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The impact of the powder fraction on the structural and magnetic properties of polymer matrix composites

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ABSTRACT

Purpose: The preparation of composite materials composed of $Fe_{66}Co_{10}Ni_2W_2B_{20}$ alloy powders and epoxy resin and determining the influence of the alloy powders fraction $Fe_{66}Co_{10}Ni_2W_2B_{20}$ on mechanical and magnetic properties of produced materials.

Design/methodology/approach: Tested samples made of $Fe_{66}Co_{10}Ni_2W_2B_{20}$ alloy powders and epoxy resin, were produced by pressing with pressure 5MPa during 10 s. In order to examine produced materials structural studies were conducted (observation under an optical microscope, a scanning electron microscope with EDS analysis), mechanical (measurement of surface roughness) and magnetic (obtaining static magnetic hysteresis loop based on measurements were made using a vibrating magnetometer (VSM)).

Results: Pressing of$Fe_{66}Co_{10}Ni_2W_2B_{20}$ alloy powders and epoxy resin allows to obtain composite materials, which are divided into three fractions, namely: 20-50 μm 50-100 μm 100-200 μm characterized, with the increasing size of the fraction of reinforcement, the better development of the area. Magnetic studies show that with increasing size of the fraction of the reinforcement, those materials have smaller coercive field, as well as the observed decrease in saturation magnetization.

Originality/value: By combining $Fe_{66}Co_{10}Ni_2W_2B_{20}$ alloy powders and epoxy resin composite materials with different fractions of reinforcement, which exhibit better properties than the starting materials used to receive are possible to obtain.

Keywords: Polymer composites; Pressing; Magnetic powders

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PROPERTIES

1. Introduction

Nowadays new materials which are able to replace the previously used ones are searched. In response to the demand those materials are used in composites which are materials resulting with a combination of at least two components [1-8]. Their major advantage is: lower production cost, the ability to design performance parameters and the most important - ease of forming [9,10].

Composite materials can include materials for electronics, for the construction of low loss transformers. Ease of remagnetization in transformer cores is a key parameter determining their suitability. Iron-based materials exhibit good magnetic properties, therefore, are used for the construction of transformer cores. Unfortunately, the shape of the cores is exactly defined, because they are produced from amorphous strips that can only roll up in toroids [10-12]. Therefore, using such processes as high-energy milling allow to obtain magnetic alloy powders, which, thanks to the many methods of consolidation can be shaped in different ways [13]. The most common methods for bonding the powders is bonding with, thermal or chemo - hardened plastics. The thus obtained powder magnetic cores are characterized by the ability to change the value of the temperature coefficient of the material permeability, high stability time and the ability to control the magnetic properties of the core by changing the particle size of the polymer matrix or magnetic material. Bearing in mind the frequency range and the value of the magnetic permeability is appropriately selected particle size of the powder [13,14].

The purpose of this study is to determine the influence of the powder fraction on mechanical and magnetic properties of composites produced from iron-based powder and epoxy resin (Epidian 100).

2. Materials and experimental methods

For the study a material produced on a basis on $Fe_{66}Co_{10}Ni_2W_2B_{20}$ which was subjected to a low-energy crushing and split it into three fractions powder: 20-50 μm, 50-100 μm and 100-200 μm (Tab. 1) was used.

Table 1.
Summary of % weight of samples used for researches

Powder fraction	$Fe_{66}Co_{10}Ni_2W_2B_{20}$, % wag.	Epoxy resin, % wag.
20-50 μm	95	5
50-100 μm	95	5
100-200 μm	95	5

Then, each fraction was combined with epoxy resin (Epidian 100) with weight ratio: 95 wt% particles of alloy and 5 wt% epoxy resin. The combined material was compressed using a hydraulic press with pressure of 5 MPa by the time of 30 s (Fig. 1).

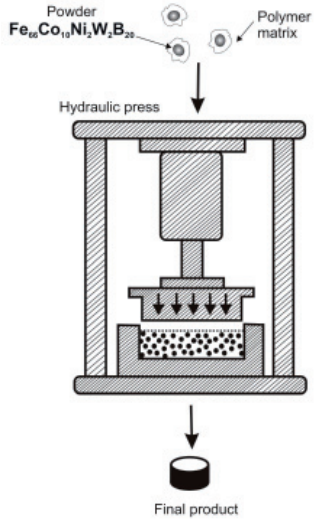

Fig. 1. Scheme of the pressing process samples

Composite having a diameter of 5 mm and a height of 3 mm (Fig. 2) were produced in this way, then composites were subjected to the annealing process at the temperature of 160˚C by the time of 2 h in order to improve the adhesion of the powders to the used resin.

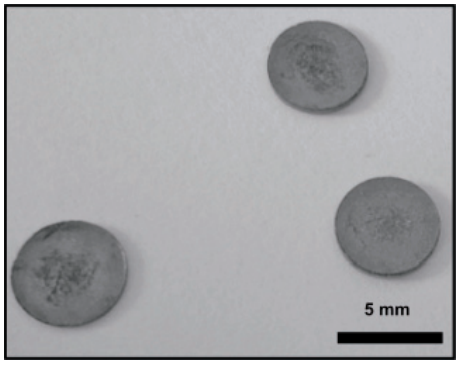

Fig. 2. Macroscopic image of produced composites

The chemical composition of the produced composites are based on EDS studies. Images of the surface of the test samples of different gradations powder was performed by using a Zeiss Supra 25 scanning microscope and Axiovert 25 metalographic one by Carl Zeiss company. Surface profiles were performed by using T1000 profilometer

Hommel. The magnetic properties of the tested samples were determined by static analysis of the hysteresis loop, which have been measured with a Lake Shore vibrating magnetometer working in the magnetic field intensity to 2 T. All tests were performed at room temperature.

3. Results

By using the optical microscope images microstructure of analyzed composites were captured. In Fig. 3 the images of individual fractions of powders of the composites were shown. Pictures were taken at a magnification of x200.

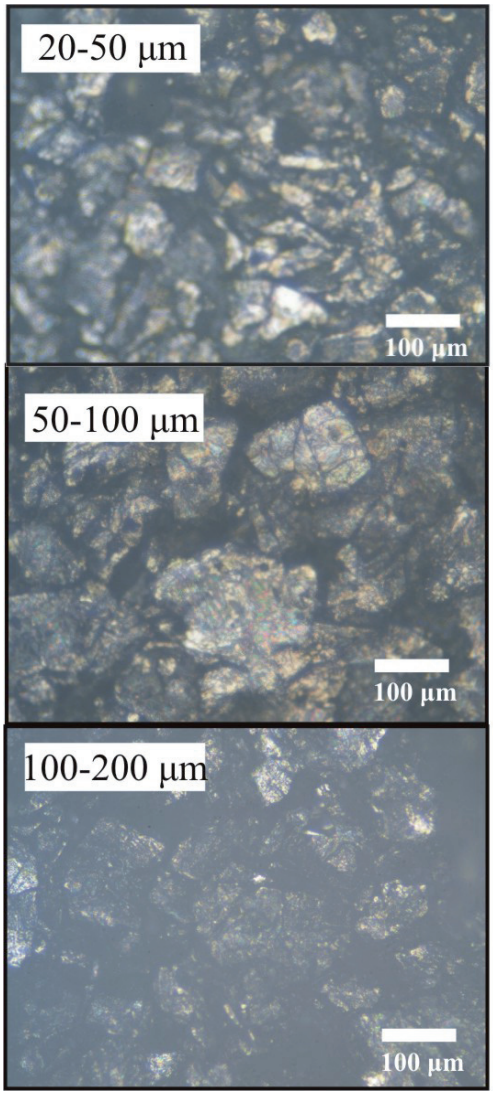

Fig. 3. Images of the surface of the composite with various fractions

In order to determine the chemical composition, the observation was performed using a scanning electron microscope with EDS analysis. In Figs. 4-9 the microstructure of samples analyzed areas in the analysis of EDS were showed. Fig. 4 shows the selected area of the composite of fractions 20-50 µm, while Table 2 refers to the EDS analysis of the sample.

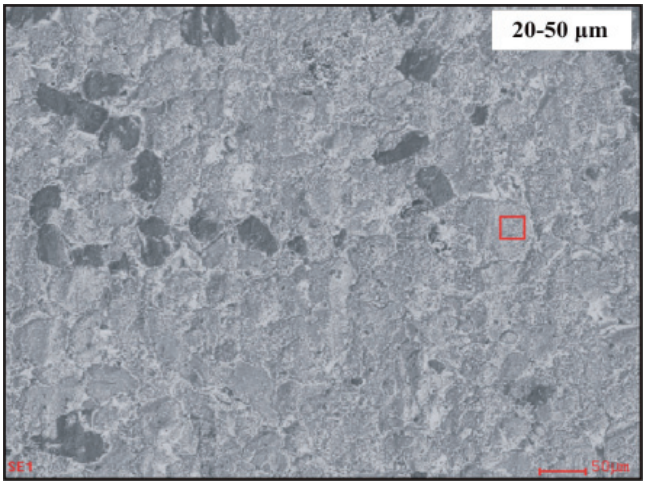

Fig. 4. Selected area for analyzing the chemical composition of the composite with fraction of reinforcement 20-50 µm

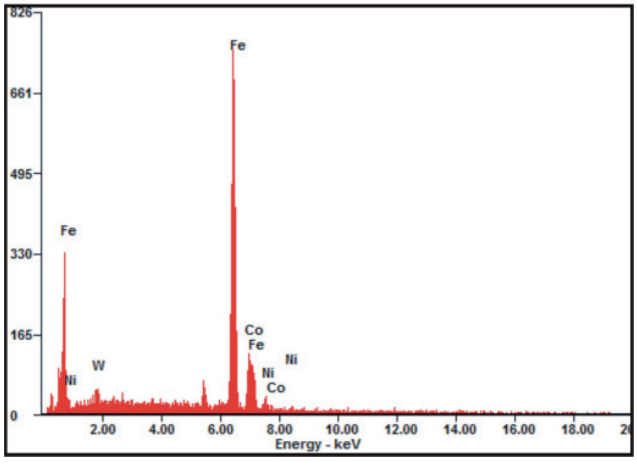

Fig. 5. EDS analysis of composite reinforcement fraction 20-50 µm

Fig. 6 shows area of EDS analysis of composite with reinforcement fraction 50-100 µm, while Table 3 shows chemical composition of analyzed samples.

Table 2.
Chemical composition of composite with reinforcement fraction 20-50 µm

Element	Wt%	At%
WM	04.70	01.49
FeK	78.71	82.10
CoK	12.69	12.54
NiK	03.90	03.87
Matrix	Correction	ZAF

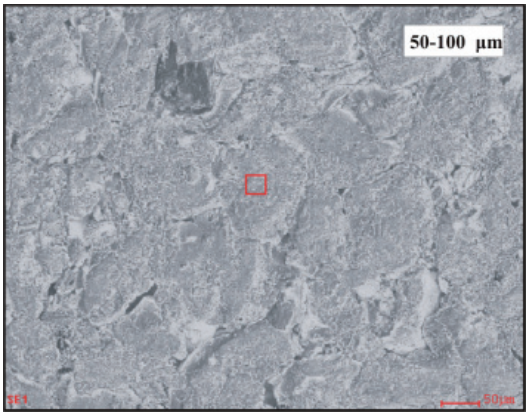

Fig. 6. Selected area for analyzing the chemical composition of the composite with fraction of reinforcement 50-100 µm

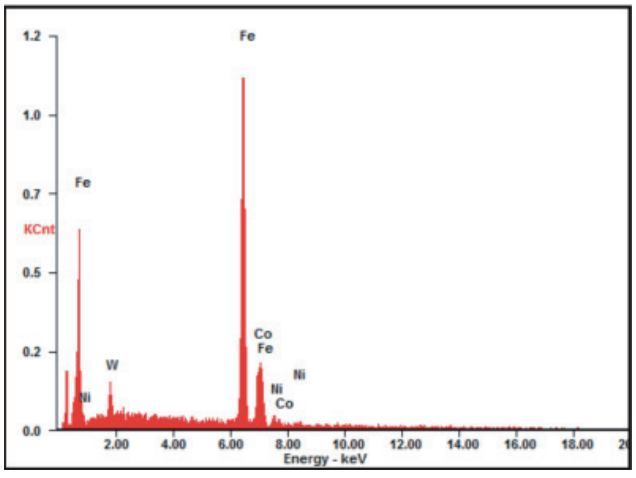

Fig. 7. EDS analysis of composite with reinforcement fraction 50-100 µm

Figs. 8, 9 show area for EDS analysis for composites with reinforcement of 100-200 µm, while Table 4 shows chemical composition of analyzed samples.

Table 3.
Chemical composition of composite with fraction 50-100 µm

Element	Wt%	At%
WM	08.33	02.71
FeK	74.23	79.56
CoK	14.53	14.75
NiK	02.91	02.97
Matrix	Correction	ZAF

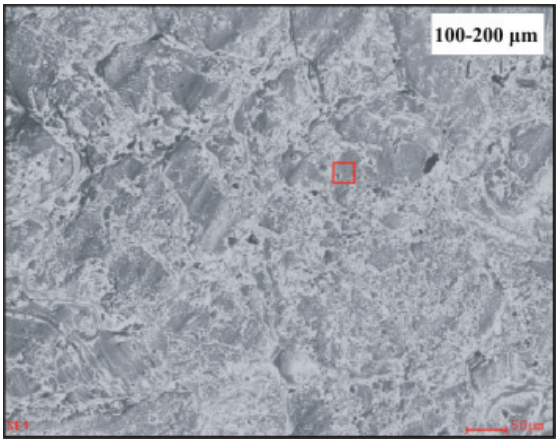

Fig. 8. Selected area for analyzing the chemical composition of the composite with fraction of reinforcement 100-200 µm

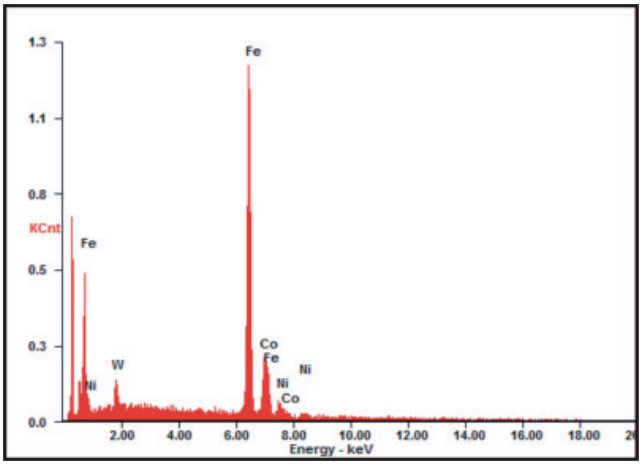

Fig. 9. EDS analysis of composite with reinforcement fraction 100-200 µm

Based on EDS analysis the chemical compositions used in the production of composites with different fractions of reinforcement was conducted.

Table 4.
Chemical composition of composite with fraction 100-200 μm

Element	Wt%	At%
WM	07.44	02.41
FeK	73.27	78.09
CoK	13.47	13.61
NiK	05.82	05.90
Matrix	Correction	ZAF

Another study was to measure the surface roughness of the analyzed samples. The measurement was carried out by using a contact measuring method. Due to the small sample size (diameter 5 mm) the length of the test section which equals 1.5 mm was selected. In Figs. 10-12 summary graphs of surface roughness measurement of test samples are presented.

Basing on the analysis of the resulting graphs (Figs. 10-12) in Table 5 the important parameters of roughness were summarized.

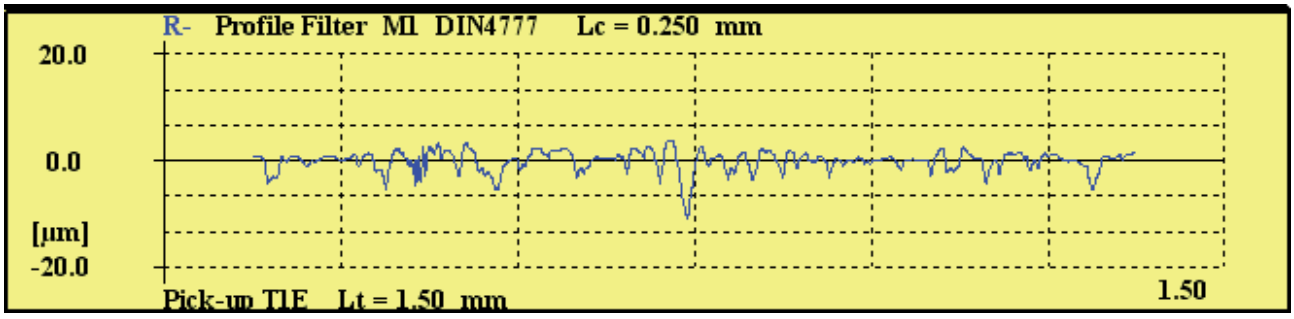

Fig. 10. Measurement of surface roughness profile of the composite with reinforcement fraction 20-50 μm

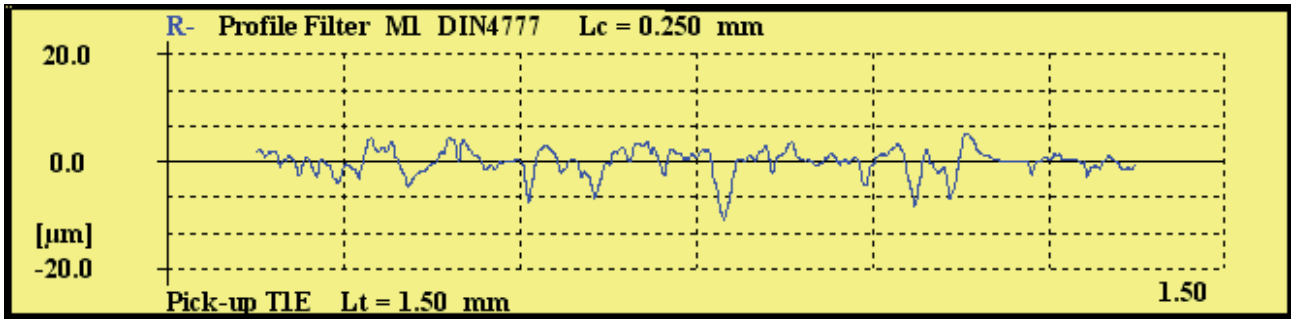

Fig. 11. Measurement of surface roughness profile of the composite with reinforcement fraction 50-100 μm

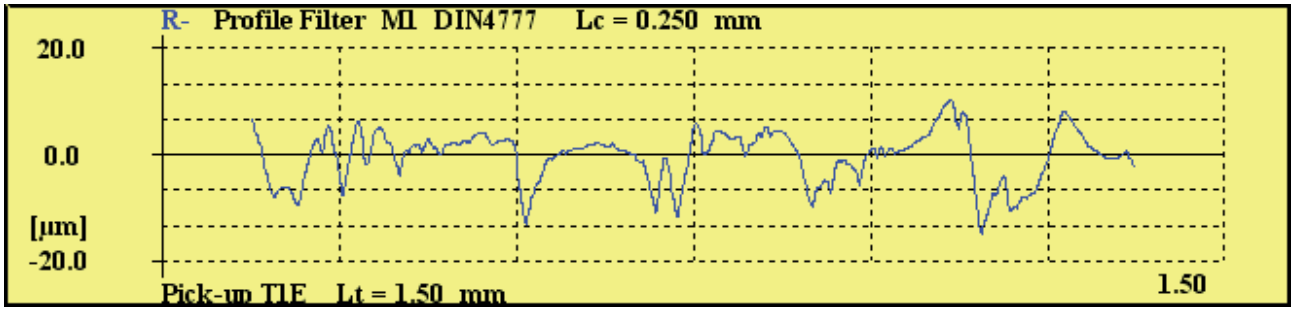

Fig. 12. Measurement of surface roughness profile of the composite with reinforcement fraction 100-200 μm

Table 5.
Summary the important parameters of roughness

Parameter	Reinforcement fraction, μm		
	20-50	50-100	100-200
R_a, μm	1.83	2.63	4.93
R_z, μm	9.96	13.15	22.48
R_{max}, μm	15.17	18.43	29.68

Description presented in Table 5 roughness parameters :
R_a – arithmetic mean deviation of the roughness profile,
R_z – average height of roughness,
R_{max} – maximum height of the roughness.

Basing on the results of measurement of surface profiles of tested composite materials can be seen that the greatest extension of area, was characterized by a composite with reinforcement fraction of 100-200 μm. The greatest arithmetic mean of deviation of surface profile (R_a) had a composite with fraction of 100-200 μm. With the increase of the size of reinforcement fraction, increasing arithmetic mean. The arithmetic mean deviation of the surface profile equal: 1,83 μm for fraction of 20-50 μm, 2.63 μm for fraction of 50-100 μm and 4.39 μm for fraction of 100-200 μm. It has happened the same in the case of values of the average roughness height. Composite with reinforcement fraction of 100-200 μm had the greatest value of maximum roughness height (R_{max}).

Static magnetic hysteresis loops obtained from measurements carried were out by using a vibrating magnetometer (VSM) presented in Figs. 13-15, while the magnetic parameters are shown in Table 6.

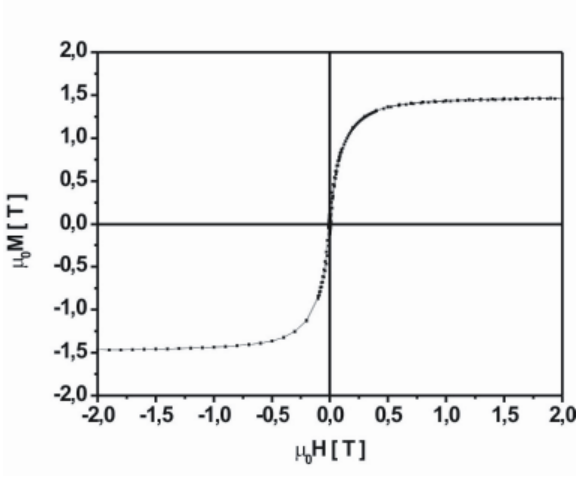

Fig. 13. Static hysteresis loop of composite with reinforcement fraction 20-50 μm

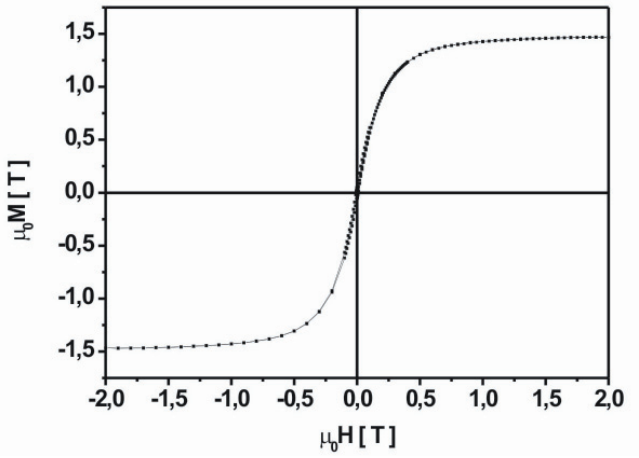

Fig. 14. Static hysteresis loop of composite with reinforcement fraction 50-100 μm

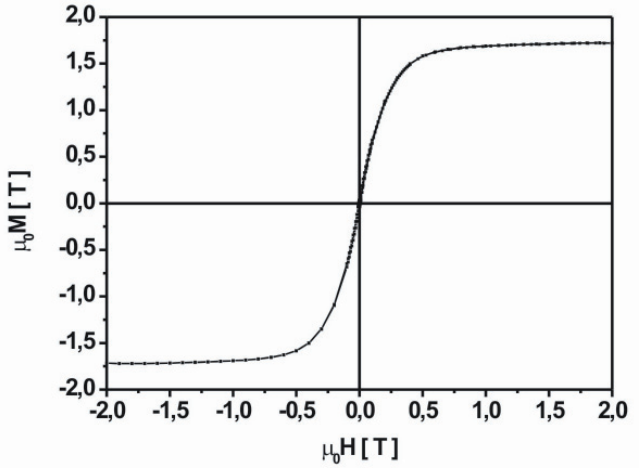

Fig. 15. Static hysteresis loop of composite with reinforcement fraction 100-200 μm

Table 6.
Statement of magnetic parameters designated from static hysteresis loop

No	Sample	$\mu_0 M_s$, T	H_c, A/m
1	Composite with reinforcement fraction 20-50 μm	1.74	5812.67
2	Composite with reinforcement fraction 50-100 μm	1.61	4496.82
3	Composite with reinforcement fraction 100-200 μm	1.73	4167.21

On the basis of the data collected in Table 6 it can be seen that there has been a decline in the value saturation magnetization with increase size of reinforcement fraction from 1.74 T for composite with reinforcement fraction 20-50 μm to 1.73 T for composite with reinforcement fraction 100-200 μm. Also area of coercivity with increase size of reinforcement fraction. For composite with reinforcement fraction (20-50 μm) area of coercivity equals 5812.67 A/m, while for composite with reinforcement fraction 100-200 μm equals 4167.21 A/m.

4. Conclusions

Obtained composites consisting of the $Fe_{66}Co_{10}Ni_2W_2B_{20}$ alloy powder and Epidian 100 base epoxy resin do not exhibit good magnetic properties. Good magnetic properties are required of the materials used for the construction of energy-efficient transformer cores. Despite this, a number of studies to be carried out on this group of materials, because they have a low production cost and ease of forming. Further research carried out on that material will be extended by changing the weight of metallic powder and epoxy resin and the modification of chemical composition of those powders.

Microscopic observation using an optical microscope were allowed to determine the shape of powders used in each of the fractions, however microscopic observations using an SEM with EDS allowed to describe chemical composition of materials. EDS confirmed study established chemical compositions.

After the measurement of the surface profile relationship that with increasing size of the fraction of reinforcement increases the roughness of the tested materials can be observed.

From the statistical analysis of the results of the hysteresis loop it can be deduced that with the increase in the size fraction the value of the coercivity increases, also the same relationship to the saturation magnetization can be observed.

References

[1] W. Kubiński, Material science, Volume I, The primary materials used in technique, Publishing House AGH, Cracow, 2010, 210-211.

[2] W. Królikowski, Modern structural polymer composite materials, Composites 2 (2002) 16-24.

[3] K. Jamroziak, Mechanical properties of composites on the polimer warp, Selected Problems of Engineering 2 (2011) 145-150 (in Polish).

[4] K.E. Oczoś, Fiber Composites-properties, applications, waste machining, Mechanic 7 (2008) 579-592.

[5] A. Boczkowska, J. Kapuściński, Z. Lindemann, D. Witemberg-Perzyk, S. Wojciechowski, Composites, Publishing House of Warsaw University of Technology, Warsaw, 2003 (in Polish).

[6] A. Boczkowska, J. Kapuściński, K. Puciłkowski, S. Wojciechowski, Composites, Publishing House of Warsaw University of Technology, Warsaw, 2000 (in Polish).

[7] J. German, Fundamentals of mechanics composite fibers, Publishig House of Cracow University of Technology, Cracow, 2001.

[8] L.A. Dobrzański, M. Drak, Composite materials, polymer matrix, reinforced alloy particles with a powder rapidly cooled belt Nd-Fe-B, Proceedings of the 11th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2002, Gliwice-Zakopane, 2002, 83-86.

[9] E.M. Nabiałek, Magnetic properties and microstructure of composites prepared on the base of amorphous alloy $Fe_{60}Co_{10}Y_8Zr_1B_{20}$ bonded with epoxy resin, Plastic Processing 1 (2012) 56-57 (in Polish).

[10] H. Leda, Polymer composites with continous fibres. Publishing House Poznań University of Technology, Poznan, 2006.

[11] R. Nowosielski, J.J. Wysłocki, I. Wnuk, Ferromegnetic properties of polimer nanocomposites containing $Fe_{78}Si_9B_{13}$ powder particles, Journal of Materials Processing Technology 162-163 (2005) 242-247.

[12] M.E. McHenry, M.A. Willard, D.E. Laughlin, Amorphous and nanocrystalline materials for applications as soft magnets, Progress in Materials Science 44 (1999) 291-433.

[13] B. Ziębowicz, D. Szewieczek, Polimer nanocomposites involving nanocrystalline alloy powders bades on Fe, soft magnetic, Plastic Processing 6 (2011) 539-544.

[14] D. Szewieczek, L.A. Dobrzański, B. Ziębowicz, Structure and magnetic properties of nanocomposites of nanocrystalline powder - polymer type, Journal of Materials Processing Technology 154-158 (2004) 765-770.