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Soft magnetic nanocomposite with powdered metallic ribbon based on cobalt and polymer matrix

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Abstract: Structure, magnetic and mechanical properties of the nanocrystalline composite material of the SILAME® type were tested. The composite material was obtained by solidification of the nanocrystalline powder obtained in the high energy ball milling of the initially crystallized $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ amorphous ribbon with the silicon polymer.
The metallic powder was mixed with the silicon polymer in a different weight ratio and next the effect of $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ powder weight ratio on the magnetic and physical properties of the composite was investigated.

Keywords: High-energy ball milling, Powders, Compozites, Magnetic properties

1. INTRODUCTION

The reason for the broad studies of these materials are their very good soft magnetic properties, to which, first of all, belong the following: high magnetic saturation B_S, low coercion value H_C, high magnetic permeability μ, very low – close to zero - magnetostriction λ_S values, and finally - very low remagnetising losses. Some of these alloys (HITPERM) are characteristic of the relatively high resistivity [1-4]. Due to their manufacturing method [5, 6] the amorphous and nanocrystalline materials obtained directly by crystallization of the metallic glasses are available only in the form of very thin ribbons.

The commercial employment of these materials is limited because of the possibility of making toroidal cores, resulting from the method of obtaining the amorphous and nanocrystalline ribbons (melt spinning).

Obtaining powder nanocrystalline materials directly by grinding the metallic glasses makes it possible to carry out research on obtaining the ferromagnetic nanocomposites whose shape and dimensions may be formed freely [7-10].

The composite with the polymer matrix reinforced with the amorphous or nanocrystalline particles obtained in the process of the high energy milling of the amorphous ribbons or mechanical synthesis features the alternative for those materials.

2. RESULTS

Basing on the microscope examinations it was found out that with the higher content of the $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ powder, its particles are homogeneously distributed in the entire silicon matrix. Along with decreasing the powder volume in the composite agglomerations of powder particles occur (Fig. 1).

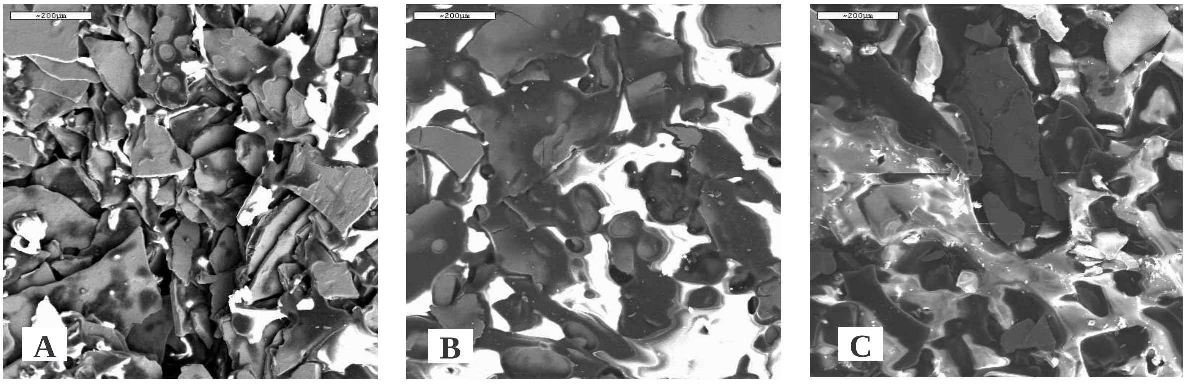

Figure 1. Structures of the nanocrystalline composite material with the silicon matrix reinforced with powder made from the $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ alloy with varying weight ratios of the nanocrystalline powder to silicon in the SILAME type composite A) 6:1, B) 4:1, C) 3:1; electron scanning microscope

Tests of magnetic properties revealed that the highest magnetic saturation was characteristic for the composite with the metallic powder to silicon weight ratio of 5:1 - B_S = 0.72 T. Magnetic saturation values decreased along with the lowering ratio of the metallic powder in the composite, reaching B_S = 0.5 T for the composite with the metallic powder to silicon weight ratio of 2:1. The highest coercive area value was characteristic for the composite with the metallic powder to silicone polymer weight ration of 6:1. Its lowest value was revealed for the composite with the 3:1 weight ratio (Fig. 2, Fig. 3).

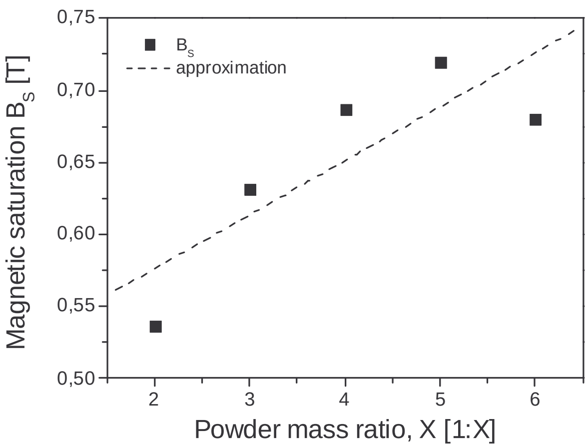

Figure 2. Magnetic flux density versus the $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ powder ratio in the composite

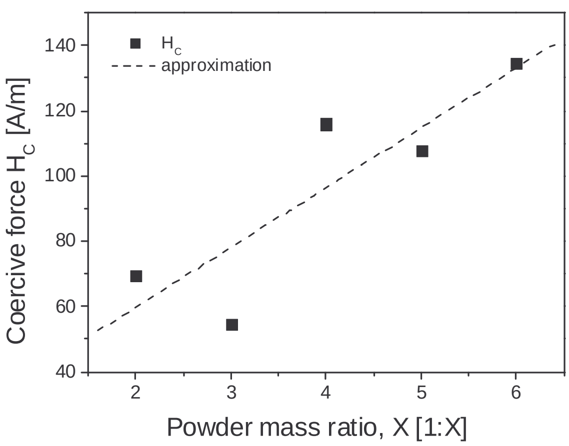

Figure 3. Coercive force versus the $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ powder ratio in the SILAME type composite

Tests of magnetic properties revealed that along with the growing ratio of the CoFeMoSiB nanocrystalline powder in the composite the inclination angle of the primary magnetization curve grows also.

Tests of mechanical properties revealed that the highest ultimate tensile strength value was demonstrated by the SILAME composite 3:1 UTS = 1.18 MPa. This composite was characterized also by the highest unit elongation values of ε = 212 % and by the lowest Young's modulus value of E_p = 0.25 MPa (Fig. 4, Fig. 5).

The SILAME composite 6:1 was characterized by the lowest ultimate tensile strength of UTS = 0.82 MPa and the lowest value of the unit elongation of ε = 44 %. However, this composite demonstrated the highest value of Young's modulus of E_p = 0.35 MPa (Table 1).

Table 1. Static tensile test results of the SILAME type composite

Weight ratio	Ultimate tensile strength UTS [MPa]	Unit elongation ε [%]	Young's modulus E_p [MPa]	Module in the load range E_{avg} [MPa]
silicon polymer	0,38	370	0,056	0.023
3:1	1.18	212	0.25	0.27
4:1	1.07	127	0.299	0.34
5:1	1.1	64	0.33	0.4
6:1	0.82	44	0.35	0.54

Tests of the mechanical properties revealed that along with the increase of the metallic powder ratio the ultimate tensile strength UTS and unit elongation ε decreased (Fig. 9). Along with the increase of the $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ powder ratio in the composite the Young's modulus E_p and the average modulus E_{avg} grew in the load range and their highest value was demonstrated by the composite with the 6:1 metallic powder to silicone weight ratio (Fig. 10).

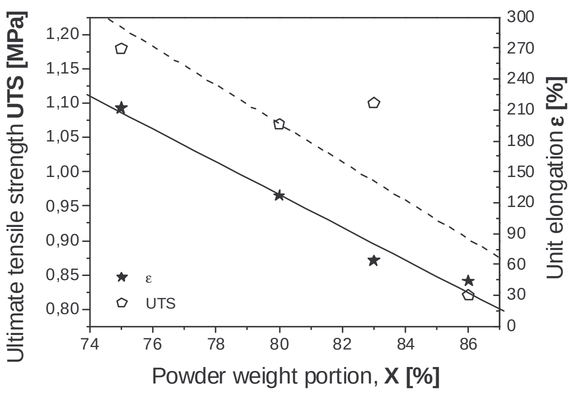

Figure 4. The ultimate tensile strength UTS and unit elongation ε versus the $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ powder ratio in the SILAME type composite

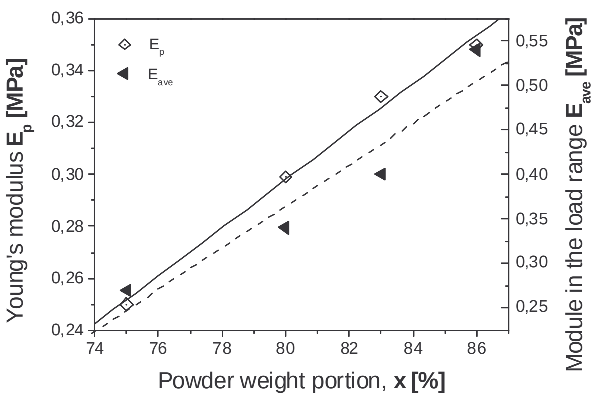

Figure 5. Young's modulus E_p and the E_{avg} modulus in the load range versus the $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ powder ratio in the SILAME type composite

3. SUMMARY

The powder magnetic properties may be controlled by a selection of the process parameters and by segregation of grains.

The analysis of the magnetic properties test results of the nanocrystalline composite material revealed that the soft magnetic properties of the composite are dependant on the metallic powder ratio in the composite, which improve with the increase of the $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ powder ratio. The mechanical properties test results of the composites reveal the significant effect of the $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ powder ratio on the mechanical properties of the composite, which deteriorate along with the decreasing powder ratio.

It was found out, basing on microscope examinations, that at the higher $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ powder portion in the nanocomposite, its particles are distributed uniformly in the entire silicone polymer matrix. Local clusters of powder grains occur when the powder volume in the composite gets smaller. The magnetic properties tests carried out of the nanocrystalline composite material revealed that the magnetically soft properties of the composite are dependant on the powder material portion in the composite. The most advantageous magnetic properties are characteristic of the composite material with the metal powder to silicone polymer weight ratio of 6:1. The lowest properties are demonstrated by composite with the weight ration of 2:1.

Basing on the results of the mechanical properties tests of the nanocrystalline composite materials it was found out that the portion of the metallic powder in the composite decides its mechanical properties. Composite with the metallic powder to silicone polymer weight ratio of 6:1 has the highest ultimate tensile strength UTS value. The UTS value decreases as this weight ratio gets smaller. The relative elongation ε, Young's modulus E_p, and the average module E_{ave}, change in a similar way, demonstrating the linear relationship (proportional) with the powder weight ratio.

Rather poor mechanical properties may be caused by the excessively low silicone polymer adhesion to the $Co_{68}Fe_4Mo_1Si_{13,5}B_{13,5}$ powder particles and joining metallic glasses with the polymers yields very weak adhesion joins. Similar results were obtained in [11].

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