JOURNAL OF MATERIALS SCIENCE 36 (2001) 1307–1311

Surface modification of an aluminium 2124 composite by eutectic alloying

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The incorporation of a hard particular dispersion in a metal matrix results in a composite material with unique mechanical and tribological properties. However, once the composite has been fabricated the particular dispersion cannot be rearranged or modified. In this study, the surface of a 2124 aluminium metal matrix composite is modified by eutectic alloying with copper. The results show that by heat treating the composite at a temperature above the eutectic temperature for the Al-Cu system, the distribution of SiC particles can be altered. There is a significant movement of particles towards the surface of the composite and abrasive wear tests show better wear resistance than the unmodified surfaces. This change in wear behaviour is attributed to the absence of severe plastic deformation due to the increase in concentration of hard SiC particles within the surface.

1. Introduction

The incorporation of a hard particular dispersion in a metal matrix results in a composite with unique mechanical and tribological properties. It is established knowledge that the addition of ceramic particles (e.g. SiC or Al_2O_3) to an aluminium metal matrix causes a significant increase in the bulk hardness of the composite and this has the effect of increasing the sliding wear resistance of the alloy. Such developments in composite technology have led to the use of particle reinforced composites in brake and piston components in automobiles and aircrafts [1].

More recently, researchers have attempted to improve the wear properties of titanium and aluminium alloys by using lasers to melt surfaces into which powdered SiC particles have been incorporated in order to develop composite surfaces [2, 3]. Laser processing has also been used as a method of producing functionally graded surfaces with improved tribological properties by alloying or cladding [4, 5].

The current scientific literature shows that the wear resistance of aluminium composites is influenced by a number of factors, for instance, the size, morphology and volume fraction of the reinforcing particles [6, 7]. Furthermore, experimental studies have shown that the abrasive wear resistance of metal matrix composites can be improved by increasing the volume fraction of particles dispersed in the matrix [8–10]. However, the distribution of particles in a composite can only be controlled and altered during the fabrication stage and the ability to change the distribution of particles within the composite once it has been fabricated has hitherto not been possible.

This preliminary study investigates the process of eutectic alloying with copper and the affect this has on the distribution of the SiC particles in the composite. The change in the abrasive wear behaviour of modified surfaces is assessed using metallurgical techniques and a pin-on-disc wear testing machine.

2. Experimental procedures

2.1. Materials and surface modification process

A 2124 aluminium metal matrix composite (MMC) with a chemical composition (in wt%) of Cu-4.4%, Mg-1.5%, Mn-0.6% reinforced by a SiC (mean size 5 μm) particular dispersion of 17% volume was used in this study in the unaged condition.

The composite was cut into rectangular blocks of dimension $11 \times 11 \times 35$ mm, and the surfaces were polished to a 6 μm finish. All samples were ultrasonically cleaned in acetone and stored in a dessicator. To modify the composite surface a pure copper foil of thickness 22 μm was placed between two blocks of composite and the assembly held in place using a clamping device. The clamped samples were placed in a vacuum chamber at a pressure of 10^{-4} mbar and heat treated at 575°C for 30 minutes and then allowed to cool to room temperature at a rate of 70°C/hr.

Metallographic examination was used to determine the effect of the modification process on the distribution of the SiC particles. A Leitz micro-hardness tester with an indentation load set at 0.05 N was used to determine any changes in surface hardness of the MMC.

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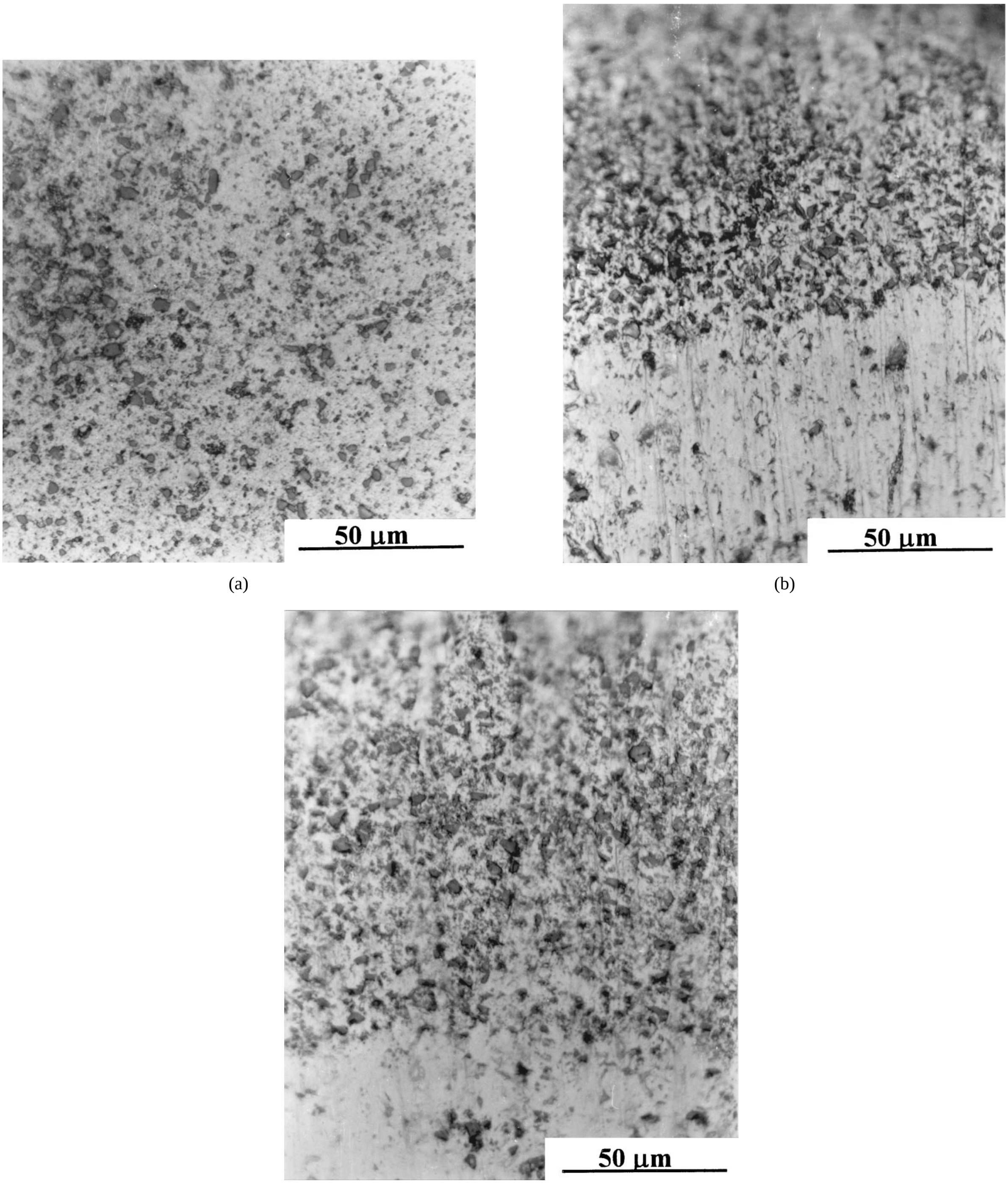


(a) (b) (c)

Figure 1 Light micrographs showing the change in SiC particular distribution: (a) light micrograph showing the SiC particular distribution in the untreated (as received) condition, (b) after 15 min. hold time, and (c) after 30 min hold time above the eutectic temperature.

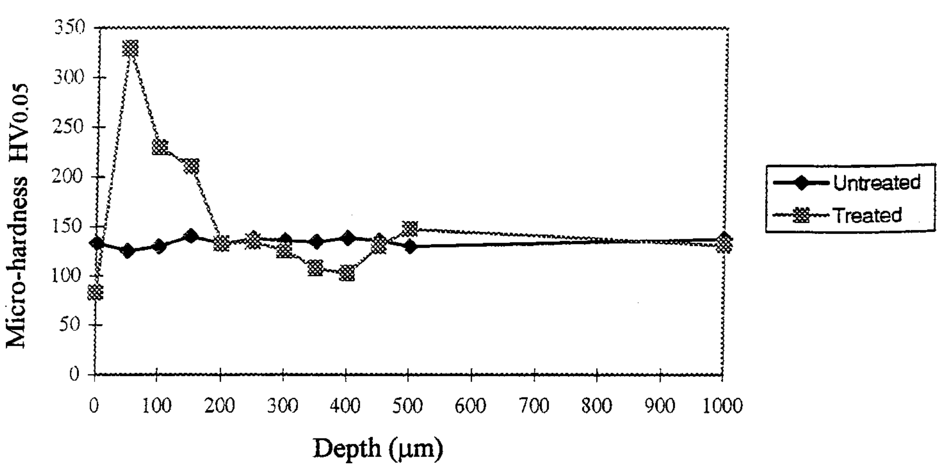


Figure 2 Micro-hardness depth profiles comparing MMC surface before and after treatment.

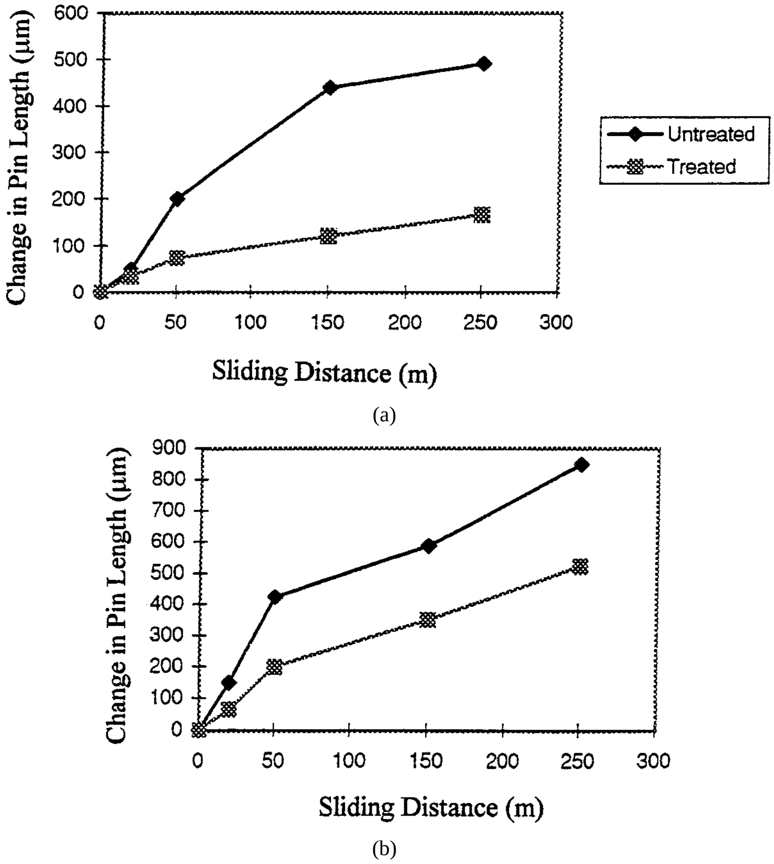


Figure 3 Wear graphs showing variation in pin length with sliding distance for a load of: (a) 10 N; (b) 25 N.

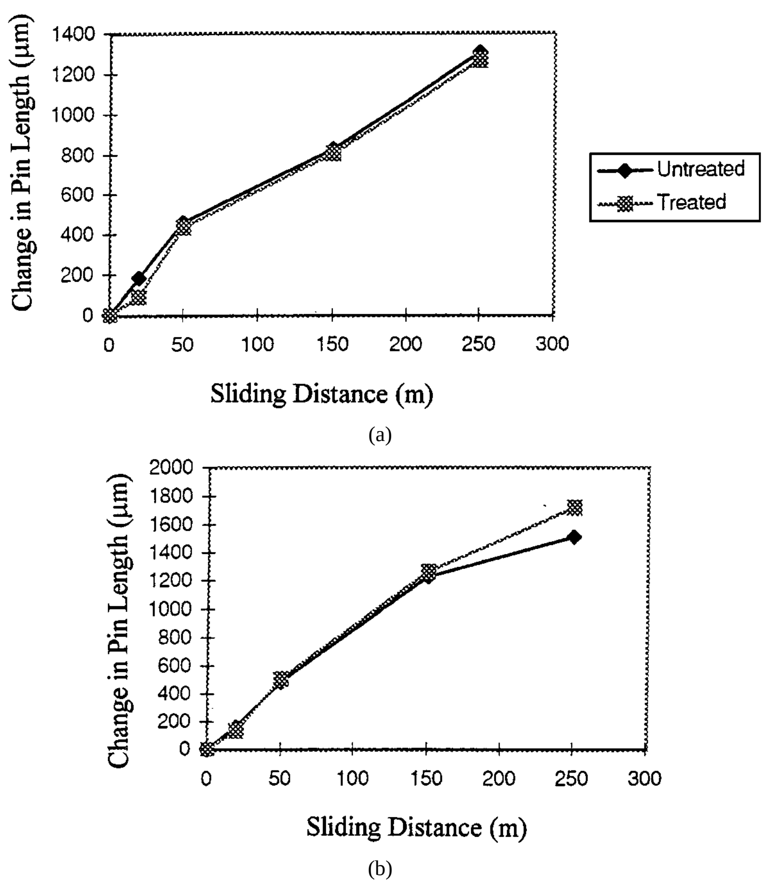


Figure 4 Wear graphs showing variation in pin length with sliding distance for a load of: (a) 50 N; (b) 75 N.

2.2. Abrasive wear test

In order to assess the affect of the modification process on the wear behaviour of the MMC, an abrasive wear test was performed using a pin-on-disc sliding test to compare untreated and treated surfaces. In these tests the aluminium composite was used as the pin and the disc consisted of a SiC 180 grit paper (mean particle size of 76 μm) which formed the abrasive counterface.

The test was performed over a range of sliding distances (25–250 m) and applied loads (10–75 N) with a constant sliding velocity set at 0.17 ms^{-1}. In order to remove debris from between the sample surface and counterface, the tests were carried out using a flow of water directed onto the disc at a rate of 500 cc/min. In addition, fresh abrasive paper was used for each test. Changes in wear behaviour were monitored by measuring the change in the length of the pin and the value for the coefficient of friction for both modified (i.e. treated) and the untreated surfaces. Both parameters were measured continuously on a chart recorder using linear voltage displacement transducers attached to the pin.

3. Results and discussion

Metallographic examination of surfaces modified by forming an aluminium-copper eutectic showed a distinct change in the distribution of SiC particles, see Fig. 1. The modification process induced the segregation of particles towards the surface of the MMC so that an increase in the number of SiC particles was observed.The depth to which segregation occurred also increased with hold time from 15 to 30 minutes.

This phenomenon was first observed by researchers studying the diffusion bonding of aluminium MMCs using copper interlayers [11, 12]. The segregation of particles is thought to occur when the eutectic melt which forms at the surface increases in width as copper diffuses into the MMC surface and engulfs the SiC particles. By continuing to hold above the eutectic temperature, particle segregation occurs as a result of particles being pushed ahead of the liquid-solid interface during isothermal solidification of the surface.

Hardness profile measurements comparing the modified surfaces with the untreated MMC are given in Fig. 2. The modified surfaces show an increase in hardness value to 329 $Hv_{0.05}$ at a depth of 50 μm below the surface. The hardness value continues to decrease to 147 $Hv_{0.05}$ at 300 μm distance below the surface. These results are consistent with the metallographic observations because high hardness values would be expected in surface regions corresponding to an increase in SiC particles.

Results from the abrasive wear tests indicate that the treated surfaces were more resistant to wear than the untreated composite, see Fig. 3a and b. When the applied load was increased to a value of 50 N the wear rate of the treated surfaces was found to be similar to that of the untreated surfaces, see Fig. 4a and b. The wear behaviour of composite surfaces is sometimes classified as either "low stress" or "high stress" abrasion. The transition from these two wear states is often determined by the applied load which at high load encourages particle fracture at a critical high load [13]. In this respect, therefore these results are in agreement with general wear behaviour of MMCs.

A comparison of the variation in the coefficient of friction (μ) with sliding distance is shown in Fig. 5. A gradual decrease in the value for μ for both the untreated and treated surfaces was a consistent feature with increasing sliding distance. This behaviour was attributed to the smoothing effect of the MMC surfaces when in contact with the abrasive paper for long sliding distances. In general, the untreated surfaces gave a higher coefficient of friction value than that obtained for treated surfaces. High surface friction is usually associated with a rough surface morphology and plastic deformation of the metal surface. In this case, the modified surfaces consist of a high concentration of closely packed hard SiC particles which offer resistance to plastic deformation and wear thereby resulting in lower values for μ. However, the untreated surfaces contain SiC particles widely dispersed in the metal matrix and therefore would be expected to suffer greater plastic deformation giving rise to a higher coefficient of friction.

The scanning electron micrographs in Fig. 6 show the worn surfaces of the MMC. The untreated surface shows evidence of plastic deformation and the "ploughing" and removal of material from the surface (Fig. 6a). This is consistent with the high coefficient of friction values recorded for the untreated surfaces. In contrast the treated surfaces show a smoother worn surface containing micro-grooves. No clear evidence for SiC particle fracture or decohesion from the matrix was found. Furthermore, because the MMC was not in the aged condition (i.e. precipitation hardening effect due to GP zones was absent) the lack of severe plastic deformation and increase in wear resistance of the modified surfaces was therefore attributed to the segregation phenomenon which resulted in a higher concentration of SiC particle at the surface.

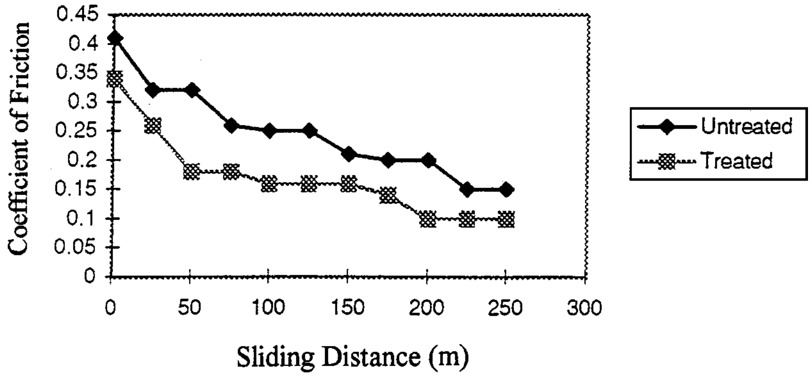
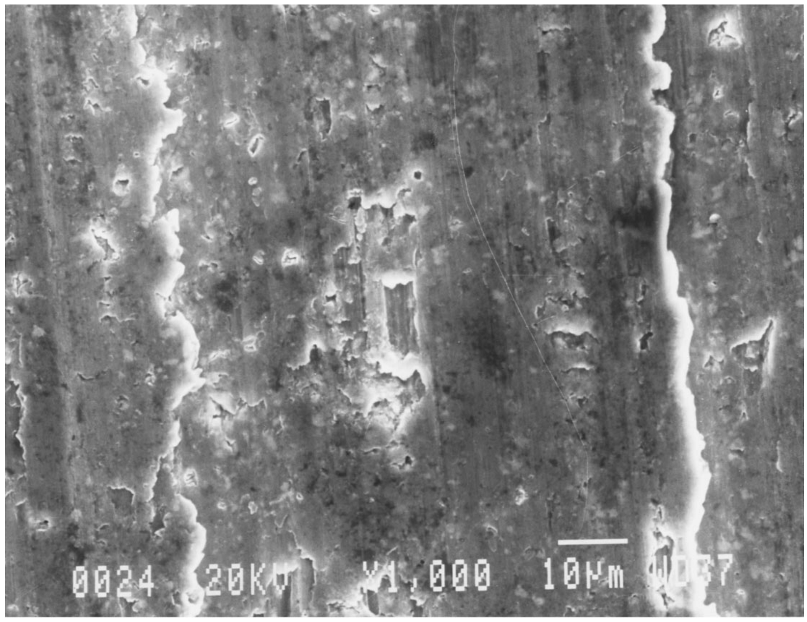
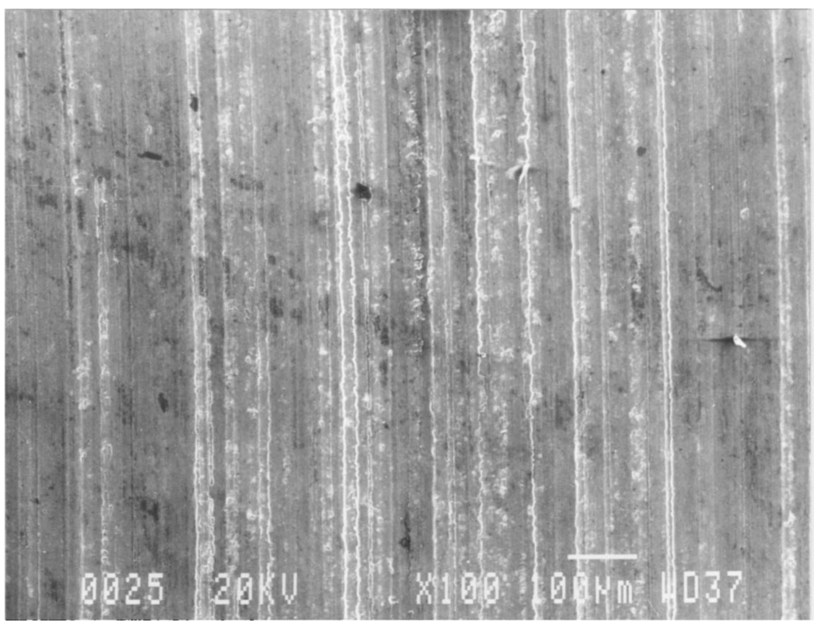


Figure 5 Graphs showing a change in the coefficient of friction with sliding distance using a load of 10 N.



(a)



(b)

Figure 6 Scanning electron micrographs showing wear surfaces of: (a) untreated; (b) treated MMC surface.

4. Conclusions

This study has shown that the distribution of SiC particles in an aluminium metal matrix composite can be altered by eutectic alloying using pure copper. When the surfaces are heat treated at a temperature above the eutectic temperature for the Al-Cu system, there is significant segregation of SiC particles to the surface of the composite. The increase in concentration of particles near the surface increases the abrasive wear resistance of the MMC and this change in wear behaviour is attributed to lower plastic deformation of the modified surfaces.

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Received 8 December 1999
and accepted 2 August 2000