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Mechanical properties and the structure of magnetic composite materials

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Materials

ABSTRACT

Purpose: The purpose of the paper is to present the material and technological solution which makes possible obtaining soft and hard magnetic composite materials: nanocrystalline material – polymer.

Design/methodology/approach: The main base of the paper is to compare the structure and mechanical properties of chosen magnetic composite materials with polymer matrix reinforced with Nd-Fe-B or FINEMET particles manufactured by one-sided uniaxal pressing. The complex relationships among the manufacturing technology of these materials, their microstructure, as well as their mechanical and physical properties were evaluated.

Findings: Modern magnetic materials have optimum technology of production with properties that allow for miniaturizing, simplification and lowering the costs of devices

Practical implications: The manufacturing of composite materials greatly expands the applicable possibilities of nanocrystalline powders of magnetically hard and soft materials however further examination obtain improved properties of magnetic composite materials. The investigations of constructing of new machines and devices with these materials elements are still needed.

Originality/value: The paper shows the base of the material and technological solution which make possible obtaining magnetic composite materials and their mechanical properties which are not commonly presented in other papers.

Keywords: Composites; Mechanical properties; Manufacturing and processing; Magnetic materials

1. Introduction

Polymer-bonded magnetic materials are the most rapidly growing section of magnet market. The reasons for this rapid expansion are the requirements of market. There is also considerable demand for polymer-bonded magnets for small motors in video recorders, camcorders, printers, office automation, automotive, and portable drills. Hard and soft magnetic materials are fundamental to the technical success of many devices and products, in particular electric machines and related devices [1-3].

Bonded magnets are generally prepared by blending magnetic powder with binder followed by compacting or molding the material to final shape. Because of the presence of the binder the magnetic properties of bonded magnet are always lower than properties of their counterpart manufactured by other methods. However two great advantages of bonded magnet are their superior mechanical properties and the fact that magnets can be prepared under net conditions. The last decades of twentieth century pay attainment to the use of actuators and small electromotors not only of low weight but also of low energy consumption [4].

There is also increase in the use of electromagnetic devices in the electronic and electric industry what has led to the enhanced pressure of finding improved or alternative magnet material. Bonded magnetic materials meet most of the criteria mentioned and their use is growing steadily. Because of the presence of the bonder the magnetic remanence is always lower than the remanence of the fully dense magnetic material. The situation is even less favorable for the energy product, being roughly proportional to the remanence squared. The major advantage is that bonded magnet can be produced in net shape or near-net shape. Even complicated shape may be involved, for example, in injection molding method. Another advantages are their superior mechanical properties. Bonded magnets based on Nd-Fe-B and FINEMET owing superior intrinsic magnetic properties offer substantial advantages in terms of size, weight, and performance.

The modern and most used method of obtaining composite materials is blending magnetic powder with a binder or by encapsulating coercive powder in a binder, followed by compacting or molding the material into the final shape. Depending on the binder, the magnet may be rigid or flexible. There are four main manufacturing routes for bonded magnet. Injection molding, extrusion, calendering and compression molding. In calendering and injection molding process the magnetic loading can be up to 70% by volume while in extrusion and compression molding method up to 75% and 80%, respectively [4].

The majority of bonded magnets are used in personal computers, camcorder, printers, cameras, watches, phones, cells. Most of the bonded magnets go into various types of electric motors, transformers, sensors, frequency converters, signal transformers, read-write head of digital devices, magnetic screens, magnetostriction converters, computer power packs. The most prominent types of electric motor are spindle motors and stepper motors. Stepper motors have fairly small size and are characterized by their ability for precise incremental positioning or adjustment with electric pulses from digital controller. The largest application of electric motors with bonded magnets are in computer peripheral, where they serve for instance as hard disk drive spindle motors, CD-ROM pick-up motors, CD-ROM spindle motors, floppy disk drive spindle motors, floppy disk head actuators [3,5,15].

The goal of the work is to investigate mechanical properties and the structure of chosen magnetic composite materials with polymer matrix reinforced with Nd-Fe-B or FINEMET particles manufactured by one-sided unaxial pressing.

2. Materials

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) (zinc stearate (0.2% w.) was used to ensure slip during compaction and pulling the test pieces out of the die) 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.. Figure 1 shows examples of manufactured magnetic composite material.

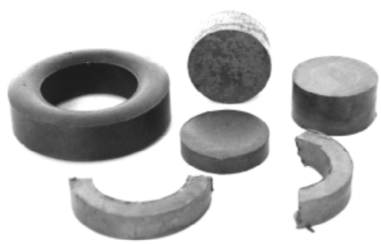
3. Technology

Advanced composite materials were compacted by the one-sided uniaxial pressing. Portion of the matrix and slip agent powders, compacting pressure as well the temperature and curing time of the polymer materials decide the technological conditions of magnets fabrications. 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 hours after compacting,
- FINEMET - PEHD– 170°C, pressure 350 MPa, pressing time 0.25 h.

The mechanical properties of the composite magnets depend mostly on the magnetic powder and binding agent types, particles shape 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. (Fig. 1, 2) [4,6-15].

a)



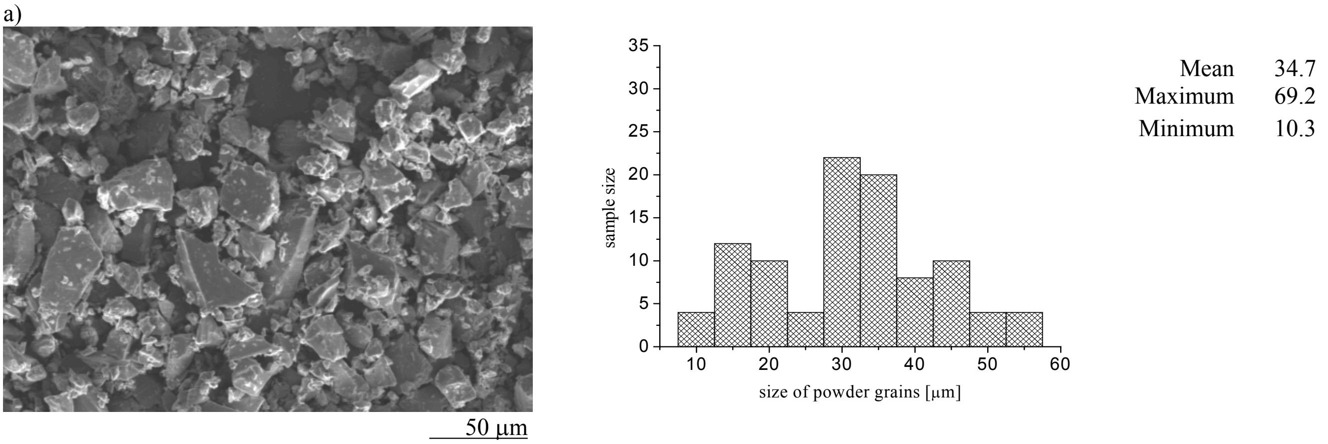
b)

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

4. Methodology

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 x using the secondary electron detection at the 20 kV accelerating voltage.

a)



b)

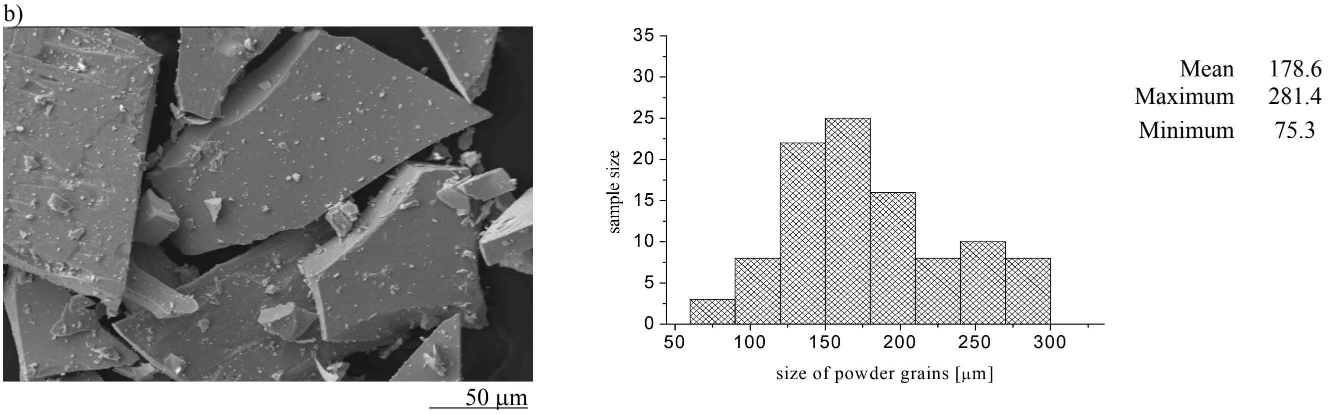
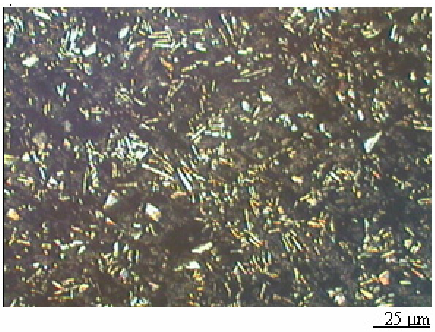


Fig. 2. Morphology, distribution and comparison of powders particle size of: a) $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$, b) $Nd_{14.8}Fe_{76}Co_{4.95}B_{4.25}$

a)



b)

Fig. 3. Topography of the surface of composite materials: a) FINEMET – PEHD b) Nd-Fe-B – EP

Table 1.
Comparison of composite materials properties

Properties	FINEMET – PEHD	Nd-Fe-B – EP
Theoretical density [g/cm^3]	7.53	7.44
Density of composite materials [g/cm^3]	4.81	5.58
Ratio of density to theoretical density[%]	68.0	75.0
Hardness [HBW]	21.0	35.0
Compressive strength R_c [MPa]	44.2	112.1

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

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.

5. Results and discussion

Figure 2 shows morphology, distribution and powder size of $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$, $Nd_{14.8}Fe_{76}Co_{4.95}B_{4.25}$ 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 μm to 281.4 μm while the $Fe_{73.5}CuNb_3Si_{13.5}B_9$ powder shows grains from to 10.3 μm to 69.2 μm. Both of these powders are characteristic of flaky shape.

Figure 3 shows structure of composite materials observed in scanning electron microscopy. Occurrence of the small portion of pores was observed in the fabricated composite material, which attests to the good compacting of powders. Results of density measurement confirm it (Table 1.). The density of composite material FINEMET – PEHD is equal to 68% of theoretical density while for composite material Nd-Fe-B – EP is observed even higher value – 75% of theoretical density. The density of composite materials is influenced by the pressing pressure. The higher pressure the higher value of density and the higher ratio of density to theoretical density.

Mechanical properties of obtained composite materials depend on the powder used and also, according to observation, on the pressing pressure. Hardness and compressive strength grow with the increase of the pressure value. For composite material FINEMET – PEHD obtained by the pressure of 350 MPa the hardness is equal 21.0 HBW and compressive strength – 44.2 MPa. Applying the higher value of pressure – 900MPa during the pressing Nd-Fe-B – EP composite materials higher values of hardness and compressive strength – 35.0 HBW and 112.1 MPa, can be obtained respectively. The other factor which can affected the mechanical properties is the shape of powder particles. Chosen flaky shape of magnetic powder particles causes that during pressing, powder particles are meshing, that results with greater adhesion forces between powder particles than in the case of another shape of particles.

6. Conclusions

Results of investigations of mechanical properties and the structure of magnetic composites allow to widen their application possibilities through their proper correlation with magnetic properties of these materials.

Mechanical properties of polymer matrix magnetic composites compacted by the one-sided uniaxial pressing are playing the growing meaning and are considered to be almost as important as their magnetic properties. This results from the fact that magnetic materials are more often uses in machines and devices endangered for substantial mechanical loads. Such devices are used more often in daily life thanks to advanced miniaturization.

References

[1] C. Kuhrt, Processing of permament magnet materials based on rare earth transition metal intermetallics, Intermetallics, 3 (1995) 255-263.

[2] J.M.D. Coey, Magnetic materials, Journal of Alloys and Compounds, 326 (2001) 2-6.

[3] D.C. Jiles, C.C.H. Lo, The role of new materials in the development of magnetic sensors and actuators, Sensors and Actuators, A 106 (2003) 3-7.

[4] B. M. Ma, J.W. Herchenroeder, B. Smith, M. Suda, D.N, Brown, Z. Chen: Recent development in bonded Nd-Fe-B magnet, J. Magn, Magn, Mat., 239 (2002) 418-423.

[5] H.J. Fastenau, E.J. Loenen, Aplication of rare earth permament magnets, Journal of Magnetism and Magnetic Materials, 1570158 (1996) 1-6.

[6] L.A. Dobrzański M. Drak, Structure and properties of composite materials with polymer matrix reinforced NdFeB hard magnetic nanostructured particles. Journal of Materials Processing Technology 157-158 (2004) 650-657.

[7] L.A. Dobrzański, M. Drak, Properties of composite materials with polimer matrix reiforced with Nd-Fe-B hard magnetic particles, Journal of Materials Processing Technology (2006) (in print).

[8] L.A. Dobrzański, M. Drak, Hard magnetic composite materials Nd-Fe-B with additions of iron and X2CrNiMo-17-12-2 steel, Journal of Alloys and Compounds (2006) (in print).

[9] D. Szewieczek, L.A. Dobrzański, B. Ziębowicz, Structure and magnetic properties of nanocomposites of nanocrystalline powder - polymer type, Journal of Materials Processing Technology, 157-158 (2004) 765-770.

[10] B. Ziębowicz, D. Szewieczek, L.A. Dobrzański, Magnetic properties and structure of nanocomposites of powder $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ alloy – polymer type, Journal of Materials Processing Technology, 157-158 (2004) 776-780.

[11] B. Ziębowicz, D. Szewieczek, L.A. Dobrzański, J.J. Wysłocki and A. Przybył, Structure and properties of the composite materials consisting of the nanocrystalline $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ alloy powders and polyethylene, Journal of Materials Processing Technology, 162-163 (2005) 149-155.

[12] B. Ziębowicz, D. Szewieczek, L.A. Dobrzański, Structure and properties of the $Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ alloy powders bound with polyethylene, Journal of Materials Processing Technology (2006) (in print).

[13] L.A. Dobrzański, M. Drak, B. Ziębowicz, New possibilities of composite materials application – materials of specific magnetic properties, Proceedings of the AMPT Conference, Las Vegas, USA, (in print).

[14] B. Ziębowicz, D. Szewieczek, L.A. Dobrzański, Manufacturing technology of the composite materials: nanocrystalline material-polymer type, Proceedings of the CAM3S'2005 Conference, Gliwice-Zakopane, 2005, 1080-1085.

[15] L.A. Dobrzański, M. Drak, Permament Magnets Nd-Fe-B, Proceedings of CAM3S'2005 Conference, Gliwice-Zakopane, 2005, 193-201.

[16] M.E. McHenry, M.A. Willard, David E. Lauglin, Amorphous and nanocrystaliine materials for applications as soft magnets, Progress in Materials Science, 44 (1999) 291-433.