Experimental Researches on the Tribological Behavior of Composite Materials Sintered with Copper Matrix

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Abstract. Particulate materials (fillers) can be used within resistance structures only embedded in a support material called a matrix. Most often, in composite constructions, completely different materials can be combined in such a way that their individual properties reach optimum action. Usually, these are pairs of materials to which one has a bearing function, while the other has the purpose of contributing to taking over the moment of inertia. In this paper, a study is carried out regarding the behavior of abrasive wear of some composite materials with the copper matrix, testing the samples obtained by sintering making for different values of the applied load as well as of the relative sliding speed. Starting from the studied literature, fractions of sintered metallic composite materials were developed and having the copper matrix, testing the samples obtained by sintering making for different values of the applied load as well as of the relative sliding speed. Starting from the studied literature, fractions of sintered metallic composite materials were developed and having the copper matrix, which were tested in terms of physical - mechanical and tribological properties. The prepared powders were dosed according to the recipes (Cu 60 ÷ 66.4%, Fe 10%, Sn 7.4%, graphite 3.5 ÷ 25%, SiC 3 ÷ 4%, SiO₂ 9.7%), and the resulting mixtures have been homogenized in order to achieve homogeneous mixtures that will ensure, finally, a good reproducibility of the physical-mechanical properties for the sintered material. For forming, a cylindrical die having a surface area of 2 cm² was used. The working pressures varied in the range 5000 ÷ 6000 daN/cm². The densities obtained for the compressed samples were determined by weighing using the METTLER analytical balance and measured with the micrometer, for volume calculation. The density values for “raw” are in the range 4.47 ÷ 5.01 g/cm³.

1. Introduction
Composite materials are different from ordinary alloys in that they are usually composed of immiscible phases (stable or metastable) over the entire temperature range of the working regime and, under the best conditions up to the melting temperature [1-5].

One of the phases is the matrix, within which the second or a collection of other component phases is contained. Inside the matrix are scattered inclusions in the form of particles, fibers, bi- or three-dimensional grids, eutectic structures etc [6-10].

The matrix is a dispersion medium that has the basic role for any composite material. This base can be metal, alloys, polymers, non-metallic substances, ceramics, etc [11].

One of the simplest schemes illustrating the methods of obtaining composite materials is shown in figure 1 [12]:
Figure 1. Methods of producing composite materials [13].

Hot pressing (HP) is a powder metallurgy (P/M) technique that combines simultaneous pressing and sintering and further offers a simple manufacturing path with many advantages. Currently powder metallurgy is the basis for obtaining the following types of materials [14]:
- metals and alloys used in electrotechnics;
- hard materials based on metal carbides, nitrides, silicas;
- porous sintered materials with self-lubricating characteristics;
- materials and alloys of high purity, with a fine and homogeneous structure, without defects, practically impossible to obtain by melting and casting;
- materials of very varied composition, without taking into account the mutual solubility of the metal-compound constituents of metals (tungsten carbide - cobalt, copper), metal - metalloids (copper - graphite), metal - plastics (iron-bakelite, bronze-teflon).

It is known that the wear is “a progressive loss of material on the surface of a solid body due to the mechanical action, which is in contact and in a movement relative to another solid body, liquid or gas” [15].

Wear is a topic that is quite difficult to understand because there are many factors involved, such as contact geometry, contact temperature, physical and chemical properties of contact body materials,
etc. Wear as a process is often neglected in the design of mechanical systems, which in many cases leads to extremely high costs of maintenance, maintenance. Thus, the design to sustainability without taking into account the effects, the wear and/or the local corrosion, lead to premature and unexpected failures in many technical applications [16].

As a result, in the technical systems such as those in the automotive, aeronautical, medical and naval industries, the wear, corrosion (tribo-corrosion) processes must be analyzed with the highest accuracy [17].

2. Obtaining and testing samples of composite materials with copper metal matrix

On the basis of the above, as well as taking into account the concrete possibilities of providing the raw materials required for the experiments, it has been chosen to obtain the sintered composite materials from the powders of the component elements, which method has the following advantages [18]:

- Raw materials can be purchased relatively easily;
- Using the same raw materials and their proportions in the composition, by varying the parameters of the pressing operations (pressing force) and sintering (temperature and duration) different physico-mechanical properties can be obtained;
- Mixtures made from the powders of the component parts have a very good compressibility, resulting in dense semi-products with high physical-mechanical and tribological characteristics.

The sequence of operations for the experimental program is as follows:

2.1. Experimental program for copper matrix sintered metal composites

a. Composition elaboration: copper base material;

b. Material preparation: drying of non-metallic powders (graphite, SiO₂, SiC) to remove moisture - metal and non-metal powders;

c. Dosage: composite copper base material;

d. Homogenisation: copper base composite material;

e. Pressing: compaction pressure: (5÷6) x10³ daN/cm² - for composite copper base;

f. Sintering: temperature 850 ÷ 920°C - for copper base composite material;

g. Determination of physico-mechanical and tribological characteristics of sintered metal composite materials: density, Brinell hardness, average friction coefficient and wear material.

2.2. Preparation of metallographic samples for structural characterization

Stages of metallographic sample preparation are essentially the same as for any metallic sample: choice of sample type; sampling; polishing; dry grinding; final polishing; attack with specialized metallographic reagents.

In recent years, by performing cutting-edge cutting machines that use very fine abrasive discs, the dry sanding step is almost eliminated, the surfaces being cut at the cutting are extremely fine [19-20].

Metallographic samples were prepared on the Buehler ans Struers apparatus. Thus, sample debiting was performed on a specialized apparatus “Buehler-IsoMet” type (figure 2) having the following general characteristics: engine power - 0.8 KW; speed - 2400 rpm; power of the recirculating pump cooling emulsion - 75 W; cooling tank capacity - 27 liters; abrasive disc diameter - 254 mm.

Sample embedding was done in a Bakelite powder on an automatic hydraulic press “Buehler-SIMPLIMET 2000”, the working parameters being:

- Working pressure: 300 bar;
- Preloading pressure: 10 bar;
- Working temperature: 60°C;
- Heating time (cooling): 8 min.

After incorporation the samples were subjected to the polishing process on a “STRUERS Tegramin” automatic machine with a platter (figure 3).
Figure 2. Cutting machine type BUEHLER IsoMet High Speed Precision Cutter

Figure 3. The "STRUERS Tegamin" sanding machine.

Sintering of samples with Cu-1 and Cu-2 composition was performed in the SAFED tunnel furnace with an "exo" type protection atmosphere, under the following conditions:

- sintering temperature: 850 ÷ 920°C;
- "exo" gas flow: 4 Nm³/h;
- speed of movement of the oven strip: 0.6 m/h.

In order to highlight the shape, size and distribution of the constituents from the experimental samples, qualitative optical microscopy studies and researches were carried out on the samples, using for this purpose an optical metallographic microscope. Recipes chosen for sintered materials with copper matrix are shown in table 1.

| Type of material | Chemical composition (% gravimetric) |
|------------------|-------------------------------------|
| Cu-1             | Cu 66.4 Fe 10 Sn 7.4 Graphite 3.5 SiO₂ 9.7 SiC 3 |
| Cu-2             | Cu 60 Fe 10 Sn - Graphite 25 SiO₂ - SiC 4 |

Table 1. Recipes of metallic materials sintered with the copper matrix.

3. Tribological tests

The sintered samples of copper-based metallic materials have been subjected to complete friction tests at speeds between 8 m/s and 23 m/s and pressures between 4, 8 and 12 daN using an IFTM type friction test machine.

For each recipe, 3 samples were tested, corresponding to their pressing forces. Given that the test results of the three samples had close values, the arithmetic mean of the results was calculated for the material characterization. Also, each determination was repeated at least 2 times.

To wear evaluation, the gravimetric method was used, the samples being weighed, on each METTLER analytical balance, after each determination (figure 4).

Figure 4. Micro analytical balance METTLER Toledo type, series XPR.
Table 2. Variation of friction coefficient and wear intensity for copper matrix sintered metal.

| Type of material | Friction speed (m/s) | Compaction pressure (daN/cm²) | Sintering temperature (°C) | Test pressure (daN/cm²) | Average friction coefficient | Mass/Energy (g/J) |
|------------------|----------------------|-------------------------------|---------------------------|-------------------------|-----------------------------|------------------|
| Cu-1             | 8                    | 5000                          | 850                       | 4                       | 0.45                        | 0.72             |
| Cu-1             | 14                   | 5000                          | 850                       | 8                       | 0.37                        | 0.59             |
| Cu-1             | 23                   | 5000                          | 850                       | 12                      | 0.38                        | 1.71             |
| Cu-1             | 8                    | 6000                          | 850                       | 4                       | 0.47                        | 0.36             |
| Cu-1             | 14                   | 6000                          | 850                       | 8                       | 0.42                        | 1.12             |
| Cu-1             | 23                   | 6000                          | 850                       | 12                      | 0.37                        | 2.66             |
| Cu-1             | 8                    | 5000                          | 920                       | 4                       | 0.43                        | 1.21             |
| Cu-1             | 14                   | 5000                          | 920                       | 8                       | 0.44                        | 1.44             |
| Cu-1             | 23                   | 5000                          | 920                       | 12                      | 0.50                        | 1.68             |
| Cu-1             | 8                    | 6000                          | 920                       | 4                       | 0.43                        | 0.39             |
| Cu-1             | 14                   | 6000                          | 920                       | 8                       | 0.45                        | 1.54             |
| Cu-1             | 23                   | 6000                          | 920                       | 12                      | 0.63                        | 1.25             |
| Cu-2             | 8                    | 5000                          | 850                       | 4                       | 0.44                        | 0.82             |
| Cu-2             | 14                   | 5000                          | 850                       | 8                       | 0.40                        | 0.42             |
| Cu-2             | 23                   | 5000                          | 850                       | 12                      | 0.49                        | 4.04             |
| Cu-2             | 8                    | 6000                          | 850                       | 4                       | 0.45                        | 0.38             |
| Cu-2             | 14                   | 6000                          | 850                       | 8                       | 0.49                        | 0.30             |
| Cu-2             | 23                   | 6000                          | 850                       | 12                      | 0.56                        | 4.72             |
| Cu-2             | 8                    | 5000                          | 920                       | 4                       | 0.48                        | 0.71             |
| Cu-2             | 14                   | 5000                          | 920                       | 8                       | 0.49                        | 0.55             |
| Cu-2             | 23                   | 5000                          | 920                       | 12                      | 0.62                        | 1.71             |
| Cu-2             | 8                    | 6000                          | 920                       | 4                       | 0.55                        | 0.78             |
| Cu-2             | 14                   | 6000                          | 920                       | 8                       | 0.49                        | 0.45             |
| Cu-2             | 23                   | 5000                          | 920                       | 12                      | 0.61                        | 1.34             |

Table 2 shows the mean friction coefficients for each recipe and test variant. For the rapid evaluation of the friction material resource, the wear intensity is expressed by the mass of dislodged material / dissipated energy ratio, also presented in table 2.

The evolution of the coefficient of friction, according to the speed at constant pressure and, respectively, according to the pressure applied to the sample, at constant speed, is shown graphically in figures 5 to 12.

**Figure 5.** The variation of the coefficient of friction, depending on the relative friction speed, at the load applied to the constant samples, for the Cu-1 material, made by pressing at 5000 daN/cm² and sintering at 850°C.

**Figure 6.** The variation of the friction coefficient, depending on the relative friction speed, at the load applied to the constant samples, for the Cu-1 material, made by pressing at 6000 daN/cm² and sintering at 850°C.
Figure 7. The variation of the friction coefficient, depending on the relative friction speed, at the load applied to the constant samples, for the Cu-1 material, made by pressing at 5000 daN/cm² and sintering at 920°C.

Figure 8. The variation of the coefficient of friction, depending on the relative speed of friction, at the load applied to the constant samples, for the Cu-1 material, made by pressing at 6000 daN/cm² and sintering at 920°C.

Figure 9. The variation of the friction coefficient, depending on the relative friction speed, at the load applied to the constant samples, for the Cu-2 material, made by pressing at 5000 daN/cm² and sintering at 850°C.

Figure 10. The variation of the coefficient of friction, according to the relative speed of friction, to the load applied to the constant samples, for the Cu-2 material, made by pressing at 6000 daN/cm² and sintering at 850°C.

Figure 11. The variation of the friction coefficient, depending on the relative friction speed, at the load applied to the constant samples, for the Cu-2 material, made by pressing at 5000 daN/cm² and sintering at 920°C.

Figure 12. The variation of the friction coefficient, depending on the relative friction speed, at the load applied to the constant samples, for the Cu-2 material, made by pressing at 6000 daN/cm² and sintering at 920°C.
4. Conclusions
In the paper, the documentary study we made has allowed us to highlight a series of factors that influence the physico-mechanical and tribological characteristics of the sintered composite materials. Thus, the factors are generally grouped into two categories: technological parameters (compaction pressure, sintering temperature, sintering time), composition of sintered composite materials.

I mention that we have designed, designed and made original molds for obtaining and testing of composite materials, depending on their type (with metallic copper matrix) and the tests to which they will be subjected (determinations of physical-mechanical characteristics as well as of tribological nature). The experiments we carried out involved the elaboration and testing of a number of six metal composite materials sintered with the copper matrix, grouped into two categories (Cu-1 and Cu-2) differentiated by composition and pressure compaction.

The values of the physical-mechanical and tribological characteristics obtained for the experimental materials having the copper matrix are: sintered compressed density: 4.50÷5.00 g/cm³, Brinell hardness: 25÷35 HB, average friction coefficient: 0.35÷0.62 and mass of dislocated material/dissipated energy: 0.1÷4.72x10⁻⁷ g/J.

In Cu matrix compositions, we aimed to produce materials with very high coefficients of friction, at the same time with good absorption capacity and energy dissipation, using fewer constituents in the recipe, so that the technological process is as high as possible simple. At the same time, we studied the influence of friction additions, SiO₂ and SiC.

To quickly and accurately select the composition required for some applications, we plotted the average friction coefficient graphs for different friction rate and sample stresses. Thus, we have concluded that the Cu-2 material has very high friction coefficients, which recommends it for operation in wet environments (oil).

5. References
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