

THE INFLUENCE OF ARTIFICIAL AGEING ON ABRASIVE WEAR OF SiC and Al₂O₃ PARTICULATE METAL MATRIX COMPOSITES.

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Abstract

Abrasive wear behaviour of unreinforced and particulate reinforced 6061 Aluminium alloy metal matrix composites (MMCs) was investigated under high stress two-body abrasion conditions using a pin-on-drum machine surfaced with bonded Al₂O₃ abrasive. The abrasive wear rates were determined in the as-fabricated, solution treated and artificially aged conditions, to determine the effect of variations in matrix hardness. The results indicate that increasing ageing time, up to peak ageing, increases hardness levels and lowers the wear rates of these materials. Reinforced 6061 MMC's appear to have enhanced the ageing kinetics compared with unreinforced 6061 alloy as indicated by higher levels of hardness achieved in the reinforced materials at shorter ageing times. At similar hardness levels, MMCs which were aged for longer periods of time exhibited greater wear resistance than those aged for shorter periods. As a result, the wear rates of composites were seen to be less dependent of hardness and more dependent upon ageing time, i.e. resulting microstructure.

Introduction

Aerospace and automotive applications have provided the main driving force for the development of light alloy Metal Matrix Composites (MMCs) [1]. This is because aluminium MMCs have good combinations of high strength, stiffness and wear resistance compared with the matrix (unreinforced) alloy. Most of the studies on abrasive wear to date have concentrated on the type, volume fraction, size and geometry of the reinforcement with relatively less attention devoted to the effect of matrix microstructure on wear behaviour [2]. To improve understanding of the wear behaviour in MMCs, it would also be useful to identify the role of other parameters such as bulk hardness and microstructure on wear resistance.

A linear relationship has been shown to exist between the wear resistance and bulk hardness for a

range of pure metals [3,4]. However, the wear resistance of heat-treated steels is found to be lower than pure metals of the same hardness level [3]. Also, a non-linear relationship is known to exist between hardness and wear resistance when a single steel is heat treated to different levels of hardness [4]. This indicates that microstructure may play an important role in the wear of materials. Moore [5], in his investigation on wear of ferritic steels, proposed that wear resistance is not only related to bulk hardness, but also related to the microstructure.

The effects of ageing on abrasive wear rate (the inverse of wear resistance) have been reported by some investigators to improve the microstructure of the matrix and consequently the wear resistance of the MMCs [6-9]. However, MMCs can become more wear resistant when overaged, compared with the underaged materials of the same hardness [2,6]. Wang and Rack [2] proposed that alloys without reinforcement exhibit similar trends in wear resistance to MMCs in the underaged (UA) and overaged (OA) condition i.e. a decrease in wear rate in the OA condition usually exists. This therefore suggests that the matrix microstructure may influence abrasive wear to a significant extent. However, various reinforcements are reported to enhance the ageing kinetics in MMCs compared with monolithic alloys [2,8,10,11].

In the present investigation the influence of reinforcement and artificial ageing response on wear properties in both unreinforced and reinforced 6061 has been studied.

Materials and experimental procedure

The materials used in this investigation were cylindrical pins (approx. 6 mm x 30 mm long) machined from 19 mm diameter extruded rods of unreinforced and particulate reinforced 6061. The reinforced 6061 consists of 10, 20% fine SiC and 10, 20% coarse Al₂O₃. More details about the materials are reported elsewhere [12].

Twenty four pins in total were tested. The different conditions that were used include (i) solution treatment (S.T.) at 530°C and water quench (ii) S.T. plus natural aging for 20 hours at room temperature, followed by 0.5, 4 and 8 hours artificial ageing at 175°C, and (iii) as-fabricated specimens. Subsequent to thermal ageing treatment the specimens were placed in a freezer to prevent further natural ageing.

Measurements of the abrasive wear rate were made in air at ambient temperature (17-25°C). The apparatus used was a pin-on-drum machine (figure 1), using a dead weight load of 66.7 N at a sliding speed of 43.82 mm sec⁻¹, and a sliding distance of 12.62 m. The pin rotates about its vertical axis at 20 rpm to maintain even wear. The pin also moves across a rotating 0.5 m diameter drum surfaced with 80µm Alumina abrasive paper (parallel to the drum axis) and follows a helical path. From the weight loss measurements of a reference pin (Bisalloy 80, quenched and tempered steel - H_v 265) for each sheet abrasive cloth, the average weight loss for the test material was adjusted using the following equation:

$$W_1 = W_2 \times k \quad (1)$$

Where:

W_1 = Corrected weight loss of material (CWL)

W_2 = Average actual weight loss of material (AWL)

K = Calibration factor (Ave. wt. loss of Standard Pin)/actual weight loss of standard pin per abrasive paper.

The abrasive wear rate was evaluated on the basis of weight loss per unit distance of sliding. From the weight loss the volume loss can be calculated by using density data for each test material. Thus the wear rate may be expressed as follows:

$$A_r = V/d \quad (2)$$

Where:

A_r = Wear rate (cm²)

V = Volume loss (cm³)

d = Sliding distance (cm)

Equation 2 can be normalised by using

$$A_r = V/(d \times A)$$

where:

A = contact area (cm²)

(Note: wear resistance = $1/A_r$).

Discussion

Figure 2 represents CWL values for 6061/MMCs as a function of ageing time where it can be seen that CWL generally decreases from ST to ageing up to 8 hours.

Since this investigation involved ageing for times up to a maximum of 8 hours for all materials, only a comparison of UA and PA conditions can be made at this stage. Unlike the MMCs, unreinforced 6061 increased in hardness consistently with increasing ageing time up to PA condition as shown in figure 3. However the hardnesses of unreinforced 6061 after 4 and 8 hours ageing are considerably lower than those for the corresponding ageing periods for the MMCs.

Unreinforced and reinforced materials usually undergo some natural ageing prior to artificial ageing. The natural ageing at room temperature may enhance the ageing kinetics and allows the PA hardness to be attained in a shorter period [2,8]. The ageing kinetics of MMCs can be enhanced in comparison to unreinforced 6061, since the reinforced matrix has a much greater density of dislocations than the unreinforced control alloy [8]. The acceleration in ageing kinetics is attributable to the decrease in incubation time required for nucleation and the increase in solute diffusivity and hence precipitation growth rate resulting from the increase in the matrix dislocation density due to the mismatch of coefficient of thermal expansion between matrix and reinforcement [11,13]. From figure 3 it can be seen that the incorporation of reinforcement in the 6061 alloy decreases time for maximum hardness.

Figure 3 shows a decrease in hardness between solution treatment and 0.5 hours ageing for 10 and 20% Al₂O₃/6061 and a decrease in wear rate is also associated with the decrease in hardness levels, for the 20% Al₂O₃, as shown in figure 4. The wear rate is at its minimum in the PA condition for MMCs. Further, there is (a) an increase in matrix hardness from 0% to 20% reinforcement, (b) a greater increase in hardness by increasing particle volume fraction from 10 to 20% in the case of SiC/6061 than there is for the same increase in the Al₂O₃/6061. Except for the solution treated condition, the increase in hardness produced by increasing from 10 to 20% SiC/6061 is approx. 17% for all levels of treatment, while for 10 to 20% Al₂O₃/6061 the increase is almost nil. For the as-fabricated materials the percentage increase for 10 to 20% Al₂O₃/6061 and for 10 to 20% SiC/6061 is approx. 18%. Wang and Hutchings [2,6] found that 20% of SiC whisker reinforcement in the PA condition, can lead to up to

60% increase in the indentation hardness. Indeed, this increase in indentation was observed for most of the SiC/6061 when compared to the unreinforced 6061. This increase in hardness, however, did not contribute proportionately to a decrease in wear rate. Therefore a comparison of microhardness results for both unreinforced and reinforced matrix alloys may not be a true indicator of the accelerated ageing phenomenon [11,12].

Conclusions

1. The weight loss decreases with increasing ageing time in all of the materials examined.
2. No simple relationship seems to be obvious between matrix hardness and wear rate.
3. Prolonged ageing within the experimental conditions decreases the wear rate. At equivalent hardness levels, the wear rate in the overaged condition is lower than that in the underaged condition.
4. An increase in volume fraction of particulate reinforcement decreases the wear rate. An increase in volume fraction of reinforcement also increases the matrix hardness. The maximum hardness in both 10 and 20% SiC/6061 was attained at 4 hours of ageing, whereas the rest of the materials reached maximum hardness at 8 hours ageing. However, despite the decrease in hardness of 10 and 20% SiC/6061 in the PA condition, minimum wear rates were reached at PA, i.e. 8 hours, for all the materials.

Acknowledgement

The authors would like to thank Dr Malcolm Couper of Comalco Research Centre, Thomastown, Victoria, for providing the materials.

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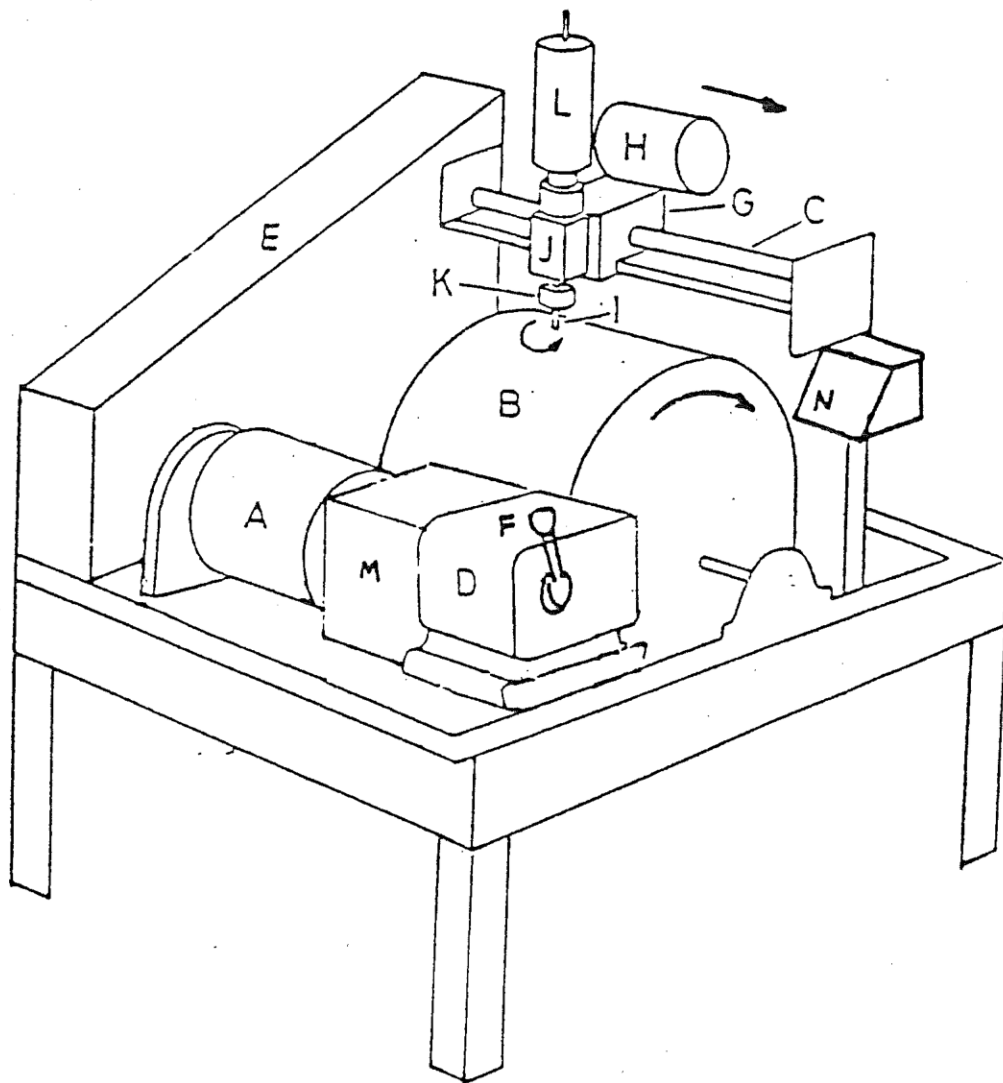


Figure 1. The pin-on-drum wear machine.

- A: Electric motor (drives drum)
- B: Drum
- C: Lead screw driven synchronously by E
- D: Variable speed gearbox
- F: Gearbox control lever
- M: Flexible coupling
- N: Control Panel
- E: Toothed rubber belt
- G: Specimen carriage
- H: Small electric motor rotates K
- I: Specimen
- J: Keyed linear bearing
- K: Chuck
- L: Dead-weight

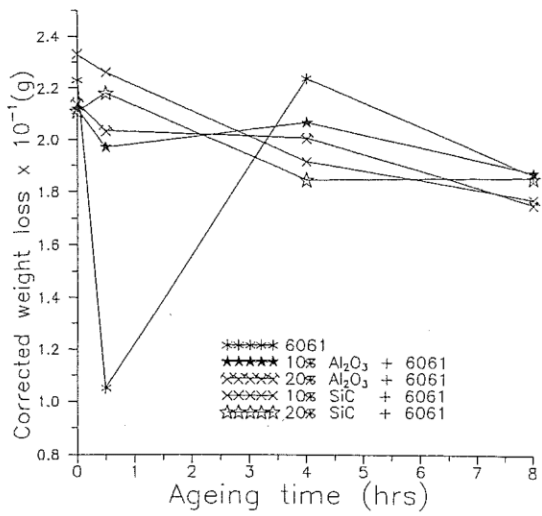


Figure 2. Variation of corrected weight loss as a function of ageing time (at an ageing temperature of 175°C) for the 6061 MMCs and control alloy.

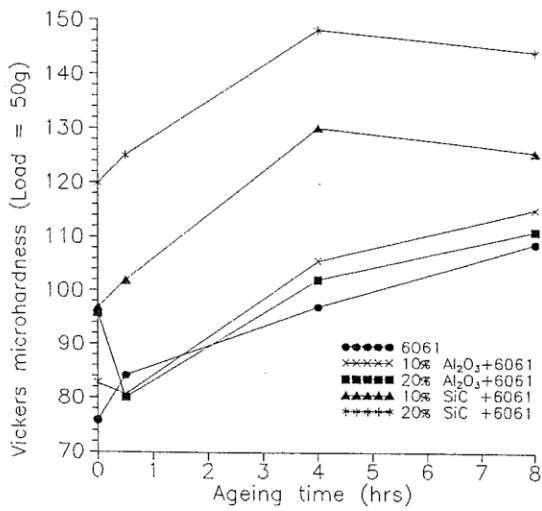


Figure 3. The effect of ageing on the matrix Vickers indentation hardness of 6061 MMCs and the control alloy.

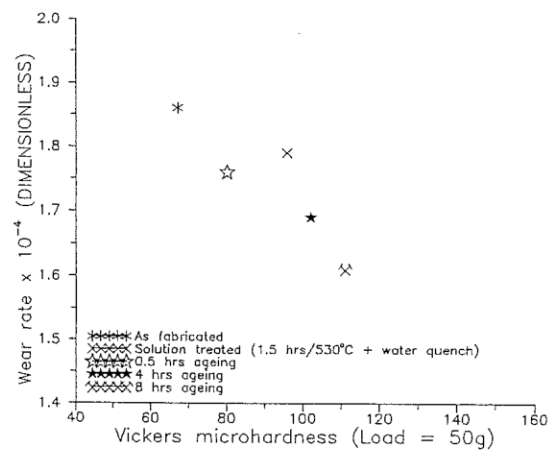


Figure 4. Wear rate versus matrix Vickers indentation hardness for 20% Al₂O₃/6061 at various ageing times.