Determination influence of graphite grade on tribological properties of friction material based on tin bronze when using "A" and ATF-III grade oils

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Abstract. The paper presents the results of metallographic and tribological studies of tin bronze samples with additives of elemental graphite (GE) and pencil graphite (GP) with an average size of 10 $\mu$m in an amount of 10\% vol. The wear rate of bronze samples with graphite GI is higher than with GP by 2 times when tested with mineral oil and 1.1 times when tested with synthetic oil. The jamming load is 1.5-2 times higher than bronze with GP graphite compared to bronze without graphite.

1. Introduction
The matrix material used in this work was a commercially pure copper powder with an average particle size of $\sim$35 $\mu$m, produced by CDH, India. Graphite powder with an average particle size of $\sim$10 $\mu$m was used as a reinforcing material. A copper matrix composite reinforced with graphite powder was produced by powder metallurgy with three different volume fractions of graphite (1, 2, and 3\%) \cite{1}. The wear test samples were manufactured in accordance with ASTM G 99-04 standards, and their dimensions were $10 \times 20$ mm. The experiments were performed at variable loads of 2.5, 5, 7.5, 10, and 12.5 N, a constant speed of 1.178 m s\(^{-1}\) (150 min\(^{-1}\)), and a duration of 15 minutes for each test. The wear resistance of manufactured composite increases with percentage of graphite particles, which acts as a solid lubricant. At 3\% graphite, the wear resistance was improved by about 88\%, compared to the copper sample without graphite additives.

Samples from the Cu-Al-Gr composite with dimensions of $17 \times 15$ mm, containing electrolytic copper powder with a particle size of 50-80 $\mu$m, graphite-200-300 $\mu$m, and aluminum powder - 70-100 $\mu$m \cite{2}. They were manufactured by powder metallurgy at a pressure of 1.77 MPa and a temperature of 820 $^\circ$C. Tribological tests were carried out according to the "disk-finger" scheme, at a speed from 200 min$^{-1}$ (3.14 ms\(^{-1}\)) to 3000 min (47.1 ms\(^{-1}\)), and a pressure of 0.5 MPa. A rotating disk with a diameter of 300 mm made of H13 steel (a disk material for high-speed trains) was used as a counterbody. The graphite content was changed from 3 to 18\%. The minimum coefficient of friction and wear intensity were obtained with a graphite content of 12\%.

Graphite 6, 8, 10, 12 and 15\% were added to the charge of the Cu-Sn-Fe-SiO2-MoS2 friction material. Samples with a graphite content of 10\% have a lower strength, but there is a significant
increase in their wear resistance [3]. As the rotation speed increases from 200 to 400 min⁻¹, the amount of graphite on the friction surfaces increases and the wear pattern changes.

The purpose of this work is to establish the influence of graphite grade and lubricant on changes in the jamming load from the sliding speed, wear intensity, and coefficient of friction.

2. Materials and equipment

Tin bronze (12% by volume of tin) obtained by mixing copper powders of the PMS-1 brand and TIN of the PO -1 brand with an average particle size of 80 and 10 µm, respectively, was used as the base of the powder friction material. The base was added graphite element grade GE-1 (GOST 7478-75) with an average particle size of 80 µm and graphite pencil GP-1 (GOST 17022-81) with an average size of 10 µm in an amount of 10% vol.

Blanks of three samples with a diameter of 35 mm and a height of 25 mm for tribological tests were made as follows: the initial powders were mixed in a "drunk barrel" type mixer for 2 hours, samples of a given shape were pressed at a pressure of 200 MPa, then sintered in a protective-reducing atmosphere of endogas at a temperature of 840 °C for 240 minutes.

Wear and tear resistance tests were performed on the MTU - 01 friction machine according to the scheme plane (sample size 12 × 20 × 70 mm, steel 65Mn ) - ring (diameter 34 mm, height 22 mm, composite powder friction material) at a load of 0.5-3 MPa and a sliding speed of 0.5-4 ms⁻¹. Two types of oil were used as a lubricant: 1-hydraulic mineral oil of the "A" brand (TU 38.1011282-89) for operation in torque converters and automatic transmissions of cars from -40°C to ambient temperatures; 2-transmission oil for automatic transmissions ATF-III (Sintoil). The lubricant was applied to the friction zone at a rate of 1 drop per second. The wear rate was determined by the expression [4]:

\[
j = \frac{\Delta h}{2\pi mn}
\]

where, \(\Delta h\) is the average linear wear, over \(n\) test cycles, \(r\) is the average radius of the sleeve sample made of composite sintered material, and \(n\) is the total number of revolutions of the mobile sample.

\[
\Delta h = h - h_1 = \tan^{-1}\left(\frac{\alpha}{2}\right)(b_0 - b_1)
\]

where, \(h\) – is the initial depth of dimple (µm), \(h_1\) – is the depth of the worn hole, (µm), \(b_0\) – initial width of the hole (mm), \(b_1\) – width of the worn hole (µm), \(\alpha\) – the angle between the surfaces of the walls of the wells. The load on the indenter during scratching was 4.9 N on the PMT-3 device. The speed of movement of the diamond indenter was 10 mm·s⁻¹ [5].

3. Results of experiments

Figures 1 and 2 show fragments of samples after friction and the formation of a bully. The friction surface of a sample of composite material with GE graphite has deeper wear grooves towards sliding, and observed pores size 50-200 µm in places where accumulates graphite (figure 2 (a)). Pore formation is associated with the transfer of graphite to the steel surface during friction. The sample with GP graphite has, the pore size smaller 50 µm and the friction surface has less deep risks towards sliding direction (figure 2 (b)).
Figure 1. Type of friction surface of samples after tribological tests: upper sample - GE graphite 10% vol; lower-GP graphite 10% vol.

Figure 2. Fragments of friction surfaces of samples after tribological tests: a-GE graphite, b- GP graphite.

Figure 3 shows the zones for determining the elemental composition on samples of bronze and counter-samples of 65Mn steel. On the friction surface of the graphite GE bronze sample, dark zones with an increased carbon content of 6.72 – 7.11% (spectra 1 and 2) containing graphite are observed, and on the counter-sample (figure 3 (c)) in the spectra 13,14 and 18,19, an increased content of copper in the range of 22-56% and graphite in the spectrum 20.

By friction, copper and graphite were transferred on the steel surface. Contain copper in the sample of bronze with graphite GP is in spectra 6-11 (figure 3 (b)) has similar values with similar spectra (figure 3 (a)). In spectrum 12, observed increase content carbon. That indirectly indicates the presence of GP graphite in this region. The transfer of iron to the friction surface is insignificant and amounts to 0.2-0.38% in the spectra 6-8, on the counter – sample of steel 65Mn (figure 3 (d)) in the spectra 31 – 33, the carbon content is in the range of 7 – 17%, and copper 71-77%.
Figure 3. Areas for determining the elemental composition of samples of bronze-graphite material with 12% tin and counter-samples of steel 65Mn: a-bronze + graphite GE, b-bronze + graphite GP, c and d-steel 65Mn.

The results of tests for the wear rate of bronze-graphite formations containing 12% tin and 10% graphite of the GE and GP grades paired with counter-samples made of 65Mn steel are shown in table 3. The Tests were performed at a sliding speed of 0.59 ms\(^{-1}\) and a pressure in the friction pair equal to 1 MPa.

The wear rate of bronze samples with GE is 2 times higher than with ha when tested with mineral oil and 1.1 times higher when tested with synthetic oil. The friction coefficients were 0.068 and 0.067 and 0.070 and 0.058 with mineral and synthetic oils, respectively. The estimation of the jamming load from the sliding speed and the type of lubricant is shown in figure 4.
Table 1. Results of wear intensity tests with mineral oil grade "A" / with synthetic oil ATF-III.

| № samples | Sample material                     | Steel wear rate | Wear rate sample |
|------------|-------------------------------------|-----------------|------------------|
| 1          | Bronze 12% Sn, porosity 20%, 10% vol. GE | 0.7565 / 0.5578 | 0.9555 / 1.2333 |
| 2          | Bronze 12% Sn, porosity 20%, 10% vol. GP | 0.7009 / 0.6677 | 0.5068 / 1.1608 |

4. Discussion
The obtained results of tribological tests show an increase in the jamming load when using mineral and synthetic oil compared to samples without graphite. The size of graphite particles also affects the results of wear intensity 2 times lower on mineral oil when using graphite GP. The friction coefficients are significantly lower when using synthetic oil. The results obtained can be used in the development of new composite bronze-graphite materials with the addition of pencil graphite.

The use of new materials will improve the reliability of friction units in transport engineering.

5. Conclusion
Studies show that the use of graphite in composite powder materials significantly increases the load of jamming in friction pairs. So at a sliding speed of 2 m s\(^{-1}\), it increases by 1.5-2 times compared to tin bronze without graphite, with graphite GP and 1.2 – 1.5 times and graphite GE when tested with mineral and synthetic oil, respectively.

References
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