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RESEARCH

Tribological Properties of Al-Si Alloy A356 Reinforced With Al_2O_3 Particles

MMCs as new and promising materials are under constant development and their application in different industries is increasing. They have better mechanical and tribological properties comparing to the matrix materials. This paper presents tribological tests results of Al-Si alloy A356 (EN-Al Si7Mg0.3), with and without 3 wt. % Al_2O_3 reinforcement. The reinforcement was in the shape of particles with 12 µm in diameter and the technology for producing of composite was compocasting. The pin-on disc tribometer was used to carry out these tests under dry sliding conditions at different loads. Worn surfaces and wear debris were also observed and analysed with scanning electron microscopy (SEM).

Keywords: Aluminium matrix composites (AMCs); dry sliding; friction; wear

INTRODUCTION

The use of different types of metal matrix composites (MMCs) is in constant growing over the years, because they have better physical, mechanical and tribological properties comparing to matrix materials. Composite materials based on light metals like Aluminium, Magnesium and Zinc, due to their low density, find application in many industries [1-5].

The idea that relatively small amount of reinforcement can improve characteristic of matrix material by several times is very interesting, so constant improvements of MMCs process technologies and possibilities for their new application are not a surprise. Better tribological properties of composite comparing to the matrix material is of great importance in all machines where parts are in contact and relatively motions.

The fact is that tribological properties are the one that define possible application of material far more than their mechanical properties, since they are in better correlation with behaviour in practice. Numerous authors have investigated friction and wear properties of aluminium matrix composites (AMCs) and have analysed different influences:

- the type of matrix and counter part material and their hardness [6-8],
- the type of reinforcements, its shape, dimension and volume percentage [9-11],
- testing conditions (load, speed, temperature, type of relative motion and lubrication and environment) [12-14].

Most of these investigations were conducted on model type pin-on-disc tribometers. A more detailed review of the used apparatus, materials and testing conditions can be found elsewhere [15,16].

The aim of this paper is to present investigation on domestically produced Al based composite [17] and to show possible directions how to improve its tribological properties, in the next phase of the project.

EXPERIMENTAL PROCEDURE

Matrix material was hypoeutectic Al-Si alloy A356 (EN-Al Si7Mg0.3) with chemical composition listed in Table 1.

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Table 1. Chemical composition (wt. %) of Al-Si alloy A356

Element	Si	Cu	Mg	Mn	Fe	Zn	Ni	Ti	Al
Percentage	7.20	0.02	0.29	0.01	0.18	0.01	0.02	0.11	Balance

Composite material was produced by compocasting technology and the reinforcement was alumina (Al_2O_3), in the shape of particles, with 12 µm in diameter and 3 wt. %. Experimental procedure and apparatus used for fabrication, as well as microstructure, are described and discussed elsewhere [17].

Two sets of specimens were used for testing; one was fabricated from the matrix material (ref. as A356) and the other one from composite material (ref. as KA356). Both specimens were subjected to heat treatment with following parameters: solution annealing at 540 °C for 6 h, water quenching and artificial ageing at 160 °C for 6 h.

Hardness of tested materials was measured under a 50 g load using a Vickers microhardness tester. Values were 70.0 and 78.8 $HV_{0.05}$ for A356 and K A356 respectively.

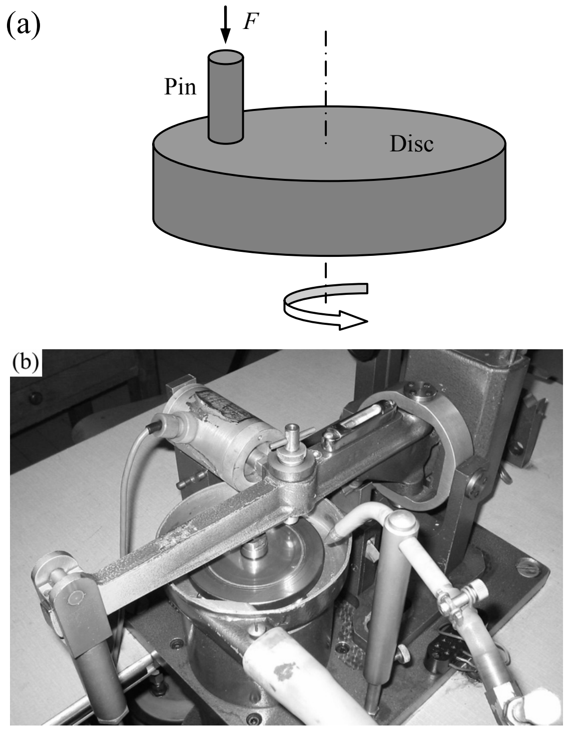

Fig. 1. Pin-on-disc tribometer: (a) schematic diagram and (b) photography

Tribological tests were carried out on the pin-on-disc tribometer under dry sliding conditions, in ambient air at room temperature (≈ 25 °C). Cylindrical pins of tested materials having 2.5 mm diameter and 30 mm length were used as wear test samples. Disc (hereafter referred to as counter body) of 100 mm diameter and 10 mm thickness was made of nodular gray cast iron. This material was chosen as a standard piston ring material with specification according to the ISO standard (Subclass Code MC 53) [18] and hardness of 220 HV10. Diagram of the load, pin, disc and the direction of the rotation and the photography of tribometer are shown in Fig. 1.

Surface roughness of pins and counter body was around R_a = 0.5 and 0.3 µm, respectively.

Before and after testing, both the pin and the counter body (disc) were degreased and cleaned with benzene. Pins were weighed with accuracy of 10^{-4} g before and after each test to calculate the mass loss. The value of friction force was monitored during the test and through data acquisition system stored in the PC, enabling the calculation of friction coefficient.

Tests were carried out at selected test conditions: constant sliding speed of 1 m/s, constant sliding distance of 5000 m and normal load of 2.3 / 5 / 7.3 and 15 N. Taking into account the contact area of approximately 5 mm^2 the specific load was 0.46 / 1 / 1.46 and 3 MPa, respectively.

After testing, worn surfaces of pins and generated wear debris were examined by scanning electron microscopy (SEM).

RESULTS AND DISCUSSION

Results of friction tests are presented in Table 2 with characteristic appearance of friction coefficient curves shown in Fig. 2. It could be noticed that matrix material doesn't show dependence of friction coefficient from specific load, while for composite material friction coefficient decrease with increase of specific load.

Table 2. Mean value of the friction coefficient for steady state period

Material				
	0.46	1	1.46	3
A356	0.38	0.38	0.38	-
KA356	0.51	0.43	0.39	0.33

This could be explained by the appearance of significant plastic deformation of pin surface, for the specific loads of 1.46 and 3 MPa (Fig. 3).

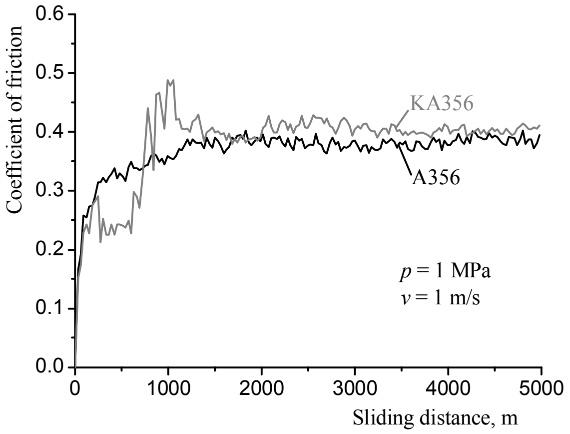

Fig. 2. Coefficient of friction vs. sliding distance for p = 1 MPa and v = 1 m/s

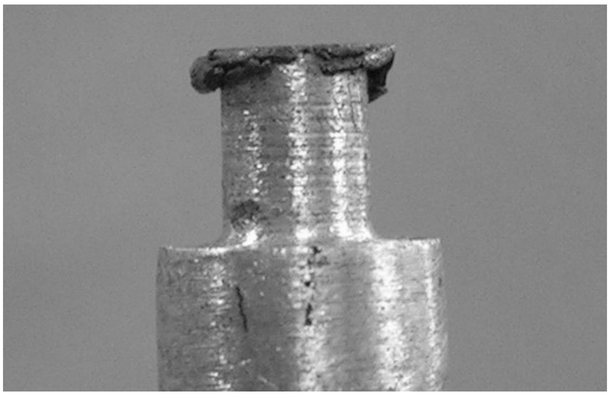

Fig. 3. Plastic deformation of pin KA356 at 1.46 MPa

Wear test results show, for the applied load range, that mass loss as a function of sliding distance increase with increase of specific loads (Fig. 4), which is expectable. Presence of 3 wt. % reinforcement in the composite material had influence on wear rate only for specific load up to 1 MPa (Fig. 5). Also it reflects on higher coefficient of friction. Reduction of wear rate for composite comparing to the matrix material was 17 and 7 times for specific load of 0.46 and 1 MPa, respectively. With higher specific loads contact temperatures become too high and plastic deformation occurs with consequence of very high wear. One of the suggestions, to prevent plastic deformation and further improve of hardness, is to increase volume percentage of reinforcement.

The surface condition of pins exposed to wear and generated wear debris analyses show that predominant mechanism of wear was adhesion followed with plastic deformation (Figs. 6 and 7).

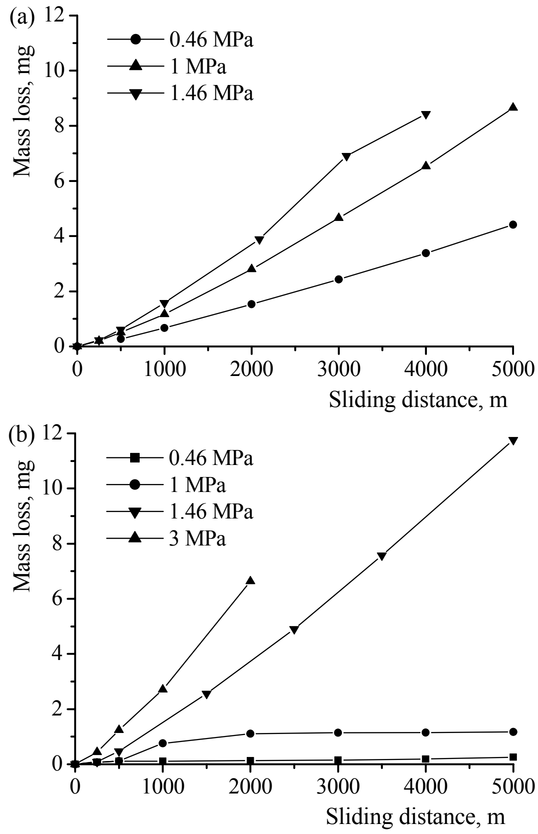

Fig. 4. Mass loss of (a) A356 and (b) KA356 for different specific loads

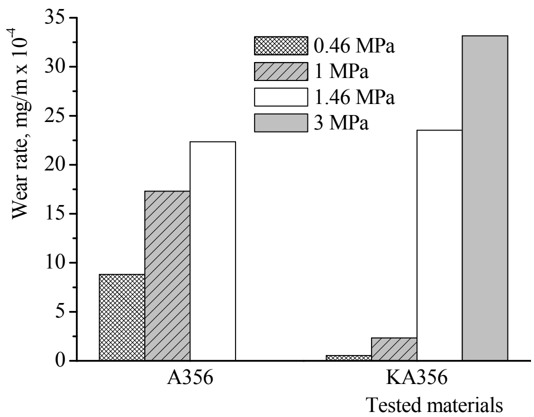

Fig. 5. *Wear rate of tested specimens for different specific loads*

The surface condition of pins exposed to wear and generated wear debris analyses show that predominant mechanism of wear was adhesion followed with plastic deformation (Figs. 6 and 7).
The SEM micrographs of pins worn surfaces show a presence of plastic deformation and formation of plate-like particles (Figs. 6a and 6b). For composite material appearance of microcracks and wear particles was much obvious comparing to the matrix material. Presence of wear debris caused by fracture, accumulated into the adhesive wear pits was also noticed (Figs. 6c and 6d).

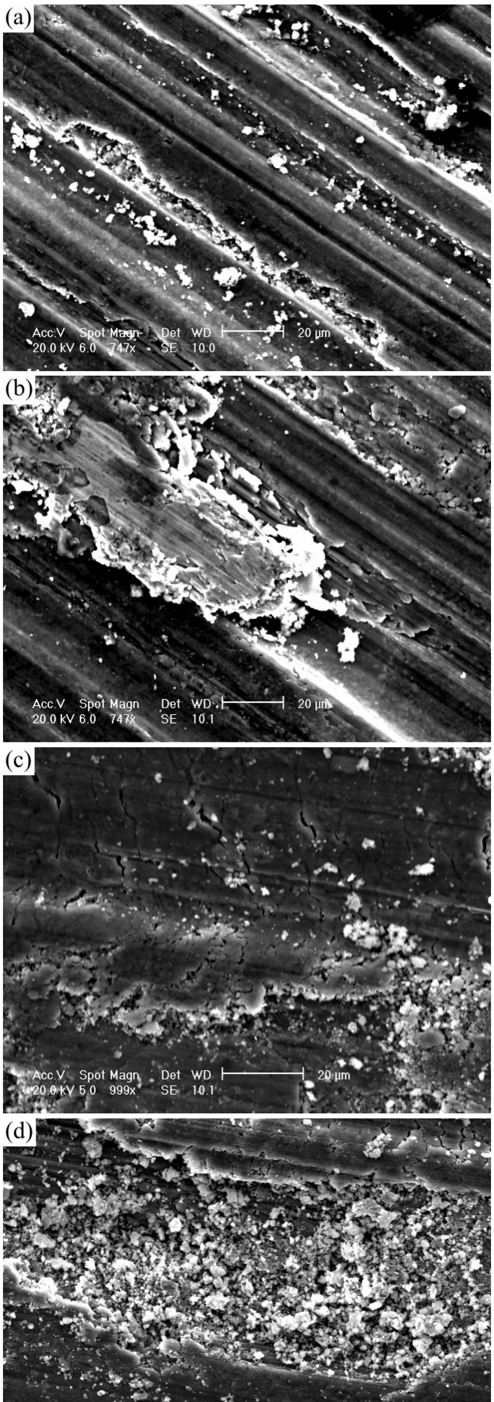

Fig. 6. SEM micrographs of pin worn surfaces: (a) and (b) A356 (1 MPa) and (c) and (d) KA356 (1 MPa)

Formation of the plate-like particles typical for adhesive wear [19,20] was confirmed with SEM analyses of wear debris. Particle distribution, shape and size were irregular. It could be noticed that matrix material wear debris was relatively smaller and uniform in shape and dimension then composite material (Figs. 7a and 7b).

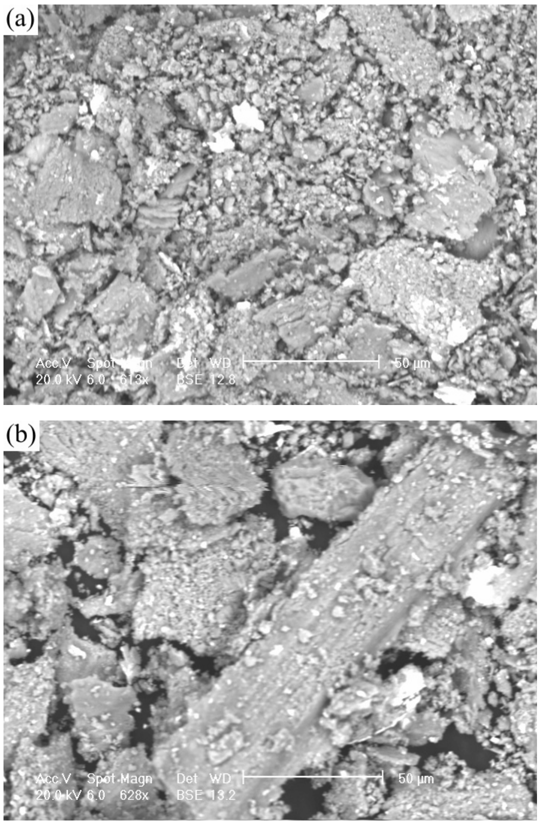

Fig. 7. SEM micrographs of wear debris: (a) A356 (1 MPa) and (b) KA356 (1 MPa)

The wear test data did not comprise wear values of the counterpart, which is necessary in order to achieve optimal operating condition of the system and required service life. Investigation was also conducted in dry condition although these materials, in machine elements, are used mostly in lubricated condition. This is done to get some preliminary results and some more experiments are planed to be done to completely understand tribological behaviour of produced composite material and to expand potential range of applicaton of these materials.

These preliminary results are very important for the further development of this composite material, since tribological properties are of the most importance for practical application.

CONCLUSION

Friction values for matrix and composite material were in expected range for light metals in dry sliding conditions, with remark that composite material, for the applied load range, showed slightly higher values comparing to the matrix material.

Improvement of wear resistance for the composite material with 3 wt. % Al_2O_3 reinforcement was significant for specific load up to 1 MPa.

Adhesive wear was a predominant mechanism of wear followed by plastic deformation with increase of specific load.

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