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COMPOSITE MATERIALS

Structure and Properties of the B83 Babbit Alloy Based Composite Materials Produced by Extrusion

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Abstract—Extruded bars of hardfacing B83 babbit alloy reinforced by silicon carbide particles with an average size of 40 μm and modified with shungite rock (MSR) were manufactured. Specimens of the powder mixture of babbit alloy and fillers produced by mechanical alloying were cold pressed, heated to the temperature of 310 ± 10 °C, exposed at this temperature for 30 min, and then extruded on a mechanical press at 320 ± 5 MPa. The structure, physical, mechanical, and tribological properties of produced composite material (CM) were studied. A uniform distribution of reinforcing fillers and changes in the morphology of intermetallic SnSb and Cu_3Sn phases with size reduced by 1.5–1.8 times were observed in the specimens produced by extrusion. The values of hardness, density, and elastic modulus measured by laser optoacoustic method were not worse than those for the cast B83 babbit alloy. Introduction of SiC and MSR particles into the babbit composition led to its strengthening and wear resistance increase by ~20% as compared with the cast material. The best wear resistance, 1.7 times greater than for the cast alloy, was obtained in SiC+MSR polyreinforced CM. This material was characterized by the least variation of the friction coefficients in the whole range of tribological loading studied and by the most stable process of friction.

Keywords: alloy babbit B83, reinforcing fillers, extrusion, composite rods, structure, laser optoacoustic method, wear resistance

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INTRODUCTION

Babbits belong to alloys that possess the best complex of antifriction properties. Alloys based on the SnSbCu system, in particular, B83, are widely used in industry. In addition to tin, it contains 10–12% Sb and 5.5–6.5% Cu and is a solid solution of copper and copper in tin (α phase), in which there are intermetallics Cu_3Sn in the form of needle formations (γ phase) and cubed crystals of intermetallics SnSb (β phase). The sharp-angled shape of large SnSb intermetallics, the vertices and faces of which are stress concentrators, as well as heterogeneity of the structure associated with the liquation processes during the crystallization and cooling of the alloy, reduces the wear resistance and fatigue strength of B83 [1–3].

The improvement in the properties of babbits may be achieved by dispersive hardening of alloys with micron particles, i.e., the obtaining of heterogeneous composite materials (CM) based on them [4, 5]. In this case, the joint action of uniformly distributed high-modulus reinforcing particles and a plastic matrix can increase the strength and fatigue life of the resulting composite without impairing its antifriction properties. It is known that such ceramic particles as SiC, TiC, SiO_2, and Al_2O_3, which have high hardness, high melting temperature, and high stability, are widely used as reinforcing fillers for hardening of plastic CM matrices [6–8]. Along with this, the introduction of low-density components into babbit may contribute to an increase in the specific strength characteristics of CM.

Table 1. Composition and mode of manufacturing of semifinished products

No.	Composition	Modes of mechanical alloying
1	B83 cast	–
2	B83 chips	200 rpm, 2 h
3	B83 + 3 wt % SiC	150 rpm, 10 min
4	B83+ 0.5 wt % MSR	200 rpm, 2 h
5	B83 + 0.5 wt % MSR + 3 wt % SiC	200 rpm, 2 h + 150 rpm, 10 min

In order to increase the wear resistance of bearings, it is promising to introduce nanosized carbon-containing particles into the matrix, which may result in dispersion of the structure and an increase in wear resistance owing to the formation of a finely dispersed mixture of wear products of CM and counterbody in the friction zone [9]. The disadvantages of foundry methods of fabrication of composite materials with discrete fillers are the difficulties of introducing reinforcing particles into the melt and providing their equal distribution in the melt volume, which results in porosity and, as a consequence, in a decrease in the strength of the material. It is possible to eliminate all these disadvantages by applying methods of powder metallurgy and extrusion.

The aim of this work was to study the structure, physical, mechanical, and tribological properties of dispersed-filled CM based on the babbit B83 alloy obtained by extrusion.

MATERIALS AND METHODS

For the production of CM, Babbit B83 (GOST 1320-74, 10–12% Sb, 5.5–6.5% Cu, Sn matrix) was used in the form of shavings obtained by mechanical treatment of the cast workpiece, as well as ~40 μm silicon carbide particles (GOST 26327-84) and shungite rock modified in the schungite laboratory of the Institute of Geology of the Karelian Scientific Center of the Russian Academy of Sciences (MSR). MSR used as a filler of CM is a complex carbon-mineral composition, which, according to the data of X-ray diffraction analysis, includes (in at %) 28–61 C, 5.1–16.6 Si, 7–39 O, 0.4–1.6 Na, 0.5–1.1 Mg, and 1.0–5.1 Al [10].

Powder for composite material was prepared from Babbit B83 shavings by grinding in RETSCH-PM100 planetary mill. The composition and modes of obtaining semifinished products by the mechanical doping method are presented in Table 1.

The weighed portions of the mixtures were pressed cold at a pressure of 320–340 MPa in a mold, which was then placed in a muffle furnace, heated to a temperature of 310 ± 10°C, held at this temperature for 30 min, and then extruded at the same temperature on an OMA mechanical press (P_{max} = 15 t) at a pressure of 320 ± 5 MPa using a spinneret with a diameter of 6 mm. The technological process for obtaining extruded rods is described in detail in [11].

From the obtained long-length rods with a diameter of 6 mm and a length of 400–600 mm, samples for optical and electron microscopy and physical, mechanical, and tribological tests were prepared.

The samples from cast babbit B83 and from babbit powder without filler after extrusion and samples of CM with filler were tested. The Brinnel hardness of the samples (*HB*) was measured on a Wilson Wolpert hardness measuring instrument at a load of 62.5 kg, when a ball with diameter of 2.5 mm was pressed in, and the density of the samples was determined by hydrostatic weighing.

The structure and the fracture surface of the rods were analyzed on LEO 430i and VERSA 3D electron microscopes, as well as on a Leika DM ILM optical microscope using the Qwin program for image analysis and determining the sizes of the structural components of the CM. Statistical analysis of the structure was carried out with respect to ten separate fields.

To measure the elastic moduli of the CM samples, a laser optoacoustic method (LOAM) was used, based on the thermo-optic mechanism of exciting broadband ultrasonic pulses of longitudinal and shear acoustic waves [12] and measuring the phase velocities of these waves in the samples. The main advantage of LOAM over conventional ultrasonic methods is the

Table 2. Composition, hardness, and density of the materials studied

No.	Composition	Hardness, *HB*	Density, ρ, g/cm^3
1	B83 cast	23.6	7.39
2	B83 (E)	23.2	7.28
3	B83 + 3 wt % SiC (E)	24.9	7.09
4	B83 + 0.5 wt % MSR (E)	24.0	7.27
5	B83 + 0.5 wt % MSR + 3 wt % SiC (E)	25.0	7.03

(E)—Samples after extrusion.

possibility of effective laser excitation of powerful probing acoustic pulses of submicrosecond duration. This makes it possible to carry out diagnostics of the structure and measurements of mechanical parameters for CM strongly absorbing and scattering ultrasound. Young's modulus E and shear modulus G, as well as the Poisson ratio ν, for the investigated CM samples were calculated from the measured values of the density and phase velocities of the longitudinal and shear acoustic waves in these samples from the known relations between the elastic constants and phase velocities of acoustic waves in an isotropic solid [13–15].

Tribological tests of CM samples were carried out under conditions of dry friction sliding on the CETR UMT Multi-Specimen Test System according to the finger scheme (CM rod)—disk (steel 45) with axial loads of 6, 10, 14, 18, and 22 N for 10 min at each load and a sliding speed of 0.37 m/s. The total friction path was L = 1100 m. The tests were carried out in air at a temperature of 20 ± 1°C and a humidity of 60 ± 4%.

On the basis of the test results, we estimated the volumetric intensity of the wear rate of the specimens $I_v = \Delta m/\rho L$, where L is the friction path and ρ is density, and the coefficient of stability of the friction process $\alpha_{st} = f_{av}/f_{max}$, where f_{av} is the average coefficient of friction and f_{max} is the maximum coefficient of friction [16].

RESULTS AND DISCUSSION

Table 2 shows the hardness and density values of the investigated samples of cast babbit, babbit powder, and composite rods obtained by extrusion.

The introduction of ceramic particles in the matrix provides an increase in the hardness of the CM as compared with the initial babbit by ~5%; the introduction of MSR barely affects the hardness of the CM, which remains at the same level as for the cast material. The hardest specimens were poly-reinforced CM samples, to which SiC and MSR particles were added.

As one can see, the density of CM is lower than that of alloy B83, evidently because of the presence of silicon carbide and MSR particles having a lower density (3.1 and 1.80–2.84 g/cm^3, respectively) in the material as compared with the matrix alloy (7.39 g/cm^3).

The results of metallographic and micro-X-ray spectral analysis (MRSA) of the samples are shown in Figs. 1 and 2. In the cast material, the intermetallics SnSb (β phase) are large inclusions of rectangular shape in solid solution of antimony and copper in tin that are not coherent with an α-solid solution of tin and, as already noted earlier, are sources of the emergence of micro- and macrocracks (Figs. la, 1b). After mechanical treatment of the shavings from B83 in a ball mill and subsequent extrusion, as a result of mechanical action, the intermetallics SnSb and Cu_3Sn are dispersed and lose their sharp-angled shape (Fig. 1c).

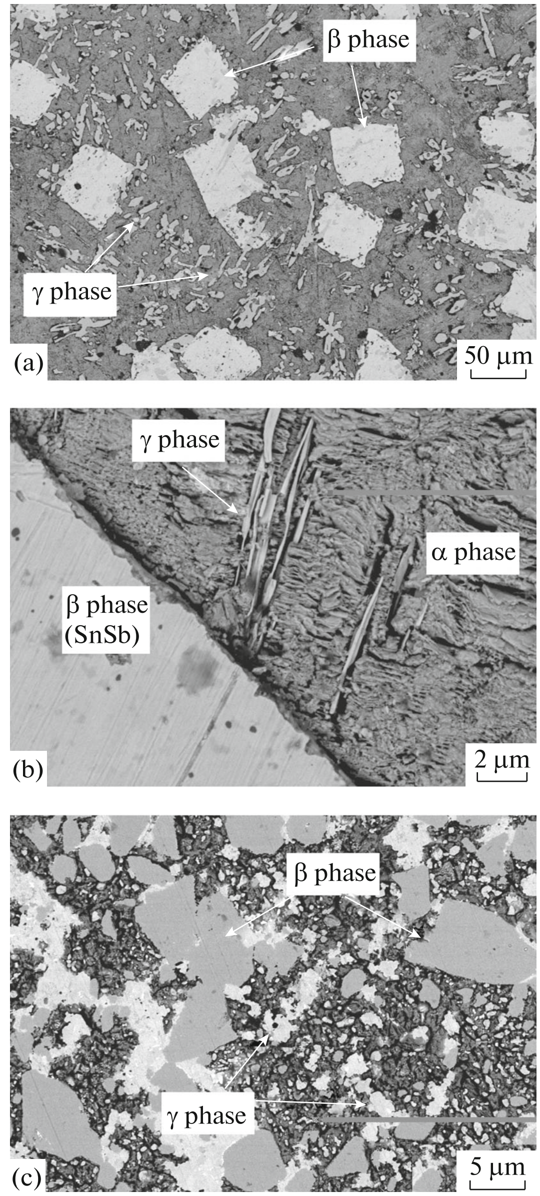

Fig. 1. Structure of the cast B83 alloy: (a) section surface; (b) SnSb intermetallic compound–matrix boundary; (c) structure of B83 alloy after extrusion.

The structure of composite rods (Figs. 3, 4) is shown in Fig. 2. As one can see, the particles of SiC and MSR are fairly evenly distributed in the matrix. At

Table 3. Size of the SnSb intermetallic phase

No.	Composition	L_{av}, μm
1	B83 cast	79
2	B83 (E)	68
3	B83 + 3 wt % SiC (E)	52
4	B83 + 0.5 wt % MSR (E)	45
5	B83 + 0.5 wt % MSR + 3 wt % SiC (E)	49

(E)—Samples after extrusion.

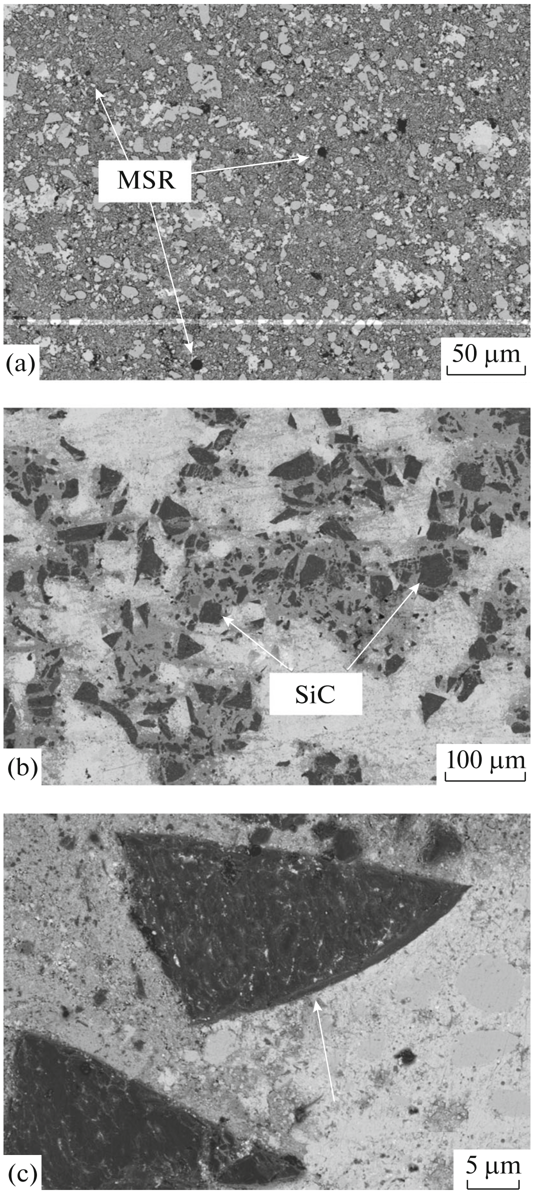

Fig. 2. Structure of the CM with composition of (a) B83 + 0.5 wt % MSR and (b) B83 + 3 wt % SiC; (c) SiC–matrix boundary.

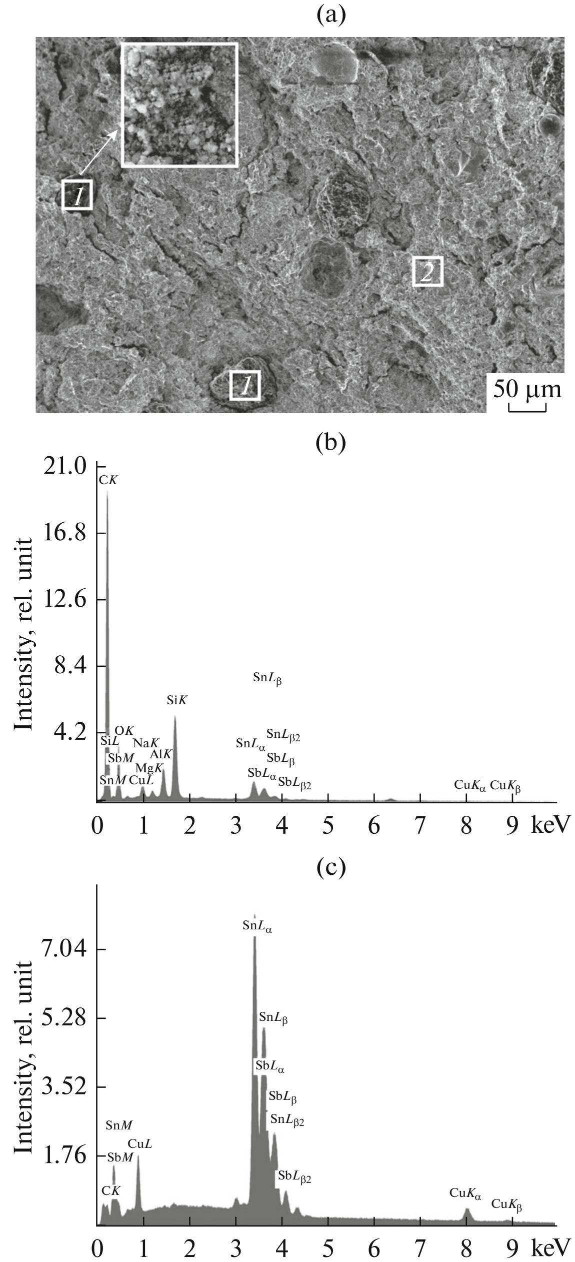

Fig. 3. SEM image (a) and X-ray microanalysis data for fracture surface of B83 + 0.5 wt % MSR composite material: (b) point *1*; (c) point *2*.

the SiC interface with the matrix alloy, there is no evidence of interphase interaction or the presence of cracks (Figs. 2b, 2c). The selected technological modes of mechanical alloying and extrusion provided the preservation of the initial particle size of the carbide phase.

The dark points on the surface of the thin section (Fig. 2a) are conglomerates of MSR with a size of 30–100 μm (Fig. 3).

MRSA of the surface of fractures of rods of the CM samples no. 4 and no. 5 confirmed the presence of SiC and MSR particles in the matrix (Figs. 3, 4). Grinding of the intermetallic phases, noted for the extruded B83 alloy, is also observed in the obtained CM. The results of measurements of the average size of the intermetallic SnSb phase performed using the Qwin program for image analysis of a cast sample, alloy B83 after extrusion, and CM are presented in Table 3. As one can see, at mechanical alloying and extrusion, the size of the intermetallic phase decreases: for CM reinforced with SiC, by a factor of 1.5; for CM reinforced with MSR, by a factor of 1.8; and for CM reinforced with SiC and MSP, by a factor of 1.6.

The results of optoacoustic measurements of the elastic parameters of samples from a powder of babbit without filler after extrusion and samples reinforced with high-strength SiC and MSR particles are shown in Table 4. Within the measurement error, the extruded babbit samples and CM samples based on it have practically identical values of the elastic parameters, comparable with the corresponding values for the cast alloy B83 [15]. This indicates the practical absence of porosity in the obtained samples, which, in turn, is one of the indicators of a sufficiently high wear resistance of extruded samples.

As one can see from Fig. 5, the intensity of babbit wear after extrusion (sample no. 2) decreased to 0.14 mm^3/m (for a cast sample, 0.152 mm^3/m). The grinding of the intermetallic phases SnSb and Cu_3Sn during the extrusion results in a decrease in wear, which may be related to a reduction in the friction surface of the overall area and the relative sizes of the areas of the solid solution prone to setting [3]. The additional introduction of particles of SiC and MSR into babbit also increases the wear resistance of extruded rods by 20% as compared with the cast material. The best results on wear resistance were shown by poly-reinforced CM (sample no. 5), the bulk wear resistance of which increased by 1.7 times as compared with the wear resistance of cast samples. Along with the grinding of the structural constituents of the matrix, the reinforcing fillers have an additional joint effect on the wear process. Large particles of SiC at low loads play the role of load-bearing supports, preventing the development of setting, and the particles of MSR falling on the friction surface act as a dry lubricant owing to carbon becoming part of their composition and, thereby, preserve the integrity of the surface layers.

Calculations of the stability coefficients showed that the friction process is the most stable on samples of the composition B83 + 0.5 wt % MSR + 3 wt % SiC (sample no. 5). For this sample, the smallest scatter in the values of the coefficient of friction is observed in all investigated intervals of friction loading, and the value of the stability coefficient is the closest to unity (Table 5).

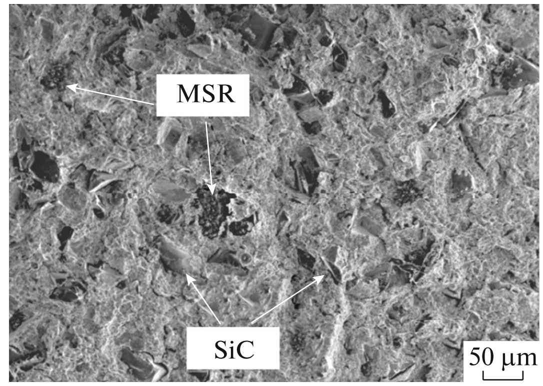

Fig. 4. The fracture surface of B83 + 0.5 wt % MSR + 3 wt % SiC composite material.

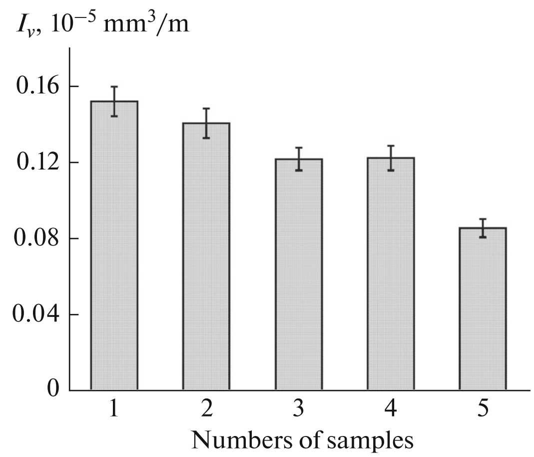

Fig. 5. Wear rate of specimens numbered as in Table 1.

CONCLUSIONS

The structure and mechanical properties, including wear resistance, of composite materials made by extrusion of a powder mixture based on babbit B83 with dispersed fillers of SiC and MSR were studied.

Mechanical alloying of powders and extrusion provide uniform distribution of reinforcing components in the matrix and grinding of intermetallic phases SnSb (β phase) and Cu_3Sn (γ phase). It is shown that samples of babbit obtained by extrusion and samples

Table 4. Results of the optoacoustic measurements of elastic properties of CM specimens produced by extrusion

No.	Composition	*E*, GPa	*G*, GPa	ν
2	B83 (E)	57.9 ± 4.6	21.9 ± 1.5	0.324 ± 0.016
3	B83 + 3 wt % SiC (E)	56.1 ± 4.5	21.1 ± 1.5	0.329 ± 0.016
4	B83 + 0.5 wt % MSR (E)	56.0 ± 4.5	21.4 ± 1.5	0.310 ± 0.016
5	B83 + 0.5 wt % MSR + 3 wt % SiC (E)	53.5 ± 4.3	20.4 ± 1.4	0.310 ± 0.016

(E)—Samples after extrusion.

Table 5. Values of the stability coefficients

Load, N	Sample number				
	1	2	3	4	5
6	0.754	0.844	0.645	0.771	0.815
10	0.803	0.875	0.926	0.832	0.845
14	0.781	0.904	0.682	0.711	0.801
18	0.843	0.789	0.784	0.809	0.854
22	0.862	0.856	0.819	0.812	0.857

of CM based on it have almost identical elastic properties comparable with the properties of cast alloy B83, which indicates an almost complete absence of porosity in extruded samples. It was found that the reinforcement of babbit with particles of silicon carbide and MSR increases the wear resistance and the coefficient of stability of the friction during friction loading under dry friction conditions. The best wear resistance values were obtained for the poly-reinforced CM of the composition B83 + 0.5 wt % MSP + 3 wt % SiC.

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