The Effect of Reinforcement Ratio on the Wear Behaviour of AlB2 Flake Reinforced Metal Matrix Composites

R. KAYIKCI\textsuperscript{a}, Ö. SAVAŞ\textsuperscript{b}, S. KOKSAL\textsuperscript{a} and A. DEMIR\textsuperscript{a}

\textsuperscript{a} Sakarya University, Faculty of Technology, Sakarya, Turkey
\textsuperscript{b} Yildiz Technical University, Faculty of Naval Architecture and Maritime, Istanbul, Turkey

Aluminium–boride composites (Al–AlB\textsubscript{2}) having two different volume fractions of reinforcing (AlB\textsubscript{2}), namely 4.0 and 10.0 per cent have been produced through synthesizing boron by reaction of boron oxide (B\textsubscript{2}O\textsubscript{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\textsubscript{2} reinforcement phase. The wear rate, however, decreased with increasing volume fraction of AlB\textsubscript{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\textsubscript{2} flakes in the melt following a direct casting route which is simple and cost effective. Tribological behaviour of the new Al–AlB\textsubscript{2} composite has been characterized by conducting dry sliding wear tests on a standard pin-on-disc arrangement.

2. Experimental procedure

For the fabrication of AlB\textsubscript{2} flake reinforced Al composites, commercially pure aluminium was used as the base material. Al/AlB\textsubscript{2} composites with 4 vol.% AlB\textsubscript{2} flakes were prepared by the reaction of boron oxide (B\textsubscript{2}O\textsubscript{3}) with Al at a reaction temperature of 1400 °C as explained elsewhere [8]. Approximately 4 vol.% AlB\textsubscript{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\textsubscript{2} particles towards the outer region to produce an Al/AlB\textsubscript{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\textsubscript{2} composites was shown in Fig. 1. So additional reinforcement with (10 vol.%) AlB\textsubscript{2} flakes was achieved in the outer region.

![Fig. 1. Schematic illustration of Al–AlB\textsubscript{2} composites production route.](image-url)
3. Results and discussion

Optical microstructure of Al–AlB₂ 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 AlB₂ 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–AlB₂ 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.% AlB₂ 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 AlB₂ flakes. As shown in Fig. 2c, high aspect ratio hexagonal AlB₂ flakes was successfully produced by in situ reaction of Al and B as a result of controlled solidification.

![Figure 2](image_url)

**Fig. 2.** (a) Optical micrograph of Al–4 vol.% AlB₂ composite, (b) optical micrograph of Al–10 vol.% AlB₂ composite, and (c) SEM images of AlB₂ flakes in deep etched aluminium.

The coefficient of friction for all tested materials decreases with the increase in applied load in the case of pure Al, Al–4 vol.% AlB₂, Al–10 vol.% AlB₂ (latitudinal), and Al–10 vol.% AlB₂ (longitudinal) composites. The friction decreased by 12%, 17%, 18% and 30% when the applied load was increased four times. This reveals that as the normal load increases, concentration of AlB₂ 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.

![Figure 3](image_url)

**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–AlB₂ composites versus applied load and sliding speeds, respectively. In Fig. 3a, the variation of coefficient of friction with different applied loads for pure Al, Al–4 vol.% AlB₂, Al–10 vol.% AlB₂ (latitudinal), and Al–10 vol.% AlB₂ (longitudinal) composites is shown. The friction coefficient decreased with increasing applied load, and the decrease is more pronounced for Al–10 vol.% AlB₂ composites.

![Figure 4](image_url)

**Fig. 4.** Volumetric mass loss values for Al and Al–AlB₂ 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 illustrate 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 AlB₂ 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.% AlB₂ (latitudinal) and Al–10 vol.% AlB₂ (longitudinal) cross-sectioned composites increases linearly with increasing sliding speed. The wear rate of unreinforced Al and Al–4 vol.% AlB₂ 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 AlB₂ reinforced aluminium matrix composites were lower than those of the unreinforced alloy. The lowest wear rate was observed with Al–10 vol.% AlB₂ 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 AlB₂ flakes. This decrease is typical of aligned SiC whisker reinforced alu-
minimum 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.% AlB₂, Al–10 vol.% AlB₂ (latitudinal), Al–10 vol.% AlB₂ (longitudinal) cross-sectioned composites, were 10, 45, and 48% lower than that of Al, respectively.

![Figure 5](image)

Figure 5 shows SEM morphologies of the worn surfaces of Al–AlB₂ 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.% AlB₂ composites compared to that of Al–10 vol.% AlB₂ composites. Sliding marks are reduced by increasing reinforcement phase. However delamination pitting wear mechanism has been observed.

4. Conclusions

1. Al/AlB₂ 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.% AlB₂, Al–10 vol.% AlB₂ 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.% AlB₂ composite exhibited the lowest wear rate while the highest wear rate was observed with unreinforced Al alloy as expected.

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References