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ABRASIVE WEAR BEHAVIOUR OF SiCp-REINFORCED 2011 Al-ALLOY COMPOSITES

VEDENJE KOMPOZITA Al ZLITINE 2011, OJAČANE Z DELCI SiCp, PRI ABRAZIJI

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In this study, the abrasive wear behaviour of aluminium-alloy (Al-2011) SiC-particle-reinforced composites was investigated and compared with that of the matrix alloy. The experimental variables were the SiC-particle proportion, sliding distance and abrasive grit size. Al-2011 reinforced composites containing volume fractions (7, 14 and 21) % SiCp were fabricated with the vortex method. Sliding-wear tests were carried out using a pin-on-disc abrasive-test machine where a sample slides against a SiC abrasive of different grit sizes at a fixed speed, under the load of 4 N at room conditions. The results show that the wear resistance of the composites was significantly larger than that of the Al-2011 alloy; it increased with the increasing SiC-particle proportion and decreased with the increasing abrasive grit size.

Keywords: abrasive wear, metal-matrix composites, vortex method, SiC particle

V tej študiji je bila preiskovana abrazijska obraba kompozita aluminijeve zlitine (Al-2011), ojačane z delci SiC in primerjana z osnovno zlitino. Eksperimentalne spremenljivke so bile: delež delcev SiC, dolžina drsenja in velikost zrn v drsni plošči. Kompoziti zlitine Al-2011 s prostorninskim deležem (7, 14 in 21) % SiCp so bili izdelani po metodi vrtinca (vorteksa). Preizkusi abrazije so bili izvršeni na napravi "pin-on disc" za preizkus abrazije, kjer vzorec drsi po plošči iz SiC z različno velikostjo zrn, pri določeni hitrosti in obtežbi 4 N pri sobni temperaturi. Rezultati kažejo, da je obrabna odpornost kompozita veliko večja kot pri zlitini Al-2011 in narašča z naraščanjem vsebnosti SiC-delcev ter se zmanjšuje z večanjem zrn abrazijske plošče.

Ključne besede: abrazijska obraba, kompozit s kovinsko osnovo, metoda vortex, delci SiC

1 INTRODUCTION

Aluminium-matrix composites (AMCs) reinforced with ceramic particles exhibit better mechanical properties than unreinforced aluminium alloys[1,2] and have been used as tribological parts in the automobile, defence and aerospace industries due to their excellent combination of higher specific strength and hardness, improved wear and higher elevated-temperature strength as compared with their base alloys.[3] AMCs find potential applications in the automobile components like pistons, brake drums, cylinder liners, crankshafts, etc.[4–6] These components showed sliding as well as abrasive wear against their counter surface during the treatment. Particulate-reinforced aluminium-alloy composites have shown a significant improvement in the tribological properties, including the abrasive-wear resistance.[7,8] Therefore, considerable attention have been paid to the particulate AMCs with respect to tribological applications because of the advantages of AMCs such as good wear resistance, light weight and high load-carrying capacity. Some investigations show that these composites have a potential for being used in abrasive-wear conditions.[9–12] The high wear resistance of particulate-reinforced AMCs is a result of the ceramic-particle content, which considerably decreases the wear of the metal matrix. For the AMCs reinforced with ceramic particles, it has been commonly agreed that an increase in the particle content increases the wear resistance.[13–15] Accordingly, the application of SiC- or Al_2O_3-particle-reinforced AMCs in the automotive and aircraft industries is gradually increasing, used for connecting rods, cylinder heads, pistons, etc., where the tribological properties of the materials are vital.[16]

The investigations about this subject reveal that the wear resistance of the particle-reinforced composites is affected by many factors such as the applied load, particle size, particle content, sliding speed, sliding distance, hardness of particles and the properties of the matrix alloy.[17] Consequently, the wear behaviour of the composites has not been fully established. The aim of the present work is to investigate the effect of the SiC-particle content, abrasive size, applied load and sliding distance on the wear behaviour of SiC-particle-reinforced 2011 aluminium-alloy composites.

2 EXPERIMENTAL WORK

2.1 Materials and characterization

In the present study, an Al–Cu alloy (Al-2011) and AMCs (Al-2011–SiC_p) containing varying amounts of SiC particles were used. The Al-2011 alloy contains about mass fractions 4 % Cu, 0.5 % Si, 0.7 % Mn, 0.7 % Mg and the rest is aluminium. The approximate size of SiC was 64 µm. The volume fractions of the SiC particles were (7, 14 and 21) %. AMCs were prepared with the vortex method. An unreinforced 2011 Al-matrix alloy specimen was also produced with the same method. **Table 1** shows the microstructural characteristics and properties of the tested materials.

Table 1: Microstructural characteristics and properties of the tested materials
Tabela 1: Mikrostrukturne značilnosti in lastnosti preizkušanih materialov

Sl. No.	Material (SiC in volume fractions)	Brinel hardness (BHN)	Density (g/cm^3)
1	Al-2011	97	2.748
2	Al-2011- 7 % SiC	109	2.803
3	Al-2011- 14 % SiC	120	2.858
4	Al-2011- 21 % SiC	125	2.913

The test specimens were prepared with the standard metallographic techniques for microstructural investigations. The samples were examined using a scanning electron microscope (SEM). A typical microstructure of 64 μm, 21 % volume fraction of SiCp-reinforced 2011 Al-alloy composite is shown in **Figure 1**.

2.2 Wear tests

In order to determine the wear behaviour of the composites and aluminum alloy, a pin-on-disc with a sandpaper device was used. A schematic representation of the abrasive-wear test is shown in **Figure 2**.

In this study, SiC sandpapers fixed on a rotating disc were used as the abrasive material. The specimens were loaded against the abrasive surface of the sandpaper with a bell-crank mechanism. Three groups of composites and the aluminum-matrix alloy were tested in the study. The wear tests were carried out at room temperature. The test specimens were abraded under the applied load of 4 N against the abrasive SiC sandpapers of (23, 36 and 52) μm. The cylindrical test specimens with a 6.35 mm diameter and 20 mm length were prepared. The total sliding distance was 600 m. The other test parameters were: the rotating speed of the disc was 350 r/min and the track diameter of the emery paper was 130 mm. Before each

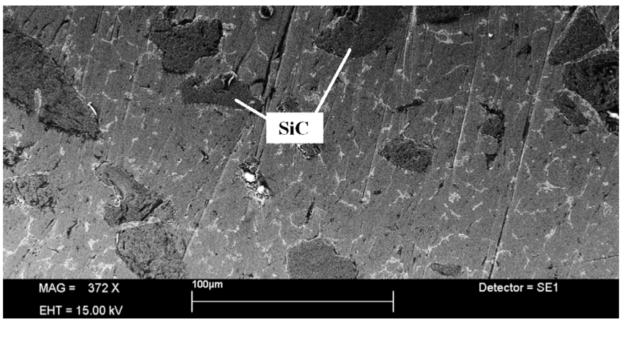

Figure 1: Microstructure of the volume fraction 21 % SiCp-reinforced 2011 Al-alloy composite with the size of 64 μm
Slika 1: Mikrostruktura kompozita zlitine Al 2011, ojačene z volumenskim deležem 21 % delcev SiC z velikostjo 64 μm

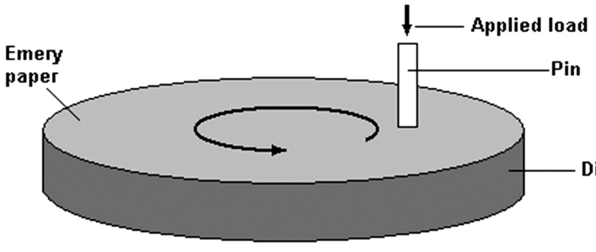

Figure 2: Schematic representation of the abrasive-wear test
Slika 2: Shematska predstavitev preizkusa abrazijske obrabe

test, the wear surface of a specimen was ground with the 500-grade abrasive paper, making sure that each of the specimens had the same contact area and surface roughness. A new abrasive paper was used for each of the tests. Before and after every test, the specimens were cleaned with acetone and then dried with a heat blower. An electronic balance with a sensitivity of 0.1 mg was used for measuring the weights of the pin specimens. Each test was performed four times. An outlier test result for each test group was removed and not included in the average calculation. Then the average of the tests was used. The wear weight loses were obtained from the weight differences for the specimens measured before and after the tests. Then, using the known densities of the Al-2011 and SiC, the wear volume losses of the specimens were calculated.

3 RESULTS AND DISCUSSION

Figure 3 shows the effect of the sliding distance on the wear volume loss of the composites with three

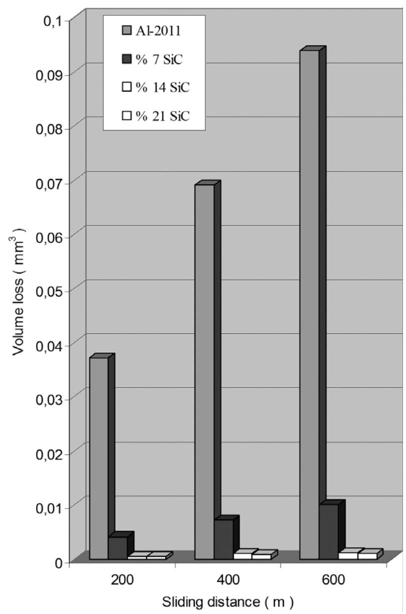

Figure 3: Volume loss as a function of the sliding distances of (200, 400 and 600) m, at 4 N, for the 52 μm SiC abrasive
Slika 3: Zmanjšanje volumna v odvisnosti od razdalje drsenja (200, 400 in 600) m pri 4 N po SiC-abrazivu z velikostjo zrn 52 μm

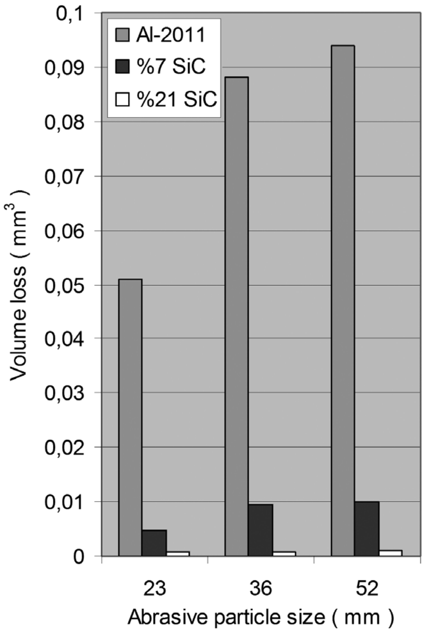

Figure 4: Fluctuation of the wear volume loss with the abrasive grit sizes at the sliding distance of 600 m

Slika 4: Spreminjanje volumna zaradi obrabe v odvisnosti od velikosti abrazijskih zrn pri razdalji drsenja 600 m

different SiC-particle contents and the matrix alloy. It reveals that the wear volume loss increases with the increasing sliding distance and decreases with the increasing SiC-particle content.[18] The wear volume loss of the 2011 Al-alloy was much higher than that of the

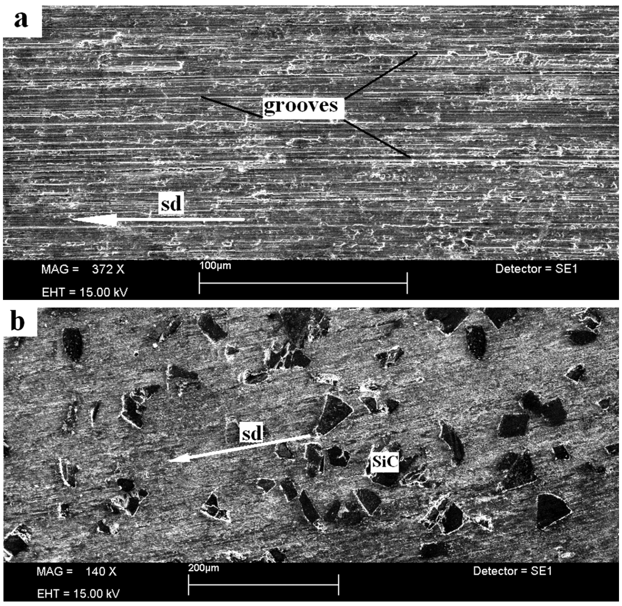

Figure 5: Surfaces worn against the 52 μm SiC abrasive at an applied load of 4 N and the sliding distance of 600 m: a) Al matrix alloy, b) volume fraction 21 % SiC_p composite, sd: sliding direction

Slika 5: Obrabljeni površini pri SiC-abrazivu z velikostjo delcev 52 μm pri uporabi obtežbe 4 N in razdalji drsenja 600 m: a) osnovna Al-zlitina, b) kompozit z volumenskim deležem 21 % SiC delcev, sd: smer drsenja

composites in the experiment as shown in **Figure 3**. It rises about linearly with the sliding distance, while the volume loss of the composites rises only slightly. It can be inferred from the figure that for the 600 m sliding distance the approximate rates of increase in the wear resistance of the composite, in comparison with that of the 2011 Al-alloy, are 9.4, 76.6 and 92.9 for (7, 14 and 21) % volume fractions of fine SiC reinforcement, respectively. It shows that the wear resistance can be improved with an increase in the SiC content.[19]

The addition of only 7 % SiC particle to the 2011 Al-alloy was very effective at decreasing the wear volume loss. The reason for this is the fact that the SiC particles raised the hardness of the matrix alloy as shown in **Table 1**. It is clear from this table that the hardness of the composite increased due to the addition of the SiC particles. The wear volume loss of the composites reinforced with the SiC particles increased slightly with the increasing sliding distance. As shown in **Figure 3**, Al-2011-21 % SiC composite showed the lowest wear volume loss, while the highest wear volume loss was observed for the Al-2011-7 % SiC composite.

The correlation between the wear volume loss and the SiC abrasive grit size is given in **Figure 4**. The reinforcing SiC particles were very effective in increasing the wear resistance against the SiC abrasives of the emery. The wear volume loss of the composites was much smaller than that of the matrix alloy. In addition, the highest wear volume loss was obtained for the Al specimen with 7 % SiC against the emery with the 52 μm SiC abrasive. Adversely, the lowest wear volume loss was observed for the Al specimen with 21 % SiC used against the emery with the 23 μm SiC abrasive. Consequently, the two important parameters for the wear volume loss are the particle content and the abrasive grit size of the emery used.

The surface of the 2011 Al-alloy worn at an applied load of 4 N and against an abrasive with the size of 52 μm is shown in **Figure 5a**. It was defined by an intense plastic deformation and an explicit evidence of ploughing and cutting. A large amount of continuous wear grooves and the flakes present in some places along the grooves were observed on the worn surface. As the SiC abrasive of the emery was much harder than the unreinforced Al-2011 alloy, the abrasive could penetrate and cut the surface. Therefore, too much wear volume loss occurred as shown in **Figure 5a**. **Figure 5b** shows the worn surface of the 21 % SiCp-reinforced composite at an applied load of 4 N and the abrasive size of 52 μm. It represents the continuous wear grooves without any SiC particles. As the SiC particles have a very high wear resistance, they look like protrusions on the worn surface.[20] These protruded SiC particles resist the abrasive effect of the abrasive medium. Consequently, **Figure 5b** shows a larger wear volume loss on the Al-alloy region of the composite than on the reinforcement region of the composite.

One of the important factors of the investigated composites is the hardness impact on the wear mechanism. The SiC particles in a composite save the softer matrix during the abrasive sliding and make the composite harder. Consequently, due to the particle reinforcement only limited deformation occurred on the surface.

4 CONCLUSIONS

1. The wear resistance of the 2011 Al-alloy composites was much higher than that of the unreinforced 2011 Al-alloy.
2. The wear volume loss of the 2011 Al-alloy increased linearly with the increasing sliding distance. But the volume loss of the 2011 Al-alloy composites was much smaller than that of the 2011 Al-alloy.
3. The high wear resistance of the 2011 Al-alloy composites was largely dependent on the excellent wear resistance and high hardness of the SiC particles.
4. The SiC particles on the worn surfaces of the composites looked like protrusions due to their high hardness and wear resistance.
5. The wear resistance of the 2011 Al-alloy composites increased with the increasing SiC-particle content.
6. The wear resistance of the 2011 Al-alloy composites decreased with the increasing abrasive grit size of the emery used.

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