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Magnetic properties of polymer matrix composites filled with ferrite powders

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ABSTRACT

Purpose: The aim of this paper was to present magnetic properties research results of polymer matrix composites. The influence of the kind of fillers and amount of fillers on the magnetic properties of the composites was studied and is presented in this paper.

Design/methodology/approach: Epoxy resin filled with three different amounts (15%, 25% and 35%vol.) of filler and three kinds of ferrite powders were prepared by gravitational casting in order to obtain gradient polymer matrix composites. Magnetic properties of polymeric composites were measured by SQUID magnetometer (MPMS XL7 Quantum Design). All measurements were carried out in the temperature 300 K and magnetic field up to 7 T.

Findings: The research findings showed that addition of ferrite powders to epoxy resin caused increased values of magnetic remanence. Moreover it was observed that the higher values of remanence were for polymer composites with anisotropic filler than that with isotropic.

Research limitations/implications: Presented studies have been limited to the content of 35%vol. of filler because of difficulties with casting of higher filled composites. Higher value of filler content caused dramatic increase of viscosity.

Practical implications: Magnetic composites with different content of magnetic filler are still investigated by scientists in order to improve magnetic properties of composite materials, which are used in various industries.

Originality/value: Presented results of magnetic properties dependence on content and type of filler of new gradient polymer matrix composites are novel and original.

Keywords: Polymer matrix composites; Magnetic properties; Casting

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MATERIALS

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1. Introduction

Composite materials with regard to the tremendous ability to modify their properties have found wide application in many various branches of modern engineering. Generally there are used in automobiles, boats, airplanes, sports equipment, appliances and many other products. Constantly they are a challenge for modern and future science. Composite materials are engineering materials that are the combination of at least two or more components (mixed and bonded) with distinct boundary between them. Components do not dissolve or merge completely into one another. Furthermore fillers and reinforcements are a good solution in order to reinforce the different physical or/and chemical properties and make these materials stronger together than would each individual material. The combination of different materials allows for the creation of a completely new composite material with a wide range of functional properties: mechanical, chemical, electrical, magnetic, optical and many others. Composite materials comprise of metallic or non-metallic (polymer, ceramic, etc.) matrix and reinforcement – fibres, powders etc. – that is specifically distributed in the matrix. Depending on the used matrix materials exist three main sorts of composite materials such as: MMCs (Metal Matrix Composites), CMCs (Ceramic Matrix Composites), PMCs (Polymeric Matrix Composites) [1-5].

Polymer Matrix Composites are the most commonly fabricated, more frequently than MMC or CMC, because of the lightweight structures and relatively low cost of preparation owing to low processing temperatures that are required for fabrication of PMC. They contain materials such as thermosets (e.g. epoxy, polyester, phenolic, polyimide resins), thermoplastics (e.g. nylon, polypropylene, polycarbonate, polymethylmethacrylate, polyethylene) and/or rubbers. Up to this time PMC were used among others for magnetic, biomedical and dielectric applications (electric insulation, capacitors, piezoelectric, ferroelectric and pyroelectric function) etc and for that reason they are still attractive attendance for a wide range of scientist [5-11].

Ferrite magnets are mostly manufactured magnets throughout the world. Powders of strontium ferrite and barium ferrite are obtained by mechanical working and heat treatment processes of iron oxides with compounds of strontium and barium. In order to produce ferrite magnets powder metallurgy methods are used. First step of process in which are obtained is ferritisation. That is annealing in air atmosphere mixture of chemical compounds that contain Ba or Sr and Fe. Strontium carbide or barium carbide are mixed with Fe_2O_3 and afterwards hold at a temperature of 1350ºC. Subsequently materials are formed by pressing and sintering. Hard ferrite magnets occur in two forms: anisotropic and isotropic. Manufacture of anisotropic magnets is performed by pressing powder in magnetic field that orientate grains towards specific direction of magnetic field. While during isotropic magnets producing process external magnetic field is not applied. For that reason anisotropic magnets achieve higher values of magnetic properties than isotropic magnets. Ferrite magnets according to their low cost are used very often for the elements of the magnetic circuits of electrical apparatus and instruments, engines, generators, various elements for electronics (alarms, microphones). Moreover they are often used in composition with plastics for manufacturing of flexible magnets and magnetic seals that are applied, for instance, in refrigerators, washing machines etc. [12-17].

Composite materials filled with ferrite particles based on polymer matrix materials – called bonded magnets – are of current research interest due to possible applications. Magnetic properties of the polymer magnetic composite materials depend on the shape and type of filler and on chosen manufacturing technology. Remanence of bonded magnets depends on e.g. quantity of non-magnetic binder, polymer matrix isolate the magnetic grains of powder reducing the influence of interchangeable between them [12, 18-21].

In this paper authors tried to manufacture polymer matrix magnetic composite materials reinforced with different amount of ferrite powders and afterwards investigate their magnetic properties. The purpose of this study was to investigate the magnetic properties and the influence of the volume fraction of magnetic powder on magnetic properties of manufactured composite materials.

2. Experimental

2.1. Materials and methods of research

Materials and specimens preparation

The components used in present experiment as a matrix were: thermosetting material – epoxy resin Epidian 6011 and hardener ET. Both matrix components were purchased from Organika Nowa-Sarzyna (Poland). As magnetic reinforcement were used three powders namely: isotropic barium ferrite and strontium ferrite powders – Fig. 1 – were obtain from ZAM Trzebinia (Poland), and anisotropic magnetic powder (AMM) Fermag s.c. (Poland). Main characteristics of used materials are presented in Table 1 to Table 4.

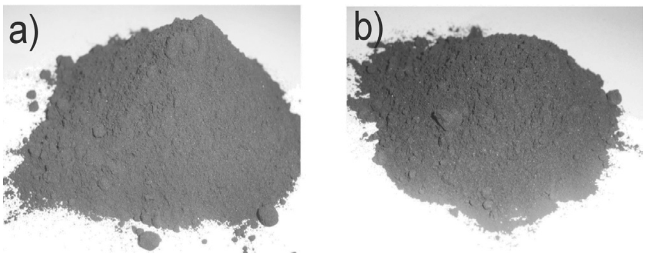

Fig. 1. Ferromagnetic powders [20], a) barium ferrite, b) strontium ferrite

Composite specimens with different content of filler were prepared using gravitational casting method. Each specimen was prepared in few steps. First there were made some calculations for each amount of component in order to achieve assumed filler volume fraction. Then epoxy resin was mixed with one type of filler powder in order to obtain homogeneous mixture, after that composition was for the second time mixed with the appropriate amount of curing agent. Subsequently mixture was cast in the mould. Scheme of specimens' preparation is shown in Fig. 2.

Table 1.
Characteristic of epoxy resin Epidian 6011

Properties	Epidian 6011
Form	pale yellow liquid
Density (20ºC) [g/cm³]	1.13
Viscosity (25ºC) [mPa·s]	200-400
Boiling point [ºC]	> 150
Ignition temperature [ºC]	120
Autoignition point [ºC]	460
Melting point [ºC]	-
Water solubility (20ºC) [mg/l]	139.14 ± 1.99
Combustibility	combustible mixture

Table 2.
Characteristic of hardener ET

Trade name	ET
Form	pale yellow liquid
Density (25ºC) [g/cm³]	1.02-1.05
Boiling point [ºC]	> 100
Ignition temperature [ºC]	162.4
Autoignition point [ºC]	360
Viscosity (25ºC) [mPa·s]	-
Amine value [mg KOH/g]	-

Table 3.
Characteristic of strontium ferrite powder

	Chemical formula	$SrFe_{12}O_{19}$
	Form	powder
	Fe_2O_3 [mol] SrO [mol]	5.6-6.2
	Humidity % max	0.5
	Density (20ºC) [g/cm³]	4.9±0.2
	Melting point [ºC]	-
	Formula weight [g/mol]	1061.77
	Solubility	water-insoluble
	Smell	inodorous
	Grain size [µm]	<100
Component, %	Fe	61.4-62.4
	Sr	8.6-9.6
	Mn max	0.5
	$SrSO_4$ max	1.0
	SiO_2	0.3-0.6

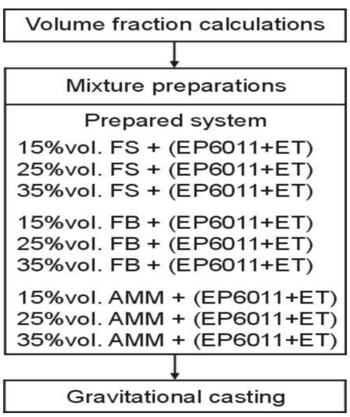

Fig. 2. Scheme of specimens' preparation

Table 4.
Characteristics of barium ferrite powder

	Chemical formula	$BaFe_{12}O_{19}$
	Form	powder
	Fe_2O_3 [mol] BaO [mol]	5.6-6.2
	Humidity % max	0.5
	Density (20ºC) [g/cm³]	5.3
	Melting point [ºC]	1315.6
	Formula weight [g/mol]	1111.46
	Solubility	water-insoluble
	Smell	inodorous
	Grain size [µm]	<100
Component, %	Fe	58.6-59.6
	Ba	12.7-13.7
	Mn max	0.5
	$BaSO_4$ max	1.0
	SiO_2	0.3-0.6

Magnetic properties of polymeric magnetic composite materials were measured by Superconducting Quantum Interference Device (SQUID) magnetometer (MPMS XL7 Quantum Design). All measurements were carried out in the same parameters – temperature 300 K and magnetic field up to 7 T.

3. Results and discussion

The hysteresis loops were recorded using SQUID magnetometer at temperature 300 K and magnetic field up to 7 T. Hysteresis loops that were achieved for polymer magnetic composite materials are shown in Figs. 3-8.

The remanence and coercive force values for polymer magnetic composites were determined from magnetic hysteresis loops according. If some magnetic flux remains in the material even though the magnetizing force is zero (H = 0), the retention of magnetization in zero is called remanence or residual flux density. Coercive force (coercivity) is obtained when the magnetic field required to reduce the external magnetization of a ferromagnetic substance to zero (B = 0). These two quantities, residual flux density and coercive force are of great importance in permanent magnets. Results that were obtained for these measured quantities are presented in Fig. 9 and Fig. 10.

As can be seen on charts and as it could be expected remanence increased while coercive force decreased with increasing volume fraction of magnetic fillers. Moreover results of remanence and coercive force of polymer composite materials with isotropic ferrite powders (strontium ferrite and barium ferrite) had approximately the same results whereas composite materials with anisotropic filler had much higher values (twice higher for remanence and about thrice higher for coercive force).

The highest value of remanence is approximately 21 [emu/g] and was obtained for specimen filled with 35%vol. of anisotropic powder amount whereas the lowest value of remanence is 13 [emu/g] for 15%vol. of AMM. The highest remanence for composite material with 35%vol. of strontium ferrite is 9 [emu/g], namely with 35%vol. of barium ferrite is 8.7 [emu/g].

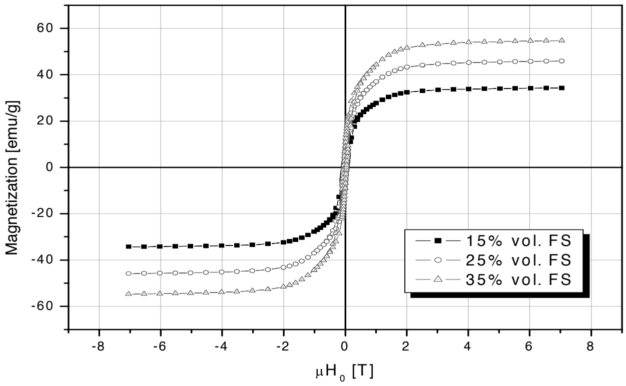

Fig. 3. Hysteresis loops of polymer magnetic composite materials specimens with 15%vol., 25%vol. and 35%vol. of strontium ferrite particles (FS)

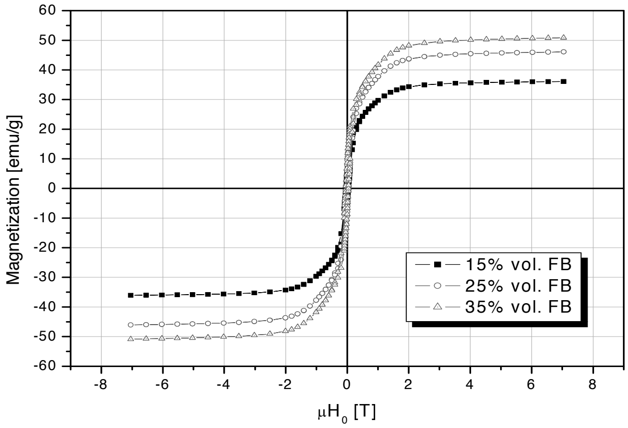

Fig. 4. Hysteresis loops of polymer magnetic composite materials specimens with 15%vol., 25%vol. and 35%vol. of barium ferrite particles (FB)

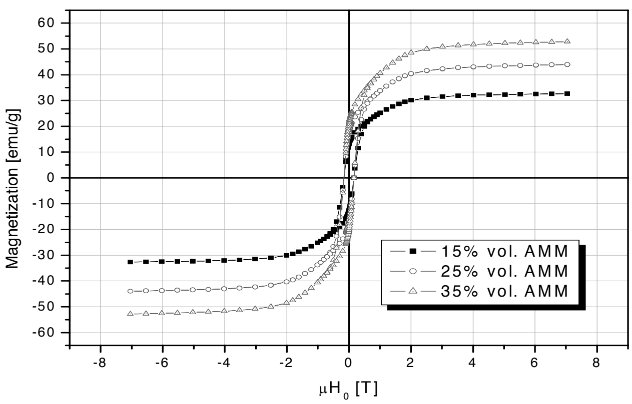

Fig. 5. Hysteresis loops of polymer magnetic composite materials specimens with 15%vol., 25%vol. and 35%vol. of AMM

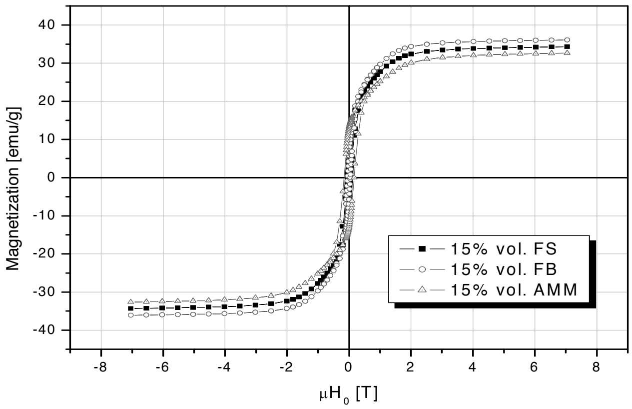

Fig. 6. Hysteresis loops of polymer magnetic composite materials specimens with 15%vol. of fillers

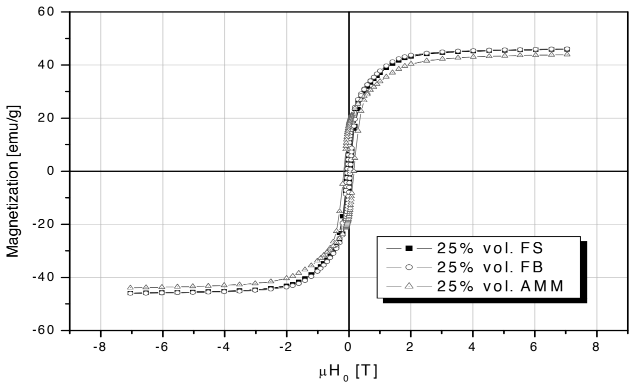

Fig. 7. Hysteresis loops of polymer magnetic composite materials specimens with 25%vol. of fillers

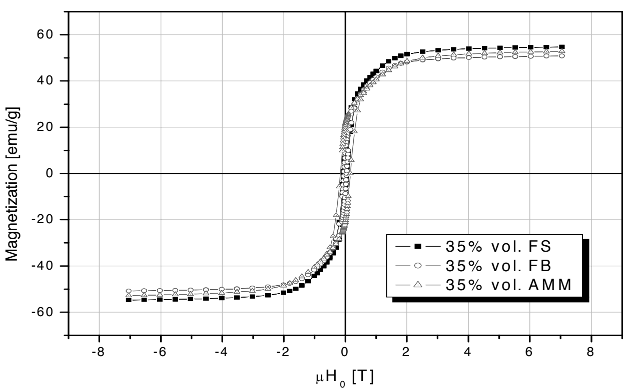

Fig. 8. Hysteresis loops of polymer magnetic composite materials specimens with 35%vol. of fillers

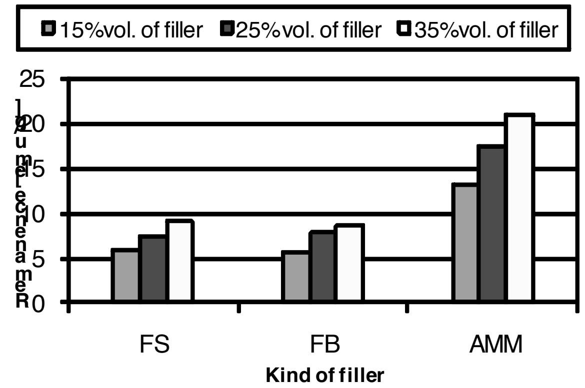

Fig. 9. Result of remanence for polymer magnetic composite materials specimens depend on kind of filler

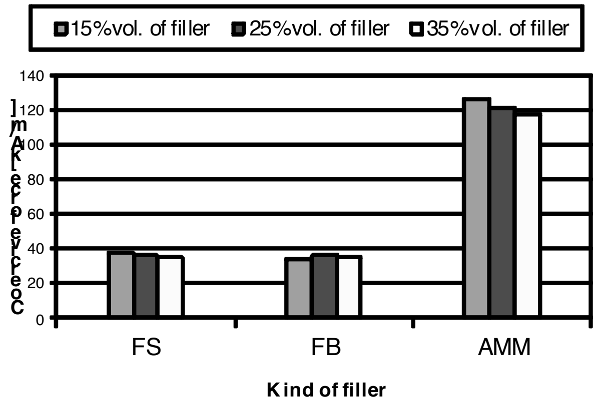

Fig. 10. Result of coercive force for polymer magnetic composite materials specimens depend on filler content

Coercive force of composite material with 35%vol. of AMM exhibit 118 [kA/m], 15%vol. of AMM – 127 [kA/m]. The highest value of coercive force for composite materials with isotropic filler was obtained for 15%vol. of strontium ferrite – 37.8 [kA/m].

4. Conclusions

The analysis results of the magnetic properties of prepared polymer magnetic composite materials showed that the magnetic properties of composite materials are dependent on the content of hard magnetic powder in the composites. Furthermore presented results of magnetic properties dependence on content and type of filler of new graded polymer matrix composites.

The limitation of the presented investigations was difficulties with casting of higher filled composites. The specimens to the content of 35%vol. of filler were only made because higher value of filler content caused dramatic increase of viscosity and by this way made casting difficult.

The highest value of remanence was approximately 21 [emu/g] and was obtained for specimen filled with 35%vol. of anisotropic powder amount whereas the lowest value of remanence exhibit 13 [emu/g]. The highest value of coercive force exhibit 127 [kA/m] for composite material filled with 15%vol. of AMM.

In future research authors want to prepare polymeric magnetic graded composites in order to obtain materials with gradation of magnetic properties.

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