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MATERIALS MECHANICS:
STRENGTH, DURABILITY, SAFETY

Study of Characteristics of Composite Materials Based on B83 Antifriction Alloy

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Abstract—Antifriction composite materials (CMs) based on B83 babbitt alloy containing silicon carbide (SiC) and modified shungite rock (MSR) particles were fabricated by hot pressing. The matrix powder was prepared using a planetary ball mill for processing chips obtained after machining of cast babbitt. The resulting powder was sifted out using a sieve analyzer. Powder mixtures for pressing were prepared by mechanical alloying in a planetary mill for 2 h at a rate of stirring of 300 rpm. Composite semifinished product was obtained by pressing the obtained powder mixtures on an OMA mechanical press (P_{max} = 150 kN) at a pressure of 320 ± 5 MPa. Semifinished products were heated in a muffle furnace in a die mold at a temperature up to 300°C, held for 30 min at this temperature, and then pressed. We showed that CMs fabricated by the powder metallurgy technique exhibited enhanced wear resistance at comparable values of the friction coefficient as compared to the same characteristics of a cast alloy. Local elastic moduli of the obtained samples were determined using the laser optoacoustic method based on the measurements of the phase velocities of thermo-optically excited longitudinal and shear ultrasonic waves. We have shown that the B83-based CMs containing MSR (0.5 wt %) and SiC (3 wt %) can be recommended as an alternative to the B83 cast alloy. The composite material with such composition exhibits a higher wear resistance as compared to the cast babbitt. The friction surface of this CM reveals sliding areas and friction grooves that are less distinct as compared with the B83 cast alloy.

Keywords: composite materials, reinforcing particles, laser optoacoustic method, mechanical properties, wear, friction coefficient

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INTRODUCTION

Antifriction tin-containing alloys, in particular, tin babbitts, are widely used in fabrication of slider bearings and friction units and as coatings of bimetallic elements of friction units in transport, turbine engineering, shipbuilding, etc. The main fabrication techniques of bearings and bimetallic elements of friction units are the casting methods [1]. However, the cast antifriction alloys do not yield sufficient levels of fatigue strength, wear resistance, and service life, which is confirmed by results of analysis of failure and off-schedule losses of friction units in devices and machines [2]. The solution of this relevant problem is enhancement of the operational characteristics of antifriction alloys by development of new compositions and processes of their fabrication. This problem can be successfully solved by performing studies on development and application of novel promising reinforcing fillers, on engineering options of their combination, and evaluation of mechanical and physical characteristics of synthesized heterogeneous materials. In particular, we propose to produce composite materials (CMs) based on a B83 antifriction tin-containing alloy. High wear resistance of these CMs can be achieved by introduction of fillers different in dispersivity and nature. It is known that enhanced tribotechnical characteristics can be achieved by introduction of small contents of natural fillers of shungite rocks and microsized refractory ceramic particles [3, 4].

The aim of this work is to obtain antifriction CMs based on a B83 tin-containing alloy reinforced with silicon carbide particles and modified shungite rocks, to evaluate their physical and mechanical properties using the nondestructive laser optoacoustic method, and to determine the tribological characteristics of the obtained heterogeneous CMs.

EXPERIMENTAL

To fabricate the CMs based on B83 babbitt reinforced with particles, we propose the hot pressing (HP) process of mixtures of B83 babbitt powder, sili-

Table 1. Compositions and hardness of the studied samples

Sample no.	Composition	*HB*
1	B83 (cast)	23.6
2	B83 (HP)	25.4
3	B83 + 0.5 wt % MSR (HP)	26.4
4	B83 + 3 wt % SiC (HP)	29.2
5	B83 + 0.5 wt % MSR + 3 wt % SiC (HP)	27.8

HP—samples after hot pressing.

con carbide ceramic particles, and modified shungite rock (MSR) particles. The matrix powder was prepared using a planetary ball mill from chips obtained after machining of B83 cast babbitt (GOST 1320-74). Next, this powder was sifted out using a RETSCH AS 200 sieve analyzer and the separated fraction of 300–630 μm in size was used as a matrix of CMs. As fillers, silicon carbide ceramic particles 40 μm in average size in the amount of 3 wt % (GOST 26327–84) and MSRs in the amount of 0.5 wt % were used. As a result of solid-phase reactions, including catalytically induced reactions between micro- and nanosized rock-forming minerals (quartz, mica) and noncrystalline carbon (shungite), the obtained composition of MSR exhibits hyper-fullerene structured carbon along with nanosized SiC fibers and particles [5]. Powder mixtures for pressing were prepared by mechanical alloying in a RETSCH- PM100 planetary mill for 2 h at a rate of stirring of 300 rpm.

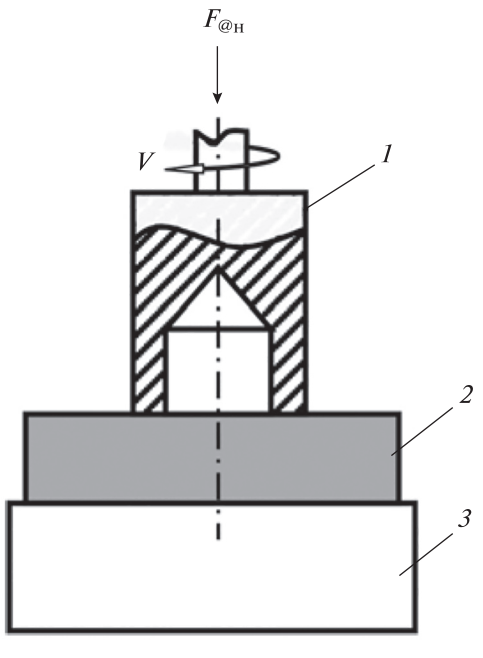

Fig. 1. Friction and wear testing setup: (*1*) grade 45 steel counterface, (*2*) tested sample, and (*3*) steel base.

Composite semifinished product was obtained by pressing the obtained powder mixtures on an OMA mechanical press (P_{max} = 150 kN) at a pressure of 320 ± 5 MPa. Semifinished products were heated in a muffle furnace in a die mold at a temperature up to 300°C, held for 30 min at this temperature, and then pressed. The compositions of CMs are presented in Table 1.

We compared the characteristics and structure of the fabricated CMs, the cast B83 industrial babbitt (no. 1), and the sample obtained by hot pressing of the B83 babbitt powder without fillers (no. 2). The Brinell hardness (HB) of the samples was determined on a Wilson Wolpert hardness tester at a load of 62.5 kg (ball diameter of 2.5 mm), and the density was determined by hydrostatic weighing.

The structure of the samples was analyzed with a Leika DM ILM optical microscope using the Qwin software code for image analysis. This software code was used to determine the sizes of the structural components of CMs. Statistical analysis of the structure was performed over ten separate fields.

Tribological tests were performed under dry sliding friction conditions on a CETR UMT Multi-Specimen Test System using the axial loading scheme, namely, a rotating bush (counterface) made of grade 45 steel (*HRC* > 63) against a stationary CM washer. The steel bush was 11.5 mm in inner and 16.2 mm in outer diameter. The CM disk was 20 mm in diameter and 8 mm in thickness. The test time for each sample was 1 h at a load of 100 N. The testing setup is shown in Fig. 1.

The tests were performed in air at a temperature of 20 ± 1°C and a humidity of 60 ± 4%. The friction coefficient was calculated via an automatic software code.

According to the friction diagrams, the friction stability coefficient was determined as follows:

$$\alpha = f_{avg}/f_{max},$$

and the friction sustainability coefficient was determined as follows:

$$k = (f_{max} - f_{min})/f_{avg},$$

where f_{avg} is the average friction coefficient at the entire tribological test stage, excluding lining break-in for 800 s, and f_{max} and f_{min} are the maximum and minimum friction coefficients, respectively.

The mass loss of the samples was determined after the entire test cycle by weighing on an assay balance. The wear of samples under dry sliding friction was estimated according to the wear intensity (g/m)

$$I_m = \Delta m/L,$$

where Δm is the mass loss of the sample (g) and L is the friction path (m).

The friction surface and wear products were examined using a QUANTA 200 3D scanning electron

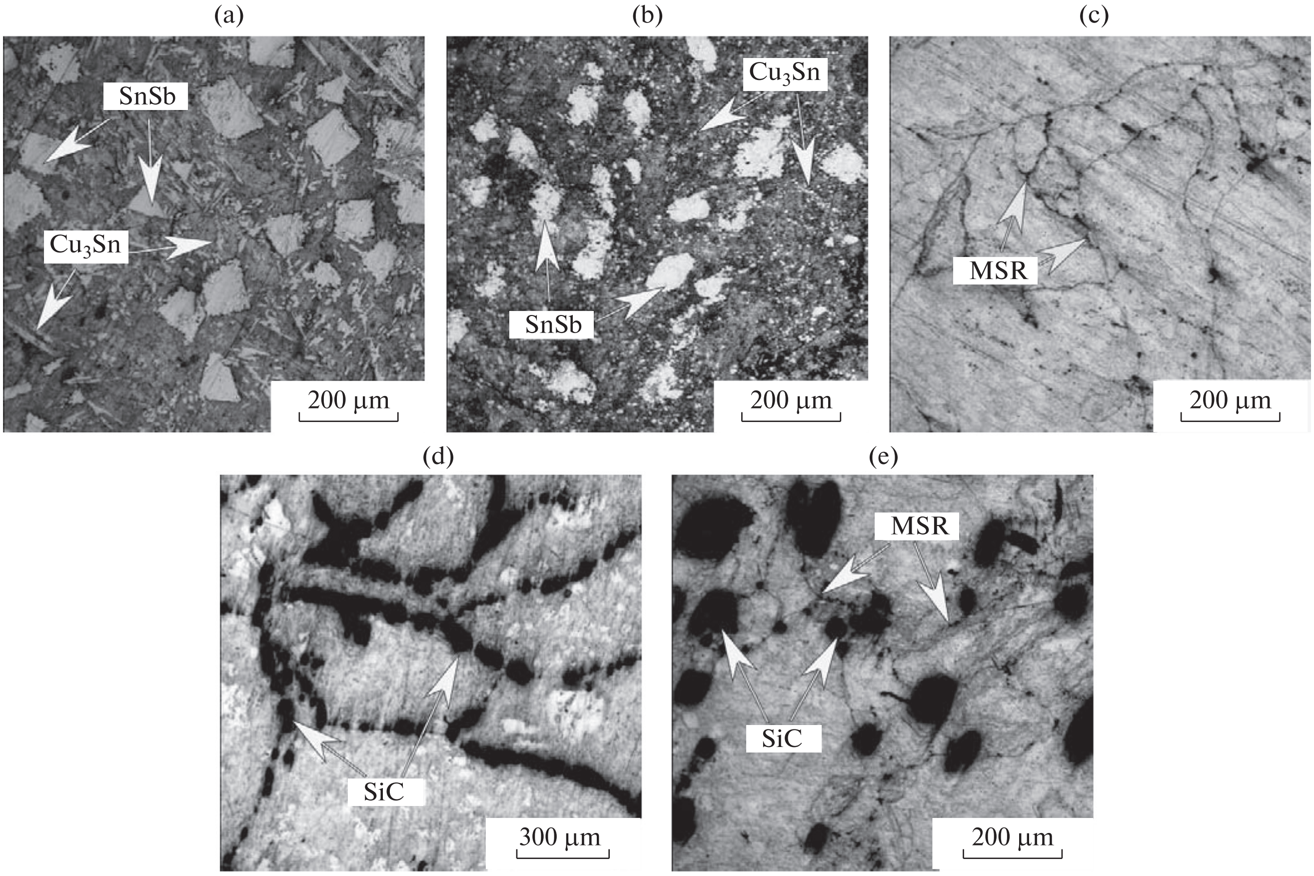

Fig. 2. Microstructure of chemically etched (a) as-cast B83 babbitt and (b) hot-pressed B83 babbitt. Surfaces of CM samples: (c) B83 babbitt + 0.5 wt % MSR, (d) B83 babbitt + 3 wt % SiC, and (e) B83 babbitt + 0.5 wt % MSR + 3 wt % SiC.

microscope equipped with a microanalysis energy dispersive spectroscopy (EDS) console.

To measure the local elastic moduli of the CMs, a laser optoacoustic method was used [6]. This method utilizes laser thermo-optic excitation of broadband pulses of longitudinal and shear acoustic waves and measurements of the phase velocities of these waves in the studied CM samples [7, 8]. The Young's and shear moduli and the Poisson ratio were calculated using the measured densities of the CM samples and the phase velocities of longitudinal and shear acoustic waves in these samples using known relations between the elastic constants and phase velocities of acoustic waves for an isotropic solid [9].

RESULTS AND DISCUSSION

Figures 2a and 2b show the microstructures of the cast and hot-pressed babbitt. Clearly, after treatment of the powder in a ball mill and hot pressing, the SnSb and Cu_3Sn intermetallics lost their sharp-angled shape and changed sizes. According to [10], the more ground structure was obtained by introduction into the babbitt powder of reinforcing MSR additives and SiC particles. So, the average size of the SnSb intermetallic in the cast material was 80 μm; after HP, it was 70 μm; and upon introduction of 0.5 wt % MSR, 3 wt % SiC, and their mixture, the average size of intermetallic inclusions was 50, 55, and 54 μm, respectively. The study of the surface of the CM samples (nos. 3–5) showed that reinforcing SiC and MSR fillers were uniformly distributed in the polished section and were concentrated at the boundaries of compressed babbitt particles (see Figs. 2c–2e).

The results of the calculation of density ρ of the studied CM samples using their hydrostatic weighing along with averaged values of the phase velocities of longitudinal (c_L) and shear (c_S) acoustic waves and the calculated average Young's modulus E, shear modulus G, and Poisson ratio ν are presented in Table 2.

The phase velocities of longitudinal (c_L) and shear (c_S) acoustic waves were measured in five arbitrarily selected domains of each sample. The standard deviation of the measured velocities from their mean value did not exceed 2 m/s, which confirms isotropy of the acoustic characteristics of samples. This deviation is an order of magnitude smaller than the errors of the measurements of the magnitudes of the phase veloci-

Table 2. Density of the samples and optoacoustic measurement results

Sample no.	ρ, 10^3 kg/m^3	c_L, m/s	c_S, m/s	E, GPa	G, GPa	ν
1	7.366 ± 0.025	3470 ± 17	1768 ± 31	61.0 ± 3.7	23.0 ± 0.9	0.325 ± 0.016
2	7.383 ± 0.025	3371 ± 17	1697 ± 30	56.6 ± 3.4	21.3 ± 0.9	0.330 ± 0.017
3	7.303 ± 0.025	3393 ± 17	1726 ± 30	57.7 ± 3.5	21.8 ± 0.9	0.325 ± 0.016
4	7.053 ± 0.025	3538 ± 18	1848 ± 32	63.2 ± 3.7	24.1 ± 1.0	0.312 ± 0.016
5	7.034 ± 0.025	3452 ± 17	1814 ± 32	60.6 ± 3.6	23.1 ± 0.9	0.309 ± 0.015

ties of longitudinal and shears acoustic waves. Because of this, in calculating the errors for elastic parameters averaged over five domains, we took into account only the errors of measurements of the magnitude of these velocities and the error of determination of the density of samples. Within the error bounds, the densities of the cast and hot-pressed babbitt samples (nos. 1 and 2) are practically the same and agree with GOST 1320-74. For the CM samples, the measured density was practically the same as the calculated value $\rho_0 = 7.1 \times 10^3$ kg/m^3 determined using the rule of mixtures with known densities and weight contents of the CM components. Thus, the proposed and realized method for the fabrication of CMs using powder metallurgy techniques makes it possible to obtain practically pore-free samples of both the B83 babbitt powder matrix and B83-based particle reinforced composites.

It is seen from Table 2 that the Young's modulus and shear modulus of the hot-pressed babbitt matrix (sample no. 2) are lower than those of the cast sample no. 1. Probably, this is because of changes in the dimensions and shape of the SnSb intermetallic inclusions during the fabrication of sample no. 2. High-intensity processing of the babbitt powder in a planetary mill disintegrated the SnSb intermetallic inclusions, reducing their sizes by 30–50% (see Fig. 2b). The addition of 0.5 wt % MSR (sample no. 3) had practically no influence on changes in the acoustic and elastic characteristics of the hot-pressed B83 matrix because of the low content of MSR. The addition of 3 wt % of high-strength SiC particles (sample no. 4) tends to increase the Young's modulus and shear modulus (by 10–12%). At the same time, the Poisson ratio decreases by approximately 5% with respect to the hot-pressed B83 matrix. However, the combined effect of SiC fillers and shungite (sample no. 5) does not lead to the same effective increase in the Young's and shear moduli as when only SiC particles are added. These moduli of sample no. 5 are practically the same as those of the cast babbitt sample no. 1. The result of the combined effect of SiC and shungite is only the decrease in the Poisson ratio. Thus, the obtained values of the density and elastic characteristics of the studied materials are comparable or superior to those of the cast material, which makes powder metallurgy a relevant technique for the fabrication of CMs on the basis of a matrix of B83 babbitt and dispersed filler.

Diagrams of the friction tests of the studied samples are shown in Fig. 3. Clearly, at the lining break-in stage for 800 s for all samples, the stability of friction for the hot-pressed babbitt and especially for the cast babbitt strongly differs from that for CMs. At the stage of stable friction (800–3600 s), diagrams for all tested materials are similar. However, the friction stability and sustainability coefficients calculated using these diagrams revealed differences in tribological behavior of the studied samples (Fig. 4). So, introduction into the hot-pressed matrix of the MSR particles (Fig. 4c) and disperse SiC particles (Fig. 4d) leads to the increase in stability coefficient α and to the decrease in sustainability coefficient k, which indicates enhancement of stability and sustainability of the friction process. The most optimum values of these coefficients were obtained for sample no. 5 (Fig. 4e).

Comparison of diagrams of the friction tests (Fig. 3) and calculated values of α and k (Fig. 4) shows that the combined contents in the CM sample no. 5 of the carbon-containing MSR acting as a dry lubricant in the contact zone along with high-strength ceramic SiC particles considerably stabilize the friction process both at its initial stage and at the stage of stationary friction.

The considerable plastic deformation of the surface layers occurring in the friction tests led to formation on the surface of samples of a grooved pattern toward the sliding direction, which is typical of abrasive wear. The surface morphology of samples after tests is shown in Fig. 5.

The most pronounced grooves of the plastic deformation were formed on the friction surface in testing of the cast and hot-pressed samples (Figs. 5a, 5b). This is in good agreement with the obtained wear intensity (Table 3), which was the maximal among all tested samples. Introduction of reinforcing SiC particles into the babbitt matrix did not lead to significant enhancement of the friction surface (Fig. 5d) and wear resistance of the material. The wear intensity of sample no. 4 containing SiC remained practically at the level of the cast material.

Occurrence of grooves is because of skiving action of hard abrasive particles forming by wear of friction couples. The wear particles can be formed from the

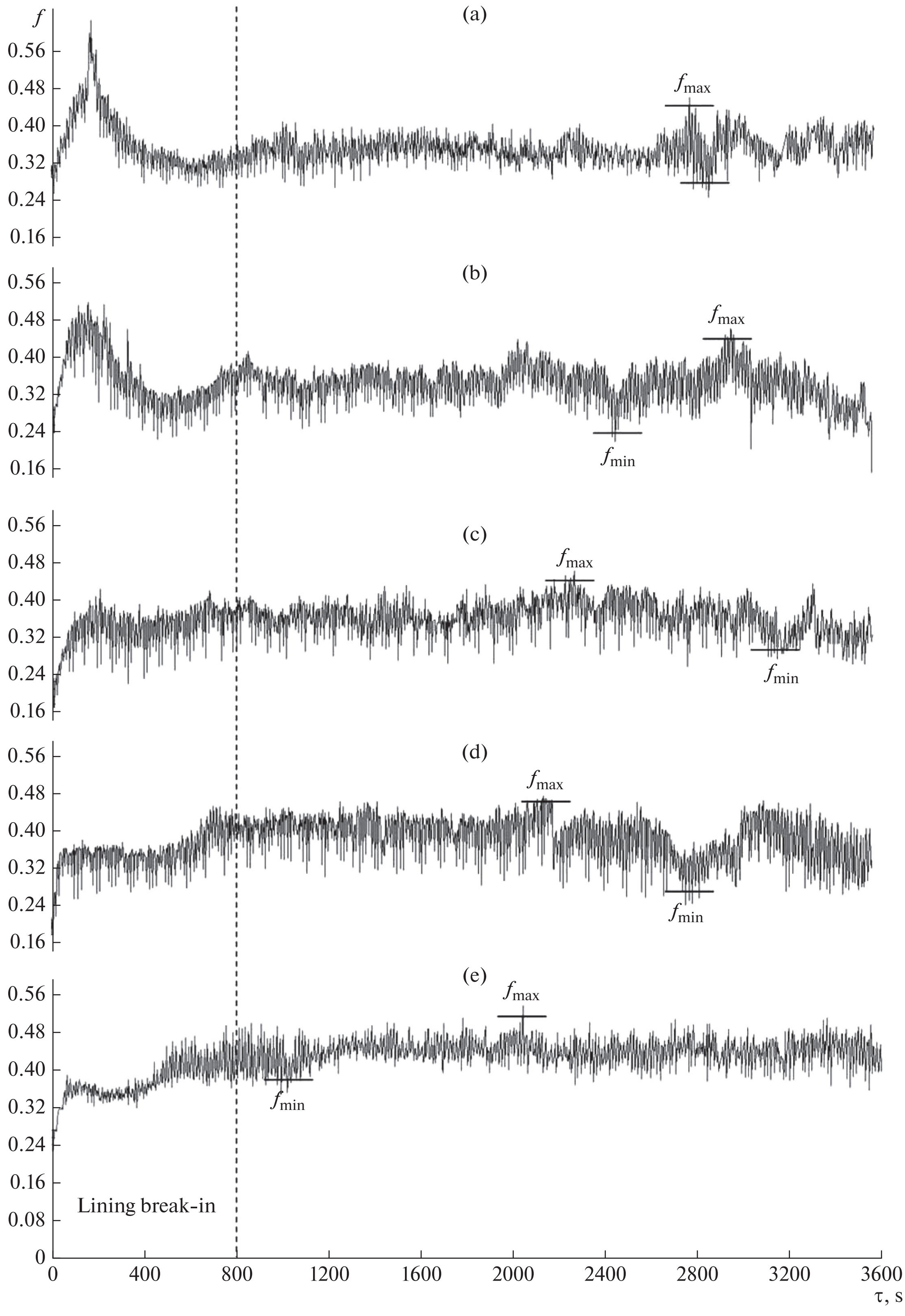

Fig. 3. Diagrams of friction tests of (a) as-cast B83 babbitt, (b) hot-pressed B83 babbitt, and CM samples: (c) B83 babbitt + 0.5 wt % MSR, (d) B83 babbitt + 3 wt % SiC, and (e) B83 babbitt + 0.5 wt % MSR + 3 wt % SiC.

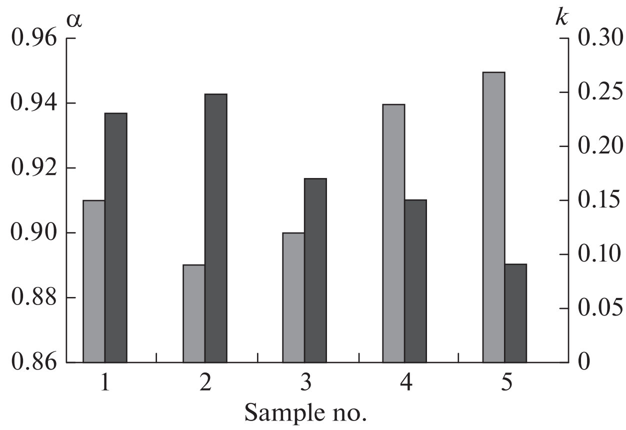

Fig. 4. Friction stability and sustainability coefficients α (■) and k (■) of studied samples nos. 1–5.

matrix material along with cracking of hard SnSb intermetallic inclusions (β phase) and reinforcing ceramic SiC particles. The formed particles can be loaded by the smooth friction surface and render an abrasive effect on the surface of a harder component of a friction unit. The most intense interaction of friction surfaces is revealed at the lining break-in stage. Further, grinding and redistribution of particles leads to mechanical alloying of the surface layers and formation of an interface between them. There are no detectable traces of intense abrasive wear (settings, tears) on the surface of CM samples. It can be seen that the friction surface has rough areas formed under action of these particles by plastic edging of the matrix material from bottom layers and smooth areas of relative sliding. The morphology of rough areas on different samples is identical.

The smooth friction surface with the least detectable grooves of plastic deformation and with the largest areas of relative sliding is typical of sample no. 3 (Fig. 5c). As a part of the shungite composition, carbon acts as a dry lubricant, yielding a protective coating and preserving the integrity of the surface layers. However, for this sample, the wear intensity is the maximum among the tested CM samples.

The minimum wear intensity is exhibited by the multi-reinforced sample, for which the large number of phases in the matrix yields not only the decrease in the load on each single reinforcing particle but also the decrease in the matrix content in the friction surface (see Fig. 5e, Table 3). The data presented in Table 5 show that all obtained CM samples exhibit friction coefficient values comparable with that for the cast material. However, the wear resistance of the sample no. 5 is considerably enhanced.

CONCLUSIONS

In this work, we have proposed and implemented a process for the fabrication of practically pore-free, particle-reinforced composite materials on the basis of a B83 babbitt matrix by powder metallurgy techniques.

The Young's modulus, shear modulus, and Poisson ratio of the obtained CM samples have been measured by the laser optoacoustic method, and the effect of silicon carbide (SiC) and modified shungite rock

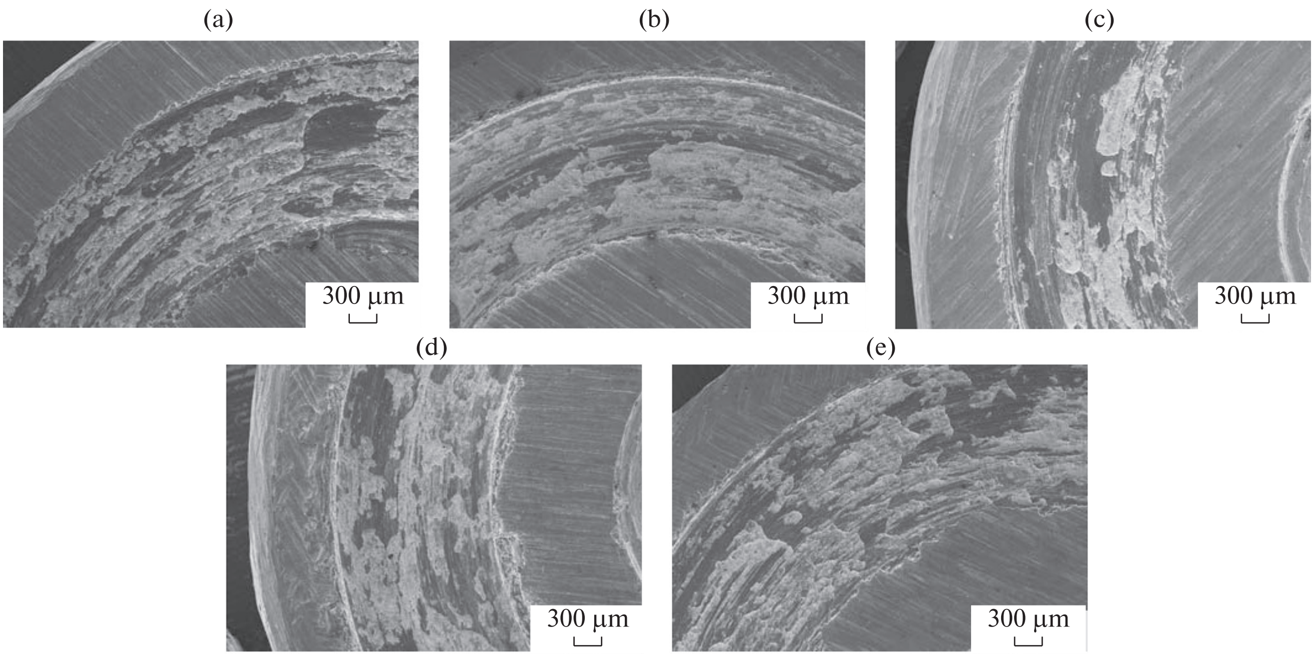

Fig. 5. @

Table 3. Wear intensity I_m and frictions coefficients f of the studied materials

Sample no.	$I_m \times 10^{-4}$, g/m	f
1	0.204	0.3519
2	0.199	0.3469
3	0.197	0.3402
4	0.190	0.3617
5	0.171	0.3595

fillers on these elastic parameters has been analyzed. Such evaluation is necessary to develop and optimize the fabrication process of composite materials and to reveal “weak” domains with reduced strength in materials before the fabrication of component parts and products.

Reinforcement of the B83 alloy with high-strength SiC ceramic particles and ultra-dispersive carbon-containing MSR particles enhances the setting resistance and leads to the increase in the area of relative sliding on the friction surface of couples, which makes it possible to enhance the wear resistance of CMs.

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