Archives of Materials Science and Engineering

Volume 83
Issue 1
January 2017
Pages 17-22

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Application of computed tomography for an analysis of composite with fine dispersive reinforcement made of the $Fe_{65}Co_{10}Ni_3W_2B_{20}$ alloy

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ABSTRACT

Purpose: The paper presents the results of microstructure and mechanical properties of composites resulting from a combination of powders of metallic glasses with an epoxy resin (Epidian 100). The study was performed using computed tomography.

Design/methodology/approach: The filler used was made of a $Fe_{65}Co_{10}Ni_3W_2B_{20}$ amorphous alloy based on, showing in the state after the formation the soft magnetic properties. The aim of the study was to determine the effect of the fraction of the composite powders on the microstructure parameters (mean pore diameter and pore volume fraction) and the properties of the obtained composites.

Findings: Based on the survey it was found out that size fraction used does not affect the value of the modulus of elasticity linear composites studied. It was also shown that the composites analysed in an attempt to compress the cross cracked grain boundaries. The influence fraction powders and change the share of the pore size depending on the fraction of the filler.

Research limitations/implications: No studies of the magnetic properties determine the usefulness of these materials in the electronics industry.

Practical implications: Practical implications are to size the test specimens in the limited range of tests. In the future, it is planned to produce samples with a larger diameter.

Originality/value: The paper presents a new group of composites-based metallic glasses conditions characterised by good properties produced a simple and inexpensive method.

Keywords: X-ray computer tomography; Composite materials

Reference to this paper should be given in the following way:
K. Szlązak, A. Siejka, M. Szota, M. Nabiałek, A. Łukaszewicz, J. Klimas, P. Pietrusiewicz, K. Błoch, Application of computed tomography for an analysis of composite with fine dispersive reinforcement made of the $Fe_{65}Co_{10}Ni_3W_2B_{20}$ alloy, Archives of Materials Science and Engineering 83/1 (2017) 17-22.

METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

The dynamic development of materials science in recent years has increased interest in composite materials [1]. Receiving new composite materials allows obtaining material which properties can be indefinitely shaped. It is due to the possibility of combining various components with different physicochemical parameters. The possibility to design properties of composites allow for their broader application [2,3].

Since the beginning of mankind newer and newer materials to be used by a man. One of the new groups of consumable materials is composite materials that are now already widely used in many branches of industries [4]. Some of the most important materials that affect the progress of civilisation are electrotechnical and electronic materials. Therefore, numerous studies are carried out on developing advanced soft magnetic materials with desirable shapes. The result of such a situation is the development of research on the combination of the alloy powders with amorphous, nanocrystalline or crystal structures which possess good hard and soft magnetic properties with thermo- or chemo-setting [5-10]. A designed process and used technology enabled to produce composites with a metallic filler of various shapes which depend solely on the core of the used mould. Composites with metallic filler (depending on its chemical composition and the amount of polymer matrix) are characterised by good magnetic properties, which may also depend on the particle size of the filler. The aim of the study was to determine the effect of fraction size filler formed by $Fe_{65}Co_{10}Ni_3W_2B_{20}$ alloy on the mechanical properties of composites combined with epoxy resin.

2. Methodology and material

The study material in the form of composites which are a combination of powder made of metallic glasses with an epoxy resin was obtained by one-sided, uniaxial compression.

The plates of metallic glasses of complex $Fe_{65}Co_{10}Ni_3W_2B_{20}$ chemical composition was used for the preparation of composite materials. The alloy used to obtain the plates was prepared from ingredients having an atomic purity: Fe, Co, Ni, W = 99.98%, while boron was added as $Fe_{45.5}B_{54.6}$ alloy.

The first stage of the preparation of solid amorphous materials is the preparation of a crystalline alloy ingot. Alloy divided into several portions is melted using the electric arc furnace under the atmosphere of inert gas. Thus obtained polycrystalline ingot was crushed and purified from external contamination. Using the method of injection casting of the liquid alloy into a water-cooled copper form, 0.5 mm thick plates were obtained. So prepared samples after suitable machining were used as filler composites. Filler powder prepared in several stages. The first step was to pre-mill the plates in knife mill for 5 minutes. Then crushed plates were milled with a planetary mill for 1 hour. The obtained powder was divided into fractions on the set of sieves: 20-50 µm, 50-100 µm and 100-200 µm. The powder prepared in this way was used to obtain a composite. As a binder epoxy resin was used (epidian 100) in proportion 5% wt. for all fractions. Composite components were mixed and pressed in a hydraulic press at pressure of 5 MPa for 30 seconds. As a result of pressing the pellet, which was subjected to heat treatment at a temperature of 150°C for 3 hours. was obtained Designed annealing process was to lead to a full cure of the resin. the pellet obtained in this way had a cylindrical shape with a diameter of ~5 mm and height ~3 mm.

2.1. X-ray computed tomography

Computed tomography is one of the main techniques for non-destructive testing, for examining a wide range of materials, such as composite materials. The study was conducted at the SkyScan 1172 microtomography (Bruker, Belgium). F CTAn programme (ver. 1.14.4.1+) which was used for quantitative measurements, and generate three-dimensional models while software CTVol (ver. 2.2.3.0) to their visualisation, was used for the analysis of obtained composites.

Static test of compression composites

A static compression test was carried out using CT with a special adapter for the compressive strength test *in situ.*

Samples were placed plane-parallel on stamps of testing machine CT and loaded them with the initial force of 10 N to avoid curved sections at the beginning of the stress-strain diagram.

Quantitative analysis of the microstructure

Imaging of composites was performed on non-deformed samples (without applied forces) and on deformed (after compression with force over 220 N – maximum force for that device). Parameters of the outcarried studies were as follows: voltage 100 kV between the cathode and the anode X-ray tube (tungsten), current – 100 µA, step rotation around the sample – 0.3° (to 180°) with time exposure - 540 ms. Aluminium-copper filter was also used to avoid the effect of beam hardening. The obtained resolution was 4.9 µm. A single radiograph was averaged from 5 projections.

3. Results and discussion

3.1. Mechanical properties of pellets

On the basis of the compression curves (Fig. 1), Young's modulus (Fig. 2) of studied composites in spring range was set. The calculated Young's modulus of composites, for each fraction, is characterised by comparable value. Fraction size does not have an influence on the magnitude of the linear elasticity modulus. The results of Young's modulus test are shown in Table 1.

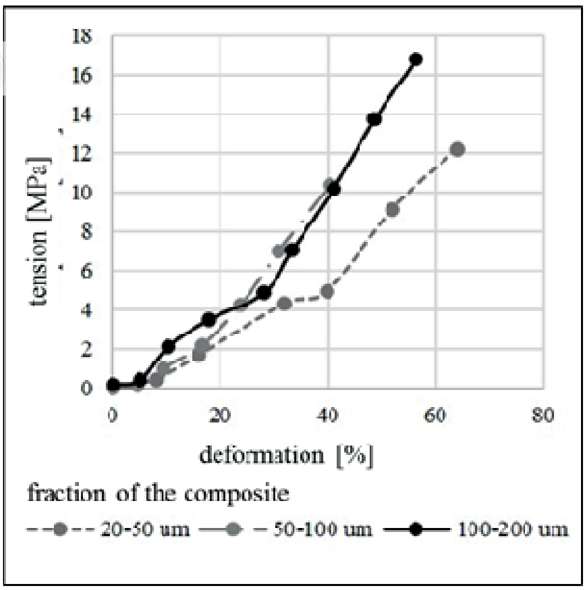

Fig. 1. Compression composite curves

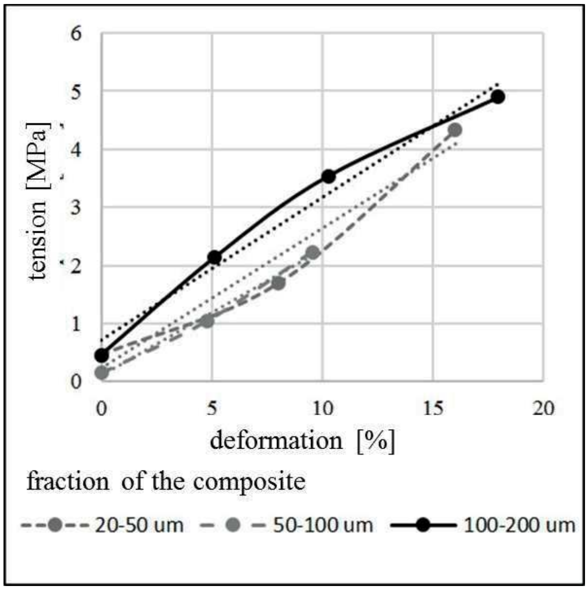

Fig. 2. Compression composite curves – elastic range

Table 1.
Young's modulus of obtained composites

Powder fraction in composite, µm	Young's modulus, MPa
20-50	0.2420
20-100	0.2181
100-200	0.2459

3.2. Quantitative analysis of the microstructure of composites

Based on the analysis of the reconstructed tomographic images, in a non-deformed state, diameters and quantitative share of fractions, segregations and pores were set. Moreover, diameters of pores were described in deformation state (Table 2). Results of the average grain powders and their distributions were obtained (Fig. 3) and they indicate for their correct separation in the production of composite materials. In the composites secretion of different size and shape were observed. The pore diameter of the largest diameter was observed in the composites with a fraction of 20-50 µm. In the case of composites with fractions of 50-100 µm and 100-200 µm average pore diameter was comparable (Table 2, Figs. 5-9), and their volume fraction was similar. The standard deviation in the case of powder fraction of 20-50 µm shows large differences in pore size, while for the other two fractions the deviation was comparable to each other. Observations carried out after the compression test showed that for all tested composite, cracking was of an intergranular character that is at the grain boundaries (Fig. 4).

Table 2.
Quantitative parameters of composites, average value, in bracket deviations

Composite powder fraction, µm	20-50	50-100	100-200
Fraction diameter, µm	26.9 (18.5)	45.9 (18.0)	78.4 (30.5)
Fraction share, %	89.5	67.4	68.7
Diameter of, µm	30.9 (16.6)	53.7 (29.2)	29.9 (24.4)
Sparation share, %	0.5	0.5	0.2
Pores diameter (non-deformation state), µm	63.5 (36.0)	35.9 (18.9)	39.8 (16.8)
Pore share (deformation state), %	10.0	32.1	31.1

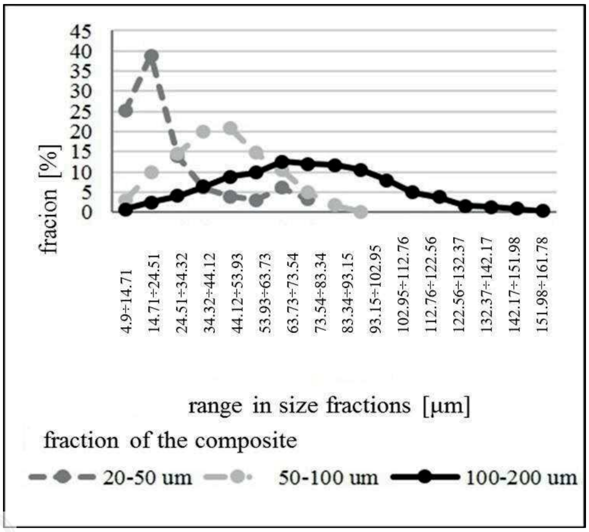

Fig. 3. Percentage share of fraction in each range

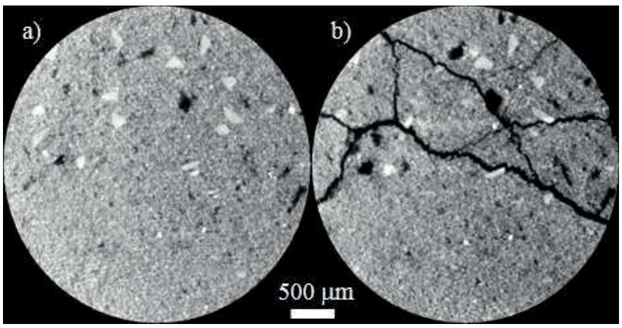

Fig. 4. The microstructure of composite with a fraction of 20-50 µm without deformation (a) with deformation (b), grey colour – fractions, white colour – separations, black colour – pores

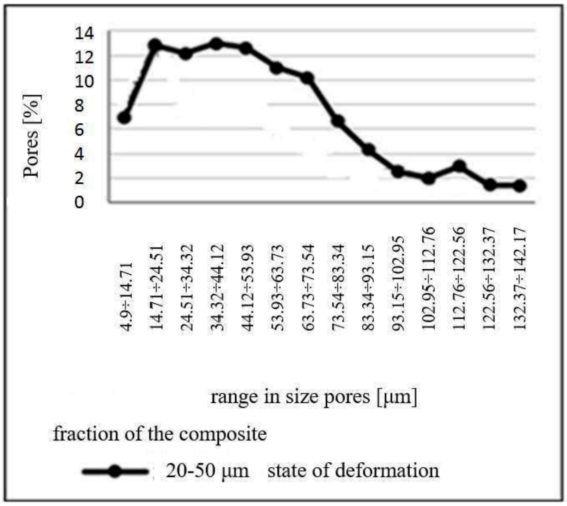

Fig. 5. Percentage share of pores in each range for composites with fraction of 20-50 µm

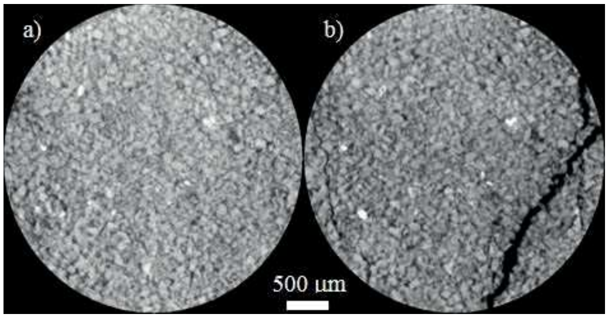

Fig. 6. Microstructure of composite with a fraction of 50-100 µm without deformation (a) with deformation (b), grey colour – fractions, white colour – separations, black colour – pores

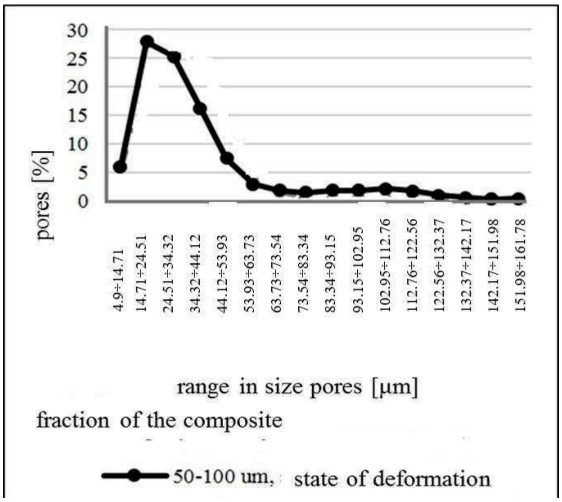

Fig. 7. Percentage share of pores in each range for composites with fraction of 50-100 µm

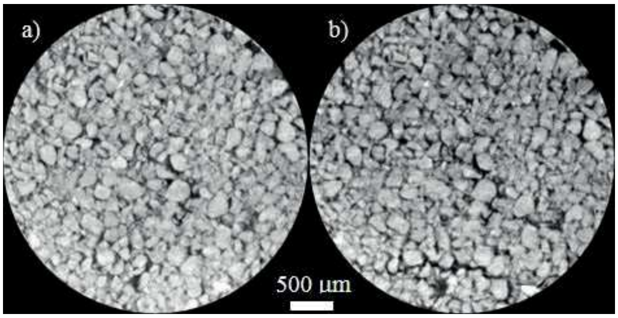

Fig. 8. Microstructure of composite with fraction 100-200 µm, without deformation (a) with deformation (b), grey colour – fractions, white colour – separations, black colour – pores

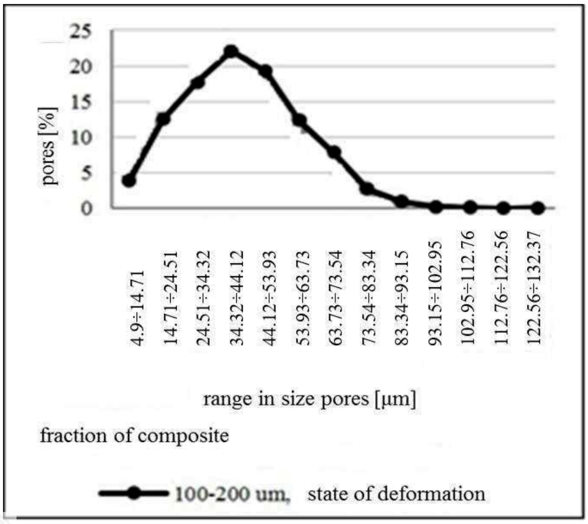

Fig. 9. Percentage share of pores in each range for composites with fraction of 100-200 µm

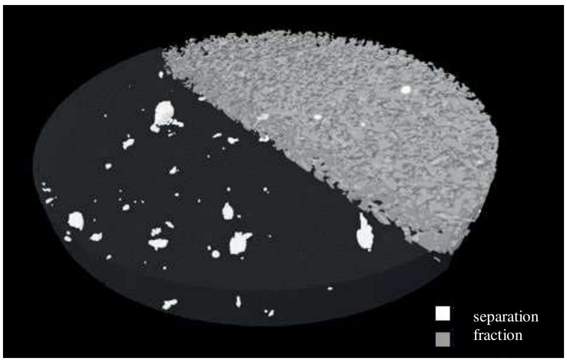

Fig. 10. 3D reconstruction image for composite with fraction 20-50 µm

To visualise the results, three-dimensional reconstructions of the individual components of the microstructure of composites in an undeformed state have been developed (Figs. 10-12). In the computer visualisation on the left side of studied composites (Fig. 10) distribution of white separation was observed, while on the right can be observed the fraction microstructure (grey colour) with pores (lacks between grains in the matrix) and separations (white colour).

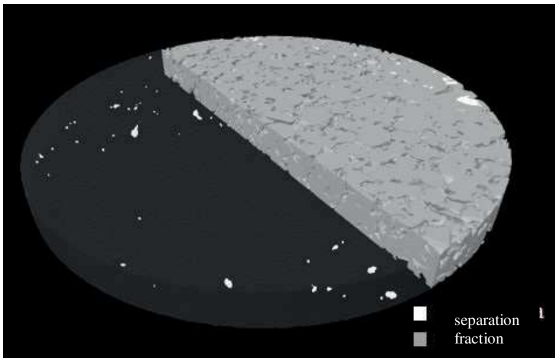

Fig. 11. 3D reconstruction image for composite with fraction 50-100 µm

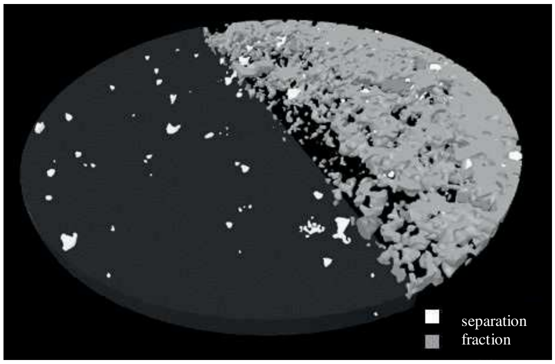

Fig. 12. 3D reconstruction image for composite with fraction 100-200 µm

4. Conclusions

The paper presents the results of microstructure and mechanical properties of composites resulting from the combination of powders of metallic glasses with an epoxy resin (Epidian 100). The studies of the microstructure indicate that composites with a fraction of 20-50 µm are of the largest average pore diameter, while for other composites studied average pore diameter was lower for about 40% and comparable to each other. Young's modulus determined by the compression was comparable to studied composites and did not depend on fraction size. As a result of the compression, test composites cracked by inter-crystalline mechanism.

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