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The Effect of Reinforcement Ratio on the Wear Behaviour of AlB_2 Flake Reinforced Metal Matrix Composites

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Aluminium–boride composites (Al–AlB_2) having two different volume fractions of reinforcing (AlB_2), namely 4.0 and 10.0 per cent have been produced through synthesizing boron by reaction of boron oxide (B_2O_3) with liquid aluminium. Friction and wear characteristic of the composites have been investigated under dry sliding condition and results compared with pure aluminium. The wear rate increases with normal load and sliding speed and is significantly lower with the composites when compared to that of monolithic material. The coefficient of friction increased with increasing volume fraction of AlB_2 reinforcement phase. The wear rate, however, decreased with increasing volume fraction of AlB_2.

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1. Introduction

Particulate reinforced metal matrix composites have shown great promise for various applications in automotive and aerospace industries where continuous fibre reinforced composites may not be required [1]. Such systems take advantage of the high stiffness, low cost and ease of machining and processing offered by the particulate reinforcement [2]. However, because of low aspect ratio of these particulates, there is no effective mechanism for achieving enhanced strength values. High modulus, high aspect ratio flake or whisker reinforcement should yield higher strengths than a low aspect ratio particulate reinforcement of equal modulus when both are uniformly distributed throughout the matrix [2–5]. *In situ* composites are multiphase materials where the reinforcing phase is synthesized within the matrix during composite fabrication [6]. *In situ* techniques offer significant advantages from both an economic and technical aspect. This method provides a potential to fabricate composites with the required thermodynamic stability while minimizing damage to the strengthening phase. Moreover, *in situ* formation of a second phase provides greater control of the size and level of reinforcement while maintaining excellent reinforcement-matrix compatibility [7].

An attempt was made in this study to develop aluminium matrix composites by *in situ* formation of AlB_2 flakes in the melt following a direct casting route which is simple and cost effective. Tribological behaviour of the new Al–AlB_2 composite has been characterised by conducting dry sliding wear tests on a standard pin-on-disc arrangement.

2. Experimental procedure

For the fabrication of AlB_2 flake reinforced Al composites, commercially pure aluminium was used as the base material. Al/AlB_2 composites with 4 vol.% AlB_2 flakes were prepared by the reaction of boron oxide (B_2O_3) with Al at a reaction temperature of 1400 °C as explained elsewhere [8]. Approximately 4 vol.% AlB_2 containing master alloy was produced. This master alloy was placed in a die and the die was heated at 750 °C in an electric resistance furnace to bring the master alloy to a semisolid state. Centrifugal action was then employed with the die containing semisolid alloy to drive the solid AlB_2 particles towards the outer region to produce an Al/AlB_2 composite with even higher volume per cent reinforcement. The centrifugation process was carried out under rotation speed of 400 rpm at 750 °C. A schematic representation of the *in situ* production and the following centrifugation process of the Al/AlB_2 composites was shown in Fig. 1. So additional reinforcement with (10 vol.%) AlB_2 flakes was achieved in the outer region.

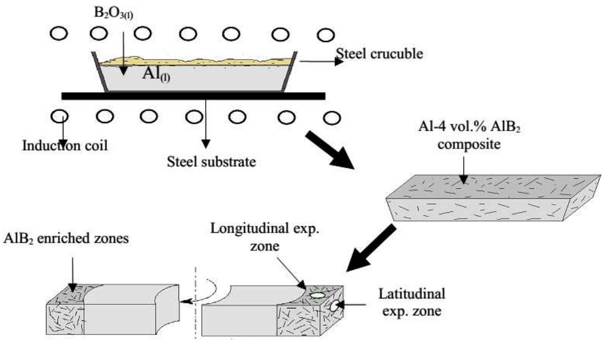

Fig. 1. Schematic illustration of Al–AlB_2 composites production route.

Dry sliding wear tests for the Al and the composites have been conducted using a pin-on-disc machine, at room temperature under dry conditions. The wear and friction tests have been conducted under three normal loads of 10, 20, and 40 N, sliding distance of 1000 m and at sliding velocities of 0.4, 0.8, and 1.2 m s^{-1}.

3. Results and discussion

Optical microstructure of Al–AlB_2 composites with Al matrix showed dispersion of reinforcing particles in flake form as shown in Fig. 2a–c. During the *in situ* composite fabrication, the boron was synthesised with aluminium to form high aspect ratio AlB_2 flakes. The formation of flake shape boride particles has been attributed to high cooling rates. Based on the wet analysis, the volume fraction of boride phase in Al–AlB_2 alloys before and after the centrifugal action were about 4 and 10 vol.%, respectively. The microstructures are shown in Fig. 2a,b. A sample of 10 vol.% AlB_2 reinforced aluminium composites was deep-etched to separate boride flakes from the aluminium matrix. Scanning electron microscopy (SEM) was carried out to examine morphology of the separated AlB_2 flakes. As shown in Fig. 2c, high aspect ratio hexagonal AlB_2 flakes was successfully produced by *in situ* reaction of Al and B as a result of controlled solidification.

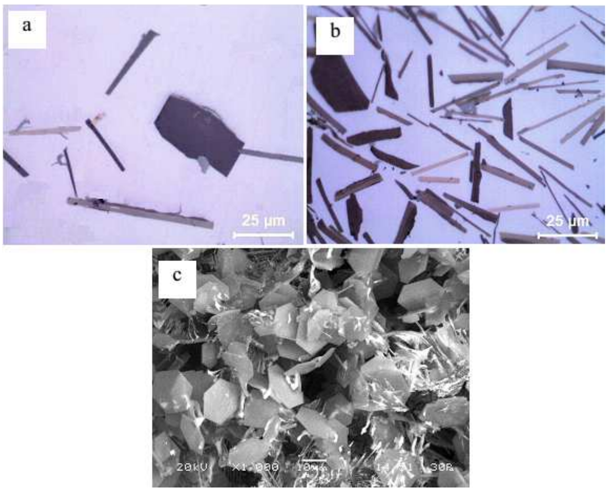

Fig. 2. (a) Optical micrograph of Al–4 vol.% AlB_2 composite, (b) optical micrograph of Al–10 vol.% AlB_2 composite, and (c) SEM images of AlB_2 flakes in deep etched aluminium.

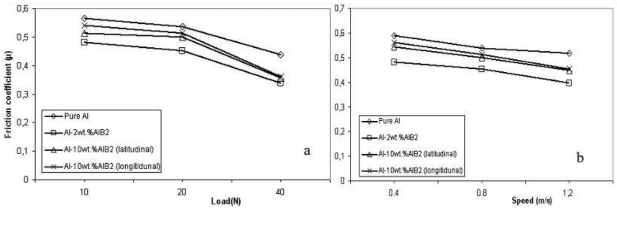

Fig. 3. Variation of coefficient of friction with (a) under different applied loads with 0.8 m s^{-1} sliding speed and (b) under different sliding speed with 20 N applied load for unreinforced Al and its composites.

Figure 3 shows the variation of friction coefficients measured with Al and Al–AlB_2 composites versus applied load and sliding speeds, respectively. In Fig. 3a, the coefficient of friction for all tested materials decreases with the increase in applied load in the case of pure Al, Al–4 vol.% AlB_2, Al–10 vol.% AlB_2 (latitudinal), and Al–10 vol.% AlB_2 (longitudinal) composites. The friction decreased by 12%, 17%, 18% and 39% when the applied load was increased four times. This reveals that as the normal load increases, concentration of AlB_2 within the surface becomes predominant. It is assumed that as the load increases, wear mechanism shifts from adhesive to abrasive nature, hence, coefficient of friction drops significantly. From Fig. 3b, for all materials there is an average 21% decrease in friction coefficient with increasing speed. It is clear from these figures that the influence of the applied load on wear of the composite is significantly higher than that of the sliding speed.

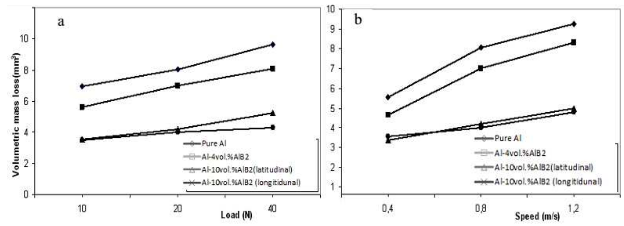

Fig. 4. Volumetric mass loss values for Al and Al–AlB_2 composites tested (a) at different loads (sliding speed = 0.8 m s^{-1}) and (b) at different sliding speed (applied load = 20 N).

Figure 4a and b illustrates the variation of volumetric mass loss with applied load and sliding speed, respectively. It can be observed in Fig. 4a that the volumetric mass loss increases linearly with increasing applied load. This is attributed to the uniform distribution of the reinforcements in the composites and their properties being more stable. It also indicates that the increase of AlB_2 flakes in Al matrix will be beneficial to improve the wear resistance. For all materials tested in this investigation and within the applied load range of 10–40 N, it is shown that the wear rate of the materials is not much influenced by applied load but by increased reinforcement rate.

In Fig. 4b, it can be seen that the wear rate of Al–10 vol.% AlB_2 (latitudinal) and Al–10 vol.% AlB_2 (longitudinal) cross-sectioned composites increases linearly with increasing sliding speed. The wear rate of unreinforced Al and Al–4 vol.% AlB_2 composites with increased sliding speed was from 0.4 to 0.8 m s^{-1}. However, when reduced to 1.2 m s^{-1} the wear rate of AlB_2 reinforced aluminium matrix composites were lower than those of the unreinforced alloy. The lowest wear rate was observed with Al–10 vol.% AlB_2 composite specimens, while the highest wear rate was observed with the pure (unreinforced) Al alloy.

This is in agreement with the wear rate values obtained by Ficici et al. [8] and Koksal et al. [9]. Similar to particulate reinforced composites, the wear rate decreased with increasing volume fraction of AlB_2 flakes. This decrease is typical of aligned SiC whisker reinforced aluminium alloy matrix composites at equal volume fractions [10]. It is assumed that the presence of the reinforcement contributes to a decrease in the friction coefficient and consequently a marked decrease in wear rate [8, 9]. The average wear rates for Al–4 vol.% AlB_2, Al–10 vol.% AlB_2 (latitudinal), Al–10 vol.% AlB_2 (longitudinal) cross-sectioned composites, were 10, 45, and 48% lower than that of Al, respectively.

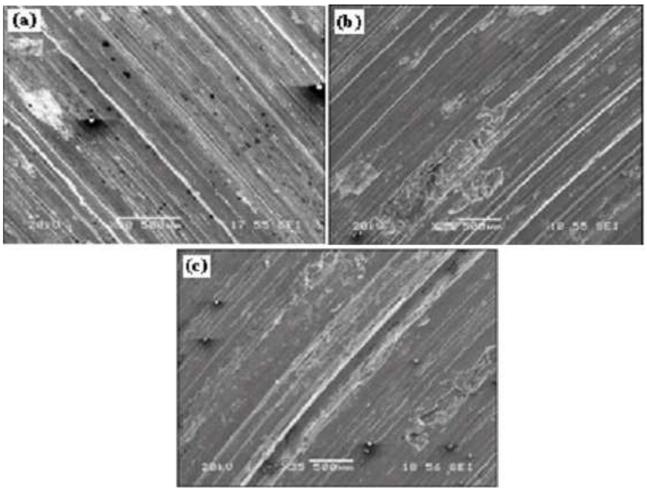

Fig. 5. SEM morphologies of the worn surface of: (a) Al–4 vol.% AlB_2, (b) Al–10 vol.% AlB_2 (latitudinal), (c) Al–10 vol.% AlB_2 (longitudinal) cross-section of the composites (applied load = 20 N; sliding speed = 0.8 m s^{-1}).

Figure 5 shows SEM morphologies of the worn surfaces of Al–AlB_2 composites pin tested under the load of 20 N and sliding speed of 0.8 m s^{-1}. The SEM images suggested that sliding surfaces of pins have almost similar wear characteristics. As shown in Fig. 5a–c, sliding marks are present parallel to sliding direction. Sliding marks are deeper for Al–4 vol.% AlB_2 composites compared to that of Al–10 vol.% AlB_2 composites. Sliding marks are reduced by increasing reinforcement phase. However delamination pitting wear mechanism has been observed.

4. Conclusions

1. Al/AlB_2 flake reinforced metal matrix composites were successfully fabricated by the direct casting route which is simple and cost effective method. Microstructures suggested uniform distribution of reinforcements phase and good bonding between matrix reinforcement was achieved.

2. The wear rate increases with normal load and sliding speed which is significantly lower in composites as compared to that of base material. Wear rates of Al–4 vol.% AlB_2, Al–10 vol.% AlB_2 latitudinal and longitudinal cross-section composite specimens are lower than that of the pure Al: 10, 45, and 48%, respectively. For test conditions and materials used in this study, a combination of abrasion and delamination wear mechanism was observed to be dominant on the surface of pin and disc.

3. The friction coefficient of Al and its composites linearly decrease with applied load. The Al–10 vol.% AlB_2 composite exhibited the lowest wear rate while the highest wear rate was observed with unreinforced Al alloy as expected.

Acknowledgments

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