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Tribological Characterization of Aluminum/Babbitt Composites and Their Application to Sliding Bearing

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Abstract

The present work studies the tribological properties of new hybrid material composed from high porosity open cell aluminum alloy (AlSi10Mg) skeleton and B83 babbitt -infiltrated into it. The porous skeleton is obtained by replication method applying salt (NaCl) as space holder. The reinforcing phase of the skeleton consists of Al_2O_3 particles. The skeleton contains Al_2O_3 particles as reinforcement. The microstructure of the obtained materials is observed and the tribological properties are determined. A comparison between tribological properties of nominally nonporous aluminum alloy, high porosity open cell skeleton, babbitt alloy and the hybrid material is presented. It is concluded that new hybrid material has high wear resistivity and is a promising material for sliding bearings and other machine elements with high wear resistivity.

Keywords: Babbitt, Composite materials, Tribological properties, Sliding bearing

1. Introduction

Development of strong light-weight metal matrix materials can be realized by employing lighter alloys, such as aluminum alloys [1, 2], magnesium alloys [3], nickel alloys [4] and zinc alloys [5]. Other way to obtain stronger and lighter metallic materials is to apply new and improved technologies for production of high porosity metallic structures. One very often used technique for production of open cell porous materials is replication method [5, 6] in which leachable preform (space holder) is infiltrated by liquid metal. Afterwards the preform is removed and the remaining skeleton represents an open-cell porous material. For its relatively high specific strength, light-weight and good heat transfer capability the high porosity open cell aluminum matrix composites (AMC) are extremely desired for various structural and functional applications in the modern industry [7].The aluminum and nickel-based alloys are the most commercially available materials for liquid metal infiltration process [5]. The most often aluminum alloys applied as matrix are A356, 2000 and 6000 alloys [8].

For the production of wear-resistant materials the AMC are reinforced with hard and strong in compression ceramic materials such as silicon carbide (SiC) [9] and alumina (Al_2O_3) [10, 11]. The presence of ceramic reinforcing phase in the Al matrix is substantial for maintaining the strength and stiffness of the AMC [12]. The results of the wear tests of the authors Shouvik Ghosh et al. [13] indicate reduction of 28% for coefficient of friction of Al-10%SiCp reinforced metal matrix composites against steel counterbody under dry conditions. The authors Faiz Ahmad et al. indicate improved wear behaviour by using 30%vol. alumina particles in Al alloy [14]. Authors El-Aziz et al. conclude that up to 25 wt.% Al_2O_3 particles improve the wear rate of Al–Si alloy [15].

The aim of the present study is the development and characterization of new light-weight material with improved wear resistivity on the base of Al-alloy (AlSi10Mg), with 5 wt.% Al_2O_3 particles as reinforcing phase and the most widespread bearing alloys based on tin and lead. For that purpose, ~~Al-alloy~~ AlSi10Mg elements with two regions were prepared. First region was dense (pore free) but second one was relatively thin and of high porosity open sell structure. This region was infiltrated with B83 babbitt alloys and obtained material was tested tribologically.

The Al-alloy elements were obtained by replication method applying salt (NaCl) as space holder. Al_2O_3 particles were used as reinforcing phase in Al-alloy. Four types of specimens has been examined:

- non porous Al-alloy AlSi10Mg matrix;
- pure B83 babbitt;
- high porosity skeleton (Al alloy with Al_2O_3 particles as reinforcement);
- hybrid material obtained via infiltration of the skeleton with babbitt. Hereinafter we will consider «hybrid material» and infiltrated skeleton to be equivalent.

The microstructure of the obtained materials is observed. Tribological properties such as linear wear, volume loss and coefficient of friction are determined and compared for all tested specimens.

2. Experimental procedure

2.1. Materials and processing techniques

The materials used for the above-mentioned elements were aluminum alloy AlSi10Mg of composition shown in Table 1 and B83 babbitt of composition shown in Table 2. The reinforcing Al_2O_3 particles (Figure 1(a)) are of size in the range 10-30 μm. The salt (NaCl) particles (Figure 1(b)) used as leachable space holder are of size in the range 500 – 1000 μm.

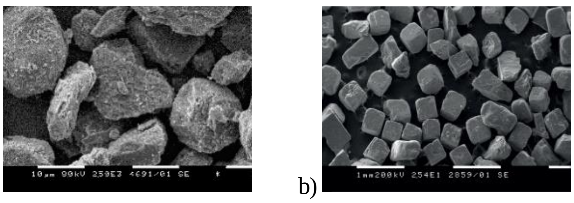
a)  b)

Fig. 1. SEM images of: (a) reinforcing phase Al_2O_3 particles with average size of 10-30 μm, (b) NaCl particles. in the range of 500−1000 μm

In this study for the preparation of specimens we applied replication method. It started with fabrication of salt compact shown in Figure 2, followed by its infiltration with molten metal and solidification under elevated pressure.

Fig. 2. Optical image of sintered salt preforms with Al_2O_3 as reinforcing phase

Then the obtained composite body was leached by dissolution in 70°C hot distilled water in ultrasonic machine in order to remove the NaCl particles. The procedure for fabrication of porous region could be described step by step as follows:

1) Preliminary drying of NaCl particles at 25 °C for 2 hours.
2) Sieving salt and reinforcing particles.
3) Mixing 5 wt.% Al_2O_3 together with 44 g salt particles and 5 ml distilled water for 20 minutes in a ball mill.
4) Compacting the obtained mixture into cylindrical steel cup of diameter 40 mm and height 70 mm under pressure of 1.5 MPa to prepare a compact.
5) Drying the compact for 24 hours at room temperature.
6) Sintering the so obtained compact at temperatures of 785°C.
7) Infiltration of the sintered compact by aluminum alloy at temperature 680 °C.
8) Removal of salt preform.
9) Infiltration by liquid B83 babbitt at temperature 430 °C.

Squeeze casting machine is employed for the salt preforms infiltration by the molten alloy. Steel die in which the infiltration is realized is preliminary heated up to 250 °C. The temperature of the salt preform before fixing into the die is 680 °C. The melt temperature before pouring was 760 °C and the squeeze pressure of 80 MPa is held for 60 s during solidification. Infiltration of babbitt into porous region, see Figure 3 (a), was done also by squeeze casting machine under pressure of 80 MPa.

The obtained by replication method high-porous composite materials are intended to be used for manufacturing of sliding bearings, Figure 3. In Figure 3 (a) is presented element with outer pores free region and in Figure 3 (b) element of outer pores free region and inner hybrid region consisting of babbitt infiltrated open cell skeleton. It should be mentioned that nonporous region and high porosity region were obtained simultaneously without additional processing.

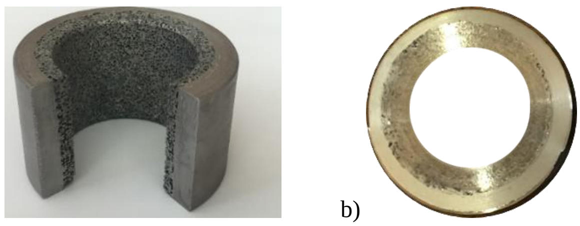
a)  b)

Fig. 3. Materials for tests: (a) element with outer pores free region and thin inner high porosity open cell region; (b) element of outer pores free region and inner hybrid region which consists of babbitt infiltrated open cell skeleton

2.2. Methodology and device for determining volume loss, coefficient of friction, linear and mass wear

The wear resistivity tests experiments were carried out on an installation certified by the American Society of Tribology and designed for “Pin/ball on the disk” tests of the company Ducom. No lubricant was used in all tests.

Table 1.
AlSi10Mg alloy composition, wt. %

Alloy	Si	Fe	Cu	Mn	Mg	Ni	Zn	Pb	Sn	Ti	Al
Composition, %	9.0–11.0	0.55	0.05	0.45	0.2–0.45	0.05	0.10	0.05	0.05	0.15	rest

Table 2.
B83 Babbitt alloy composition (standard?), wt. %

Alloy	Fe	Al	Cu	As	Pb	Zn	Sb	Bi	Sn
Composition, %	0.1	0.005	5.5–6.5	0.05	0.35	0.004	10–12	0.05	80.94–84.50

An analytical balance Boeco BAS32 Plus with a scale accuracy of 0.1 mg and possibility of automatic internal calibration was used for determination of mass wear.
The methodology for determining coefficient of friction**,** linear and mass wear consisted of the following:

1) Before tests all specimens were treated by alcohol to prevent static electricity.
2) Initial mass is determined by analytical balance.
3) Specimens were placed vertically with its radius rounded tip perpendicular to a flat counterpart disk for the Pin on disk tests.
4) Tested specimens were pressed to the counterpart disk at a specific load by means of a lever with weights attached at its other end.
5) During the tests the results were reported in real time as plots.
6) Final mass is determined by analytical balance after the end of each tribology test.

When each test was over, we had obtained plots of linear wear (μm) vs sliding distance (m)/time (sec), coefficient of friction vs sliding distance (m)/time (sec) and friction force (N) vs sliding distance (m) /time (sec).

The parameters of all tribological experiments were as follow:

1) Time: 16.00min
2) RPM: 137
3) Linear Velocity: 1.0042m/s
4) Load: 50N
5) Disk diameter: 140mm
6) Friction condition: dry
7) Friction time: 980 s.

Volume loss for each specimen was determined by using the formula related to pin-on-disk tests from ASTM Standards [20] assuming that there is no significant disk wear:

$$v_p = \left(\frac{\pi h}{6}\right)\left(\frac{3d^2}{4} + h^2\right) \qquad (1)$$

where,

$h = r - (r^2 - d^2/4)^{1/2}$;
v_p – pin (spherical end)vol loss;
d – wear scar diameter;
r – pin end radius.

3. Results and discussion

We first consider the results of two test samples after finished wear tests. In Figure 4 are presented SEM images of the tested surfaces after the tribological tests of the Al-alloy matrix and the skeleton.

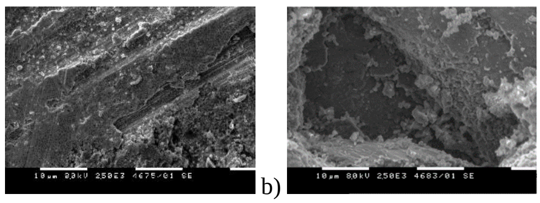
a) 

Fig. 4. SEM images of samples after conducted wear tests: (a) Al-alloy matrix, (b) skeleton.

In Figure 4 (a) could be seen the tracks on matrix material after its wearing. Figure 4 (b) presents an open pore close to the surface of the skeleton. It could be seen that the cell walls of the skeleton are smooth and free of cracks.
In Figure 5 are shown the SEM images of the tested surfaces for the other two specimens: pure babbitt and infiltrated skeleton. We can notice cracks on both images on Figure 5 (a) and (b), due to the brittleness of the SnSb (β) phase because its hexagonal lattice has a limited number of slip planes available for plastic deformation [21]. Under the cracked babbitt surface layer on the infiltrated skeleton in Figure 5 (b) it could be seen Al-alloy struts which serve play role of reinforcement and makes the Al-alloy/babbitt hybrid material stronger.

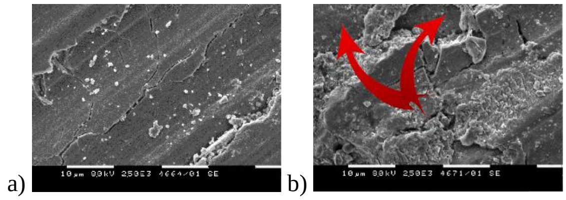


Fig. 5. SEM images of samples after conducted wear tests: (a) pure babbitt, (b) infiltrated with babbitt skeleton

In Figure 6 are presented SEM images of wear scar minimum and maximum diameter for all tested specimen, which are used in Formula (1) for determining volume loss.

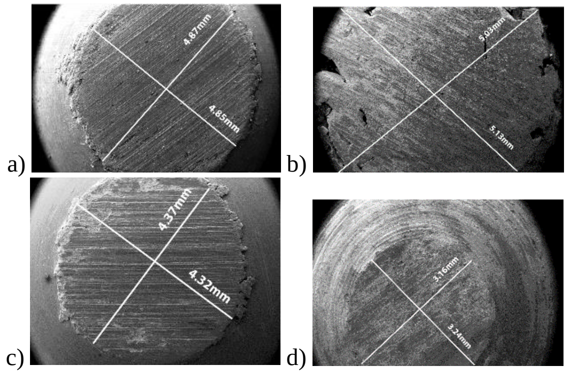


Fig. 6. SEM images of wear scar diameter measurement: (a) Al-alloy matrix, (b) Skeleton, (c) Pure babbitt, (d) Infiltrated skeleton

Table 3 shows the wear test data of friction force, coefficient of friction (COF), linear wear, maximum, minimum and average scar diameter and calculated by formula (1) volume loss for all samples. In Figure 7 and 8 are represented the measured changes in wear and the friction coefficient for the materials under consideration and their changes during tribological tests. As can be expected, non-infiltrated skeleton is less wear resistive compare to the rest materials. The linear wear for the skeleton is 595 μm and for the Al matrix 425 μm, see Table 3. This is due to brittle and thin struts which could be easily destroyed during the friction on the disk. For the nonporous matrix such brittleness does not exists and its linear wear and volume loss are smaller.

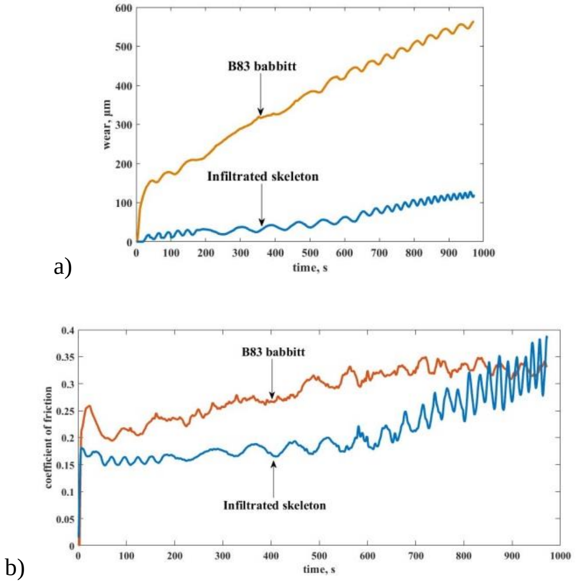


Fig. 7 Pure babbitt vs infiltrated skeleton subjected on a load of 50N: (a) linear wear, (b) coefficient of friction

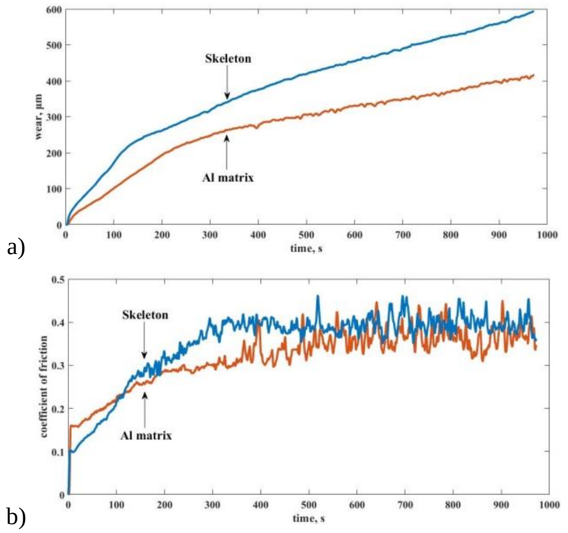


Fig. 8 Al matrix vs skeleton subjected on a load of 50N: (a) linear wear, (b) coefficient of friction.

Table 3.
Wear test data for all samples

Sample	Friction Force, N	COF (average)	Linear wear, μm	d_{max}, mm	d_{min}, mm	$d_{average}$, mm	V_{loss}, mm^3
Al matrix	14.75	0.295	425	4.87	4.85	4.86	5.973
Skeleton	17.10	0.351	595	5.03	5.13	5.08	7.196
Pure babbitt	14.15	0.283	570	4.37	4.32	4.34	3.726
Infiltrated skeleton	10.40	0.208	128	3.24	3.16	3.20	1.066

It could be seen (Table 3) that the pure babbitt sample has a significant linear wear of 570 μm compared with infiltrated skeleton with 128 μm of linear wear. The average coefficient of friction for the pure babbitt is 0.283 and for infiltrated skeleton is

0.208. These numbers indicate significant improvement of tribological parameters for the hybrid material obtained after babbitt infiltration into Al-alloy skeleton.

The linear wear of the pure babbitt increases constantly during the test and reaches value of 570 µm at 980 s but for the hybrid material (infiltrated skeleton) changes very slowly until 650 s when reach value of 50 µm, see Figure 7 (a). Then the wear start to increases more promptly to 128 µm at 980 s. The reason for such good wear resistivity is that the Al-alloy skeleton serves as solid support of the relatively more plastic babbitt and keeps it on the working surface, see Figure 5 (b). From the other hand the infiltrated babbitt onto high porosity skeleton protects and thus makes it more resistive against destroying. The curves in Figure 7 (b) indicate that the coefficient of friction for pure babbitt is higher in comparison to the coefficient for the new hybrid material. The last one keeps average 30 % lower coefficient of fiction that pure babbitt.

Figure 7 (a) shows that during the test the linear wear the Al-alloy matrix is lower around 28% in comparison with the linear wear of the skeleton while the coefficient of friction for the matrix is lower around 15% compare to that coefficient for the skeleton.

4. Conclusions

New hybrid material with improved tribological characteristics was obtained. The material consists of high porosity open cell Al-alloy skeleton infiltrated with babbitt. The tribological properties of the new material were tested in dry friction conditions and compared with those of the babbitt, the skeleton and the Al-alloy matrix. It could be concluded:

1. Coefficients of friction for skeleton and matrix alloy are almost equal;
2. Linear wear and volume loss for skeleton and matrix alloy differs significantly;
3. Infiltrated babbitt improves mechanical properties of high porosity skeleton and inhibits strides destroying during friction process. Skeleton plays role of reinforcement and prevents babbitt against fast wear;
4. In comparison to babbitt, the new hybrid material has approximately 27 % lower average coefficient of friction, 77% lower linear wear and 71% lower volume loss.

The obtained hybrid composite is a promising material for manufacturing of sliding bearings and different machine elements with high wear resistivity.

Acknowledgements

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