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A study of microstructure and wear behaviour of TiB_2/Al metal matrix composites

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Abstract

The present paper deals with the study of microstructure and wear characteristics of TiB_2 reinforced aluminium metal matrix composites (MMCs). Matrix alloys with 5, 10 and 15% of TiB_2 were made using stir casting technique. Effect of sliding velocity on the wear behaviour and tribo-chemistry of the worn surfaces of both matrix and composites sliding against a EN24 steel disc has been investigated under dry conditions. A pin-on-disc wear testing machine was used to find the wear rate, in which EN24 steel disc was used as the counter face, loads of 10-60N in steps of 10N and speeds of 100, 200, 300, 400 and 500 rpm were employed. The results showed that the wear rate was increased with an increase in load and sliding speed for both the materials. However, a lower wear rate was obtained for MMCs when compared to the matrix alloys. The wear transition from slight to severe was presented at the critical applied loads. The transition loads for the MMCs were much higher than that of the matrix alloy. The transition loads were increased with increase in TiB_2 and the same was decreased with the increase of sliding speeds. The SEM and EDS analyses were undertaken to demonstrate the effect of TiB_2 particles on the wear mechanism for each conditions.

Keywords

MMC composites, wear, microstructure.

1 INTRODUCTION

Aluminium alloys are widely used in automotive, aerospace and mineral processing industries to make their products due to its excellent properties such as low density and high thermal conductivity [3, 4]. However, it has a poor wear resistance behaviour. To overcome this drawback, these types of alloys are reinforced with some other materials so that its hardness, Young's modulus and abrasion wear resistance are increased. The material like MMC exhibits different strengthening mechanisms when compared to the other conventional materials and continuous reinforced composites. Dry sliding wear characteristics of MMCs based on aluminium alloys have been studied by Basavarajappa et al. [2], and abrasive wear behaviour by Rohatgi et.al.[8].

The effect of parameters such as reinforcement volume fraction and size, sliding distance and speed, applied load, sliding speed, hardness of the counter face and the properties of reinforcement phase on dry sliding wear behaviour were examined in [2]. The influencing parameters on sliding wear rate and wear behaviour were reported in [5–7]. Hence, the present study was attempted to improve the dry sliding wear behaviour of Al 6061 alloy reinforced with TiB_2 at different loads and speeds. The worn surfaces were studied using scanning electron microscopy and the results are reported in this paper.

2 EXPERIMENTAL STUDY

The chemical composition of the matrix alloy is given in Table 1. The matrix alloy was reinforced with 5, 10 and 15% of Titanium diboride (TiB_2) by using compo-casting technique. The production process of matrix alloy and composites is as follows: TiB_2 particles were preheated at 400 °C and then it was added to the semi-solid matrix alloy at 600 °C. Argon atmosphere was maintained over the melt to reduce oxidation. The mixture was rapidly heated to 750 °C and the composite slurry was poured into a preheated permanent iron die. Samples for microscopic examinations were prepared based on the standard metallographic procedures, etched with Keller's agent and examined under computer interfaced optical microscope. Optical microstructure of die-cast Al 6061-garnet particle composite is shown in Fig. 1.

A pin-on-disc machine was used to investigate the dry sliding wear behaviour of the aluminium alloy and TiB_2/Al composites as per ASTM G99-95 standards. Specimen of 10 mm in diameter and 30 mm in length were cut by specimen cutter, machined, and then polished metallographically. Wear tests were conducted with loads ranging from 10 to 60N and sliding speeds of 1.25, 2.56, 3.05 and 4.26 ms-1 for a sliding distance of 3 km at room temperature. It is noted that three samples were tested for each conditions in the present analysis. During the test, the pin was pressed against the rotating EN24 steel disc by applying the normal load. All the specimens followed a track of 100 mm diameter with tangential force. A friction-detecting arm connected to a strain gauge held and loaded the pin specimen vertically into the rotating hardened steel disc. The frictional traction experienced by the pin during sliding was measured continuously by a computer-based data logging system. After running through a fixed sliding distance, the specimens were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. The weight of the specimen before testing and after testing was measured. Difference in weight between before and after testing was measured to determine material loss (i.e. wear) in the composite specimen. The wear of the composite specimens were studied as a function of the volume percentage of reinforcement, sliding distance, applied load and sliding velocity.

Worn surfaces and transfer layers were examined with SEM micrographs. Energy Dispersive X-ray analysis (EDS) was carried out on the debris and worn out surface to determine their chemical composition.

3 RESULTS AND DISCUSSIONS

3.1 Metallographic study

Microstructures of matrix alloy and 15 wt.% TiB_2 reinforced Al 6061 MMCs microscopy are shown in the Fig 1. It is observed from Fig. 1(b) that in all the MMCs, TiB_2 particles were rejected by the α-aluminium dendrites and were segregated in the interdendritic regions.

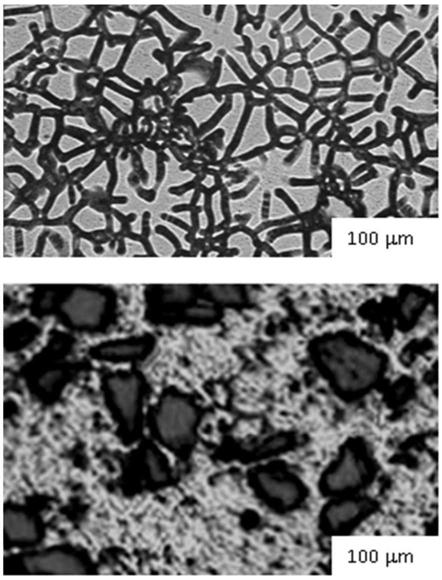

Figure 1 Microstructure of: (a) Al 6061 alloy (with etching) and (b) Al/15% TiB_2 MMCs (without etching).

3.2 Effect of TiB_2 and load on wear transition

The average wear rate of Al matrix alloy and Al/TiB_2 MMCs are plotted in Fig. 2. The wear rate is compared between the normal alloy (unreinforced) and the reinforced composites in this section. It is found from figures that the wear rate of both matrix alloy and composite specimens were increased with increase in applied load. However, a lower wear rate was obtained for the MMC alloy when compared with matrix alloy. Also, the wear rate was decreased with increase in TiB_2 content in the Al/TiB_2 MMC specimens.

Wear transition was obtained at a load of 30 N for the matrix alloy and Al/ 5% TiB_2 MMCs, 40 N for the Al/10% TiB_2 MMCs and 50 N for Al/15% TiB_2 MMCs. It is observed that the presence of TiB_2 in the reinforced composites delays the wear and increases the load at the transition. The transition load is increased almost by 10 times for Al/TiB_2 15% reinforced composite when it is compared with the matrix alloy. The results indicate that at lower loads, comparatively low wear rates exist, indicating the regime of mild wear. In this regime of mild wear, the composites demonstrate significant wear-resistance than the alloy counterpart. At higher loads, the materials exhibit a rapid increase in wear rate. At loads greater than the transition load, severe wear occurs which is leading to seizure of the materials. The severe

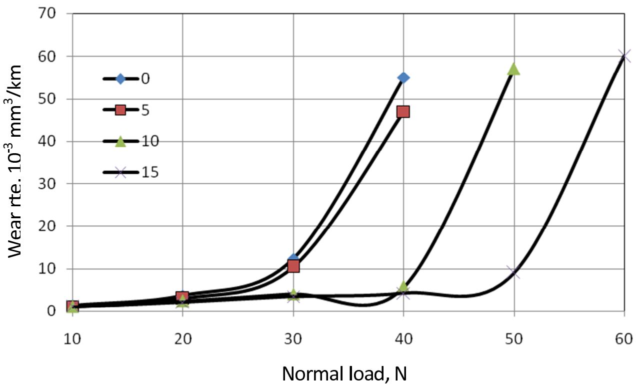

Figure 2 Wear rate of Al matrix and Al/TiB_2 MMCs as the function of normal load.

wear manifested by a rapid rate of material removal in the form of generation of coarse metallic debris, and also by massive surface deformation and material transfer to the counter-face.

3.3 Effect of sliding speed on wear rate

The effect of sliding speed on wear rate is shown in Fig. 3 for Al and Al/TiB_2 reinforced MMCs tested for different loads of 10, 20, 30 and 40N respectively. Wear rate was increased with increase in sliding speed during initial stage and then it was decreased with increase in sliding speed. At loads of 10N and 20N, wear rate of all four specimens were showed a nominal difference. However, a large difference in wear rate was observed at 30N and 40N loads.

3.4 Effect of TiB_2 particles on wear rate

It is has been found that the transition load increases with increase in TiB_2 content in the reinforced composites. Also, noticed that wear rate of the composite was lower than the base alloy. This is obviously due to the release of TiB_2 by the composite specimens on to the mating surface during sliding which provide resistance to wear. Alpas and Zhang [1] studied the sliding wear behaviour of Al-Si alloys reinforced with TiB_2 particles. They indicated from their study that TiB_2 reinforcement provides the significant improvement in the wear resistance.

During sliding wear, TiB_2 particles get sheared and adhere to the metal surface with the major axis which is parallel to the sliding direction to form a thin film between the mating surfaces. Moreover, the hard film of TiB_2 has very limited ductility and it has the ability to withstand stress without plastic deformation or fracture under low load conditions. It is well established by the researchers that the wear rate and surface damage can be minimized if the plastic deformation of the material at the counter interface is prevented. The hard film of TiB_2 withstands high stresses and is very effective in reducing the wear rate in the case of composites. Hence, it is concluded that the ability of the sheared reinforcement layers adhere to the sliding surface decides the effectiveness of the TiB_2 particles in the composite materials to reduce the wear rate.

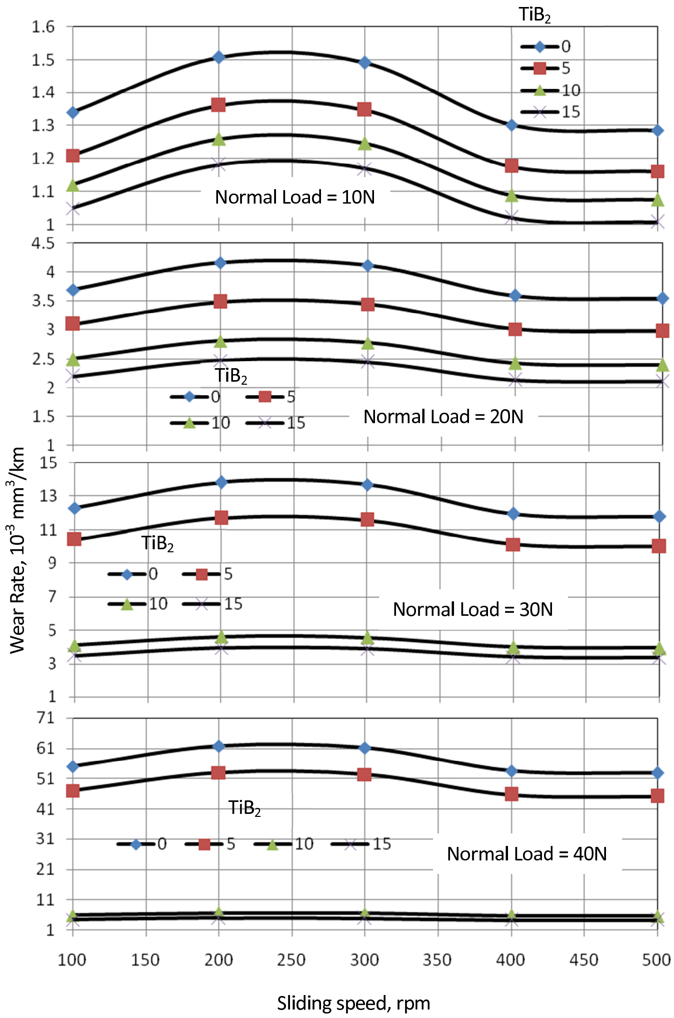

Figure 3 Wear rate of Al matrix and Al/TiB_2 MMCs as the function of sliding speed for different normal load.

The microstructure of the matrix base alloy and the Al/TiB_2 MMC composites are shown in Fig. 4 for the load case of 30 N and speed of 300 rpm. The worn surface was characterized by fairly long and extensive ploughing grooves for the aluminium alloy. Short cracks parallel to sliding direction at the bottom of the grooves were present. It is noticed from Fig. 4 that groove width size in the aluminium alloy was bigger when compared to composites.

The area of the composite worn surface is covered by small particles. TiB_2 particles were not exposed and grounded within the matrix layer when the surface became softer at sliding due to lower melting point of the matrix alloy. During sliding, the Al alloy specimen is exposed to air which is leading to the formation of Al_2O_3 (it is confirmed by EDS results as shown in Fig. 5), this layer is brittle and acts as a thermal insulator, whose temperature increases with further sliding. This raise in temperature causes transition wear. The formation of Al_2O_3 layer

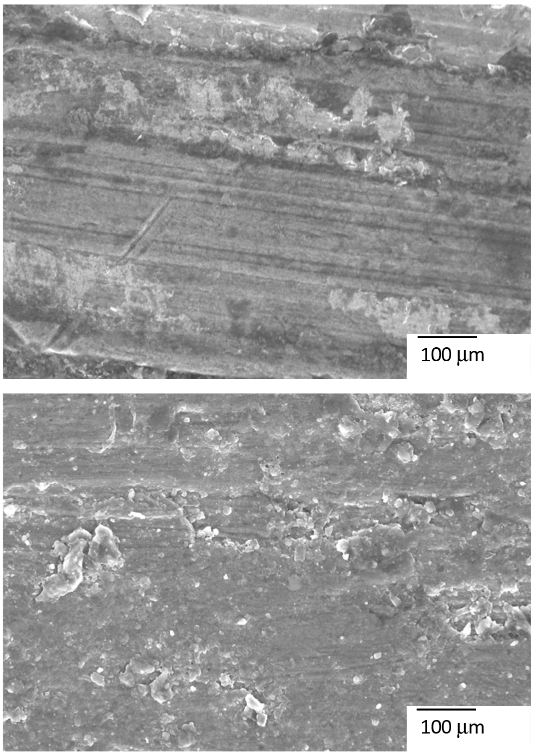

Figure 4 Structure of wear track of: (a) Al alloy and (b) Al /TiB_2 composite materials at a load of 30N and speed of 300 rpm.

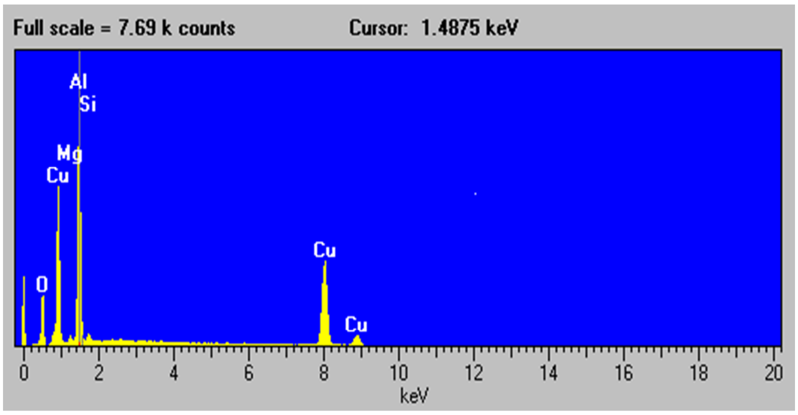

Figure 5 EDS spectrum for Al/15% TiB_2 composites worn surface.

would not allow the TiB_2 particle to get exposed during the sliding. The XRD spectrum of this specimen shows the presence of TiB_2 and Al_2O_3 indicating that materials transfer occurs across the interface during the wear test as shown in Fig. 6.

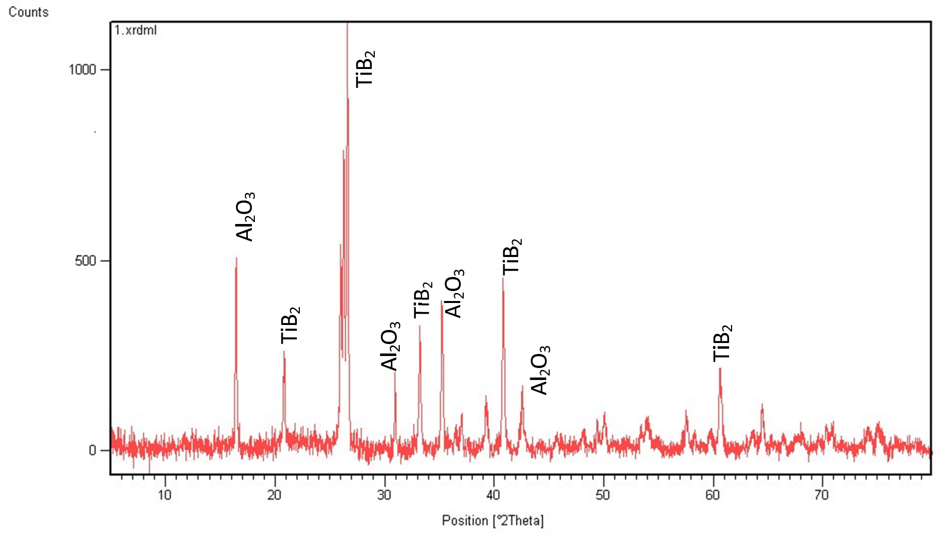

Figure 6 XRD Spectrum for Al/15% Composites worm surface.

4 CONCLUSIONS

The wear rate obtained through the present experimentation is reported in this paper. It is shown in this paper that the observed wear rate was higher for the unreinforced aluminium alloy when compared to the Al/TiB_2 reinforced composites. Wear rate was decreased with increasing TiB_2 content in the MMC composites. The wear rate of the MMCs as well as the matrix alloy was increased with the increase in applied load. However, it was decreased with increase in speed. The MMC specimens were demonstrated abrasion wear at low loads, whereas, in the case of higher applied loads, de-lamination wear was dominant. The wear rate increased abruptly just above the critical load. The transition to high wear rate regime was induced by massive surface damage and material transfer to the counter-face. The presence of TiB_2 particles would help in delaying of the transition wear from mild to severe.

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