EFFECT OF MATRIX STRENGTHENING ON SLIDING WEAR PROPERTIES OF SiC_p/2024Al COMPOSITES①

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ABSTRACT The sliding wear tests on the SiC_p/2024Al composites fabricated by the powder metallurgy technique were carried out. It was indicated that both the reinforcement size and matrix strengthening have a significant effect on the wear properties of the composites. The wear resistance of the composites increases with increasing SiC particulate size and is improved considerably after the T6-treatment; the effect of the matrix strengthening on the wear resistance of the composites increases with decreasing SiC particulate size. For the composites containing various particulate sizes, the wear properties of the composites cannot be directly correlated to the bulk hardness (HRB) of the composites.

Key words composite aluminum SiC wear particulate

1 INTRODUCTION

The ceramic particulates reinforced aluminum alloy composites exhibit high specific modulus and strength, also get a significant improvement in the tribological properties[1-6]. As a result, the ceramic particulate composites are becoming a cost-effective alternative to conventional materials in a few specialized application areas.

The effects of the applied load, the particulate size and reinforcer content on the wear properties of the particulate composites have been investigated by several workers. The investigation by Hosking *et al*[7] has indicated that the wear resistance of the alumina particulate composites increases with increasing particulate size and content. However, Tokinen and Andresson[8] have reported that the effect of the particulate size on the wear resistance of the 20% (volume fraction) SiC_p/6061Al composite was dependent on the nominal contact stress, i. e., an increase in the particulate size from 5 to 29 μm resulted in a reduction of the wear rate at a nominal contact stress of 3.2 MPa, but not at 12.7 MPa. The investigation by Skolianos and Kattamis[9] on the SiC particulate reinforced Al-4.5% Cu-1.5% Mg alloy composite has indicated that with an increase in SiC particulate size from 10.7 to 29 μm, the specific wear rate of the composite increases.

In a previous paper, the sliding wear behavior of the SiC_p/2024Al composites containing various particulate sizes and contents was investigated[10]. It was found that the main wear mechanism of the small particulate composites was cutting and ploughing, and the improvement in wear resistance of the composites was mainly attributed to the matrix strengthening by SiC particulates. For the large particulate composites, the main wear mechanism of the composites was the gradual grinding of the SiC particulate. The wear behavior can be described by the particulate decoherence model suggested by Roy *et al*[11], and the improvement in wear resistance was mainly accounted for by the excellent wear resistance of large SiC particulates. In present work, the sliding wear behavior of the

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as-extruded and T6-treated SiC_p/2024Al composites containing various particulate sizes was compared. The purpose is to investigate the effect of the matrix strengthening on the wear properties of the SiC particulate reinforced aluminum matrix composites.

2 EXPERIMENTAL

Atomized 2024Al (containing (%): 4.20 Cu, 1.47Mg, 0.56Mn, 0.02Zr, 0.40Si, 0.27 Fe) powder with an average size of 60 μm was employed as the matrix. α-SiC particulates with a mean size of 3.5, 10 and 20 μm were used as the reinforcers. The composites containing 15% (volume fraction) SiC particulates were fabricated by a P/M technique which involved mixing SiC particulates with aluminum alloy powders, hot compaction in vacuum, and then hot extrusion at 450 ℃ at an extrusion ratio of 20∶1.

The specimens for wear and hardness tests were machined from the extruded rods. Half of the specimens were subject to T6-treatment (500 ℃/1 h solutionized, water quenched, and 170 ℃/5 h aged). All the specimens before tests were mechanically polished. The sliding wear testes were performed on a reciprocating grooving tester with a sliding speed of 0.01 m/s. The slider was made of Si_3N_4 with the top plane of 2 mm × 2 mm. After wear tests, the cross-section area was accurately measured using a profilometer. The volume loss was calculated, and converted into a wear rate defined as the volume loss per unit of sliding distance. The wear tracks were examined on a scanning electron microscope (SEM). The Rockwell hardness (HRB) of the composites was measured.

3 RESULTS

Fig. 1 shows the effect of the contact stress on the wear rate of the composites. The wear rate of all the composites increases with increasing the contact stress. It appears that the small particulate composites exhibit a larger increase of the wear rate with increasing the contact stress compared to the large particulate composites. From Fig. 1, it is evident that the wear resistance of both as-extruded and T6-treated composites increases with increasing particulate size. After the T6-treatment, the wear resistance of the composites improves markedly due to the matrix strengthening. However, it should be noted that the effect of the T6-treatment on the wear properties of the composites varies with the sizes of SiC particulates. Under the applied wear loads, the wear resistance of the T6-treated composites containing SiC particulates of 3.5, 10 and 20 μm is 2.6~3.1, 1.2~2.6 and 1.4~1.9 times larger than that of the as-extruded composites, respectively. It is indicated that the effect of the matrix strengthening on the wear resistance of the composites tends to decrease with increasing particulate size. In order to illustrate this effect clearly, the variation of the wear rate of both the as-extruded and T6-treated composites with the SiC particulate size is shown in Fig. 2 at a contact stress of 2.94 MPa. Apparently, the effect of the T6-treatment on the wear resistance of the small particulate composite is larger than that of the large particulate composite. It is interesting to note that above contact stress of 2 MPa, the wear resistance of T6-treated SiC_p(3.5 μm)/2024Al and SiC_p(10 μm)/2024Al composites is higher than that of as-extruded SiC_p(10 μm)/2024Al and SiC_p(20 μm)

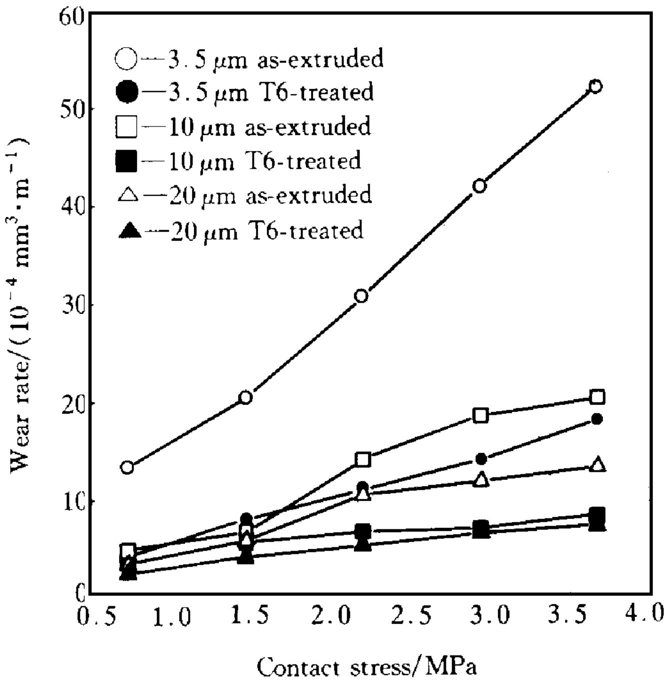

Fig. 1 Variation of the wear rate of the composites with contact stress

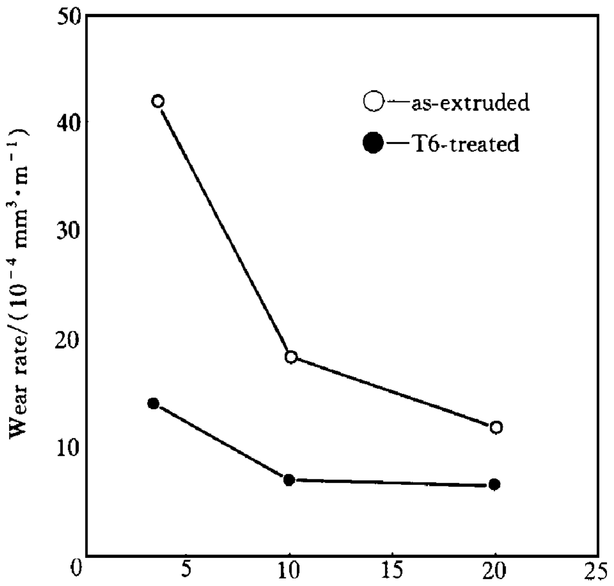

Fig. 2 Variation of the wear rate of the composites with SiC particulate size under a contact stress of 2.94 MPa

/2024Al composites, respectively, indicating the important role of the matrix strengthening in improving the wear resistance of the composites.

The Rockwell hardness (HRB) of the composites is listed in Table 1. The hardness of the composites is obviously higher than that of the monolithic alloy due to the incorporation of SiC particulate. Furthermore, the hardness of both the composites and monolithic alloy is markedly improved after the T6-treatment. For the as-extruded materials, the difference in hardness between the composites and monolithic alloy is 11.58~13.97, and the hardness of the composites tends to increase slowly with increasing SiC particulate size. On the other hand, the difference in hardness between the T6-treated composites and monolithic alloy is 7.01~8.88, and the hardness of the composites tends to decrease slowly with increasing SiC particulate size. Apparently, the difference in hardness between the T6-treated composites and monolithic alloy is considerably lower than that between the as-extruded composites and monolithic alloy. It is important to note that the T6-treated composites exhibit a gradual decrease tendency in the bulk hardness with increasing particulate size. However, a quite different variation tendency with the particulate size has been observed for the wear behavior of the T6-treated composites (Fig. 2). This implies that the bulk hardness of the composites cannot be considered as the direct indicator of the wear resistance for the composites, at least for the T6-treated composites, under the present test conditions.

Table 1 Rockwell hardness (HRB) of the composites and monolithic alloy

Condition	2024Al	SiC_p (3.5 μm)/2024Al	SiC_p (10 μm)/2024Al	SiC_p (20 μm)/2024Al
As-extruded	58.14	69.72	69.73	72.11
T6-treated	80.2	89.08	88.37	87.21

Fig. 3 shows the SEM micrographs of the worn surfaces of the composites. For the composites containing SiC particulate of 3.5 μm, the worn surface is characterized by large plastic deformation, deep grooves and cuts, and the block-like material removal (Fig. 3(a), (b)). The plastic deformation on the worn surface of the composites containing SiC particulate of 10 μm is less severe than that of the 3.5 μm, the grooves and cuts become shallow, and some fine scratches are also observed on the worn surface (Fig. 3 (c), (d)). As the SiC particulate size is increased to 20 μm, the plastic deformation on the worn surface is further reduced, and the worn surface is mainly characterized by fine scratches (Fig. 3(e), (f)). It is noted that there exist certain differences between the worn surfaces for the T6-treated and as-extruded composites. For the small particulate composites, large scale of plastic deformation occurs on the worn surface of the extruded composite, with deep grooves and cuts and the obvious block-like material removal. However, the plastic deformation on the worn surface of the composite is reduced after the T6-treatment, and the grooves and cuts become shallow. For the large particulate composites, the plastic deformation on the worn surface is somewhat reduced after T6-treatment, and the morphologies of the worn surfaces of the T6-treated composites are analogous to those of the as-extruded composites. The observations support the above wear test results that the effect of

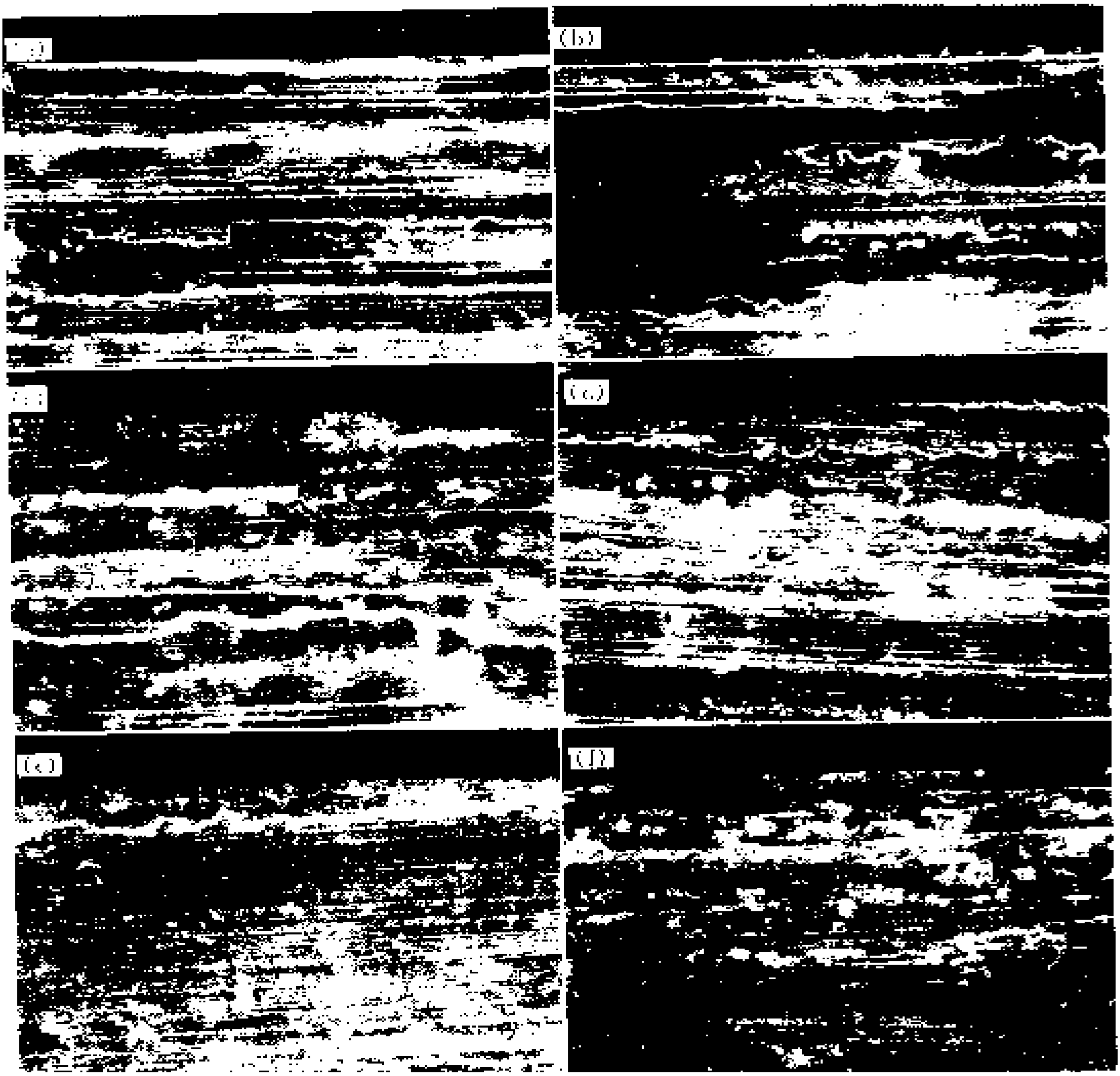

Fig. 3 SEM micrographs showing worn surfaces of the composites
(a), (b) —3.5 μm; (c), (d) —10 μm; (e), (f) —20 μm;
(a), (c), (e) —Extruded; (b), (d), (f) —T6-treated

the T6-treatment on the wear resistance of the small particulate composites is larger than that of the large particulate composites.

4 DISCUSSION

For the small SiC particulate reinforced aluminum matrix composite, the wear of the composites is mainly from cutting and ploughing by the ceramic slider[10]. The small SiC particulates cannot resist the cutting and grinding by the ceramic slider so effectively as the large SiC particulates, and the composite as a whole resists the cutting and ploughing by the ceramic slider. Because the small SiC particulate can coordinate with the plastic deformation of the matrix to a certain extent, the large plastic deformation occurs on the worn surface of the small particulate composite, and the small particulates and the matrix are overall removed in the block-like form by the ceramic slider[10]. This indicates that the characteristics of the composite matrix should have a significant effect on the wear properties of the composites. The wear resistance of the as-extruded composite is considerably lower due to a softer matrix, so the worn surface experiences large plastic deformation, and is characterized by deep grooves and cuts, and large material loss. After the T6-treatment, the strength and hardness of the composite matrix increase significantly due to the precipitation hardening. On the other hand, it is generally known that the dislocation density in the composite matrix increases considerably due to the quenching[12], which makes the effect of the Orowan strengthening mechanism increase substantially in the small particulate composite. Therefore, the wear resistance of the small particulate composite is significantly improved after the T6-treatment, and is 2.6~ 3.1 times larger than that of the as-extruded composites. It is due to the important role of the matrix strengthening in improving the wear properties that the wear resistance of T6-treated SiC_p(3.5 μm)/2024Al and SiC_p(10 μm)/2024Al composites is higher than that of as-extruded SiC_p(10 μm)/2024Al and SiC_p(20 μm)/2024Al composites, respectively, above contact stress of 2 MPa.

For the large SiC particulate reinforced aluminum composite, the large SiC particulates can resist the cutting and grinding caused by the ceramic slider effectively. The wear process of the composite occurs mainly by the gradual machining and grinding of the large SiC particulates induced by the ceramic slider[10]. Therefore, the plastic deformation on the worn surface of the large particulate composites is much less than that of the small particulate composites, and the material loss is obviously reduced. For the T6-treated large particulate composite, firstly, the effect of the Orowan strengthening mechanism in this composite is lower than that in the T6-treated small particulate composite due to large interparticle spacing; secondly, the wear properties of the large particulate composite exhibit less independence on the characteristics of the composite matrix than those of the small particulate composite because the wear of the large particulate composite is mainly caused by the gradual machining and grinding of the SiC particulates. Therefore, the effect of the T6-treatment on the wear resistance of the large particulate composite is much lower than that of the small particulate composite. For example, for the composites containing the SiC particulate of 20 μm, the wear resistance of the T6-treated composite is 1.4~ 1.9 times larger than that of the as-extruded composite. This effect is substantially less than that for the composites containing the SiC particulates of 3.5 μm.

Hardness tests support the above analyses. For the as-extruded composites with soft matrix, the bulk hardness of the composites displays mainly as the resistance of the SiC particulate to the press-in of steel ball, and the large SiC particulate can resist the press-in of the steel ball more effectively compared to the small particulate. Therefore, the difference in hardness between the as-extruded composites and monolithic alloy is large (11.58~ 13.97) and the bulk hardness of the as-extruded composites increases slowly with increasing the SiC particulate size. After the T6-treatment, the hardness of the composite matrix increases substantially due to the precipitation strengthening and dislocation strengthening. The properties of the composite matrix contribute greatly to the increase in the hardness of the composites, and the composite as a whole can resist the press-in of the steel ball effectively, resulting in the obvious improvement in the hardness of the T6-treated composites and considerably reduced difference in hardness (7.01~ 8.88) between the T6-treated composites and monolithic alloy. Compared to the large particulate composites, the dislocation-particle interaction, i. e. Orowan strengthening, in the T6-treated small particulate composite is great due to small interparticle spacing and higher dislocation density generated by the quenching. Therefore, the hardness of the T6-treated composites increases slowly with decreasing particulate size. Furthermore, the hardness test results indicate that the increase in hardness of the small particulate composites after the T6-treatment is larger than that of the large particulate composites, which is consistent with the wear properties of the composites (Fig. 2).

Although the variance in the bulk hardness of the composites after T6-treatment has indicated the important role of the matrix strengthening in improving the wear resistance of the composites, the wear properties of the composites cannot be directly correlated to the bulk hardness of the composites because of the complicatedness of the wear process dependent on both matrix properties and reinforcement size. For example, the hardness of the T6-treated SiC_p (3.5 μm)/ 2024Al composite is obviously higher than that of the as-extruded SiC_p(20 μm) / 2024Al composite, but the wear resistance of the former is much lower than that of the latter. Even for the composites containing the same size particulate of 3.5 μm, the hardness of the composite increases by 28% after the T6-treatment, but the wear resistance of the T6-treated composite is 3.1 times larger than that of the as-extruded composite under the applied wear pressure.

5 CONCLUSIONS

(1) The wear resistance of both as-extruded and T6-treated composites increases significantly with increasing SiC particulate size.

(2) The wear resistance of the composites is significantly improved after the T6-treatment. The effect of the matrix strengthening on the wear properties of the composites increases with decreasing SiC particulate size.

(3) The wear properties of the composites are dependent on both matrix properties and SiC particulate size, and cannot be directly correlated to the bulk hardness of the composites.

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