics Inc. VSM vibratory magnetometer with the working voltage of 30 V, maximum field intensity 1800 kA/m and the time-constant 3 s. The examination results were collected and processed using the IDEAS™ VSM Software package which featured the integral part of the VSM system.

Compression tests were made on the INSTRON 1150 all-purpose testing machine at room temperature. Hardness tests of the composite materials were carried out with the Brinnell method using the 2.5 mm ball and load of 31.25 N.

3. Results and discussion

Fig. 2 shows morphology, distribution and powders sizes of $Nd_{14.8}Fe_{76}Co_{4.95}B_{4.25}$, $Fe_{73.5}CuNb_3Si_{13.5}B_9$ observed in scanning electron. Powders used for fabrication of the composite materials differ with grain sizes. The $Nd_{14.8}Fe_{76}Co_{4.95}B_{4.25}$ powder is characteristic of grains from 75.3 to 281.4 μm while the $Fe_{73.5}CuNb_3Si_{13.5}B_9$ powder shows grains from 10.3 to 69.2 μm. Both of these powders are characteristic of flaky shape.

Table 1
Comparison of composite materials properties

Properties	$Nd_{14.8}Fe_{76}Co_{4.95}B_{4.25}$		$Fe_{73.5}CuNb_3Si_{13.5}B_9$	
	Powder	Composite material	Powder	Composite material
Remanence, B_r (T)	0.86	0.724	0.0039	0.0061
Coercive force, H_{cB} (kA/m)	455	448.5	0.521	0.537
Maximum energy product, BH_{max} (kJ/m^3)	112	84.6	–	–
Compressive strength, R_c (MPa)	–	112.1	–	44.2
Hardness (HBW)	–	35.0	–	21.0
Theoretical density (g/cm^3)	7.64	7.44	7.70	7.53
Density of composite materials (g/cm^3)	–	5.58	–	4.81
Ratio of density to theoretical density (%)	–	75.00	–	68.00