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Tribological characterization of high porosity aluminum based composite materials

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Abstract

The present work aims to study the effect of the reinforcing phase on dynamic coefficient of friction and mass wear of specimen with different compositions under various friction conditions.

Porous materials with different compositions and reinforcing phase are obtained by replication method applying salt (NaCl) space holder. The reinforcing phase is Fly Ash (FA) particles. The microstructure of the obtained materials is observed and the tribological properties such as mass losses and the dynamic coefficient of friction are determined. A comparison of the tribological properties between nominally nonporous matrix, porous matrix and porous composite are presented in this study.

Keywords: *aluminum based composite materials, tribological properties, fly ash, reinforcing phase*

1. Introduction

During the last two decades, the development of new light-weight materials became a focus of intensive R&D activity. Without any doubt, the porous materials and especially the metallic porous materials are part of our engineering environment as structural and functional elements. Development of lighter and stronger light-weight metal 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 produce lighter and stronger metallic materials is to apply new and improved technologies. One of the most often used technique is replication method [5,6] in which leachable preform (space holder) is infiltrated by liquid metal. Afterwards the preform is removed and the reminding skeleton represents an open-cell porous material. That process is an effective way for production of high porous metal materials with an open-cell structure. The aluminum and nickel based alloys are the most commercially available materials for liquid metal infiltration process [5].

The salt (NaCl) is one of the most applied space holder methods for obtaining different metallic open-cells materials because of its advantages like relatively high melting temperature, low cost, free of toxicity and fast dissolution in water [6–10]. Fly Ash (FA) cenospheres fraction of size from 60 μm to 125 μm is used as reinforcing phase.

In the present paper, the effect of the reinforcing phase on dynamic coefficient of friction and mass wear of specimen with different compositions under various friction conditions are studied. The high-porous materials are obtained by replication method and the aim is to study their applicability for production of slide bearings. The aluminum alloy AlSi12CuNiMg is used as matrix and FA as reinforcing phase in order to obtain the porous composite material.

2. Materials and methods

2.1. Materials and processing techniques

The replication technique begins with fabrication of leachable space holder, followed by its infiltration with molten metal and solidification under elevated pressure. Then the obtained composite body which contains two interconnected networks, one of NaCl and the other of aluminum alloy, is leached by dissolution in water in order to remove the NaCl.

The matrix material used for the infiltration is the AlSi12CuNiMg alloy, widely used in practice, with composition given in Table 1.

Table 1. AlSi12CuNiMg alloys composition, wt. %

Alloy	Si	Cu	Ni	Mg	Fe	Mn	Al
AlSi12CuNiMg	11.0−13.0	1.5−3.0	0.8−1.3	0.8−1.3	<0.8	0.3−0.6	rest

The porous materials are obtained by replication method with NaCl particles in the range of 800−1000 µm applied as space holder, see Figure 1a. The porous matrix specimen is fabricated following the procedure:

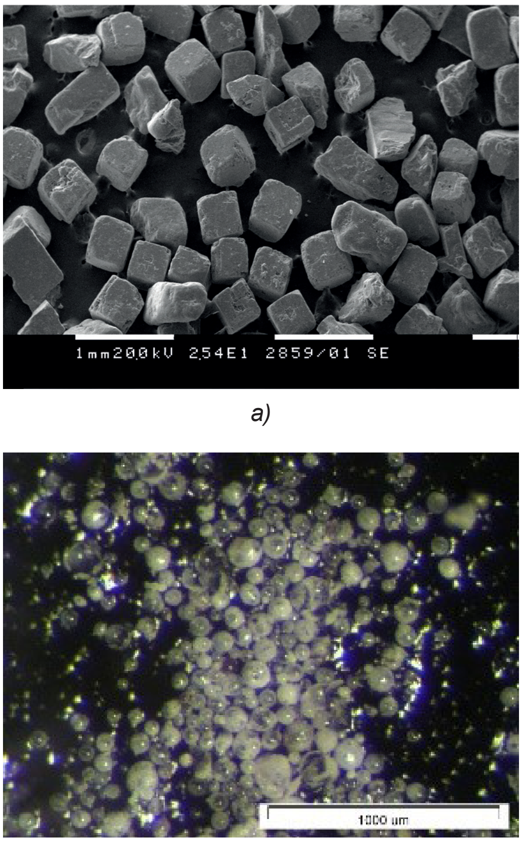
1. Removing the moisture of the NaCl particles by preliminary drying them at 25° ±3°C for 2 hours.
2. Sieving the salt particles.
3. Mixing 44 g salt particles with 5 ml distilled water for 20 minutes in a ball mill.
4. Compacting the obtained mixture into cylindrical steel cup of diameter 40 mm and height 70 mm under pressure of 1.5 MPa to prepare a pre-sintered preform.
5. Drying pre-sintered preform for 24 hours at room temperature.
6. Sintering the so obtained compact at 785° ±1°C for 2 hours and cooling at room temperature in order to have salt preform.

The porous composite specimen is fabricated by following the same procedure but 20 wt. % FA is added and mixed together with the salt in step 3. Fly Ash particles of size in the range 60−125 µm are applied as reinforcement. This fracture is obtained after sieving of as-received FA, see Figure 1b. The obtained under the above procedure salt preforms can be seen in Figure 2.

The structure characteristics of matrix, porous matrix and porous composite specimens are presented in Table 2.

Table 2. AlSi12CuNiMg alloys composition, wt. %

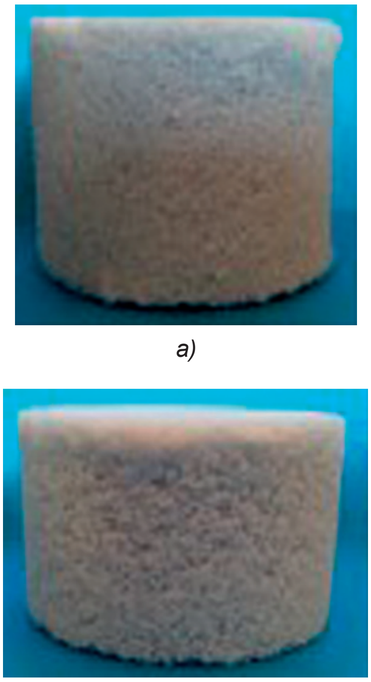
Specimen type	Relative porosity	Reinforcing phase size, µm	Preform particles size, µm	Average preform particles size, µm	Density, g/cm^3
Matrix	0	–	–	–	1
Porous matrix	0.61	–	800−1000	900	1.050
Porous composite	0.59	60−125	800−1000	900	1.083



a)

b)

Fig. 1. SEM images of the specimen a) NaCl particles in the range of 800−1000 µm, b) as-received FA particles



a)

b)

Fig. 2. Optical images of sintered salt performs: a) without reinforcing phase, b) with FA as reinforcing phase

Squeeze casting machine is used for the preforms infiltration by the molten alloy. The steel die, in which the infiltration is realized, is preliminary heated up to 200° ±10°C and the temperature of the salt preform before fixing into the die is 680° ±2°C. The melt temperature before pouring is 760° ±10°C and the squeeze pressure of 80 MPa is held for 60 s during solidification, see Figure 3.

a)

b)

Fig. 3. Images of a) cast specimen with high porous core and dense outer region, b) specimen for compressive mechanical tests of open-cell AlSi12CuNiMg/FA composite material

Three types of specimens are fabricated. The first one is nominally nonporous matrix, the second one is porous matrix and the third one is porous composite.

2.2. Methodology and device for testing the dynamic coefficient of friction and the mass wear

The methodology of the dynamic coefficient of friction consists of the following [11]:

- The dynamic coefficient of friction μ for each specimen is determined by measuring the frictional force T for a given load P under the same boundary friction conditions applying the formula: $\mu = \frac{T}{P}$.
- The friction force T is measured on the wearing specimens under the following conditions: friction time is 5 minutes, friction distance S = 270 m, sliding speed v = 0.9 m/s. The abrasion surface is high-alloy steel with hardness HRC65 and the lubricant is 15W40 engine oil.

The methodology for the determination of the mass wear consists of the following:

- The starting mass of each specimen is measured with an electronic scale WPS180/C/2 with accuracy of 0.1 mg and the specimen are prepared for the experiment by alcohol to prevent static electricity.
- All specimens are placed vertically with its porous part at a depth of 25 mm for 30 minutes, in 15W40 engine oil bathtub.
- Specimen are taken out of the oil and placed on filter paper for 20 minutes, before the wear begins.
- The specimen is than placed in a thermo-chamber with a ventilation system where it stays for 4 hours at 250°C.
- Mass wear is obtained by the difference between the starting and final mass of the specimen.

3. Results and discussion

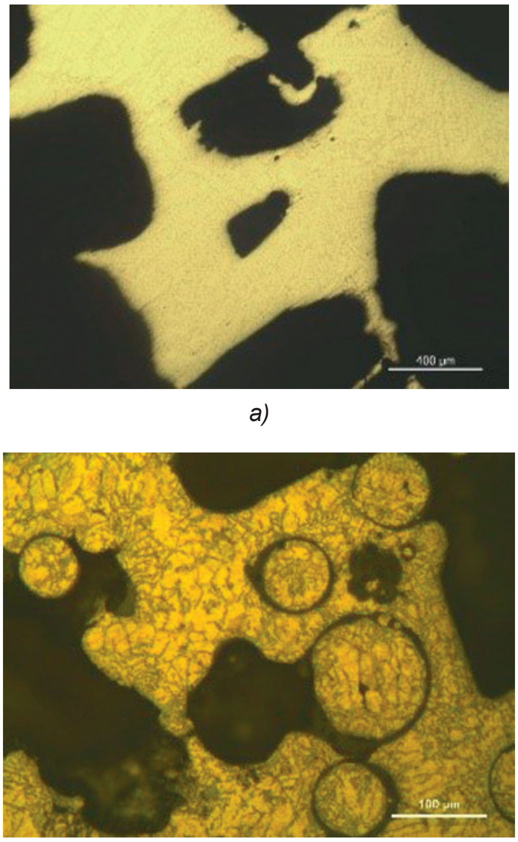
In Figure 4 can be seen the optical micrograph images of open-cell aluminum AlSi12CuNiMg alloy porous materials with and without the reinforcing phase.

The open pores with average diameter of 900 μm are dispersed homogeneously. The inner cell surfaces are smooth and free of cracks. The cell walls are solid which indicates effective liquid phase processing technology, i.e. the squeeze pressure of 80 MPa guarantees successful preform infiltration and sound solid skeleton. The pores have almost the same size as the NaCl particles. The black circles in Figure 4b indicate the existence of reinforcing FA particles.

The results obtained for the mass wear of the porous matrix and the porous composite specimens are presented in Table 3.

Table 3. Mass wear of tested specimens

No. of specimen	Startup mass, g	Mass after friction, g	Mass loss, mg
Matrix	8.8648	8.8557	9.1
Porous matrix	5.2982	5.2940	4.2
Porous composite	5.3899	5.3835	6.4



a)

b)

Fig. 4. Optical micrographs images of open-cell aluminum AlSi12CuNiMg alloy materials a) without reinforcing phase, b) porous composite

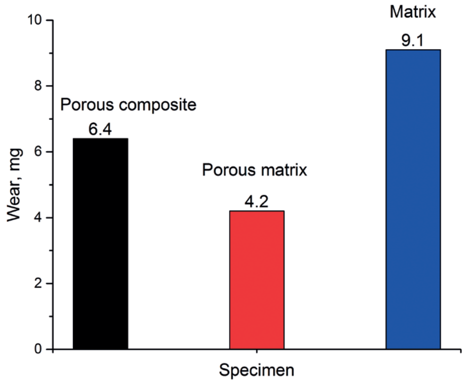


Fig. 5. Visualized results for the mass wear of the tested specimen

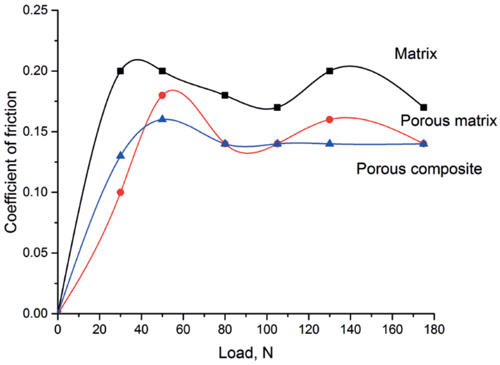


Fig. 6. Visualized results for the dynamic coefficient of friction

It can be observed in Figure 5 that the mass loss of the reinforced porous specimen exceeds with approximately 25% the mass loss of the non-reinforced porous matrix at the same porosity. The reason for this is the brittleness of the reinforced cell walls caused by relatively high size of reinforcing phase.

The specimens are tested at different loads of 30 N, 50 N, 80 N, 105 N, 130 N and 175 N. The results obtained for the dynamic coefficient of friction of the porous matrix and the porous composite specimens are shown in Table 4.

As can be seen in Figure 6, the dynamic coefficient of friction for the porous specimen with 61% porosity is approximately 20% smaller in comparison with the nominally nonporous one at different loads. The porous composite specimen with FA as reinforcing phase has 8−10% lower coefficient of friction in comparison with the porous matrix with equal porosity at different loads.

4. Conclusions

The present work aims to study the effect of FA on the tribological properties such as frictional force, dynamic coefficient of friction and mass wear of high porosity

Table 4. Frictional force T and dynamic coefficient of friction μ

No. of specimen	Load, N											
	P_1 = 30 N		P_1 = 50 N		P_1 = 80 N		P_1 = 105 N		P_1 = 130 N		P_1 = 175 N	
	T	μ	T	μ	T	μ	T	μ	T	μ	T	μ
Matrix	6	0.20	10	0.20	14	0.18	18	0.17	26	0.20	30	0.17
Porous matrix	3	0.10	9	0.18	11	0.14	15	0.14	21	0.16	24	0.14
Porous composite	4	0.13	8	0.16	11	0.14	15	0.14	18	0.14	25	0.14

aluminum based composite materials obtained by replication method.

It is observed that the inner cell surfaces are smooth and free of cracks and the cell walls are solid which indicates effective liquid phase processing technology. The porous composite material with 20 vol. % FA as reinforcing phase has 8−10% smaller coefficient of friction in comparison with the matrix material with the same porosity. The dynamic coefficient of friction for the materials with 61% porosity is 20% smaller in comparison with the nominally nonporous material at different loads. Mass loss of the reinforced porous specimen is about 25% greater in comparison with the mass loss of the non-reinforced porous matrix at the same porosity. In order to reduce the mass loss and brittleness of the composite porous materials the size of reinforcing particles should be diminish. For that purpose, the application of fibers and whiskers seems to be very promising reinforcing phase.

Acknowledgements

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