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RESEARCH ON THE INFLUENCE OF THE COMPLEMENTARY PHASE PERCENTAGE ON THE PROPERTIES OF COPPER-BASED COMPOSITES

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ABSTRACT

The article presents the method to obtain copper matrix composite with Cu-Al-Fe alloy particles as complementary phase. The samples were obtained by powder metallurgy methods using different percentages of complementary phase: 10, 20, 30, 40, 50% Cu-Al-Fe of average size of 100 μm. After cold pressing at a pressure of 863 MPa samples were sintered at 910 °C for 90 minutes. Characterization of the samples was focused on the microstructural aspects and abrasive wear behavior.

KEYWORDS: powder metallurgy, microhardness, abrasive wear

1. Introduction

The major essential advantage of composites is the possibility to modulate the properties, thus obatining a very large range of materials whose use may extend to almost all technical fields.

In most cases, the composite material comprises a core/base matrix, where the additional/complementary material is dispersed into as fibers or particles, and the main properties that are intended to be obtained in an improved form are: breaking resistance, resistance to wear, density, high temperature resistance, surface hardness, dimensional stability, vibration damping ability [1, 4, 8]. Metal matrix composites have been developed primarily from the need to reduce the weight of machinery and equipment and to extend their service life, a very important objective in the aviation industry or the construction of vehicles. Compared to polymer matrix composites, metal composites are more resistant to high temperatures and are not flammable or hygroscopic. As complementary material, use is made of metal fibers, nonmetal fibers or various particles diversified by their chemical nature, type and size [1, 4, 8].

Copper chosen as matrix has in this case very good electrical and thermal conductivity, as well as the advantage that it can be manufactured/processed easily. It is used in the production of conducting and superconducting composite materials as well as those intended for bearings and filters [1, 4, 8]. Particles, large or small (micro, nano), spherical, flat or of other configuration, are mainly used to produce composites of high resistance to wear, ensuring a lightweight product, outstanding dimensional stability and high vibration damping capacity [1, 4, 8]. Biphasic aluminum bronzes which form the complementary phase particles are known for their outstanding resistance to abrasion, cavitation, corrosion, etc., being used in naval, petrochemical, chemical industry, etc. (bearings, rods, valve, pump impellers, shafts sleeves for anchor, worm and impeller of the compressor, etc.). In the special Cu-Al alloys there are additions of Fe, Ni, Mn, which change the solubility of aluminum in copper and lead to new phases. Iron finishes the grain and improves mechanical and anti-friction properties. Nickel and manganese increase corrosion resistance and contribute to additional hardening by alloying solid solutions [1, 4, 8].

The research undertaken in this paper aimed to achieve, by powder metallurgy methods, copper matrix composites using the complementary phase of Cu-Al-Fe alloy particles. Samples thus obtained were characterized in terms of microstructural and wear behavior.

2. Experimental conditions

To obtain the samples two types of powder were used: one composed of pure copper which has ensured the matrix and another one of Cu-Al-Fe alloy that formed complementary phase, and has the following chemical composition: 9.5%Al; 2.2%Fe;

88.3%Cu. The size of the powder particle Cu-Al-Fe was about 100 μm.

Copper powder has an irregular shape determined by the atomization in water and Cu-Al-Fe alloy powder has a spherical shape due to gas atomization. The micrographs of this powder are shown in Fig. 1.

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

Table 1. *Composition of powder tablets*

Sample code	Composition
A1	90%Cu + 10% Cu – Al – Fe
A2	80% Cu + 20% Cu – Al – Fe
A3	70%Cu + 30% Cu – Al – Fe
A4	60% Cu + 40% Cu – Al – Fe
A5	50%Cu + 50% Cu – Al – Fe

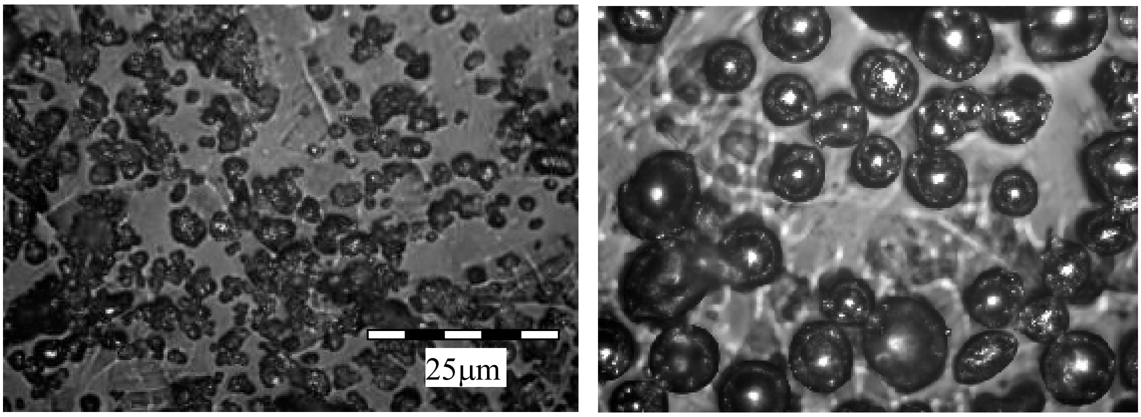
The sample tablets were cylindrical of approximately 8x6 mm.

The compression method used was cold pressing by the universal mechanical testing machine. Powder compacting pressure used was 863 MPa, determined after making several attempts.

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

The 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 inside the cylinder, thus ensuring a protection atmosphere.

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



a. b.

Fig. 1. *Aspect of copper powder – a, and Cu-Al-Fe alloy powder – b*

The microscopic analysis of the powders and samples obtained was performed using a microscope Neophot 2 with computerized data acquisition.

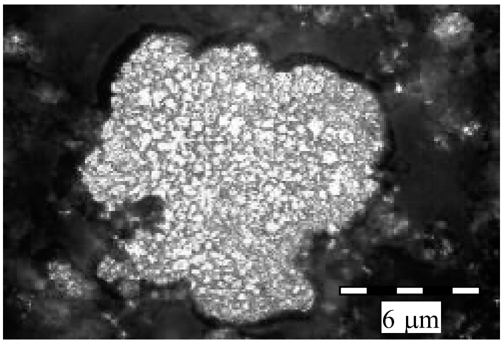
The microhardness measurements were carried out using microdhardness meter PMT 3.

The wear behavior of the samples obtained was studied using the method for determining the mass abrasion wear on a rotating disk. It uses a friction pin/disc coupling, class IV-1. The method involves successively pressing, under the same conditions, the two samples of size 8x6 mm, one of the examined material, the product of composite powders and the other of the material chosen for comparison-sintered copper on a rotating disc covered with sanding paper grit of 120 granulation. 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 perpendicular to the sandpaper to 0.123 N/mm^2 pressure. At a speed disc of 25 rev/min, a lenght of 11.6 m has been run.

3. Results and discussions

For a metallographic study, powders were embedded in a cyanoacrylate adhesive and 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 Cu-Al-Fe alloy powder, the microscopic analysis on samples embedded, polished and attacked with ferric chloride highlights spherical particles and their good compactness. The particles feature a very fine acicular structure of martensite type. Microhardness determined on the polished section of the particles under 100 g load was HV0.1 = 2766.5 MPa.



a.

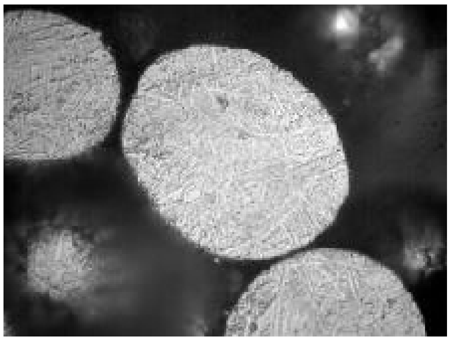

b.

Fig. 2. *Microstructure of Cu powder – a and Cu-Al-Fe alloy powder – b*

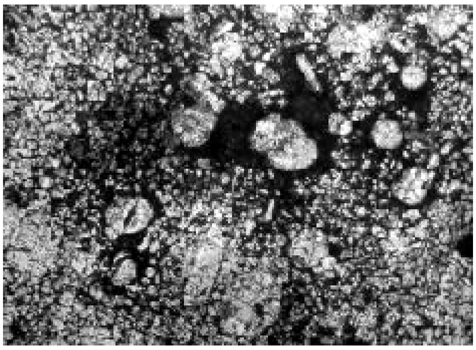
Microscopic analysis of pressed tablets reveals the presence of pores and their shape (Figure 3).

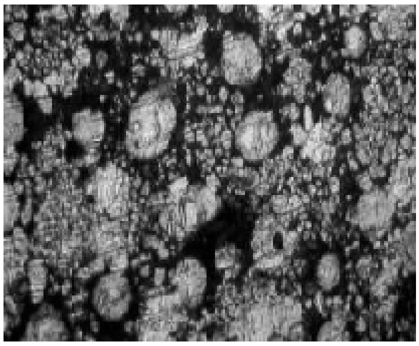
Looking at Fig. 3 it can be seen that with the increasing of the powder alloy Cu-Al-Fe, of spherical shape, there is also an increase in the included phase. However there is a decrease in the sample compactness with increasing percentage of the included phase.

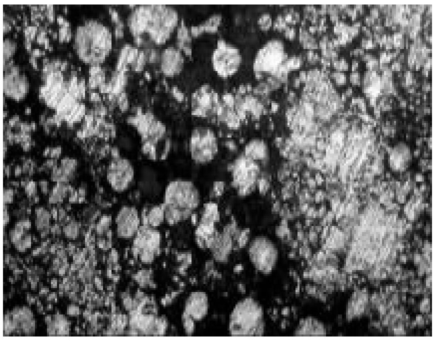
This is due to the different capacity of deformation of the two types of powder.

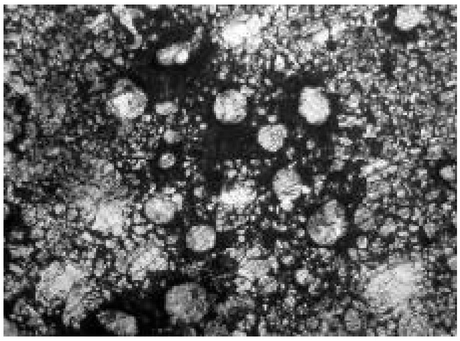
Fig. 4 illustrates the microscopic appearance of the unattacked sintered samples. It is noted their reduced porosity and the higher compaction.

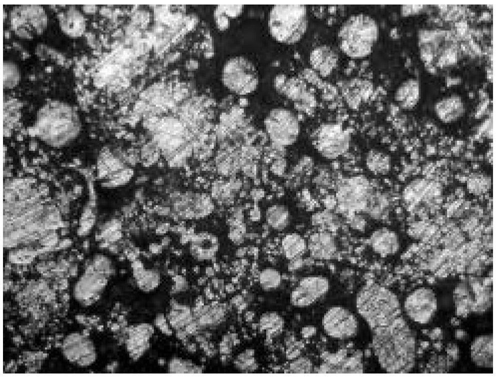
Fig. 5 shows the microscopic appearance of the tablets obtained with Cu matrix reinforced with Cu–Al–Fe alloy particles, sintered and attacked with ferric chloride reagent. It can be seen that their structure consists of Cu showing twinned with particles of Cu–Al–Fe alloy comprising intermetallic compounds Fe–Al.


A1- 90% Cu + 10% Cu – Al – Fe

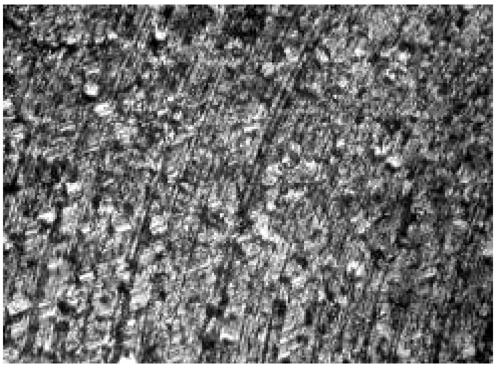

A2- 80% Cu + 20% Cu – Al – Fe


A3 - 70% Cu + 30% Cu – Al – Fe


A4 - 60% Cu + 40% Cu – Al – Fe

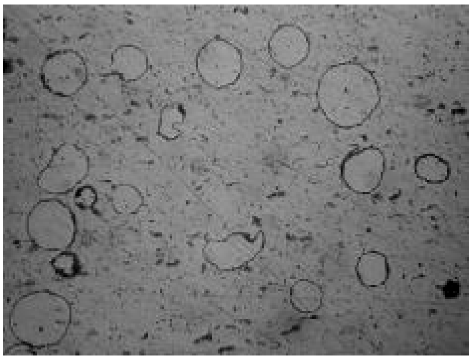


A5 - 50% Cu + 50% Cu – Al – Fe

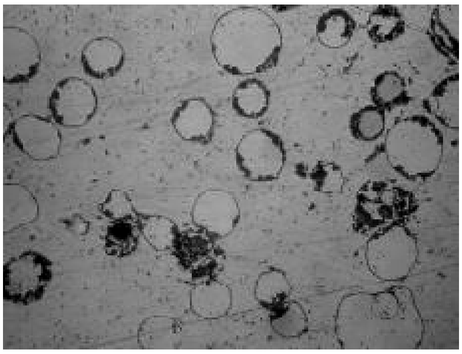


100% Cu

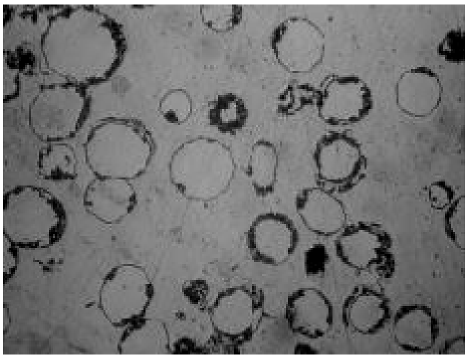
Fig. 3. *Microstructure of pressed powder tablets in Cu matrix reinforced with Cu–Al–Fe alloy particles*



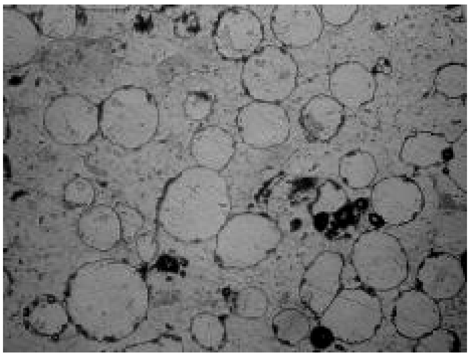
A1- 90% Cu + 10% Cu – Al – Fe



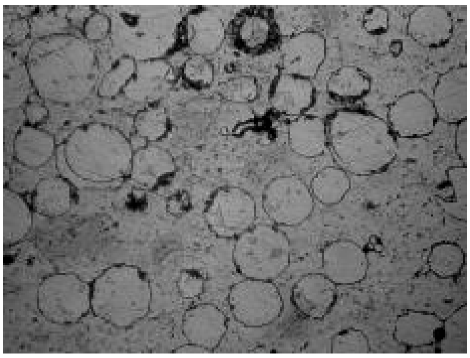
A2- 80% Cu + 20% Cu – Al – Fe



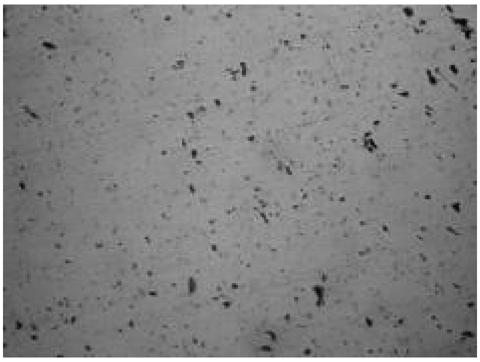
A3 - 70% Cu + 30% Cu – Al – Fe



A4 - 60% Cu + 40% Cu – Al – Fe

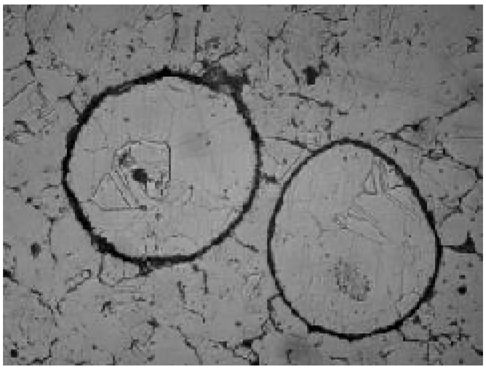


A5 - 50% Cu + 50% Cu – Al – Fe

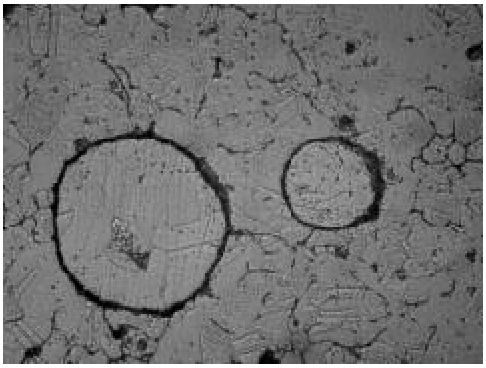


100% Cu

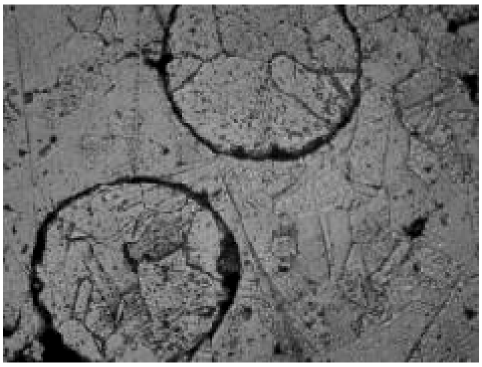
Fig. 4. *Microstructure of sintered, unattacked powder tablets in Cu matrix reinforced with Cu–Al–Fe alloy particles*



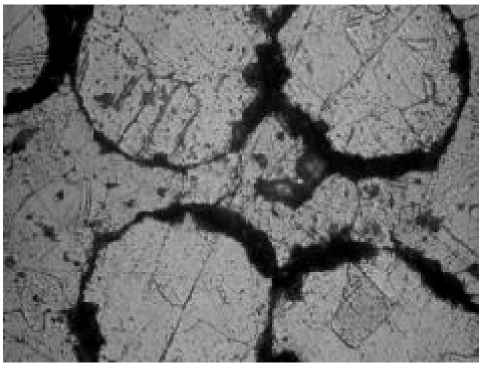
A1- 90% Cu + 10% Cu – Al – Fe



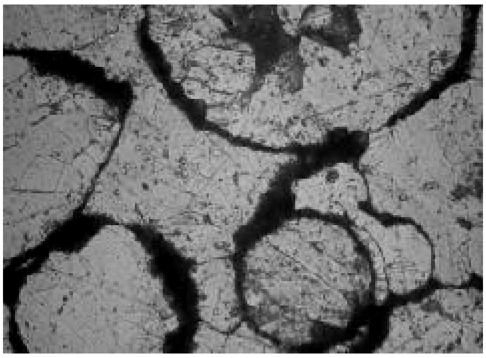
A2- 80% Cu + 20% Cu – Al – Fe



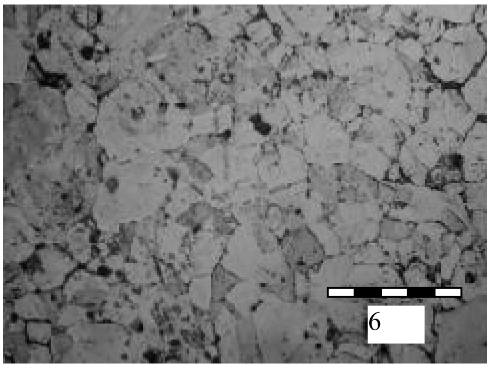
A3 - 70% Cu + 30% Cu – Al – Fe



A4 - 60% Cu + 40% Cu – Al – Fe



A5 - 50% Cu + 50% Cu – Al – Fe



100% Cu

Fig. 5. *Microstructure of sintered powder tablets in Cu matrix reinforced with Cu-Al-Fe alloy particles, subjected to ferric chloride attack*

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	23.7362	23.6964	0.0398	0.003431
A1 - 90% Cu + 10% Cu – Al – Fe	24.1758	24.1434	0.0324	0.002793
A2 - 80% Cu + 20% Cu – Al – Fe	24.1611	24.1249	0.03620	0.00312
A3 - 70% Cu + 30% Cu – Al – Fe	24.1358	24.0761	0.0597	0.00514
A4 - 60% Cu + 40% Cu – Al – Fe	24.085	24.0242	0.0608	0.005241
A5 - 50% Cu + 50% Cu – Al – Fe	24.5141	24.452	0.0621	0.005353

The Cu sintered samples and the composite 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 A1 and A2. The increase in the proportion of powder Cu-Al-Fe by 20% leads to a decrease in wear resistance because of their pluking during the test. This may also be due to the reduced compaction of the tablets when increasing the included phase. These particles, running between the abrasive surface and the surface of the sample being analyzed, give rise to additional wear of the surface examined, Fig. 6. In Fig. 7-12 there are 3D images of the surfaces obtained after the abrasive wear test conducted with an Image J software. Analyzing Figures 7-12 we see good wear behavior from samples A1 and A2, 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.

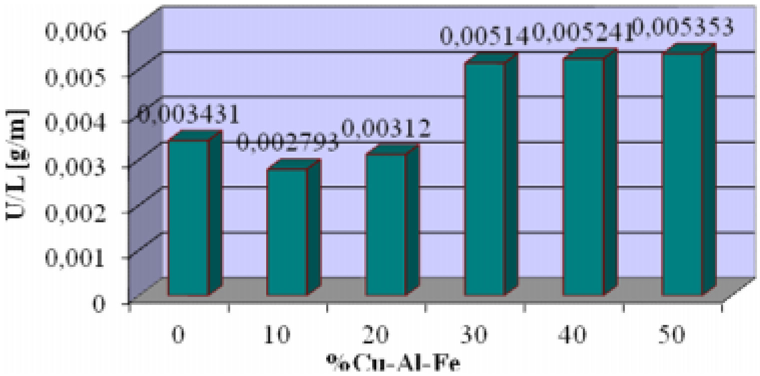


Fig. 6. *Abrasive wear behavior of sintered powder products*

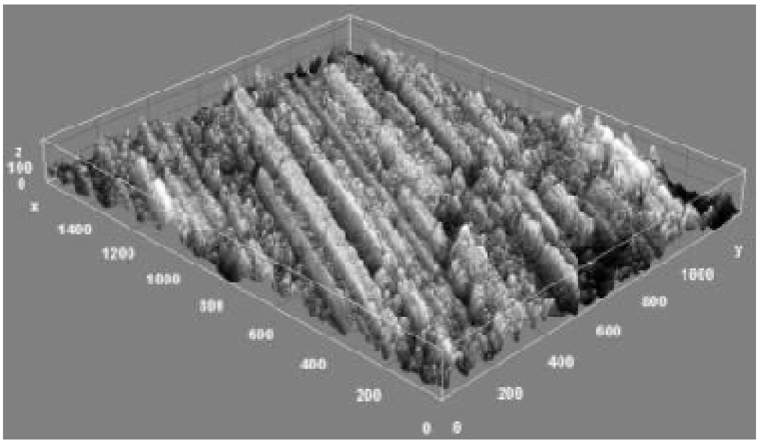


Fig. 7. *3D image of the Cu sample surface subjected to abrasive wear*

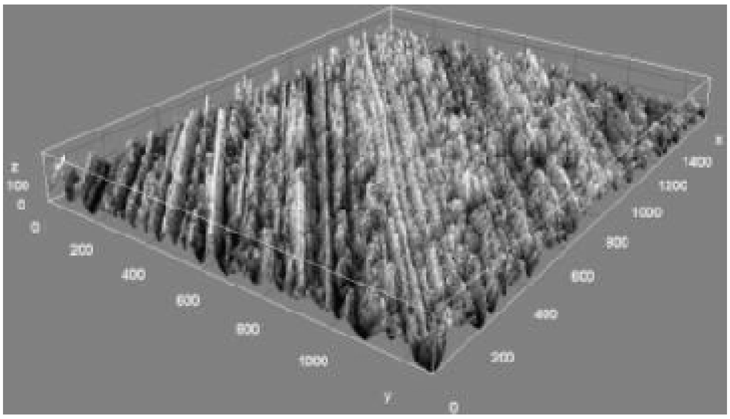


Fig. 8. *3D image of the A1 sample surface subjected to abrasive wear*

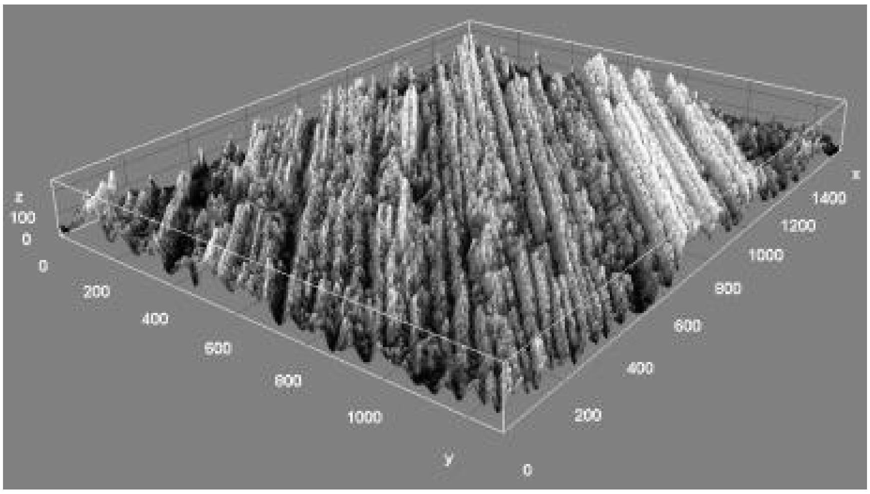


Fig. 9. *3D image of the A2 sample surface subjected to abrasive wear*

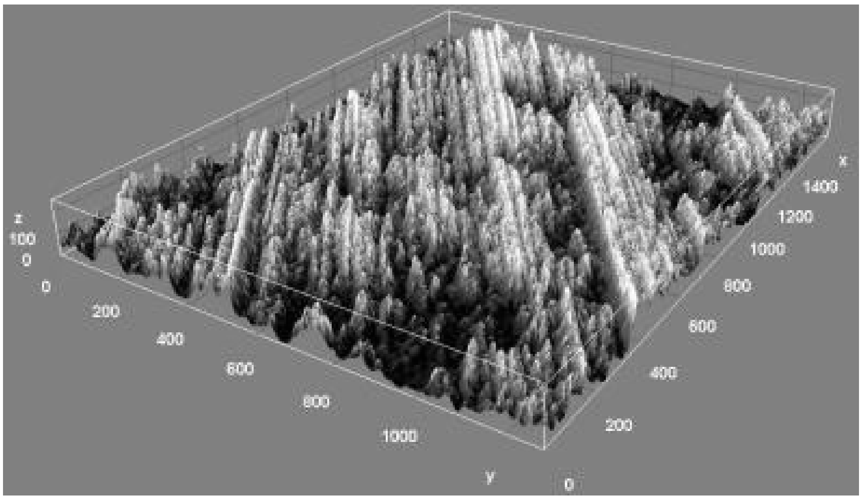


Fig. 10. *3D image of the A3 sample surface subjected to abrasive wear*

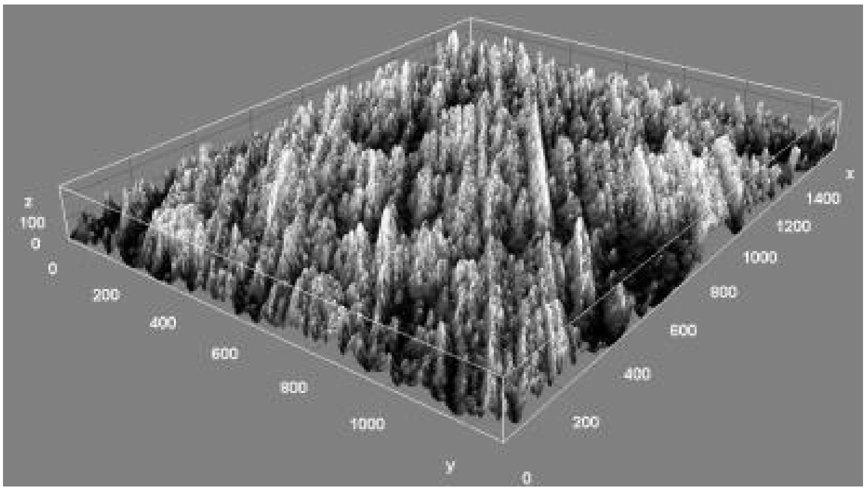


Fig. 11. *3D image of the A4 sample surface subjected to abrasive wear*

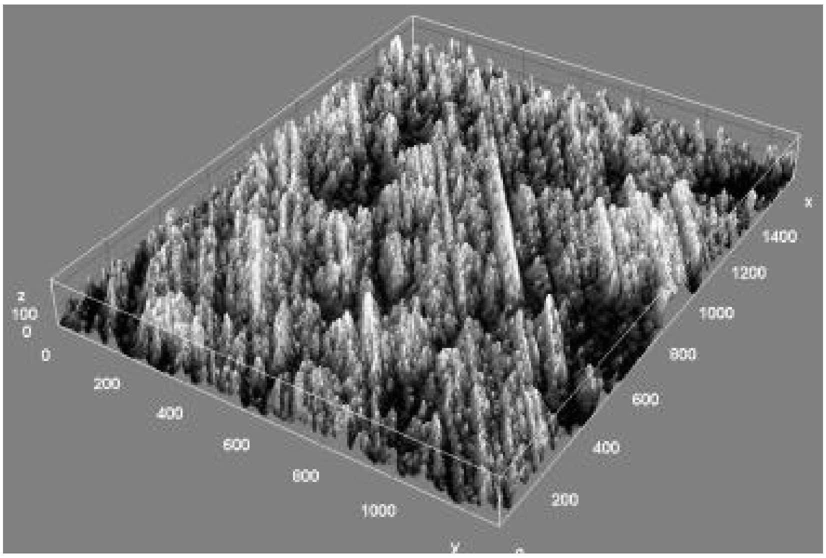


Fig. 12. *3D image of the A5 sample surface subjected to abrasive wear*

4. Conclusion

❖ Obtaining composites reinforced with particles of CuAlFe alloy revealed the following:

❖ The powder used in experimental research as matrix has irregular shape caused by atomization in water;

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

❖ The compaction pressure was 863 MPa;

❖ It has been found that with increased content of CuAlFe 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 Cu-Al-Fe alloy particles show a relatively uniform distribution of the included phases; it is made from Cu matrix consisting of twinned particles and copper based alloy comprising intermetallic compounds ($FeAl_3$) distributed in a very fine mass;

❖ As far as the resistance to abrasive wear is concerned, it was found that the best reaction to wear is shown by samples A1 and A2 with 10 and 20% Cu-Al-Fe alloy; the increase in the Cu-Al-Fe powder proportion over 20% 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 Cu-Al-Fe alloy.

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