The technology of obtaining copper-ferrochrome composite material

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Abstract: *The research of the technology of obtaining new copper-ferrochrome composite material has been done. The results of its structure and properties analysis are presented. The material structure consists of the copper base, non-dissolved coarse inclusions of ferrochrome, diffused zones, forming around these inclusions and phases, having formed in the place of completely dissolved inclusions of ferrochrome fine particles. The material has good mechanical properties and a high wear resistance due to the formed solid solutions of the carbides in the copper.*
Keywords*: COMPOSITE MATERIAL, COPPER, FERROCHROME, PRESSING, SINTERING, STRUCTURE, CARBIDES, HARDNESS, STRENGTH, WEAR RESISTANCE*

1. Introduction

To manufacture antifriction and construction details the alloys on the copper base – bronze and brass – are widely used. The products from these materials are obtained by casting and pressure treatment of compact materials [1] or from metallic powders by pressing and sintering [2]. The mechanical properties of the powder materials depend on the chemical composition, obtaining technology, porosity, dispersion of the initial powder components: having the same porosity, they increase with the decrease of the size of the powder particles. The promising tribotechnical materials are powder bronzes, being alloyed with chrome [3]. The disadvantage of cast and powder bronzes is their comparatively low carrying ability and a high price for the tin. Due to this, the development of the technology for obtaining composite material on the base of copper, and being reinforced by the dispersed inclusions, is of great interest.

2. Premises and means for the problem solution

The works [4, 5] present the results of researching the properties of the composite materials tin bronze – ferrochrome FC 800 with the particles' size of 40-50 μm. It is ascertained that during the sintering of the samples with low porosity the more increase in the sizes occurs the more the content of Fe-Cr is, the highly porous samples undergo the shrinkage. At the porosity of 15 % the increase of Fe-Cr content up to 3 % leads to the increase of the yield point and to the decrease of the unit elongation. With the further increase of Fe-Cr content the strength and the plasticity decrease. The composition, containing 5% of Fe-Cr, has the maximum tribotechnical characteristics. The researches have shown that to work in the loaded units it is efficient to use pore-free composite material on the copper base, containing ferrochrome and a solid lubricant, i.e. graphite. Such material can be obtained by the technology of the powder metallurgy which includes the following actions: mix material preparation, pressing the porous workpieces, sintering, compaction up to the pore-free state. Moreover, considering a high cost of the copper powder, it is reasonable to use a cheaper copper powder, got from the industrial waste.

The given paper presents the results of researching the structure and properties of the composite material on the copper powder base, obtained from the copper electric conductor waste, mixed with ground ferrochrome.

3. The problem solution

The samples for the research were made from the mixture of copper powders 93.8 %; ground ferrochrome of FC-400A brand 5 % (ISO 5448-81) and 1.2 % fine-dispersed graphite. The ferrochrome and the copper powder were sifted through the sieve with the cells of 80 μm.

According to the conducted chemical analysis, the ferrochrome contains 54.97 % Cr, 3.8 % C, the rest is iron. When introducing the mix material of FeCr – 5%, C – 1.2 %, Cu – 93.8% into the composition the content of the components in the mixture will be as follows: Cr – 2.75%, Fe – 2.06% and C – 0.19%. The density of the powder pore-free composite material, calculated by the additivity formula, is 8.46 gr/cm^3.

The workpieces with the dimensions 12.6x54.3x10.0 mm and 10% porosity were pressed from the obtained mix material in the moulds in the hydraulic press. The lubricant – molybdenum disulfide – was applied on the matrix surface. The mass of the powder sample for pressing workpieces, which was calculated considering the mass loss during the pressing and sintering, was 53.7 gr. The pressing pressure was taken as equal to 600 MPa. The rated force of the pressing was 410.5 kN.

The pressings were sintered in the synthesis gas environment in the furnace according to the stepped regime with equalizing during 25 minutes at the temperatures 200-220^{o}C and 300-320^{o}C, the growth up to 400-420^{o}C, equalizing during 90 minutes, heating up to the temperature 500-520^{o}C and 600-620^{o}C with the equalizing of 25 minutes at each temperature, the rise up op the temperature of 900-920^{o}C and equalizing of 90 mins.

The sintered workpieces were stamped in the closed stamp with the cross flow of the metal with a fringe for 90 ^{o}, and then were sintered in the same environment at the temperature of 780-820^{o}C for 30 minutes. The stamping pressure was 800 MPa, and the stamping strength was 535.7 kN. The samples for tension testing with the diameter 5 mm and the initial calculating length was 25 mm were turned from the prismatic samples.

While doing the researches the visual examination was done, the mass and the sizes were controlled. The samples for pressing workpieces were weighed on the laboratory scales with the precision up to 0.05 gr, the mass of the produced samples was determined by weighing on the electronic scales with the precision up to 0.0001, the density was calculated.

The hardness was measured by Brinnel hardness test with the ball of 5 mm under the load of 2452 N. The structure was researched on the metallographic sections before the etching, and after the etching in the iron acid the structure was studied by the microscope MIM8 (МИМ8). The microhardness was determined by the device PMT-3 under the load of 200 N.

4. Results and discussion

The visual examination of the samples after pressing, sintering and stamping showed that cracks, tightening, fissures and other defects of the shape were absent.

The composite has a high compression rate. The density of the compressed workpieces was 7.74-7.59 g/cm^3, this corresponds to the calculating porosity 6-10%. However, during sintering there was a growth of the samples, it is explained by the "hydrogenous disease" of the copper. The decrease of the sizes was 1.3% in length, 1.6% in the width, 8.7% in the height. As a result the porosity increased up to 19-20%.

The density of the stamped samples was 8.44 gr/ cm^3, i.e. practically pore-free material was obtained (the calculating porosity does not exceed 0.4 %). The hardness of the material after stamping was HB 68-72. As a result of annealing the sizes and the density of the samples did not change, while the hardness decreased and was HB 42-47. The limit of the strength under tension was 117 MPa, the unit elongation was 1.6 %, it is lower than of the chrome-tin bronzes.

To determine the wear resistance the tests were done on the friction machine according to the scheme "disc-block" of the tested material and a known antifriction powder material on copper base (APMCP), containing 5-10.5% of chrome [4]. The counterbody from steel 45 had the hardness HRC 43. The pressure on the samples was 5.25 MPa, the rubbing speed was 2.1 m/s. Before the tests the samples were weighed on the analytical balance, and were well-lubricated, the lubrication consisted of molybdenum disulfide and machine oil. During the test the lubrication was not supplied to the friction zone. After the test end the samples were washed out by acetone, then dried and weighed again. The wear resistance was evaluated by the intensity of the wear:

(1), $$I = \frac{W}{L},$$

where:

W is the value of the linear wear of the friction samples;

L is the friction length of the given sample, the friction length corresponds to the wear W , m.

While determining the wear by weighting, the value of the linear wear W was determined by the formula:

(2), $$W = \frac{\Delta G}{\rho A},$$

where:

ΔG is the change of the samples' mass under the test, kg;

ρ is the density of the worn out materials, kg/m³;

A is the contour contact area of the samples, m².

The friction length was defined by the ratio:

(3), $$L = \pi d N ,$$

where:

N is the amount of full disc turns (determined by the counter registration of the turns' number on the friction machine);

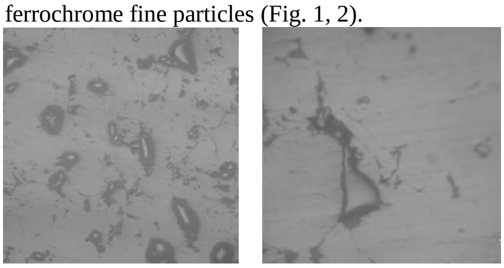
d is the diameter of the roller, mm.

As it is evident from the tests' results, presented in Table 1, the wear resistance of the researched material is by 1.9 times higher and it wears out the counterbody by 1.7 times faster.

Table 1: *The results of the trial on the friction machine*

Material	The intensity of the wear, micron/km	
	Counterbody	The tested material
Antifriction powder material on copper base (APMCP)	$5.22{\cdot}10^{-6}$	$2.62{\cdot}10^{-8}$
The tested one	$2.98{\cdot}10^{-6}$	$1.39{\cdot}10^{-8}$

The structure of the obtained material is heterophase, and consists of the copper base, non-dissolved coarse inclusions of ferrochrome, diffused zones, forming around these inclusions and phases, having formed in the place of completely dissolved inclusions of ferrochrome fine particles (Fig. 1, 2).



a b

Fig. 1. *The microstructure of the non-etched samples from the copper-ferrochrome composite material: a – 320x, b – 500x*

According to the chemical analysis, ferrochrome contains 3.8 % of carbon. Apparently, it contains a great amount of carbides of the following type $(Cr, Fe)_7C_3$ and $(Cr, Fe)_{23}C_6$. Besides, it may contain solid and fragile σ-phase (intermetallic compound FeCr). The carbides $(Cr, Fe)_7C_3$ and $(Cr, Fe)_{23}C_6$ have a complex crystalline lattice. Such carbides easily dissolve in the steels under heating in $\gamma - Fe$ [6]. The information about dissolubility of carbides in the steel is not found in the reference literature. It is possible to presume that carbides dissolve in the copper well due to the fact that $\gamma - Fe$ has a face-centered cubic lattice with the period 0.3645 nm and the atomic radius 0.1411, the copper also has a face-centered lattice with the period 0.3608 nm and the atomic radius 0.1413.

Table 2 presents the results of measuring the microhardness of different phases of the composite material. The microhardness of powder copper without alloying additions is given for comparison. As it is seen, the hardening of the copper base happens. It is possible to presume that the copper hardening takes place due to the formed solid solutions of the carbides in the copper. The structure of the diffused zone can be presented by a mechanical mixture of solid solutions on the basis of copper and carbides.

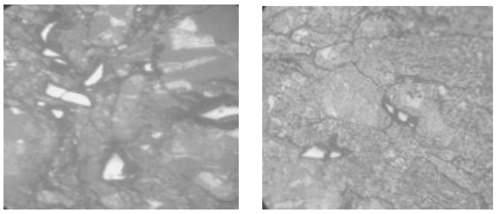


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Fig. 2. *The microstructure of the samples from the copper-ferrochrome composite material after etching: a – 320x; b – 500x*

Table 2. *The results of the microhardness' measurement*

Material	Limits of the microhardness values, MPa	Average value, MPa
Unalloyed powder copper before annealing	748-944	845
Unalloyed powder copper after annealing	228-412	345
Copper as the base of the composite material	616 – 719	706
Diffused zone	1463 -1738	1553
Ferrochrome in the composite	10478 – 19855	14955

The carried out researches have demonstrated that the copper-ferrochrome composite material has very good mechanical properties and a high wear resistance. Such material can be used for manufacturing details, working in the friction units. The obtained results also indicate that further enhancement of the composite properties is possible due to the use of more dispersed ferrochrome particles, and also due to the thermal material processing, i.e. hardening and aging.

5. Conclusion

The research of the new copper-ferrochrome composite material has been done. The material structure consists of the copper base, non-dissolved coarse inclusions of ferrochrome, diffused zones, forming around these inclusions and phases, having formed in the place of completely dissolved inclusions of ferrochrome fine particles. The material has sufficient strength properties and high wear resistance. The reason for this is hardening of the copper due to the formed solid solutions of the carbides in the copper.

6. References

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