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№ 5230

# Influence of Porosity on Mechanical and Tribotechnical Characteristics of Copper-Graphite Composition Materials

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March 29, 2021

# Influence of porosity on mechanical and tribotechnical characteristics of copper-graphite composition materials

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***Abstract*— The article considers the effect of porosity on the mechanical and tribotechnical properties of copper-graphite and copper + copper-graphite powder composite materials applied in friction joints. It has been found that Cu-C and Cu + (Cu-C) materials obtained after sintering at 18% porosity get the optimal value of hardness and impact viscosity. The highest value of tribotechnical properties has been determined in Cu + (Cu-C) material.**

***Keywords*— Friction joint, antifriction materials, copper-graphite, cold pressing, sintering, porosity, physical-mechanical properties, tribotechnical properties.**

## I. INTRODUCTİON

The production of powder is the first of the main operations in grinding metallurgy. Powders having various properties and names are produced by known methods. This allows the production of details from materials with various applications and properties by the methods of grinding metallurgy. When producing items with new technology using powder, its quality, economic efficiency and other indicators are high. From this point of view, there is a certain need for the production of copper-graphite powder, which has high tribotechnical and electrical properties, thermal conductivity, as well as arc-quenching properties. It is known that an increase in the amount of graphite in the copper-graphite composition leads to a sharp decrease in the mechanical properties of the obtained material [1]. Therefore, there is a need to increase the amount of graphite in the composition without damaging the mechanical properties. It should be noted that copper-based antifriction materials are widely used in friction joints both in mechanical and electrical engineering, and the most interesting parameter that ensures their reliability is porosity. The effect of porosity on mechanical and tribotechnical characteristics allows to estimate the impact viscosity and hardness limits (according to Brinel) in the copper and copper-based copper-graphite materials used in this research.

## II. MATERİAL AND METHOD

During the research, unmixed S11000 copper powder has been used. Sedimentation analysis has been conducted to determine the granulometric composition of S11000 copper powder. The basic principle of the sedimentation method is to determine precipitation rate of a dispersed phase particle that depends on any viscous medium (liquid or gas). The theoretical substantiation and expression of this principle is governed by Stokes' law [2].

Sedimentation analysis has been performed on “Mastersizer-2000” devise. Based on the results of the analysis, the average size for copper powder has been calculated and determined to be 36 μm (αm or = 36 μm) (Figure 1, Table 1).

One of the other components, Cu-C, has been obtained by electrochemical copper plating of the graphitized carbon electrode (GC) material used in the research. Separate copper plating has been carried out for different fractions of graphite powder, which were selected and grinded.

For electrochemical copper plating of graphite, a special copper-electrolysis device has been used applying a mobile-shaped cathode, which ensures the economic efficiency of copper [3, 4].

Elemental analysis has been performed to determine the amount of copper in the composition of electrochemically obtained copper-graphite powder. The analysis has been conducted in the centralized laboratory "Methods of physical and chemical analysis" of ASOIU. МГА-915 type atomic absorption device has been used for element analysis. The working principle of the atom-absorption device is based on the absorption of free element atoms by light energy.

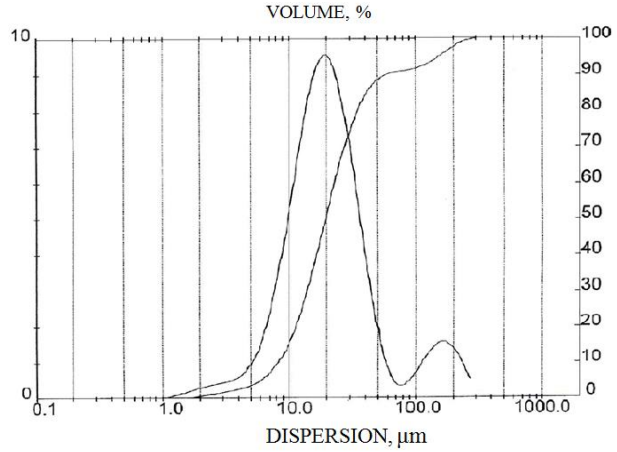


Fig. 1. Sedimentation analysis of copper powder

Table 1

Granulometric composition of copper powder

| Copper grinding size (μm) and volume (%) | | | | | | | |
|---|---|---|---|---|---|---|---|
| size | volume | size | volume | size | volume | size | volume |
| 1,06 | 0,02 | 4,88 | 3,48 | 22,49 | 58,80 | 103,58 | 91,94 |
| 1,24 | 0,08 | 5,69 | 4,54 | 26,20 | 67,55 | 120,67 | 92,92 |
| 1,44 | 0,18 | 6,63 | 6,15 | 30,53 | 75,09 | 140,58 | 94,23 |
| 1,68 | 0,36 | 7,72 | 8,58 | 35,56 | 81,08 | 163,77 | 95,75 |
| 1,95 | 0,60 | 9,00 | 12,12 | 41,43 | 85,41 | 190,80 | 97,29 |
| 2,28 | 0,92 | 10,48 | 17,00 | 48,27 | 88,22 | 222,28 | 98,61 |
| 2,65 | 1,29 | 12,21 | 23,34 | 56,23 | 89,79 | 258,95 | 99,54 |
| 3,09 | 1,72 | 14,22 | 31,07 | 65,51 | 90,55 | 301,68 | 100,00 |
| 3,60 | 2,19 | 16,57 | 39,91 | 76,32 | 90,93 | | |
| 4,19 | 2,75 | 19,31 | 49,37 | 88,91 | 91,31 | | |
| average size – $\alpha_{m\,or}$=36 μm | | | | | | | |

Preparation of the charge composition consisting of the above components has been carried out by the method of mechanical mixing of copper-graphite powder obtained by electrolysis and copper powder of S11000 brand. The amount of components in the charge - copper and copper-graphite powder (for each fraction of graphite) was 90 and 10% (by weight), respectively [5, 6].

Mixing of the charge has been carried out in a special device, in a mixing environment, by weighing the mass fraction of each component separately. After mixing for a given period of time, the total mass of each sample or a large number of samples from the finished mixture is weighed for pressing and after pressing, the mass fraction of briquettes is checked and the density of the pressed samples is determined.

During the research, Yosuzuka mechanical press has been selected for pressing samples and balls. Pressing in this press has been performed with a nominal force of 50 kN. Using a special press mold high-density sliding balls have been obtained at low pressure (100-250 MPa).

To determine the density and porosity of sintered samples, the dry weight of the sample (in air) and the weight of the oil soaked sample in water have been determined. It should be noted that all the above weighing operations are carried out on a weighing device equipped with special equipment. Porosity and density of prepared samples and items are determined in accordance with GOST-18898-73.

Sintering of samples prepared for the research has been carried out in a laboratory condition in СШОЛ-1.1,6 / 12 brand furnace. The structure of the furnace is shaft type. The sintering temperature of samples made of copper-graphite and copper + copper-graphite composition was $85^0$-$1000^0$ C. Sintering time varies within 1-4 hours.

Calibration of sintered balls and samples has been performed on a KD2128 calibration press with the help of a special press mold. One of the main requirements during calibration is to maintain porosity on the friction inner surface.

The effect of the dispersion of the components used on the structure of the composition has also been studied in separate researches [5, 6, 8]. In this case, the microstructure and shape of the sintered samples, as well as Cu-C and Cu + (Cu-C) powders have been studied with the help of a Japanese-made PME OLYMPUS TOKYO optical microscope.

Hardness of sintered and calibrated samples has been measured on ИТ 5010-01 hardness tester. After sintering and calibration, the test has been carried out on a P-10 grinding machine to determine strength limit of the ball in compression and tension.

Antifriction characteristics have been studied in a МИ-2 machine with a specific pressure of 0.8 kg g/cm$^2$ and a sliding speed of 2.0 m / s. 07X16H6 brand steel has been chosen as the material of the counter-samples.

The selected technological regimes and the properties of the abrasives used in the charge provided samples with a porosity of 10 to 30%. Among the samples with a porosity of more than 16%, the largest precipitation was in pure copper powder. This can be explained by the fact that the powder has different dispersions and the copper powder used is <70 microns. A relative increase in volume has been observed during the sintering of samples of Cu-C and Cu + (Cu-C) powder materials with a porosity of <23%, containing -250 + 160 μm graphite powder. Such an increase has also occurred in pure copper powder material. However, in samples made of copper powder, the volume change depending on the porosity was ± 1.2%, while in Cu-C and Cu + (Cu-C) powder charge materials it was ± 1.5%. It would be more accurate to explain the reason for the increase by the solubility and adsorption of gases in the powder. In addition, the formation of large water molecules during the reduction of copper oxide (with hydrogen) in copper powder can also cause this.

The determination of temporary strength in such materials, its theoretical substantiation has been completely studied in various researches [7, 8].

In the study of the dependence of hardness and impact viscosity on porosity, it has been found that with the porosity increase in these materials the impact viscosity decreases (Figures 2 and 3). This is due to the reduction of inter-particle contact areas.

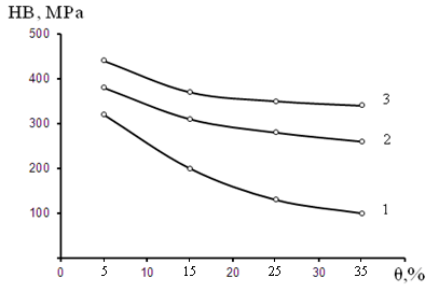


Fig. 2. Porosity dependence of hardness: 1 - copper powder, <70 μm; 2 - Cu-C, $\alpha_m$ = (- 250 + 160) μm; 3 - Cu + (Cu-C), $\alpha_m$ = (- 250 + 160) μm

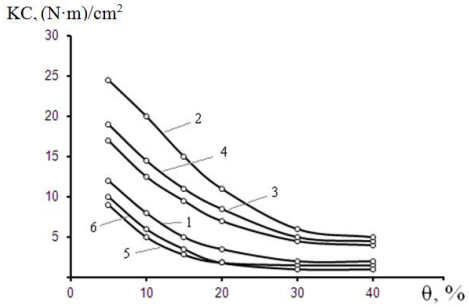


Fig. 3. Dependence of impact viscosity on the porosity: 1 and 2 - copper powder; 1 - <70 μm, 2 -> 70 μm; 3 and 4 - Cu-C and Cu + (Cu-C), $\alpha_m$ = (-250 + 160); 5 and 6 - Cu-C and Cu + (Cu-C), $\alpha_m$ = (- 160 + 63)

It can be seen from both graphs that the hardness and impact viscosity have higher values in the samples made of large-size grinded chips. Although the impact viscosity of copper has a high value depending on the porosity, it is characterized by a relatively low value for hardness. It can be assumed that such a change in the dependence of the impact viscosity and hardness on the porosity is due to structural features. Although the impact viscosity of materials obtained from the grinding of copper graphite and the addition of copper graphite to the copper base is relatively lower than in pure copper, but it is superior in terms of hardness. Achieving a high value of hardness is very important for a friction surface layer.

Figure 4 shows the results of the fractography analysis of the samples after testing using the TESCAN VGA3 electron microscope. As it can be seen from the figure, the porous structure is prominent in all samples (especially in samples with large particles). The study of copper and copper-graphite composite material shows that the internal and intergranular pores differ from each other. Although such a difference is evident in large fractions, their contact areas are larger. Large contact areas have been found in samples made of Cu-C and Cu + (Cu-C) charges. The optimal value has been obtained by copper plating of coarse-grained graphite from graphite carbon electrode material. Here, the optimal variant of adding Cu-C to the copper base has been obtained in 20-25% amount of copper graphite. As the porosity (after sintering) is 18%, the impact viscosity and hardness of this abrasive material are considered to be more optimal.

When determining the impact viscosity in copper samples (Fig. 4, a, b), micropores form, grow and appear as hole-shaped in the inter-particle contact areas during the refraction of the sample. This process is fully confirmed by the presence of a hollow (hole-shaped) fracture in the area of inter-particle contact.

In the copper-based composite material Cu + (Cu-C), the presence of copper base is <70 μm, the added Cu-C-containing copper graphite fractions, as well as the large contact area of the particles prevent the formation and development of this type of micro hole.

The dependence of the impact viscosity on the fraction size of copper graphite and copper powders is explained by the larger inter-particle contact area. The addition of copper graphite to the copper base directly solves the problem. If a smaller porosity is obtained, the impact viscosity may be in the range of 20-25 N • m/cm$^2$.

The hardness of the material made of pure copper powder does not depend on the granulometric composition of the powder and decreases slightly (several units) as the porosity increases.

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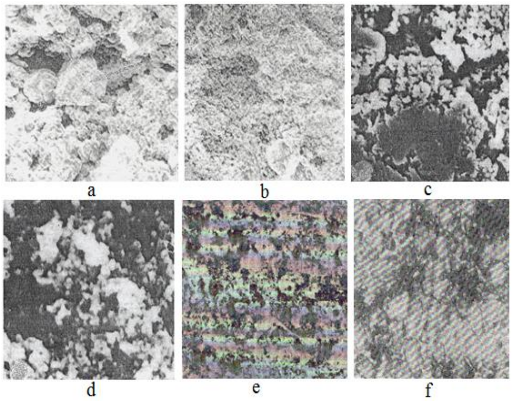


Fig. 4. Fractography of the refractive appearance of copper (a, b) and copper-based powder composite materials (c, d, e, f) with porosity of 18% (a, c, e) and 16% (b, d, f), x1500 : a -> 70 μm; b - <70 μm; c, d – αm = (- - 250 + 160) μm; e, f - αm = (- 160 + 63) μm

During the friction process, the copper particles gradually move to the surface of the counter sample and form a stick. As a result, a dark black coating (or layer) is found on the friction surface. The thickness of this layer is approximately 15 microns, taking into account the roughness. The appearance of the friction surface does not depend on the size of the abrasion and the porosity.

The surface cleanliness of the counter sample is determined by the porosity of the copper-powder. The coefficient of purity (Rα) after friction of copper grinding material with porosity of 10 and 35% is 7.5 and 0.4, respectively. An increase in purity with a decrease in porosity on the surface of the counter sample is probably due to an increase in hardness.

Studies of Cu-C and Cu + (Cu-C) friction composite materials in the friction process show that what happened to the copper friction material at the beginning of the process was similarly observed in these samples. During the process, copper graphite in samples made of Cu-C and Cu + (Cu-C) materials undergoes a number of changes after friction. The copper layer has parts which can decompose and do not decompose during friction. The gradual presence of graphite in the friction improves the antifriction properties, as well as the durability of the material. The formation of a lubricating layer on the surface of the counter sample reduces the roughness and increases the cleanliness of the friction surface of the copper-graphite material. Among these samples, the highest purity sample was found to be in Cu + (Cu-C) material.

When the size of these abrasives is increased and the porosity is more than 20%, the intensity of wear increases in all three powder materials. Here, the best results are obtained with a composite material containing Cu + (Cu-C) (Figure 5).

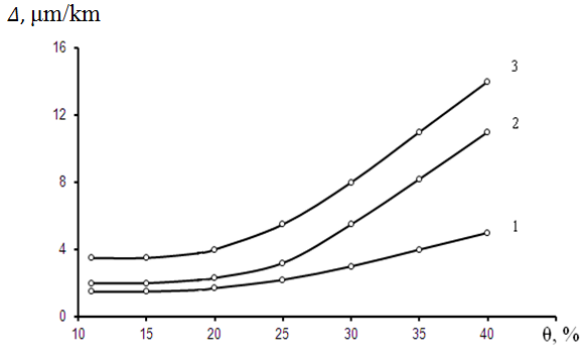


Fig. 5. Dependence of wear intensity of copper and copper-based powder materials on porosity: 1 - Cu + (Cu-C); 2 - Cu-C; 3 – copper powder

Wear particles are formed by cracks caused by friction and increasing stress concentrators. Copper powder involves a pore such as a stress concentrator. Although this principle retains its force at the beginning of friction, it cannot be amplified by the effect of graphite. To explain the dependence shown in the figure, it would be more accurate to study the structural transformation in the subsurface layers under the influence of friction.

In order to study the structural transformation, a sample made of -200 + 160 fraction has been taken from the surface layers after friction and wear. Since the increase in wear intensity was observed at a value of 30% of the porosity, microstructures at different distances from the friction surface have been studied in a sample made of this porous material. Copper-based copper-graphite, which is considered more optimal, has been used as the abrasive material. The copper content of graphite was 25%. Surface friction of such abrasive composite material indicates that the friction occurs under the influence of weak plastic deformation compared to copper abrasive material. However, the process of gradual closure of pores in the surface layer does not occur here. In samples taken from pure copper powder, the pores disappear or close as a result of deformation. The degree of deformation increases as the friction surface area approaches. This is due to the gradual decrease and reduction of the number of pores. From this point of view, the cross-sectional area of the "steam channels" gradually narrows, and as a result, the pore walls meet, and then turn into microcracks. The depth of the deformation zone of copper-graphite samples is 150 microns, while in copper samples this depth is 200-250 microns. Such a small depth of deformation zone is due to the fact that the composition of the powder material Cu + (Cu-C) consists of copper powder and copper graphite <70 μm.

Changes in the porosity and abrasion dispersion of a material containing Cu + (Cu-C) do not have a significant effect on the value of the coefficient of friction, which varies in the range of 0.09–0.18. Friction coefficients were set at 0.30–0.45 for copper powder and 0.10–0.25 for copper graphite (Cu-C). It can be concluded that the structure and composition of the outer surface layer must be taken as the main factor influencing the value of the coefficient of friction.

The dark black coating formed on the surface during the friction process fills and identifies the roughness on the friction surface and has a certain separation limit on the copper base. This can be explained by the relatively high hardness on the surface of samples containing copper graphite and Cu + (Cu-C), low plastic deformation and the effect of graphite.

Studies show that the coating layer on the surface contains copper, graphite, oxygen, iron, chromium, nickel (copper samples do not contain graphite). In some areas of the samples, the oxygen content is even increased to 36%. This confirms the presence of an oxide layer ($Cu_2O$) on the surface in the form of a film. 36% of the oxygen content was found only in copper samples. The relatively high hardness of the surface layer of the samples may be due to the combined effect of the elements entering the counter-sample and the wearing particles of copper that disperse during sintering. In addition, the effect of high local temperature and pressure on the counter-sample and powder copper samples in the formation of this oxide layer is great. Compared to Cu-C and Cu + (Cu-C) powder composite materials, it was observed that the friction coefficient of grinding copper has a relatively high value regardless of the porosity. It has been shown that a very thin surface layer in the porosity range of 10-35% has a submicrocrystalline structure and does not differ in phase composition. Thus, since the porosity of the copper samples does not affect the structure of the surface layer, the coefficient of friction does not depend on the porosity.

## Conclusions

The use of samples made of Cu + (Cu-C) composite material reduces the intensity of plastic deformation, which leads to the disappearance of pores in the surface layer. The inclusion of the formed submicrocrystalline solid graphite, which consists of the main elements of the friction pairs and oxygen, has a strong effect on the antifriction properties. It has been found that when the porosity increases from 10 to 35%, the wear resistance of the copper decreases, and this does not affect the coefficient of friction. In other materials containing Cu-C and Cu + (Cu-C), the wear resistance begins to decrease after 20% porosity and the coefficient of friction increases after 25% porosity. In general, Cu + (Cu-C) material has the best tribotechnical properties.

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