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Development of an aluminium matrix composite material with the addition of dispersed particles of graphite, operating under conditions of increased friction

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Abstract. The paper proposes a method for obtaining a composite material based on aluminum with the introduction of dispersed particles of graphite powder at the stage of obtaining samples. On the obtained experimental samples, which are cylinders with a diameter of 20 mm. and a height of 10 mm, and the properties of this material, namely hardness and wear resistance.

1 Introduction

Overcoming friction resistance absorbs 20-25% of the generated energy worldwide. Antifriction materials are widely used for the manufacture of bearings, guides, supports, hinges, sealing devices and other tribocouple elements and are designed to reduce losses in friction units and increase the efficiency of various machines. Antifriction materials must combine a certain set of mechanical, thermophysical and tribotechnical characteristics, which composites most fully possess. As antifriction composite materials, powder compositions based on copper and iron, impregnated with liquid lubricants (oils) or filled with solid additives (graphite, molybdenum disulfide, polymers), are widely used, for the formation of which methods of powder metallurgy, surfacing, gas-thermal spraying, electrochemical deposition are used. and others [1]

The modern development of technology is moving along the path of increasing the load-speed modes of operation of tribo-coupling units, which stimulates the direction of creating new anti-friction composite materials with improved properties. A promising direction in the creation of antifriction composite materials is the development of composites containing graphite powder in their composition. [6]

The main technological problem in the formation of a dispersion-strengthened alumina-matrix composite material with a carbon filler is to ensure the wettability of the filler by the matrix. The successful distribution of particles in the matrix should lead to an increase in certain mechanical and performance properties.

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The purpose of this work is to study the hardness and tribotechnical properties of an aluminum matrix composite material with a different composition of the reinforcing filler.

2 Materials and methods

The object of study in this work is a composite material, the matrix of which is AD0 grade aluminum, and the reinforcing element is particles of graphite powder. Reinforcement of samples at the melt stage was carried out with graphite particles, the content of which varied from 1% to 1.5%. The chemical composition of the matrix is presented in Table 1. Production method: melting of the AD0 semi-finished product [3]. Matrix melting range: 700-720°C.

Table 1. Chemical composition of aluminum grade AD0 [3]

Concentration of elements, *wt. %*								
Al	**Si**	**Fe**	**Mn**	**Mg**	**Cu**	**Zn**	**Ti**	**Other**
99,50	0,25	0,40	0,05	0,05	0,05	0,07	0,05	0,03

Graphite powder particle size is 40…80 μm. The chemical composition of this powder is presented in Table 2.

Table 2. General indicators of graphite [4]

Material	**General indicators**	
Graphite brand GE-1 GOST 7478-75	Ash content, % no more	10
	The release of volatile substances, % no more	1
	Copper content (Cu) %, max	0,05
	Residue on the sieve 0.16 mm%, no more	40
Density, g/cm^3	2,08-2,23	
Particle size	40-80 micron	

To introduce the filler into the matrix, graphite, as well as molybdenum disulfide, were mixed with copper powder in the proportions shown in Table 3. The composition of the powders was carried out by mechanical stirring in a ceramic mortar, then the resulting mixture of powders was distributed in the aluminum melt to obtain a composite material.

Table 3. Chemical composition of the resulting mixture of powders

Concentration of elements, wt. %						
For AD0 + 1%C + 1%Cu		**For AD0 + 1%C + 1%Cu + 0.5% MoS_2**			**For AD0 + 1,5%C + 0,5%Cu**	
C	**Cu**	**C**	**Cu**	**MoS_2**	**C**	**Cu**
1	**1**	**1**	**1**	**0,5**	**1,5**	**0,5**

Structural analysis methods. The structure of the composite material after aluminum casting with graphite powder distributed over the matrix was studied by metallographic analysis methods. Two sets of samples were prepared for examination with an optical microscope: the first is a pure matrix, and the second is a composite material under study. The metallographic analysis of the samples without etching was performed on an Olympus GX53 microscope at ×500 and ×1000 magnifications.

Hardness. Hardness was measured according to Brinell D = 2.5 mm with a load P = 62.5 (613) kgf (N). on the HB-3000B hardness tester on samples without reinforcing components and with embedded graphite particles.

Tribotechnical characteristics. Wear tests were carried out under conditions of dry sliding friction according to the rod-disk scheme on a Nanovea T50 tribometer. A ball made of ShKh15-SHD steel with a diameter of 6 mm acted as a counterbody, the sliding friction path was 400 m. -SHD, r = 6 mm, friction path - 400 m. Formula for calculating the wear rate: $W = s \times \frac{l}{F \times L}$ where l is the circumference of the wear track, mm; S is the cross-sectional area of the wear groove, mm^2; F – load, H; L is the friction path, m. During the test, the kinetics of the change in the dry friction coefficient of sliding was recorded, according to the test results, the width and depth of the sliding track were measured at five points. Based on these data, the wear intensity was calculated for a given friction pair.

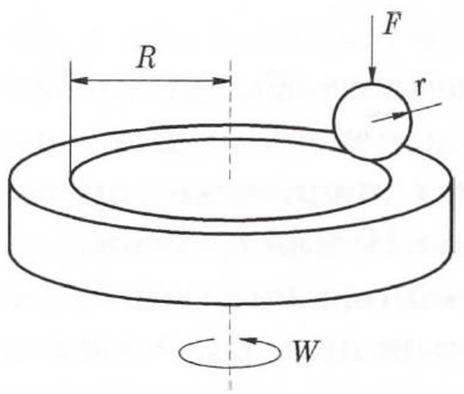
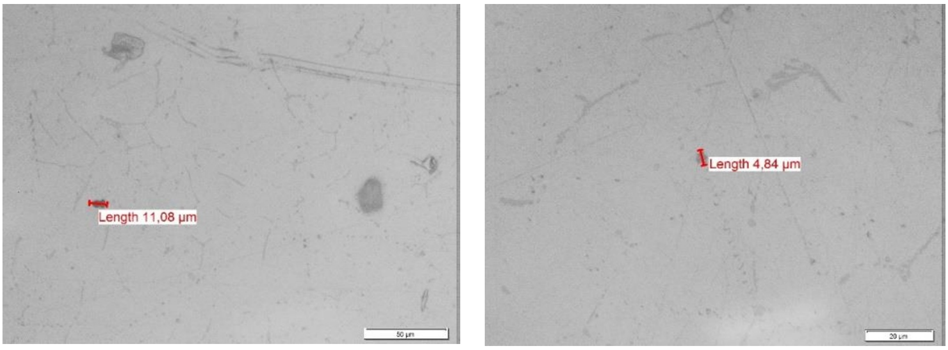


Fig. 1. Scheme of installation for wear testing

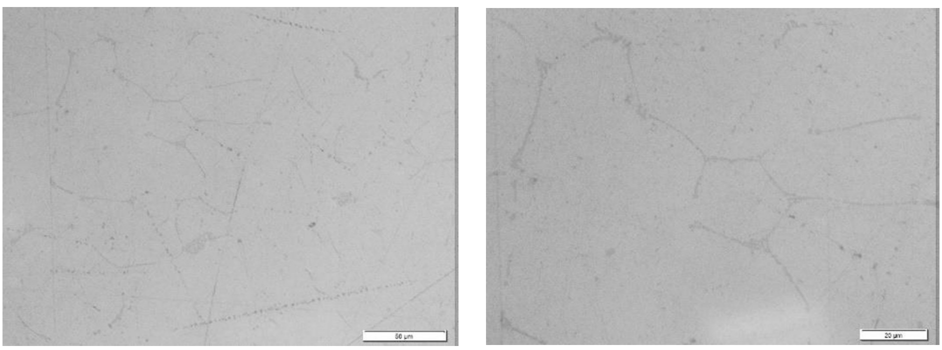
3 Experimental results and discussion

The figure 2 shows the microstructure of samples of aluminum matrix composite material with the addition of 1% C and 1% Cu. The structure is a solid solution of aluminum with graphite inclusions (highlighted by a "ruler"), as well as the presence of porosity in the samples, formed as a result of obtaining samples by crystallization from a liquid melt. On FIG. 3 shows the structure with an unfilled matrix.



a) b)

FIGURE 2. Structure of CM with the addition of 1% C and 1% Cu at ×500 (a) and ×1000 (b) magnification



a) b)

Fig. 3. Microstructure of AD0 aluminum at magnification ×500 (a) and ×1000 (b)

According to the results of the durometric analysis (table 4 and figure 4), it was found that the addition of a reinforcing component has a positive effect on increasing hardness. The greatest increase in hardness (21.6%) was shown by samples with the addition of 1% C + 1% Cu (C - purified). Presumably, this is due to the formation of the mechanism of dispersion strengthening of aluminum by filler particles, which in most cases affects the mechanical characteristics of the composite [5]. The additional introduction of molybdenum disulfide together with graphite did not have a significant effect on the increase in hardness.

Table 4. Results of hardness measurements

№	**Sample**	**Measurement number**					**Average**	**Hardening in %**
		1	2	3	4	5		
1	AD0	23,6	22,4	24,4	22,8	22,4	23,1	-
2	AD0 + 1%C + 1%Cu	26	26,5	26,8	26,9	25,9	26,4	14,3
3	AD0 + 1%C + 1%Cu, C – purified	28,2	28,2	26,4	27,6	30,2	28,1	21,6
4	AD0 + 1%C + 1%Cu + 0,5% MoS_2	27,8	26	27,5	26	27,6	27	16,9

5	AD0 + 1%C + 1%Cu + 0,5% MoS_2, C – purified	26,1	26,4	25,9	26,8	27,2	26,5	14,7

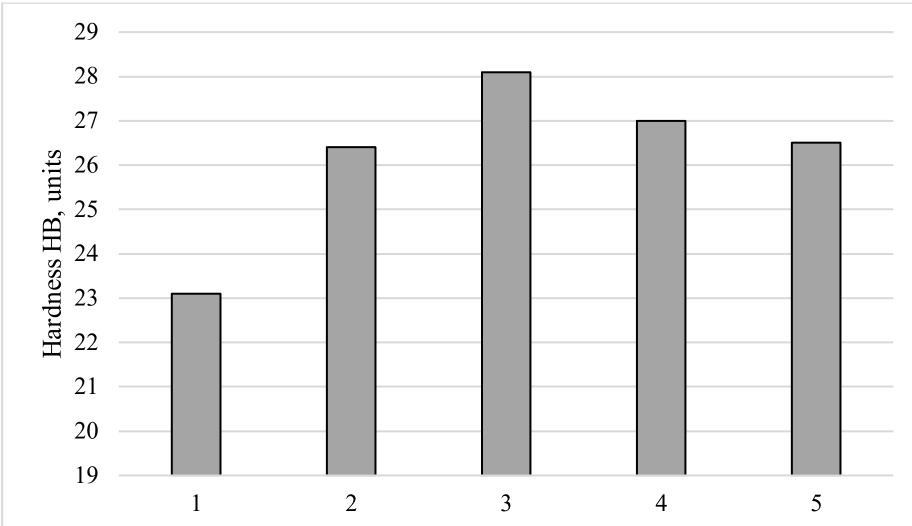
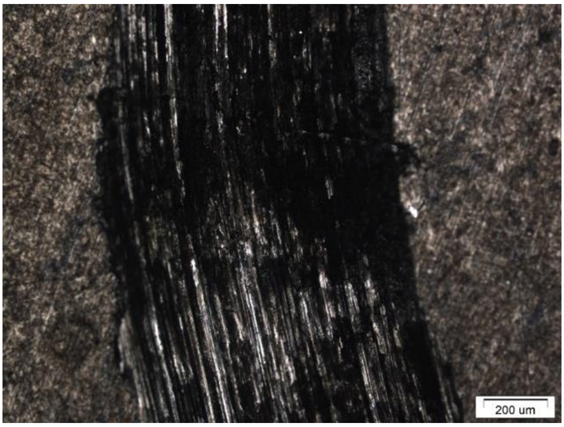


Fig. 4. Dependence of hardness on the chemical composition of the sample

The results of wear tests showed that the frictional interaction of pure aluminum without reinforcing components accompanies multiple surface failures (microcracks, scuffing grooves, chipping). Reinforcement with graphite and copper in a ratio of 3 to 1 led to an increase in wear intensity by 1.6 times compared to pure aluminum, and the damage to the sliding path also increased. Reinforcement with these components in a ratio of 1 to 1 led to a significant increase in wear resistance - the wear rate decreased 8 times. The surfaces before and after the tests are shown in figure 5. Figure 6 shows the results of the wear test.

a) b)



c)

Fig. 5. Surface of materials after testing a) Initial aluminum b) Al + 1%C + 1%Cu c) Al + 1.5%C + 1%Cu

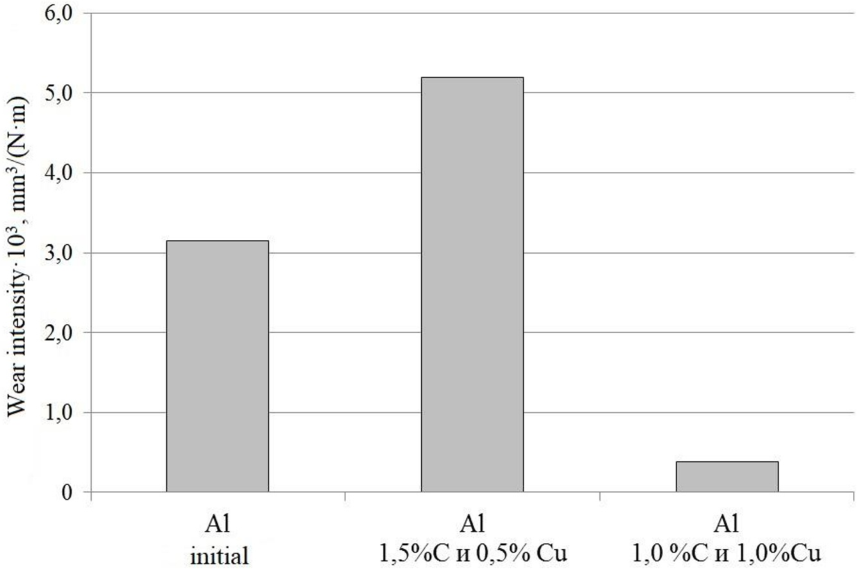
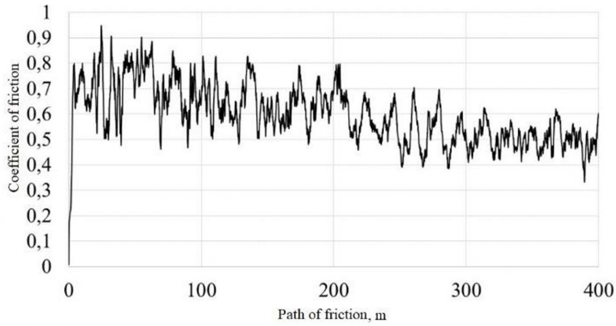
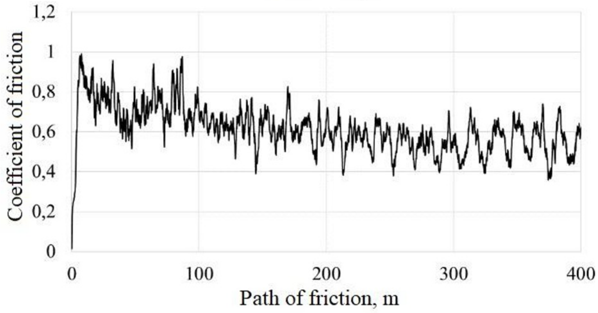


Fig. 6. Wear intensity depending on the reinforcing component of the aluminum matrix composite material

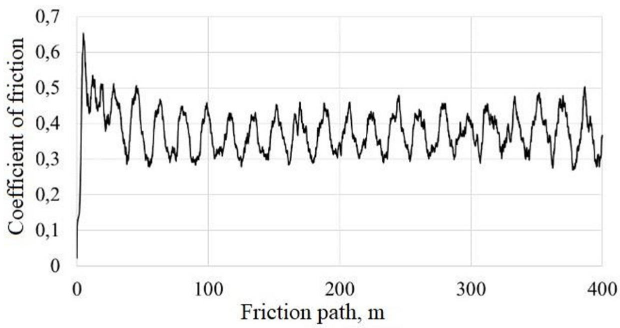
The positive ratio of the reinforcing components also led to a decrease in surface damage, the friction path before running in, and a decrease and stabilization of the dry friction coefficient of sliding. For samples without reinforcing components, the average friction coefficient was 0.55, the friction path before running in was 250 m. the ratio of 1 to 1 led to a decrease in the average coefficient of friction to 0.35, the friction path to 50 m.





a)

b)



c)

Fig. 7. Paths of friction before running-in a) Initial aluminum b) Al + 1.5% C + 1% Cu c) Al + 1% C + 1% Cu

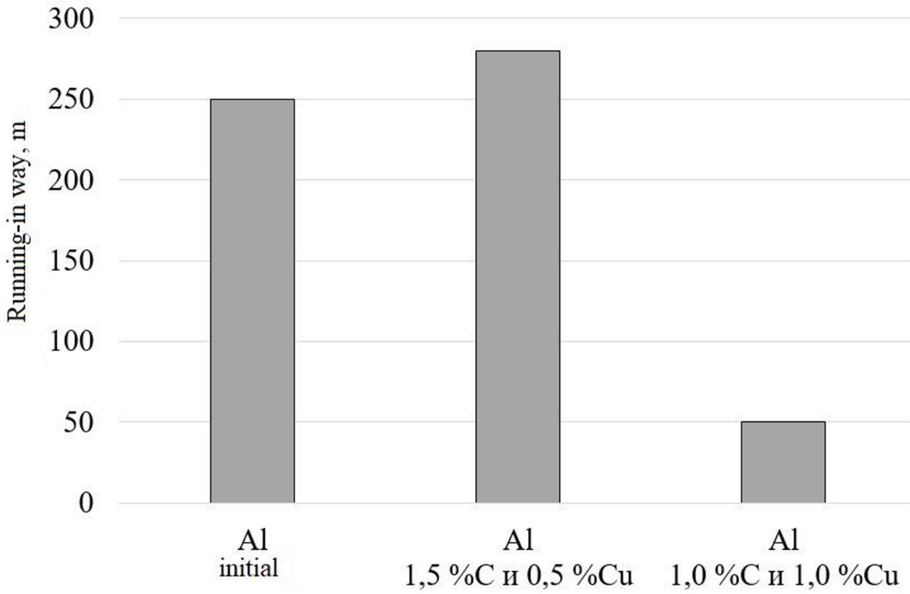


Fig. 8. Path of friction before running in depending on the reinforcing component of the aluminum matrix composite material

4 Conclusion

1. The introduction of dispersed graphite particles into the aluminum matrix contributes to an increase in the hardness of the samples, which is presumably associated with the implementation of the dispersion strengthening mechanism.
2. Graphite in the ratio of 1%C and 1%Cu helps to reduce the wear rate by 8 times, the average friction coefficient to 0.35, the friction path to the running-in of the friction pair with steel ShKh15-SHD to 50 m, which will lead to an increase in the wear resistance of parts in this friction pair.

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