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Hard magnetic materials Nd-Fe-B/Fe with epoxy resin matrix

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Materials

ABSTRACT

Purpose: The purpose of the paper is to present the technological solution of obtaining hard magnetic composite materials based on Nd-Fe-B with addition of iron powder and bounded by epoxy resin.

Design/methodology/approach: Composite materials reinforced by Nd-Fe-B particles or Nd-Fe-B with addition of iron powder with polymer matrix were manufactured by one-sided uniaxal pressing. The complex relationships among the manufacturing technology of these materials, their microstructure, as well as their magnetic and mechanical properties were evaluated.

Findings: This kind of composite materials can broader the possibilities of application of magnetic materials and reduce the cost of their manufacturing.

Practical implications: The manufacturing of hard magnetic composite materials by addition of other powder and bounding them by polymer matrix can greatly extend the applicable possibilities of these materials. There are still made investigations that allow to improve properties of hard magnetic composite materials and influence on the miniaturization of magnets and devices they are used in.

Originality/value: The paper shows the technological solution which make it possible obtaining hard magnetic composite materials, their structure and properties.

Keywords: Composites; Mechanical properties; Magnetic materials

1. Introduction

Hard magnetic materials are widely use in contemporary technology. Depending on the kind of magnetic materials can be divided into: traditional (steels, AlNiCo magnets, ferrites magnets) and modern (Sm-Co magnets, Nd-Fe-B magnets). There is still observed the development in permanent magnets especially in improving of their magnetic, mechanical, physical and chemical properties that allows to broader their application [1-3].

The progress in the field of permanent magnets rapidly grows in the last fifty years. Understanding of physical phenomena responsible for hard magnetic properties led to discovery of new families of permanent magnets based on rare earth – transition metal compounds. The search for new materials with superior properties focuses on materials with high values of Curie temperature, magnetic saturation and coercive force. Figure 1 shows the development of hard magnetic materials. Each of magnets shows the same magnetic field but the progress in hard magnetic materials allows to reduce the volume of magnets.

Modern hard magnetic materials can be manufactured by different technology. Depending on the powder obtaining technology (mechanical alloying, melt quenching, Hydrogenation Disproportionation and Hydrogenation, Disproportionation, Desorption, Recombination methods) and powders compacting technology (sintering, injection molding, calendering, extrusion and compression molding, extrusive compaction) permanent magnets show different properties. That allows to manufacture magnets meeting the requirements of many modern applications (Table 1) [4-6].

Rare earth permanent magnets RE-TM are based on the intermetallic compounds of rare earth metals (RE) and transition metal (TM) iron or cobalt. The combination of properties of the rare earth sublattice and the 3d sublattice of transition metal lead to the spectacular development in hard magnetic materials. The two most relevant classes of RE-TM magnets are based on samarium and cobalt exhibit very high coercive force, low temperature coefficients, and neodymium iron boron which are unrivalled in terms of its maximum energy product [1, 5, 7-11].

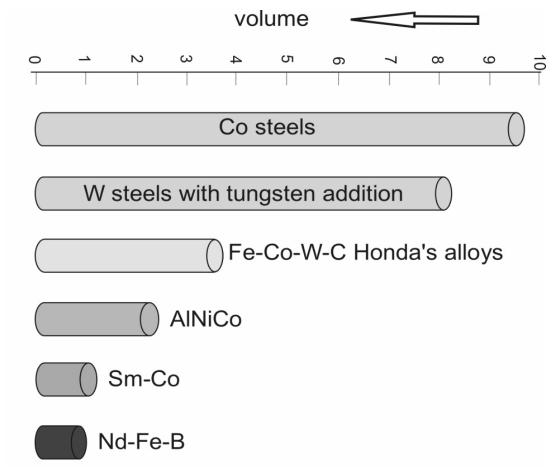


Fig. 1. Comparison of hard magnetic materials volume

Table. 1.
Comparison of magnetic parameters of traditional and modern hard magnetic materials

Material	H_c [kA/m]	B_r [T]	BH_{max} [kJ/m^3]	T_c [°C]
Steels	5.3-19	0.95	2.3-7.4	745-890
AlNiCo casted	35-130	0.7-1.3	10-68	780-900
AlNiCo sintered	42-125	0.5-1.0	10-36	800-900
Ferrites bonded	92-155	0.15-0.2	3-8	450
Ferrites sintered	145-240	0.2-0.4	20-30	450
Nd-Fe-B sintered	850	1.16	255	310
Nd-Fe-B bonded	550	0.7	85	310
Nd-Fe-B hot pressed	800	0.8-1.2	110	310
Sm-Co bonded	650-800	0.6-0.8	55	870
Sm-Co sintered	700-900	0.9-1.05	170-215	870

H_c - coercive force, B_r – remanence, BH_{max} - maximum energy product, T_c - Curie temperature

Permanent magnets made from powders have low mechanical properties. Mechanical stresses occurring in magnets during assembling and in normal work can damage them. It is necessary to develop magnets with better mechanical properties. The mechanical properties of magnets depend mainly on their composition: amount of hard magnetic powder, resin amount and manufacturing technology. Mixing the hard magnetic powder with metal powder is one of the ways of improving mechanical properties of hard magnetic composite materials. The addition of metallic powders improves also corrosion resistance of composite materials, and the application properties of these magnets are higher in comparison with magnets without addition. Manufacturing of composite materials with addition of metallic powder is similar with manufacturing of magnets without additions but lower costs of addition powders in comparison with basic hard magnetic powder allow to reduce cost of composite materials [12-18].

The goal of the work is to investigate the structure, magnetic and mechanical properties of hard magnetic composite materials with polymer matrix reinforced by powders of Nd-Fe-B or by Nd-Fe-B with addition of iron 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 powder Nd-Fe-B mixed with 5-15% wt. of iron powder bonded and with thermosetting epoxy resin (EP) (zinc stearate (0.2% wt.) was used to ensure slip during compaction and pulling the test pieces out of the die). The amount of polymer matrix was 2.5% wt.. The Nd-Fe-B powder was obtained by melt quenching method (Fig. 2) and composite materials were manufactured by process shown in Fig. 3.

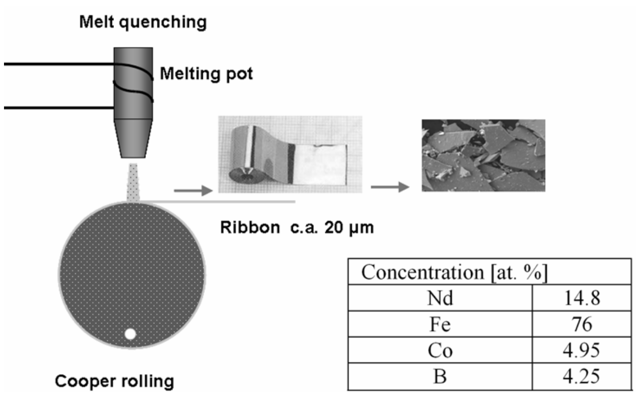
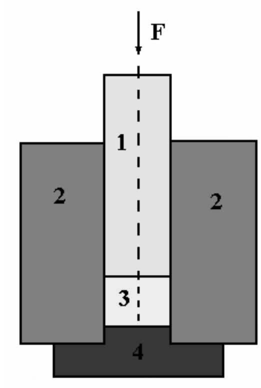


Fig. 2. Melt quenching process of Nd-Fe-B powder preparation



Pressing parameters:
- unilateral uniaxial compaction,
- room temperature,
- pressure 800 - 900 MPa,
- curing of the polymer matrix of the composite materials after compacting at the temperature of 180°C for 2 hours

- 1-stamp
- 2-die
- 3-powder
- 4-base

Fig. 3. One-sided unaxial pressing of Nd-Fe-B/Fe –epoxy resin composite materials

Hard magnetic nanomaterials are usually produced as powders or thin strips. In this geometrical form their range of application is limited. Therefore, to extend their potential applications it is useful to connect the magnetic materials with other materials – creating thus the composite materials. The thermosetting or chemically cured polymers are used most often to manufacture composites, which volume portion in the composite does not exceed 20 % and the low-melting metals, e.g., zinc in the amount of about 15 % mass. [4, 12-17]

3. Methodology

Observations of morphology of powders used and the obtained composite materials were made on the DSM 940 OPTON scanning electron microscope (SEM) at the maximum magnification of 400 x 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.

Compression tests were made on the INSTRON 1150 all-purpose testing machine. The tests were carried out at room temperature with compression rate 5 mm/min 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.

Examination of magnetic properties of 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 basing on the measured magnetic induction B_0 and the external magnetizing field intensity H_0.

4. Results and discussion

Morphology of $Nd_{14.8}Fe_{76}Co_{4.95}B_{4.25}$ and iron powders observed in scanning electron is shown on Figure 4. Nd-Fe-B powder used for fabrication of the composite materials is characteristic of flaky shape and grains from 75.3 µm to 281.4 µm while iron powder is characteristic of irregular particles with size from 43.3 µm to 180.4 µm (Table 2).

Table 2.
Comparison of powders grains sizes

Powder	Powders grain size [µm]		
	Maximum	Minimum	Mean
Nd-Fe-B	281.4	75.3	178.6
Iron	180.3	43.2	103.7

Figure 5 shows structure of composite materials observed in scanning electron microscopy. The magnetic powders particles are uniformly distributed in the polymer matrix.

a) b)

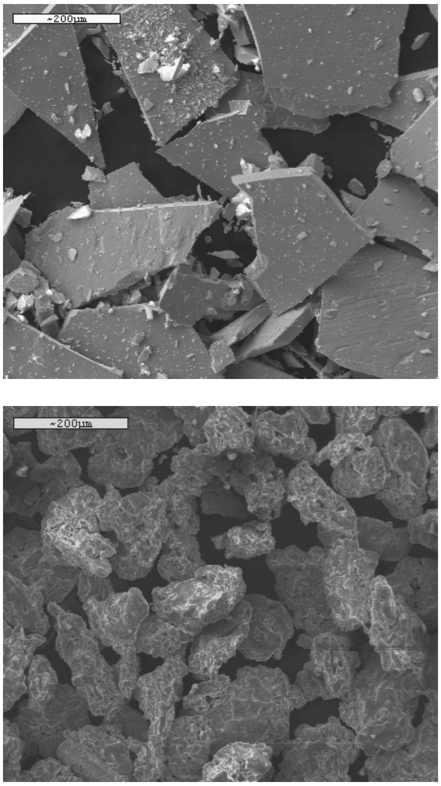


Fig. 4. Morphology of powders particles of: a) of rapid quenched Nd-Fe-B powder particles, b) iron (SEM)

Their grains are irregularly shaped and are elongated in one direction, arranged in parallel along their bigger surfaces, perpendicularly to the compacting direction. Occurrence of the small portion of pores was observed in the fabricated composite materials, which attests to the good compacting of powders. Density measurement ρ_r/ρ_t results confirm it (Table 3) The density of composite material Nd-Fe-B – EP is equal to 75% of theoretical density while for composite material Nd-Fe-B/Fe-EP is observed even higher value – 78.75% of theoretical density for 15% of iron portion.

Results of the magnetic properties examinations of Nd-Fe-B-EP magnet are included in Table 3. Magnets show magnetic properties comparable with commercial bonded magnets. [11] This results from the high density of composite materials caused by the homogeneous distribution of the Nd-Fe-B powder in the polymer matrix and by occurrence of the low portion of pores, which is confirmed by examinations on the scanning electron microscope. Soft magnetic iron powder causes slight changes in remanence to 0.684 T, exert influence on decrease of coercive force to 581.4 kA/m and maximum energy product to 51.8 kJ/m^3 for 15% of powder addition.

Examinations of mechanical properties of composite material without powder addition show that this material is characteristic with compressive strength – 112 MPa and hardness of about 35 HB. Addition of iron powder causes decrease of magnetic properties of composite materials but is beneficial taking into consideration mechanical properties.

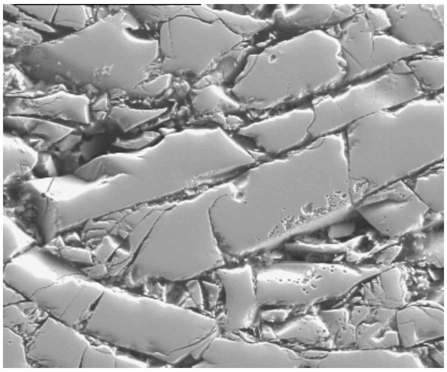


Fig. 5. Structure of a composite material Nd-Fe-B –EP (SEM)

Table 3.
Comparison of composite materials properties

Material	H_c [kA/m]	B_r [T]	BH_{max} [kJ/m^3]	R_c [MPa]	HB	ρ_r/ρ_{t} [%]
Nd-Fe-B	743.5	0.724	84.65	112.1	35.0	75.00
Nd-Fe-B /Fe 5%	679.3	0.694	66.08	118.8	36.6	78.12
Nd-Fe-B /Fe 10%	611.4	0.690	62.57	130.6	37.1	78.42
Nd-Fe-B /Fe 15%	581.4	0.684	51.81	136.2	37.7	78.75

H_c – coercive force, B_r – remenance, $BH_{(max)}$ maximum energy product, R_c – compressive strength, HB hardness (Brinnell scale), ρ_r/ρ_t the ration of the real density to the theoretical density.

Improvement of mechanical properties is caused by increase of density of composite materials with addition of metallic powders and result also from better mechanical properties of addition powder in comparison with brittle Nd-Fe-B powder. The other factor which can affected the mechanical properties is the shape of powder particles. Maximum compressive strength is characteristic for composite materials with addition of 15% of iron powder – 136.2 MPa. The same dependence is also found for hardness – the highest one has the composite materials with 15% of iron powder – 37.7 HB.

5. Conclusions

Composite materials with polymer matrix reinforced with Nd-Fe-B powder from rapid quenched tape are characteristic of good magnetic properties. This results from the high density of composite materials caused by the homogenous distribution of the Nd-Fe-B powder in the polymer matrix and by occurrence of the low portion of pores.

Addition of iron powder causes decrease of magnetic properties of composite materials but is beneficial taking into consideration mechanical properties.

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.

The range of hard magnetic materials application is broadening and these material will allow to miniaturize and simplificate devices they are used in.

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