UDK 539.92:669.018.9:66.017
Original scientific article/Izvirni znanstveni članek

ISSN 1580-2949
MTAEC9, 49(1)117(2015)

TRIBOLOGICAL BEHAVIOUR OF A356/10SiC/3Gr HYBRID COMPOSITE IN DRY-SLIDING CONDITIONS

TRIBOLOŠKO VEDENJE HIBRIDNEGA KOMPOZITA A356/10SiC/3Gr PRI SUHEM DRSENJU

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Prejem rokopisa – received: 2014-01-21; sprejem za objavo – accepted for publication: 2014-03-12

The paper presents tribological behaviour of hybrid aluminium composite A356/10SiC/3Gr in dry-sliding conditions. Hybrid composites were made with a modified compocasting procedure and tribological tests were conducted on a tribometer with a block-on-disc contact geometry. An analysis of the effects of three sliding speeds ((0.25, 0.5 and 1) m/s) and two normal loads (10 N and 20 N) on the wear volume and wear rate was conducted for different sliding distances. The total sliding distance was 300 m. SEM and an EDS analysis of the wear surfaces of the tested material were also performed. The analysis of the wear surfaces shows an intensive adhesive wear of hybrid composites. Also, the appearance of mechanically mixed layers (MMLs) was confirmed, i.e., an increase in the concentration of iron in the hybrid composite material.

Keywords: hybrid composites, wear, aluminium, SiC, graphite, testing

Članek opisuje tribološko vedenje hibridnega aluminijevega kompozitnega materiala A356/10SiC/3Gr pri suhem drsenju. Hibridni kompoziti so bili izdelani s prilagojenim postopkom "kompokasting", tribološki preizkusi pa so bili opravljeni na tribometru s kontaktno geometrijo "blok na disku". Opravljena je analiza vpliva treh drsnih hitrosti ((0,25, 0,5 in 1) m/s) in dveh normalnih obremenitev (10 N in 20 N) na intenzivnost in velikost obrabe pri različnih dolžinah drsenja. Skupna dolžina drsenja je bila 300 m. Hkrati sta bili izvršeni tudi SEM-mikroskopija in EDS-analiza obrabljene površine preizkušanega materiala. Analiza odrgnjenih površin pokaže intenzivno adhezivno obrabo hibridnega kompozita. Potrjen je bil pojav mehansko mešanih plasti (MML) oziroma povečane koncentracije železa v hibridnem kompozitnem materialu.

Ključne besede: hibridni kompoziti, obraba, aluminij, SiC, grafit, preizkušanje

1 INTRODUCTION

Composite materials with aluminium bases have an increasing application in the automotive, airline and aerospace industries. In the automotive industry, these materials are used for building engines, cylinder linings, valve tappets, brakes, cardan shafts, etc. An improvement in the mechanical and tribological characteristics is achieved by adding appropriate reinforcements to these materials. Graphite (Gr), silicon carbide (SiC) and alumina (Al_2O_3) are commonly used as reinforcements. By combining two types of reinforcements, hybrid composites with improved characteristics with regard to the basic material are obtained. The composites reinforced with SiC and graphite are called Al/SiC/Gr hybrid composites[1–5].

Tribological behaviour of the hybrid composites with Al2219 aluminium bases and reinforced with (5, 10 and 15) % SiC and 3 % Gr was investigated by Basavarajappa et al.[6] The composite materials were made with the liquid-metallurgy procedure. Tribological tests were realized on a tribometer with a pin-on-disc contact geometry in accordance with the ASTM G99-95 standard and they showed that an increase in the SiC fraction increases the wear resistance of hybrid composites and the wear is decreased. The wear rate increases with the increasing sliding speed and normal load.

Mahdavi and Akhlaghi[7] tested the tribological characteristics of Al/SiC/Gr hybrid composites obtained with an in-situ powder-metallurgy technique. A hybrid composite had a matrix made of the Al6061 aluminium alloy reinforced with 9 % Gr and (0–40) % SiC. The wear rate of the tested composites decreased with an increase in the SiC amount up to 20 %. A further increase in the SiC amount increased the wear. Other investigations of the same authors relate to the hybrid composites with 30 % SiC and a variable amount of graphite (0–13 %). The results of the tribological investigations showed that the wear rate also increases with the increasing sliding distance and the increasing graphite amount.

Suresha and Sridhara[8] investigated the tribological behaviour of the hybrid composites obtained using a stir-casting procedure, with variable SiC and Gr amounts (0–5 %) and the total ratio of 10 %. Ravindran et al.[9] investigated the tribological behaviour of the hybrid composites with aluminium alloy A2024 bases. The hybrid composites were obtained with powder metallurgy using 5 % of SiC and (0. 5 or 10) % of Gr. Hybrid composite Al/5SiC/5Gr (5 % SiC and 5 % Gr) showed the best tribological characteristics, while a further increase in the graphite amount increased the wear.

The literature gives a small amount of information about the effect of graphite and SiC particles on wear properties. Considering the previous statements, the aims of this paper are to investigate the tribological behaviour of the hybrid composites with an A356-aluminium-alloy base reinforced with SiC and Gr and to provide new information and knowledge. The compocasting procedure was selected to obtain hybrid composites because it is economical and it enables a good distribution of the reinforcements and a favourable composite structure. The quality/price ratio of the obtained composites is the best for this procedure, which is also very important. An investigation of tribological characteristics was conducted by varying normal loads and sliding speeds for different sliding distances in dry-sliding conditions. An analysis of the wear was conducted on the basis of the obtained values of the wear rates and SEM and EDS analyses of the test samples. Within the framework of this investigation, the tribological behaviour of the Al/SiC/Gr hybrid composites obtained with the compocasting procedure and an A356-aluminium-alloy base reinforced with 10 % SiC and 3 % Gr is presented.

2 EXPERIMENT

2.1 Procedure for obtaining the composites

Hybrid composites were obtained with the compocasting procedure or with an infiltration of the particles into the half-hardened melt of the A356 alloy. The preparation of the materials consisted of the chemical cleaning of the base (the A356 alloy) and its infiltration into a previously preheated electro-resistance furnace crucible, the melting and overheating up to 650 °C (the liquid-phase domain) to clean the slag. In order to obtain a hybrid composite (A356 alloy + 10 w(SiC) + 3 w(Gr)), the measured quantities of SiC and Gr were previously homogeneously mixed in the solid state, then preheated at 150 °C and later used in the infiltration process. The commercial procedure T6 was used for the heat treatment, consisting of solution annealing at 540 °C (for 6 h), water quenching and artificial aging at a temperature of 160 °C for 6 h. The mean value of the SiC-particle diameter was 39 μm and for the graphite-particle diameter it was 35 μm. The newly obtained composite had w(SiC) = 10 % and w = 3 % of graphite.

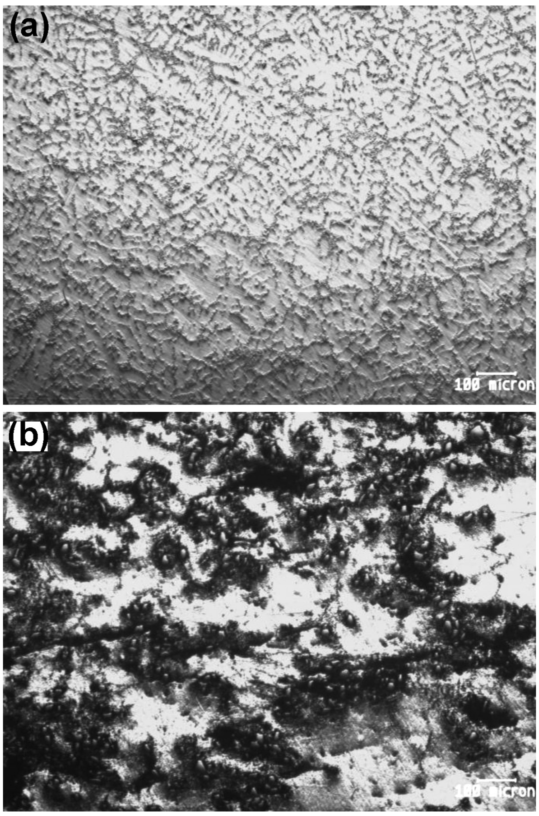

Figure 1: Metallographic structure of: a) basic material A356, b) A356/10SiC/3Gr hybrid composite

Slika 1: Mikrostruktura: a) osnovni material A356, b) hibridni kompozit A356/10SiC/3Gr

Figure 1a presents the structure of the basic material and **Figure 1b** shows the structure of the Al/10SiC/3Gr composite. In the hybrid composite, it is noticed that the base is well filled with the reinforcement particles, so that the base surface without any particles is decreased, which indicates a good distribution of the particles in the base. The soft particles of graphite did not sustain their mean value (35 μm) during the procedure of obtaining the composite. In fact, their erosion and size reduction occurred in the process of preparation (mixing them with the SiC particles).

2.2 Description of the experiment and equipment

The wear behaviour of a block was monitored in terms of the wear-scar width (**Figure 2**). Using the wear-scar width and the geometry of the contact pair, the wear volume (in accordance with ASTM G77-83) and the wear rate (expressed in mm^3/m) were calculated.

The tested blocks were made of the basic A356 material and the A356/10SiC/3Gr hybrid composite. The block dimensions were 6.35 mm × 15.75 mm × 10.16 mm, while the roughness of the ground contact surface was R_a = 0.2 μm. The counter body (disc) was made of 90MnCrV8 steel with a hardness of 62–64 HRC, a diameter of 35 mm and a width of 6.35 mm. The roughness of the contact surface of the disc was R_a = 0.3 μm. Tribo-

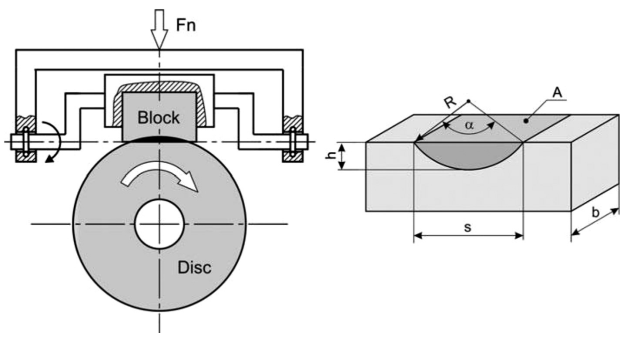

Figure 2: Scheme of the contact-pair geometry

Slika 2: Shematski prikaz geometrije kontakta logical tests were conducted in dry-sliding conditions for different sliding speeds ((0.25, 0.5 and 1.0) m/s) and loads (10 N and 20 N). All the experiments were repeated 5 times.

The tests were performed for a sliding distance of 300 m. The first tests were used to form wear-rate curves, while the other tests were conducted without stopping.

3 EXPERIMENT TEST RESULTS

The results of tribological tests were obtained for different sliding speeds and different normal loads in dry-sliding conditions and they are presented in the following diagrams. The diagrams showing the dependence between the material wear volume and the sliding distance were obtained on the basis of the wear-scar widths. The wear-scar widths were measured after the (30, 60, 90, 150 and 300) m of the sliding distance. **Figure 3** shows the variations in the wear volume in relation to the sliding distance for all three sliding speeds ((0.25, 0.5 and 1.0) m/s). Full lines show the results for the basic A356 material, while dashed lines present the results for the A356/10SiC/3Gr hybrid composite.

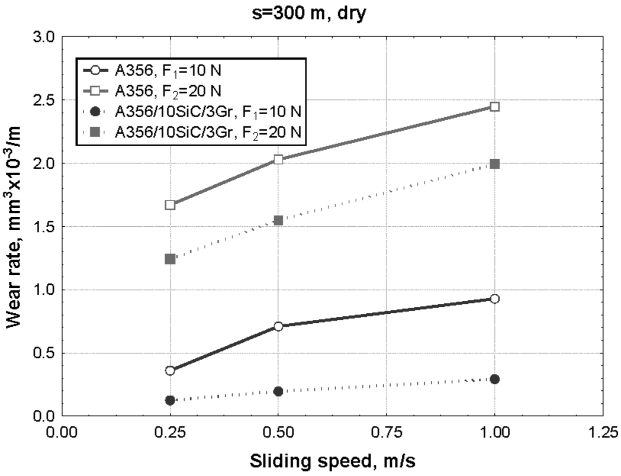

Figure 4: Dependence between the wear rate and the sliding speed
Slika 4: Odvisnost med obrabo in hitrostjo drsenja

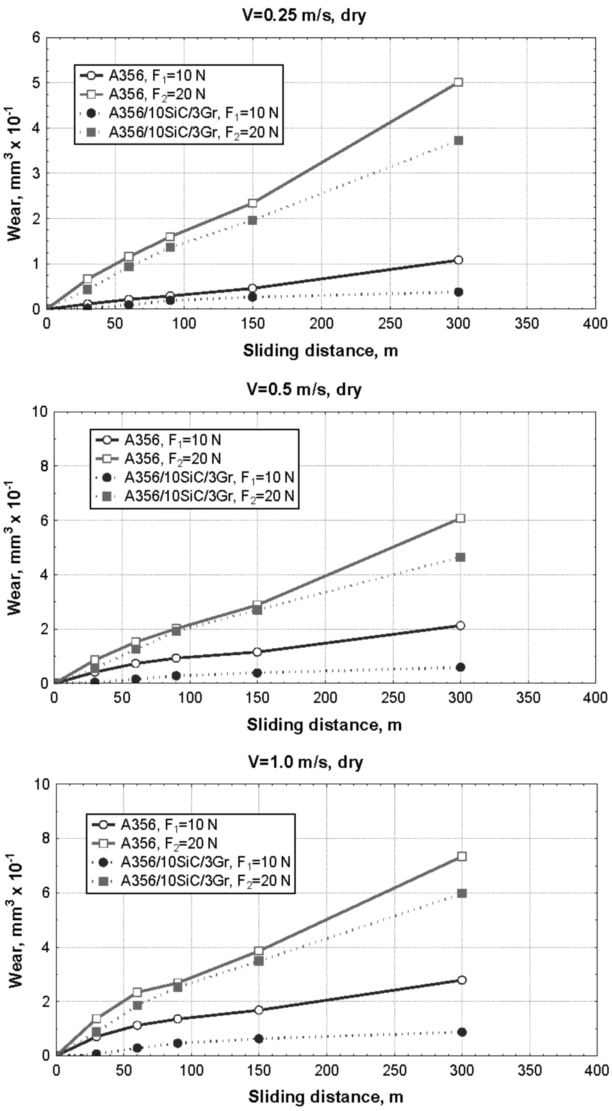

Figure 3: Dependence between the wear volume and the sliding distance for all three sliding speeds
Slika 3: Odvisnost med volumnom obrabe in dolžino poti drsenja za vse tri hitrosti drsenja

The run-in distance for the tested materials depends on the sliding speeds and normal loads and its range was between 50 m and 100 m. This is best seen on the wear-rate curves or the curves showing the dependence between the wear-scar widths and the sliding distance[10]. After this sliding distance, the tested materials entered the period of normal wear. When analysing the obtained diagrams, it became clear that the curves obtained for the base material were steeper than the curves for the hybrid composite. It was obvious that an addition of SiC and Gr prolonged the period of normal wear of the tested hybrid materials.

The effects of the sliding speed and normal loads on the wear rate of the tested materials for a sliding distance of 300 m are shown in **Figures 4** and **5**. With an increase in the sliding speed, the intensity of the wear increases for both the base A356 material and for the hybrid A356/10SiC/3Gr material. The dependence between the wear and the sliding speed is almost linear (**Figure 4**).

Figure 5 shows that an increase in normal load induces an increase in the wear rate for all the test regimes, i.e., for all the sliding speeds. According to the positions of the curves, it may be concluded that the effect of normal load on the wear rate is quite pronounced. Also, according to the positions of the curves, it is obvious that the wear rate of the hybrid composite with SiC and graphite is considerably smaller than the wear rate of the base material, especially at the normal load of 10 N. The wear rate of the basic A356 material for the normal load of 20 N is (on average) three times higher than the wear rate for the normal load of 10 N.

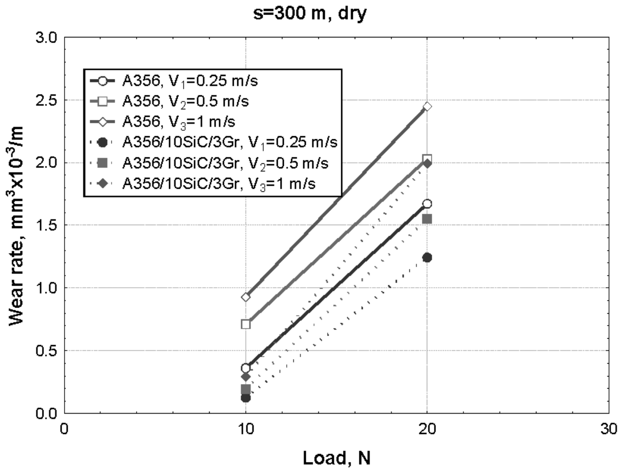

Figure 5: Dependence between the wear rate and normal load
Slika 5: Odvisnost med obrabo in obremenitvijo

The wear rate of the A356/10SiC/3Gr hybrid composite for the normal load of 20 N is (on average) seven times higher than the wear rate for the normal load of 10 N.

4 DISCUSSION

For a more complete analysis, **Figures 6a** and **6b** show the SEM microphotographs of the worn surfaces of

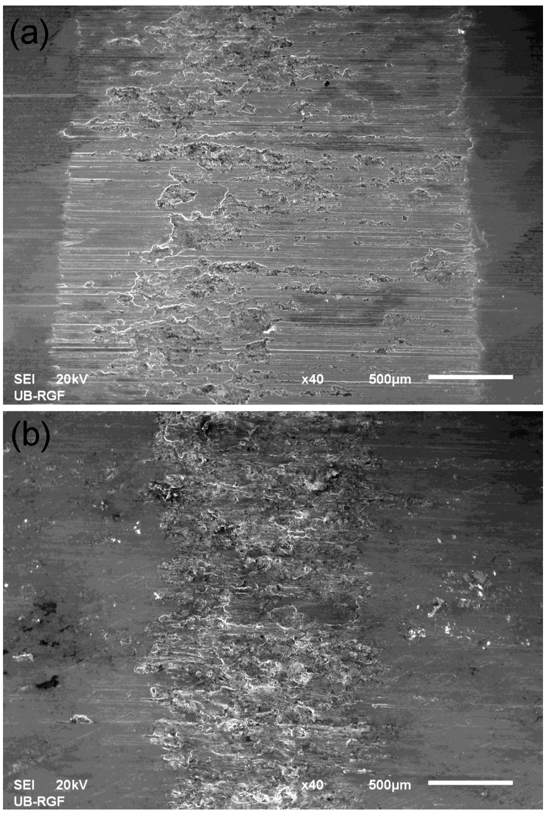

Figure 6: SEM microphotographs of worn surfaces of: a) A356, b) A356/10SiC/3Gr
Slika 6: SEM-posnetka obrabe površine: a) A356, b) A356/10SiC/3Gr

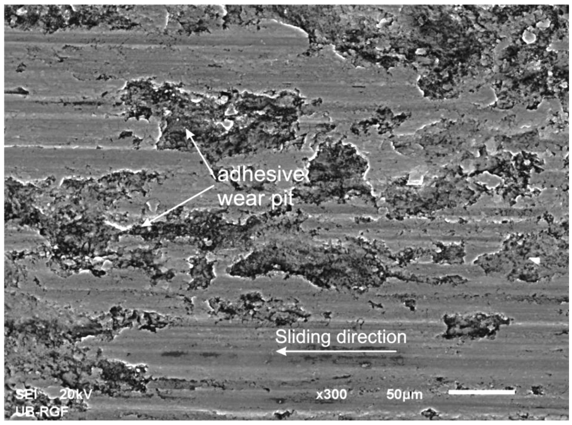

Figure 7: Forming of the adhesive-wear pits
Slika 7: Nastanek jamic zaradi adhezivne obrabe

the tested materials. These microphotographs were obtained during the tribological tests with the sliding speed of 0.25 m/s and the normal load of 10 N.

When observing the samples, it is clear that the adhesive wear is the basic wear mechanism. Adhesive wear occurred as a result of an alternate formation and destruction of the frictional connections caused by an atomic and intermolecular interaction of the boundary layers of the contact bodies. Due to the adhesive wear, there is a pulling of the material out of the contact surface of the composite material (block). As a consequence of the adhesive wear, pits of irregular shapes and depths are visible on the surface of the block[6] and in **Figure 7**. A tribolayer was formed on the surface of the A356/10SiC/3Gr composite during sliding and it formed a protective lubricating film preventing a direct contact between the aluminium matrix and the steel counter body. High-volume-fraction ceramic particles act as load-bearing elements, preventing the subsurface damage during sliding and suppressing the spalling of tribolayers from the surface.

In order to rationalize the wear behaviour of the observed composite, it is important to analyze the composition of the microstructure of the tribolayer formed during the wear process. The EDS analysis was performed together with the SEM of the tested material. The EDS analysis was employed to determine the elements on the worn surface, as shown in **Figure 8**. An occurrence of iron (Fe) and oxygen (O) may be spotted on the analyzed samples. The presence of iron and its oxide confirms that the wear of the steel disc occurred. The disc wear occurs due to the effects of SiC from the composite material as well as of the Si phase from the A356 aluminium matrix. Worn particles of iron enter the surface layer of the composite causing a formation of a mechanically mixed layer (MML) which is characteristic for a MMC with an aluminium matrix[7,11–13]. The presence of iron and its oxides is confirmed by EDS Spectrum 2 in **Figure 8**. Spectrum 1 in **Figure 8** shows the presence of SiC in the hybrid composite. The lubrication

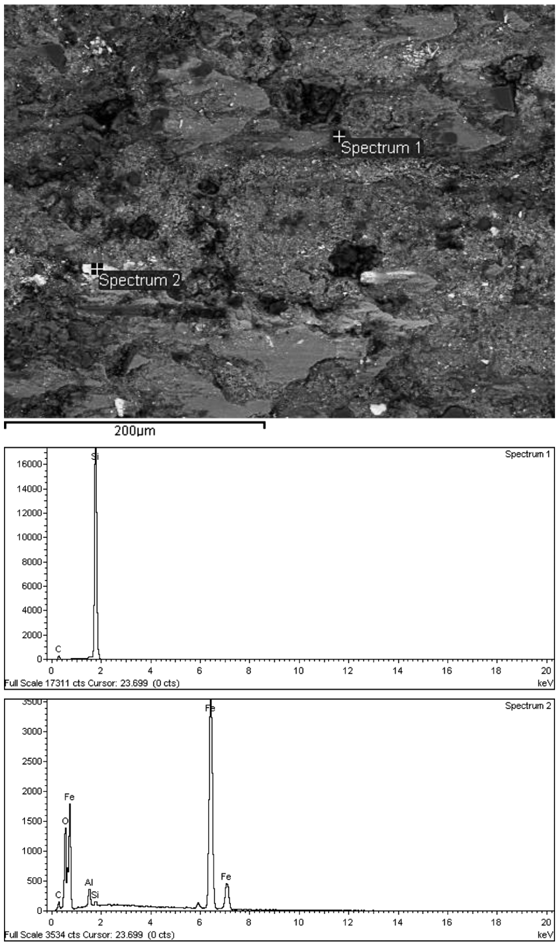

Figure 8: EDS analysis of hybrid A356/10SiC/3Gr composite
Slika 8: EDS-analiza hibridnega kompozita A356/10SiC/3Gr

layer is composed of the Al, Si, Fe, O and C elements. The occurrence of oxygen implies that the surface elements, such as Fe, were at least partially oxidized during the sliding. Thus, it may be concluded that the tribolayer is composed of a mixture of iron oxides, graphite and fractured SiC particles and some fine particles containing aluminium.

5 CONCLUSIONS

The testing of the tribological behaviour of the hybrid A356/10SiC/3Gr composite in dry-sliding conditions shows superior characteristics of this material compared to those of the base A356 material. With an increase in the sliding distance, the amount of the wear or wear rate of the hybrid composite is always smaller than that of the base material. The run-in sliding distance of the tested materials ranges between 50 m to 100 m, after which the materials enter the period of normal wear. The wear rate of the tested materials increases with the increasing sliding speed and normal load for all the test regimes. SEM confirms a homogenous distribution of SiC particles within the hybrid composite. Additionally, SEM microphotographs and an EDS analysis show the presence of Fe and its oxides as well as the formation of a mechanically mixed layer (MML).

Acknowledgement

This paper presents the results obtained during the research within the framework of project TR35021 supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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