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RESEARCHES ON THE PRODUCTION OF COPPER-BASED COMPOSITES BY POWDER METALLURGY METHODS

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ABSTRACT

The article presents how to obtain copper matrix composite with alloy particles of NiCrBFeAl as complementary phase. The samples were obtained by powder metallurgy methods using different percentages of the additional phase: 20, 30, 40, 50% NiCrBFeAl of 60 μm average size. After cold pressing to 863 MPa pressure, the samples were sintered at 910 °C for 90 minutes. The characterization of the samples was focused on the microstructural aspects, variation of microhardness and abrasive wear behavior.

KEYWORDS: powder metallurgy, microhardness, abrasive wear

1. Introduction

The production of composite materials has applications in almost all areas of technology. Due to the special perspectives they have opened and the obvious advantages they feature, the composites will experience a permanent diversification and will attract for a long time the attention of specialists as strictly necessary materials for future technologies being considered revolutionary materials with real prospects to improve their properties. This is due to the fact that they have a number of unique mechanical properties such as low density, high mechanical strength, toughness, wear and corrosion resistance.

In the last two decades, metal matrix composites with (micrometer or nanometer) particles as complementary phase are of particular interest. In these materials the hardening particles and the strength are combined with ductility and toughness of the metal matrix.

Metal matrices have been used because of the need to obtain composites able to be used to relatively high temperatures as compared to those of organic nature. Metals have other properties too that recommend them as matrix: good mechanical properties, high thermal and electrical conductivity, high resistance to ignition, dimensional stability, good processing capability, low porosity.

Copper chosen as matrix has very good electrical and thermal conductivity and the advantage that it can be processed easily. That it why it is used in the production of composite superconducting and conducting materials as well as for the bearings and filters.

The research undertaken in this paper aimed at produceing, by powder metallurgy methods, copper matrix composites using Ni–Cr–B–Fe-Al alloy particles as complementary phase. The samples thus obtained were characterized in terms of microstructure, microhardness and wear behavior.

2. Experimental conditions

To obtain the samples, two types of powder were used: one composed of pure copper for the matrix and the other of NiCrBFeAl alloy to provide the complementary phase, which has the following chemical composition: 8.9%Cr; 4.5%Fe; 5.1%B; 2.4%Al; 0.6%Cu; the rest is Ni. The particle size of the nickel-based powder was about 60 μm.

The copper powder has an irregular shape caused by atomization of water and the nickel –based powder has a spherical shape due to gas atomization. The images of these powders are shown in Fig. 1.

There have been several samples of different concentrations of complementary phase as shown in Table 1.

The compressed samples have cylindrical shape of approximately 8x6 mm.

The compression method used was cold pressed by means of the universal mechanical testing machine. The pressure used for powder compaction was 863 MPa, determined after making several attempts.

***Table 1.** Composition of powder tablets*

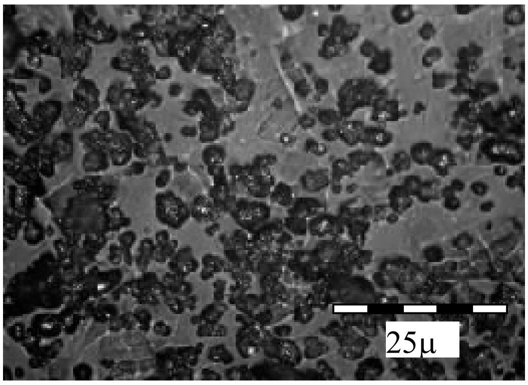
Sample code	Composition
P1	80%Cu + 20% Ni-Cr-B-Fe-Al
P2	70% Cu + 30% Ni-Cr-B-Fe-Al
P3	60%Cu + 40% Ni-Cr-B-Fe-Al
P4	50% Cu + 50% Ni-Cr-B-Fe-Al

Sintering of powder tablets was carried out in an electric furnace. The sintering temperature was 910 °C to 90 minutes exposure. After sintering, all samples were cooled slowly in the oven.

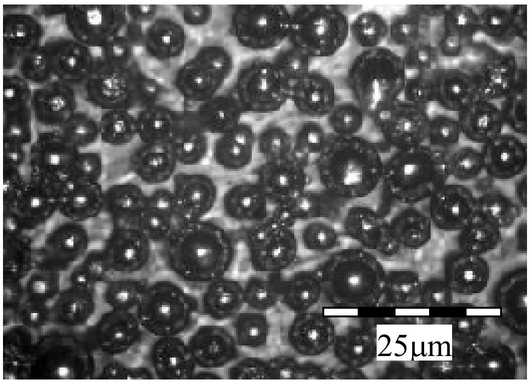
Samples were placed in a ceramic cylinder and graphite was added. The graphite has an important role in the prevention of entry of the cooling air within the cylinder, thereby providing a protection atmosphere.

The main purpose of sintering is to reduce porosity. The sintering is most often accompanied by changes in the material, some desired and some not: changes in the mechanical strength, hardness; the size and shape of the particles may also be affected, there is variation in the shape and size of the pores; it can alter the chemical composition and the crystal structure can be altered due to chemical reaction processes in the solid phase.

Microscopic analysis of powders and the samples obtained was performed using a microscope Neophot 2 with computer data acquisition.



a.



b.

***Fig. 1.** Aspect of copper powder – a, and nickel–based powder – b*

Measurement of micro-hardness was carried out using microhardness meter PMT 3.

Wear behavior of the samples obtained was studied using the method for determining the mass wear to abrasion test on rotating disk. It uses a friction pin/disc couple, class IV-1.

The method involves successively pressing under the same conditions the two samples of 8x6 mm, one of the examined material, the product of the composite sintering powder and the other of a material chosen for comparison-of the sintered copper on a rotating disc covered with sanding paper grit 120. A mechanism for radial displacement of the specimen by 0.5 mm/rev provides spiral path on the rotating disk surface. A device for applying a load of 6229 N ensures pressing of the specimen perpendicularly to the sandpaper at 0.123 N/mm^2 pressure. At a speed disc of 25 rev/min, a lenght of 5.791 m has been run.

3. Results and discussions

For a metallographic study, powders were embedded in an adhesive cyanoacrylate metallographically prepared by grinding and chemical attack with a suitable reagent.

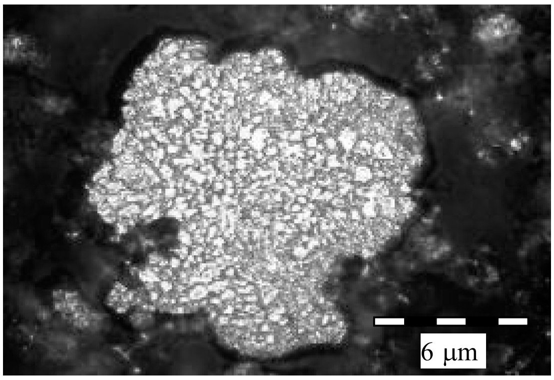
Microscopic analysis (Fig. 2) performed on copper powder particles embedded, polished and attacked with ferric chloride highlights their irregular shape and good compactness.

Microhardness determined on the polished section of the copper particles under 10 g load was HV0.01 = 516.2 MPa.

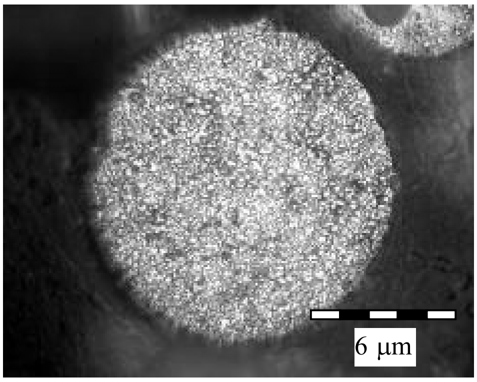
In the case of nickel base powder, the microscopic analysis on samples embedded, polished and attacked with Nital 2% highlights spherical particles and their relative compactness. Inner hollow particles are observed. Particle microstructure consists of numerous intermetallic compounds (NiB, Ni_2B, CrB, Cr_3B_4 and FeB) distributed in a very fine martensitic matrix.

Microhardness determined on the polished section of the particles under 100 g load was HV0. 1 = 9522.2 MPa. Microscopic analysis of pressed tablets reveals the presence of pores and their shape, Figure 3.

Looking at Fig. 3 it can be seen that with increasing content of Ni-based spherical powder, there is a growth in the included phase. However there is a decrease in the sample compactness with increased percentage of included phase. This is due to the different deformation of the two types of powder.

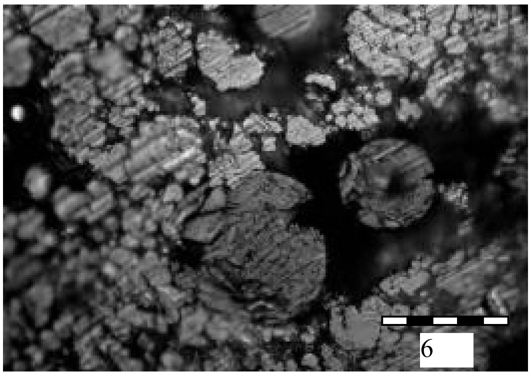


a.

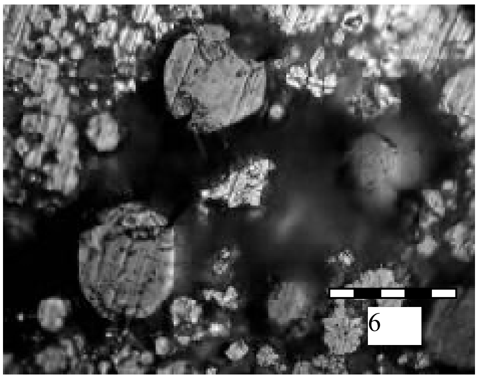


b.

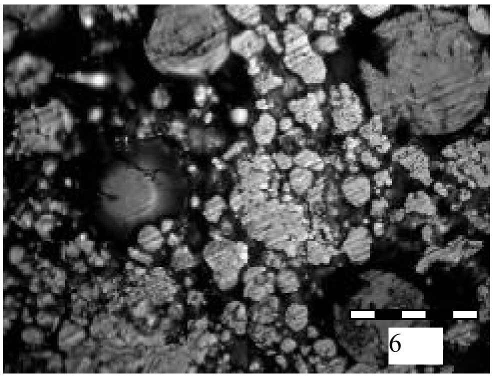
Fig. 2. *Microstructure of Cu powder – a and nickel based powder – b*



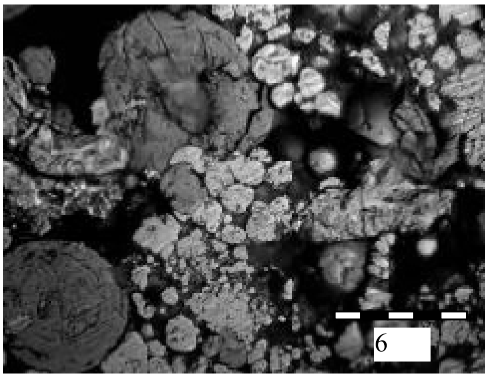
P1 - 80%Cu + 20% Ni-Cr-B-Fe-Al



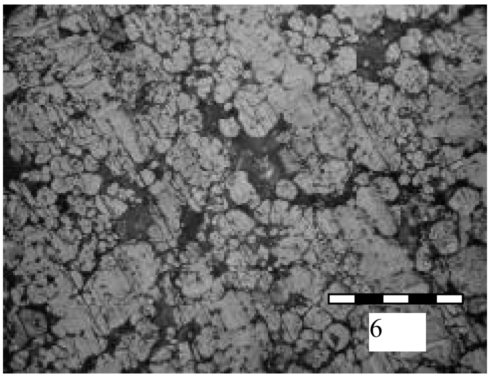
P2 - 70% Cu + 30% Ni-Cr-B-Fe-Al



P3 - 60%Cu + 40% Ni-Cr-B-Fe-Al



P4 - 50% Cu + 50% Ni-Cr-B-Fe-Al



100% Cu

Fig. 3. *Microstructure of powder tablets in Cu matrix reinforced pressed with Ni based alloy particles*

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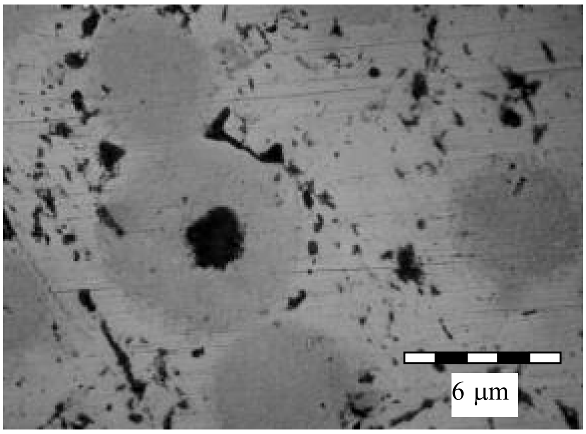
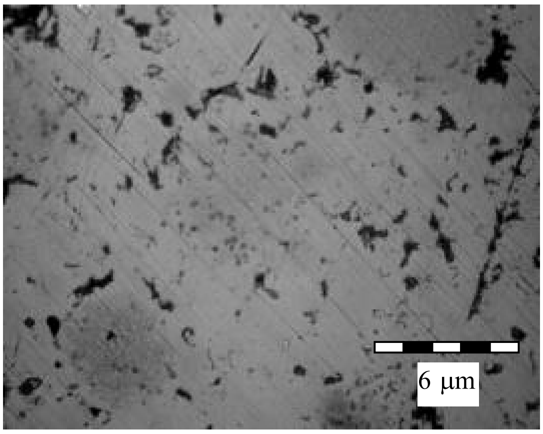
Fig. 4 shows the microscopic appearance of the sintered unattacked samples. It is noted a reduction in porosity and a higher compaction.

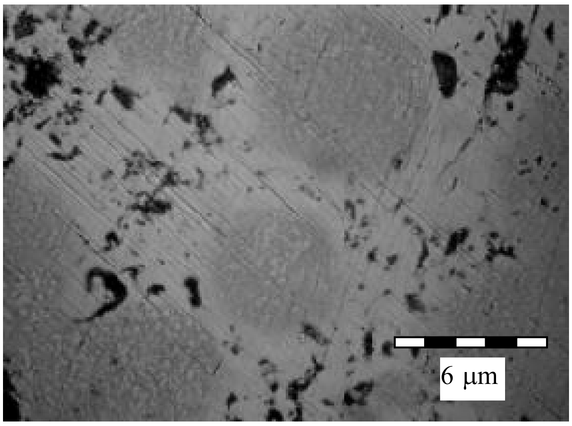
Fig. 5 shows the microscopic appearance of the tablets obtained with Cu matrix reinforced with *Ni-Cr-B-Fe-Al*, alloy particles, sintered and attacked with ferric chloride reagent. It can be seen that their structure consists of Cu showing twinned with particles of nickel based alloy comprising intermetallic compounds (NiB, Ni_2B, CrB, Cr_3B_4 and FeB) distributed in a very fine martensitic mass.



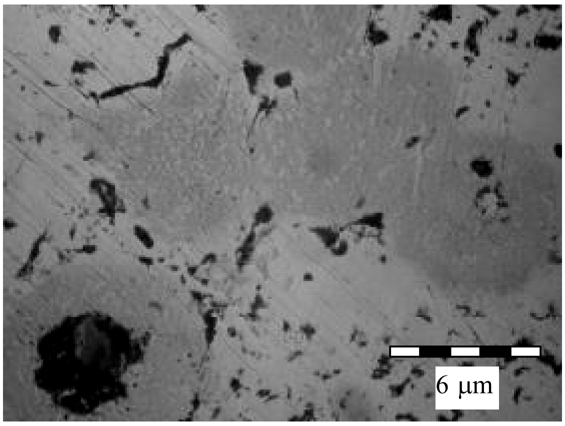
P1 80%Cu + 20% Ni-Cr-B-Fe-Al



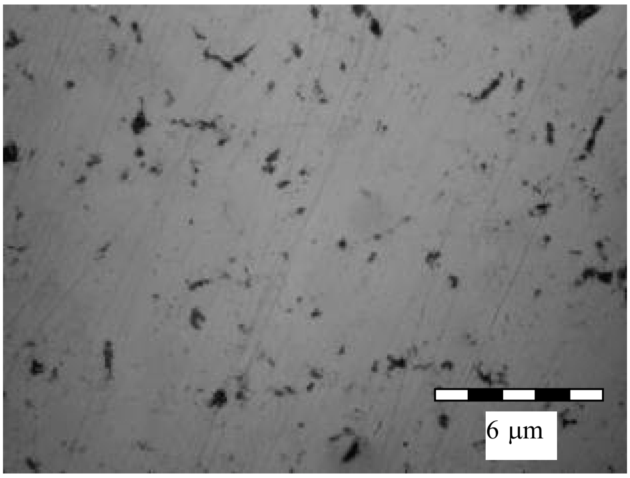
P2 70% Cu + 30% Ni-Cr-B-Fe-Al



P3 60%Cu + 40% Ni-Cr-B-Fe-Al

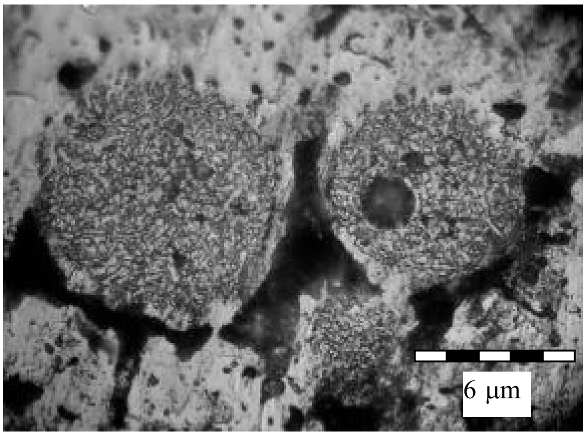


P4 50% Cu + 50% Ni-Cr-B-Fe-Al

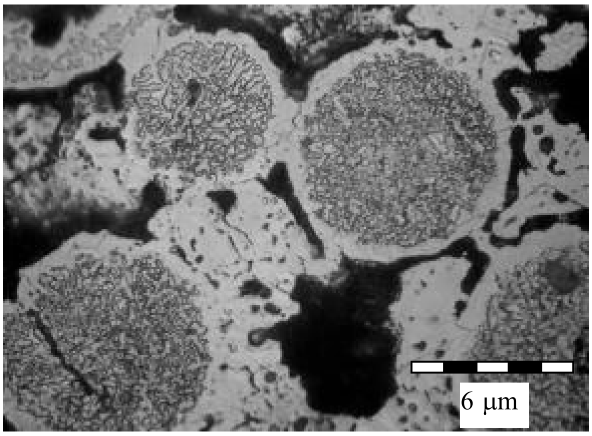


100% Cu

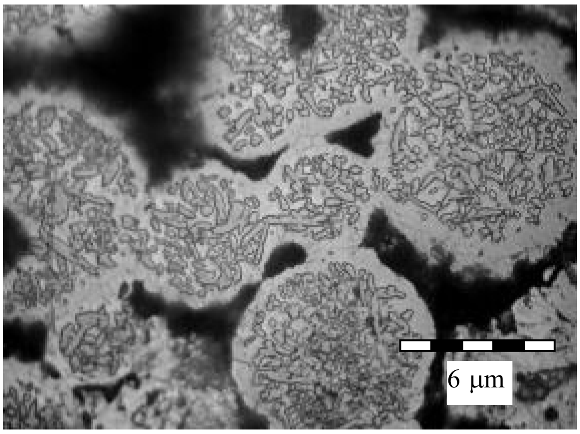
Fig. 4. *Microstructure of powder tablets in Cu matrix reinforced with sintered, unattacked Ni based alloy particles*



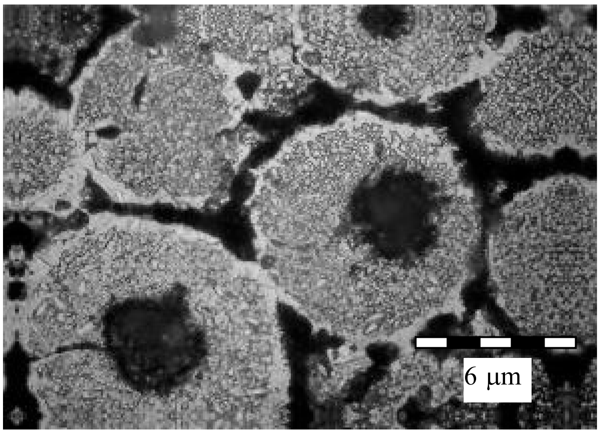
P1 80%Cu + 20% Ni-Cr-B-Fe-Al



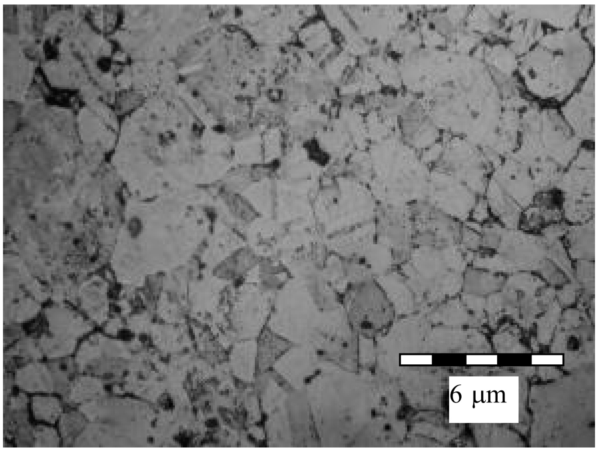
P2 70% Cu + 30% Ni-Cr-B-Fe-Al



P3 60%Cu + 40% Ni-Cr-B-Fe-Al



P4 50% Cu + 50% Ni-Cr-B-Fe-Al



100% Cu

Fig. 5. *Microstructure of powder tablets in Cu matrix reinforced with sintered Ni based alloy particles, sunjected to ferric chloride attack*

Microhardness $HV_{0.1}$ determined on the tablets of sintered powders took the following values: for Ni HV 0.1 = 9350 MPa, and for the Cu matrix HV 0.1 = 793.6 MPa. There is an increasing hardness of the Cu matrix vs the value reported for powder.

The Cu sintered samples and the composite Cu - NiCrBFeAl ones were tested to wear on rotary disk and sanding paper. The results obtained are shown in Table 2, which are the average of three determinations.

Analyzing the Table above we can see that the best reaction to wear is that of samples P1 and P2. The increase in the proportion of powder Ni-Cr-B-Fe-Al by 30% leads to a decrease in wear resistance due to a decrease in the degree of sample compactness when increasing the percentage of included phase and, on the other hand because of their pluking during the test. These particles give rise to additional wear of the surface examined, Fig. 6.

Figures 7 - 11 illustrate 3D images by a Image J software of the surfaces obtained from the abrasive wear test.

Analyzing the following images we see good wear behavior from samples P1 and P2, better than that of Cu sintered sample. In the darker areas it can be observed the absence of reinforcement particles that, running between the sample surface and abrasive, have led to additional wear.

Table 2. *Abrasive wear behavior of sintered powder products*

Samples	Initial mass [g]	Final mass [g]	Mass wear [g]	Wear/length run [g/m]
Cu	1.3057	1.2641	0.0416	0.007183
P1 - 80%Cu + 20% NiCrBFeAl	1.9954	1.9734	0.022	0.003798
P2 - 70% Cu + 30% NiCrBFeAl	2.0273	1.9965	0.0308	0.005318
P3 - 60%Cu + 40% NiCrBFeAl	1.3148	1.2556	0.0592	0.010222
P4 - 50% Cu + 50% NiCrBFeAl	1.3276	1.2736	0.0543	0.009324

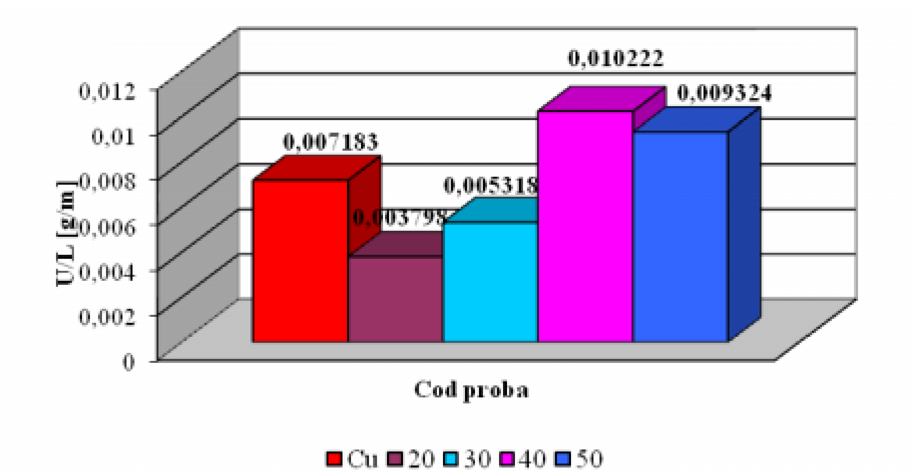


Fig. 6. *Abrasive wear behavior of sintered powder products*

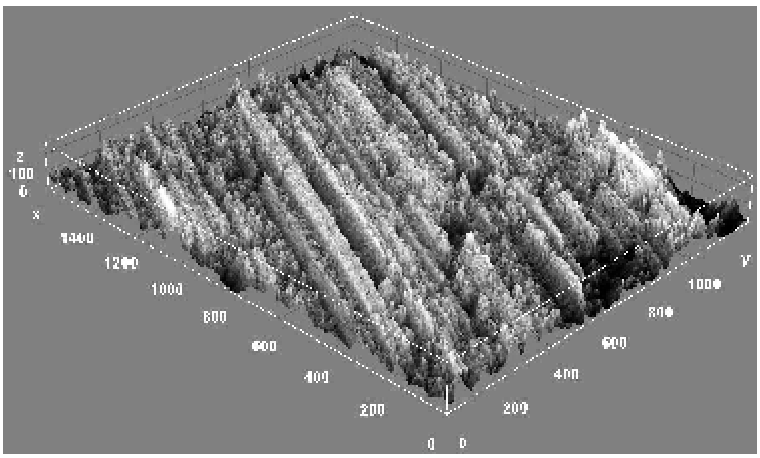


Fig. 7. *3D image of the Cu sample surface subject to abrasive wear*

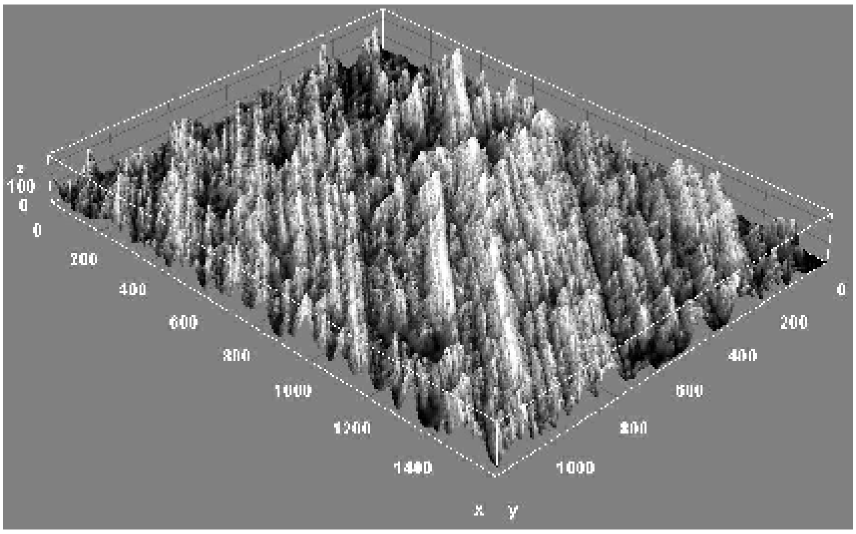


Fig. 8. *3D image of the P1 sample surface subject to abrasive wear*

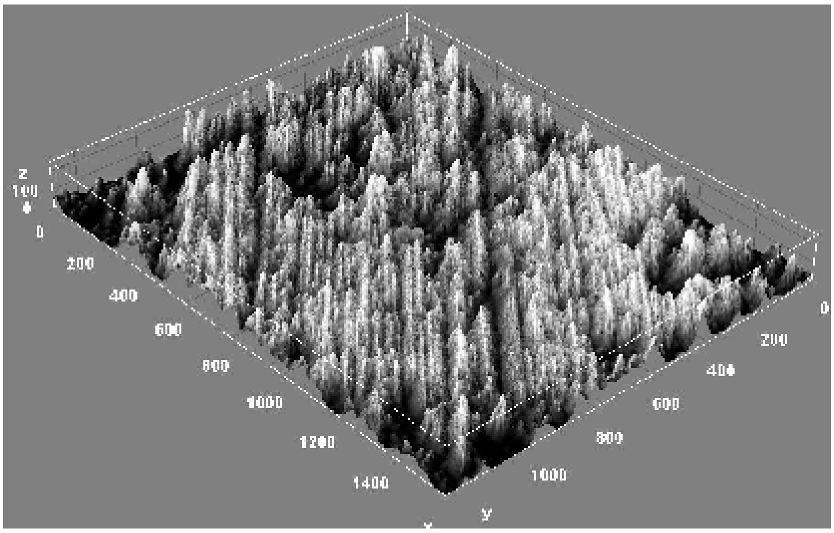


Fig. 9. *3D image of the P2 sample surface subject to abrasive wear*

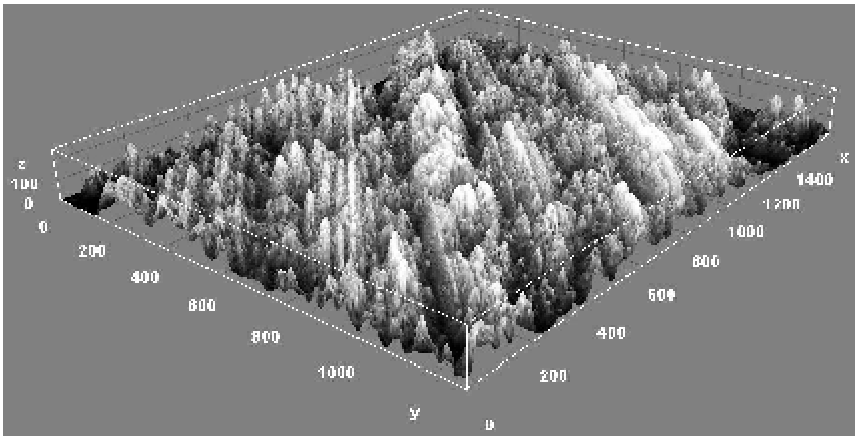


Fig. 10. *3D image of the P3 sample surface subject to abrasive wear*

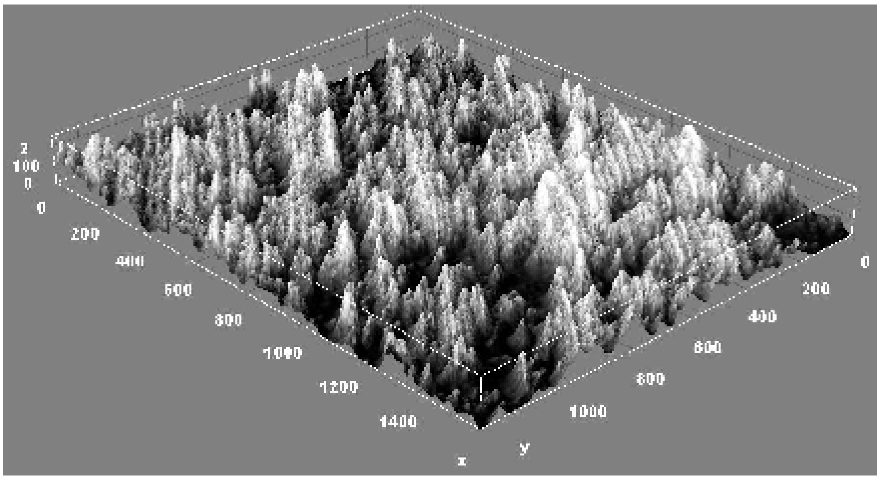


***Fig. 11.** 3D image of the P4 sample surface subject to abrasive wear*

4. Conclusions

❖ obtaining composites reinforced with particles of NiCrBFeAl alloy, revealed the following;

❖ the powder used in experimental research as reinforcing element has spherical shape specific to gas atomization;

❖ the powder used as matrix has an irregular shape caused by atomization in water;

❖ the compaction pressure was 863 MPa;

❖ it has been found that with increased content of NiCrBFeAl powder, of spherical shape, it is increasing the percentage of the inclusion; however there is a decrease in the degree of the sample compactness obtained through different deformation capacity of the powders;

❖ tablets powder sintering at 910 °C, for 90 minutes has reduced their porosity;

❖ microstructure of composites reinforced with Ni-based alloy particles shows a relatively uniform distribution of the included phases;

❖ it is made from Cu matrix consisting of twinned particles and nickel based alloy comprising intermetallic compounds (NiB, Ni_2B, CrB, Cr_3B_4 and FeB) distributed in a very fine martensitic mass;

❖ HV 0.1 microhardness determined on sintered powders tablets for Ni particles was HV 0.1 = 9350 MPa, and for matrix HV 0.1 = 793.6 MPa, with higher values of the powders in their initial condition;

❖ as regards the resistance to abrasive wear it was found that the best reaction to wear is shown by samples P1 and P2 with 20-30% NiCrBFeAl alloy; the increase in the NiCrBFeAl powder proportion over 30% leads to a decrease in wear resistance due to their plucking during the test. These particles give rise to additional wear of the surface considered;

❖ the 3D analysis of the surface resulting from the wear test conducted with Image J software, shows additional wear as a result of the separation of the hard particles from the NiCrBFeAl alloy.

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