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Tribological Properties of the Babbit B83–Based Composite Materials Fabricated by Powder Metallurgy

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Abstract—Technological processes are developed to fabricate composite materials based on B83 babbit using hot pressing of a mixture of powders in the presence of a liquid phase. As a result, the structure of the matrix B83 alloy is dispersed, the morphology of intermetallic phases is changed, and reinforcing micro- and nano-sized fillers are introduced and uniformly distributed in the matrix. The tribological properties of the synthesized materials are studied. The friction of the B83 babbit + 0.5 wt % MSR + 3 wt % SiC (MSR is modified schungite rock) composite material at high loads is characterized by an increase in the stability coefficient, and the wear resistance of the material increases by a factor of 1.8 as compared to the as-cast alloy at comparable friction coefficients.

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INTRODUCTION

Antifriction alloys, such as babbits, are widely used in the products of modern mechanical engineering. Tin babbits, including B83 babbit, have the best set of antifriction properties. The disadvantages of tin babbits are their low wear resistance and fatigue strength because of the acute-angled shape of coarse SnSb intermetallics, the vertices and edges of which serve as stress concentrators, and their structural heterogeneity, which is related to the segregation processes that occur during solidification and cooling [1, 2].

The properties of babbits can be improved by modification with ceramic microparticles and nanoparticles, i.e., by the formation of precipitation-hardened composite materials (CMs) based on them [3, 4].

The introduction of ceramic particles into a matrix alloy can increase the load-bearing capacity and the wear resistance of CMs, and the introduction of carbon-containing nanoparticles, in particular, the hyperfullerene structures formed upon modifying treatment of schungite rock, can refine structure and increase the wear resistance due to the formation of a fine mixture of the products of wear of CM and the counterbody in the friction zone. Such a mechanical mixture is often defined as an intermediate layer, or a "third body," which hinders direct contact between interacting surfaces. As a result, the critical loads, at which the soft wearing mode changes into intense wear, become higher [5–7].

The general disadvantages of the casting methods of producing CMs are the difficulties that appear when fillers are introduced into a melt, the complex problem of achieving their uniform distribution in the melt volume, the susceptibility of the melt to segregation upon melting, and the formation of casting cavities during solidification. These disadvantages can be eliminated using powder metallurgy and hot pressing.

The purpose of this work is to develop technological methods to produce a babbit B83–based CM by hot pressing of a mixture of powders and to analyze the structure and the tribological properties of the produced material.

EXPERIMENTAL

To prepare CM, we used babbit B83 (GOST 1320–74) chips, which was formed upon mechanical processing of an alloy B83 casting in the as-delivery state (in wt %, 10–12 Sb, 5.5–6.5 Cu, Sn for balance); ceramic silicon carbide particles with an average size of 40 μm (GOST 26327–84); and modified schungite rock (MSR). The modifying treatment of schungite rock was performed by Kovalevskii at the Schungite Laboratory of the Institute of Geology, Karelia Scientific Center, Russian Academy of Sciences. As the initial raw materials, we used the rock mined by OOO NPK Karbon-Schungite and corresponding to specifications 88-003–90 (in wt %, C ≥ 20, $SiO_2 \leq 70$, $S_{tot} \leq 1.5$). As a result of solid-phase reactions, includ-

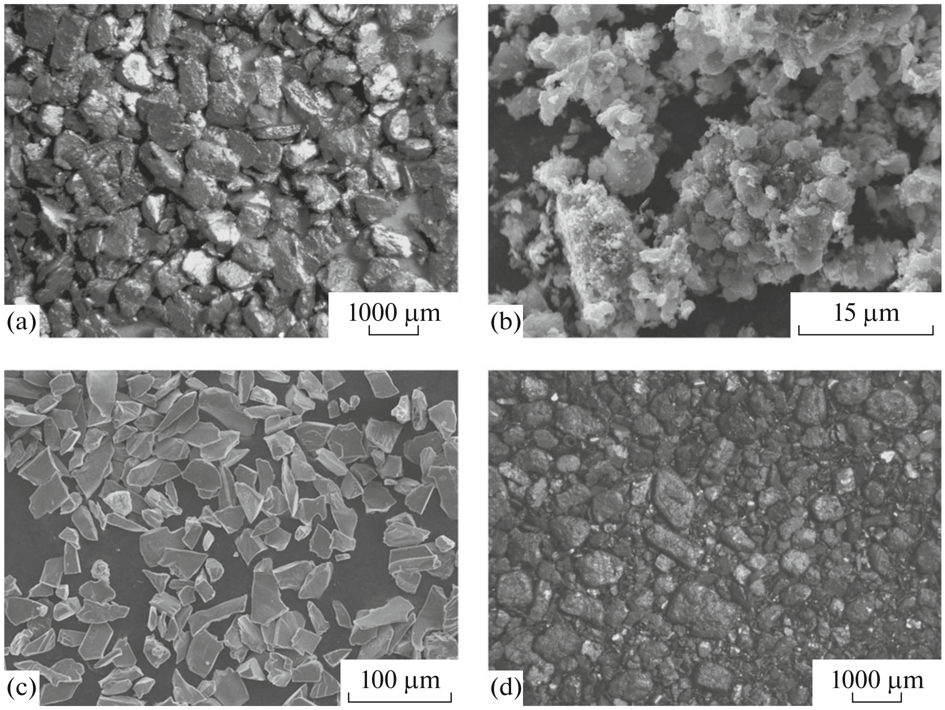

Fig. 1. Appearance of the initial powders ((a) B83 babbit, (b) MSR, and (c) SiC) and their mixture ((d) B83 babbit + 0.5 wt % MSR + 3 wt % SiC CM).

ing catalytically initiated ones, between rock-forming mineral micro- and nanoparticles (quartz, mica) and noncrystalline carbon (schungite), MSR contained carbon in the form of hyperfullerene hollow spherical or ellipsoid particles, nanofibers, and SiC nanoparticles [8, 9]. The appearance of the initial powders is shown in Figs. 1a–1c.

A mixture of the initial powders was formed by mechanical alloying in a Retsch-PM100 planetary mill by choosing treatment conditions (time of interaction of components, rate of mill rotation) in an experimental manner using the criterion of complete penetration of MSR into a babbit powder.

A composite semiproduct made of a mixture of powders was formed by pressing on an OMA mechanical press (P_{max} = 150 kN). 20-g samples of a mixture of powders were pressed at a force of 320 ± 5 MPa, and the semiproduct samples were 20 mm in diameter and 7 mm in height.

Sintering of the semiproduct samples was performed in a muffle furnace upon heating in a mold to achieve a liquid phase at a temperature of 260 ± 10°C, and this phase was held for 30 min at this temperature.

Hot pressing (HP) was carried out at a pressing force of 320 ± 5 MPa and an initial temperature of 260 ± 10°C, and the sample was then air cooled.

Brinell hardnesses *HB* of samples were determined on a Wilson Wolpert hardness tester at a load of 625 N (ball diameter of 2.5 mm), and their densities were measured by hydrostatic weighing.

The structure of CM samples was analyzed with a Leica DM ILM optical microscope equipped with the Qwin software package for image analysis. Using this software package, we determined the sizes of the structural constituents of CM. Statistical analysis of the structure of samples was carried out on ten individual fields.

Tribological tests of CM samples were performed under dry sliding friction conditions on a CETR UMT Multi-Specimen Test System using the axial loading scheme, namely, a rotating bush (counterbody) made of grade 45 steel (*HRC* > 63) against an unmovable CM washer. The outside diameter of the steel bush was 11.5 mm and the inside diameter was 16.2 mm. The diameter of the CM washer was 20 mm and its thickness was 8 mm.

Each sample was tested at two stages during sequential steplike loading: the first stage at a load *P* = 15, 25, 35, 45, and 55 N (total friction path of 1110 m); the second stage at a load *P* = 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, and 350 N (total friction path of 2440 m). The test time at each load was 10 min.

The tests were carried out in air at a temperature of 20 ± 1°C and a humidity of 60 ± 4%. The friction coefficient was calculated with a computer. The sample mass loss was detected after the full cycle of two stages of tests by weighing samples on an analytical balance.

Apart from the friction coefficient, we also used wear intensity I_m and friction stability coefficient α_{st} to

Table 1. Sample composition, *HB* hardness, and density ρ

Sample	Sample composition	*HB*	ρ, g/cm^3
1	B83 babbit (as-cast)*	23.6	7.39
2	B83 babbit (HP)	25.4	7.38
3	B83 babbit + 0.5 wt % MSR (HP)	26.4	7.30
4	B83 babbit + 3 wt % SiC (HP)	29.2	7.19
5	B83 babbit + 0.5 wt % MSR (HP) + 3 wt % SiC (HP)	27.8	7.25

* Sample 1 was prepared by mechanical processing of a babbit B83 pig in the as-delivery state.

estimate the behavior of samples during dry sliding friction [10],

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

$$\alpha_{st} = f_{av} / f_{max},$$

where Δm is the sample mass loss; L is the friction path; and f_{av} and f_{max} are the average and the maximum friction coefficient, respectively.

RESULTS AND DISCUSSION

To form CMs by hot pressing, we prepared a babbit powder and mixtures of the babbit powder with fillers. The babbit powder with a particle size of 300–500 μm was prepared by processing cast alloy B83 chips in a planetary mill for 60 min at a rate of rotation of 300 min^{-1}. A mixture of the babbit powder and MSR was processed in a planetary mill for 2 h at a rate of rotation of 200 min^{-1} until MSR particles were completely incorporated in the metallic powder. SiC particles and the babbit powder were mixed at the same rate of rotation for 5 min to exclude the fragmentation of SiC particles. The same mixing parameters were used to introduce an SiC powder into a mixture of babbit B83 and MSR.

Figure 1d shows the appearance of the powders of the mixture containing hardening SiC microparticles, carbon nanoparticles, and SiC fibers after processing in a planetary mill.

Table 1 gives the compositions and the properties of the CMs fabricated by hot pressing. For comparison, we also studied a sample of commercial cast babbit B83 alloy (sample 1).

Figure 2 shows the characteristic structures of the samples of commercial cast babbit B83 alloy, the bab-

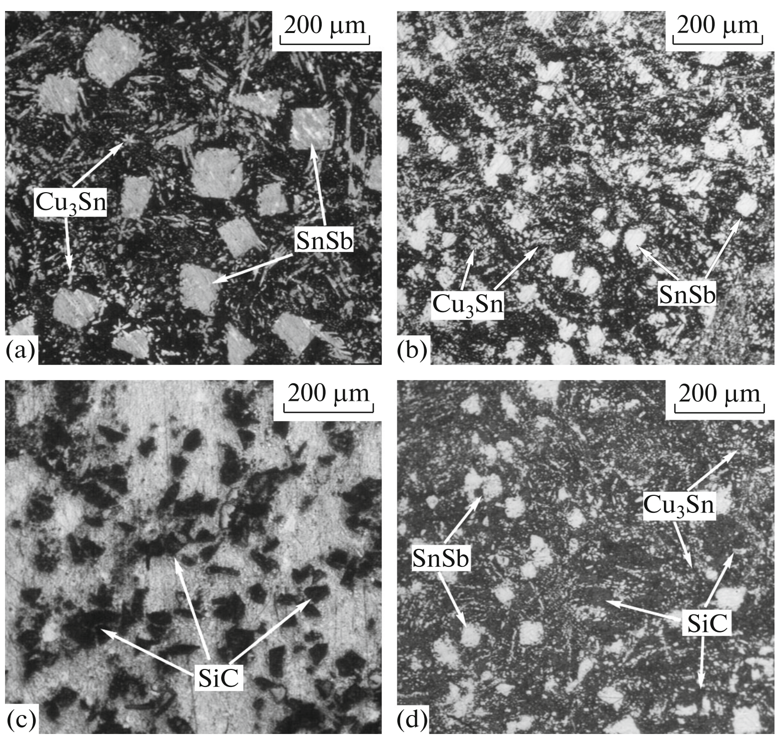

Fig. 2. Structures of (a) as-cast B83 babbit, (b) B83 babbit fabricated by a powder technology, (c) B83 babbit + 3 wt % SiC CM, and (d) B83 babbit + 0.5 wt % MSR + 3 wt % SiC CM. (a, b, d) Chemical etching of the surface.

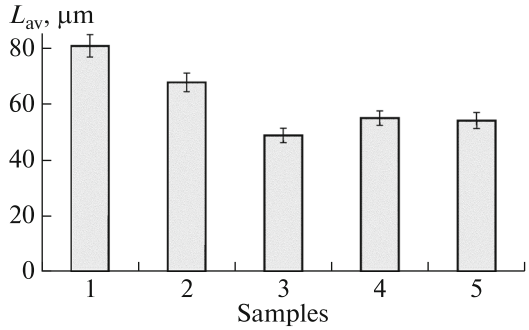

Fig. 3. Average size L_{av} of the SnSb intermetallic phase in samples 1–5 (see Table 1).

bit fabricated by a powder technology, and the CMs prepared by HP of some mixtures.

Tin B83 babbit consists of a relatively soft matrix (solid solution of antimony and copper in tin, α phase) and hard intermetallic crystals (SnSb (β phase), Cu_3Sn (γ phase)). It is seen that, after HP of the babbit powder, the SnSb intermetallics decreased in size and changed their initial acute-angled shape (Fig. 2b). The same dispersion of SnSb intermetallics was also observed in the CMs under study. This behavior is related to an intense mechanical action in mixing of the initial powders and the solidification of samples under pressure in the presence of high-strength and refractory hardening additions, which serve as thermal stoppers bounding solidifying volumes.

The dispersion of the SnSb phase is accompanied by changes in its morphology (Figs. 2b–2d). The SnSb intermetallics change their shape from the acute-angled shape of the initial as-cast state to a more rounded one, and they acquire a more developed surface. The change in the morphology of SnSb intermetallics is likely to increase their adhesion to the matrix, which should promote an increase in the fracture strength of the contact surface during friction and should widen the tribological loading range. Figure 3 shows the results of measuring the average grain size of the intermetallic SnSb phase in the B83 alloy produced by a powder technology and the CM fabricated by a powder technology.

Table 2. Friction coefficients f_{av} of samples (numerator) and friction stability coefficients α_{st} at the first stage (denominator)

Sample no.	f_{av}/α_{st} at load, N				
	15	25	35	45	55
1	0.50/0.65	0.44/0.79	0.40/0.99	0.39/1.00	0.38/1.00
2	0.52/0.86	0.49/0.86	0.43/0.89	0.38/0.97	0.37/0.95
3	0.48/0.92	0.43/0.85	0.41/0.81	0.39/0.98	0.39/1.00
4	0.53/0.91	0.48/0.98	0.45/0.95	0.45/0.95	0.45/0.96
5	0.51/0.91	0.49/1.00	0.42/1.00	0.42/0.99	0.39/0.98

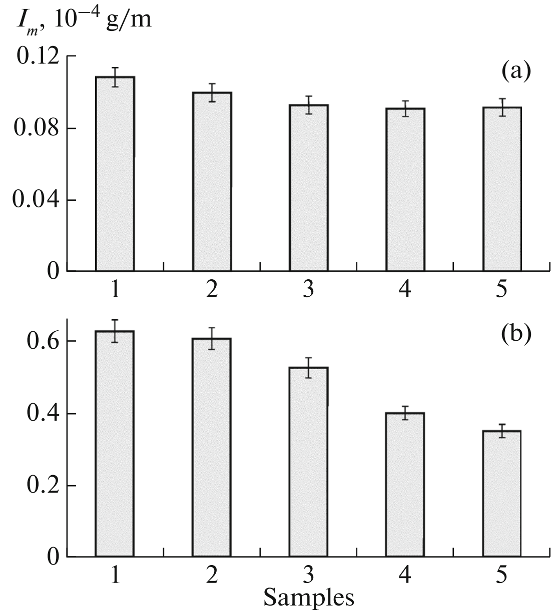

Fig. 4. Intensity of wear of samples 1–5 at the (a) first and (b) second stages of tribological tests.

Silicon carbide SiC particles are rather uniformly distributed in the CM volume due to intense mixing with the matrix babbit powder (see Fig. 2c) and a mixture of the babbit powder and MSR particles (see Fig. 2d).

The measured *HB* hardnesses of the CM samples are close to or higher than the hardness of as-cast babbit, which is most pronounced for the samples reinforced by SiC or SiC with MSR (see Table 1). The density of the CM samples with SiC particles, MSR particles, or their combination decreases with increasing particle content, which is caused by the significant difference between their specific densities. In the general case, the specific densities of the CMs are close to the calculated density at the given ratio of components, which excludes porosity and supports the prospects of producing such materials by powder metallurgy methods.

The results of two stages of tribological tests of the samples are presented in Tables 2 and 3.

At the loads corresponding to the first stage of tests, the friction coefficient and the friction stability coefficient are at the level of the antifriction B83 alloy (see Table 2). As compared to the as-cast B83 alloy, the wear resistance of the CM remains almost unchanged: a weak tendency toward its increase is visible (Fig. 4a).

Table 3. Friction coefficients f_{av} of samples (numerator) and friction stability coefficients α_{st} at the second stage (denominator)

Sample no.	f_{av}/α_{st} at load, N										
	100	125	150	175	200	225	250	275	300	325	350
1	0.37/0.83	0.31/0.84	0.27/0.92	0.23/0.93	0.21/0.91	0.18/0.80	0.14/0.71	0.11/0.61	0.06/0.55	0.05/0.53	0.04/0.47
2	0.38/0.72	0.31/0.95	0.31/0.95	0.29/0.87	0.25/0.94	0.19/0.95	0.15/0.85	0.09/0.98	0.07/0.98	0.08/0.93	0.10/0.53
3	0.45/0.86	0.42/0.96	0.40/0.94	0.35/0.91	0.32/0.92	0.32/0.96	0.26/0.85	0.21/0.98	0.20/0.98	0.17/0.95	0.14/0.98
4	0.38/0.80	0.41/0.94	0.37/0.90	0.30/0.81	0.24/0.82	0.21/0.91	0.15/0.65	0.12/0.84	0.09/0.78	0.08/0.93	0.07/0.80
5	0.37/0.92	0.36/0.95	0.31/0.93	0.30/0.95	0.23/0.89	0.15/0.94	0.06/0.93	0.05/0.97	0.04/0.98	0.05/0.99	0.05/0.94

These data demonstrate that powder metallurgy methods are promising for creating antifriction alloys.

A more significant increase in the wear resistance of the synthesize materials was obtained at higher loads at the second stage of tests (Fig. 4b). For example, the wear resistance of the B83 babbit + 0.5 wt % MSR + 3 wt % SiC CM increased by a factor of 1.8 as compared to the as-cast alloy. Figure 5 shows the diagrams of changing the friction coefficients of the as-cast babbit alloy (sample 1) and the B83 babbit + 0.5 wt % MSR + 3 wt % SiC CM (sample 5) for tests for time τ. At higher loads (P > 225 N), the friction coefficients are comparable and the friction stability coefficients tend toward unity; that is, friction is more stable (see Table 3).

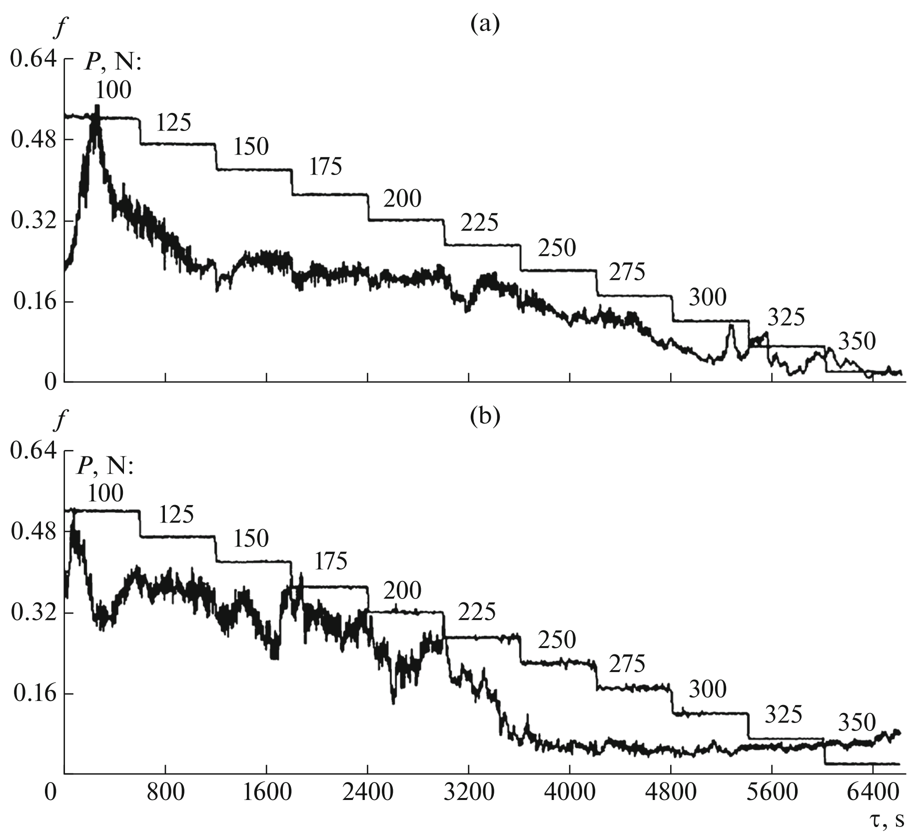

Fig. 5. Diagrams of friction tests of samples (a) 1 and (b) 5.

The dispersion of the intermetallic SnSb phase (decrease in its size by 15–40%) and the change in its morphology (absence of acute angles, i.e., stress concentrators) that were reached upon processing in a ball mill and the compacting of powder mixtures of given compositions under pressure allowed us to increase the fracture strength of the surface layer of the babbit B83–based CM during friction. The experimental results support the necessity of introducing schungite nanoparticles into a matrix to provide self-lubrication under dry sliding friction conditions and introducing high-strength silicon carbide microparticles, which serve as load-bearing supports on the friction surface. Thus, when introducing modified schungite rock nanoparticles and high-strength ceramic particles into a tin matrix, we were able to ensure conventional processes of friction and wear over a wider range of tribological loading parameters, i.e., to solve the problem of increasing the service life of the babbit alloy at high loads.

CONCLUSIONS

(1) We developed a technology, which is based on powder metallurgy methods in combination with hot pressing in the presence of a liquid phase, in order to decrease the size of the intermetallic SnSb phase, to change its morphology, and to achieve a uniform distribution of reinforcing and modifying fillers.

(2) The presence of high-strength ceramic silicon carbide particles and schungite nanoparticles in the alloy B83 matrix makes it possible to increase the wear resistance of the composite material and the stability of friction at high loads.

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