Wear behaviour of A356 aluminium alloy reinforced with micron and nano size SiC particles

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Abstract

A method for producing metal matrix composites MMC was successfully implemented for mixing nano and low micron ("Hybrid") sized SiC reinforcing particles in an aluminium alloy matrix. Due to the improved specific modulus and strength, MMC's are particularly useful in the application of moving engineering parts. Tribology of these components is therefore a critical evaluation towards their service performance. Pin on disc wear behaviour of the fabricated hybrid composites under dry sliding conditions was performed. Mild steel disk was used as the wear counter-face at ambient temperature (~ 25ºC). A significant improvement in wear resistance was achieved for the MMHC. The wear mechanism was evaluated using stereo and scanning electron microscopy and found to be sliding and adhesive type of wear.

1. Introduction

The demand for lightweight materials and high mechanical performance has seen MMCs being transformed from a topic of scientific and intellectual interest to a material of broad technological and commercial significance [1, 2]. The strengthening mechanisms which operate in MMC alloys are less temperature and time dependent than those in classical particle strengthening alloys where the service temperatures and time can dramatically reduce the strength of these alloys [3].

Micron-ceramic particles are used to improve the yield and ultimate tensile strength of the matrix metal but the ductility of MMCs drops with increasing content of reinforcing particles [4]. This is due to the tendency of the "larger" particles to occupy the grain boundaries [5]. This leads to low fracture toughness, low strength and hardness at high temperatures and poor machinability [6]. The development of nano-ceramic particle reinforcements in Metal Matrix Nano Composites (MMNCs) brings the potential to influence the microstructure at the atomic level which could lead to ultra high performance materials. Liquid phase casting process of MMNCs has the ability to produce near net shape lightweight bulk components with uniform reinforcement distribution and structural integrity. The major drawback in fabrication of MMNCs has been the difficulty to obtain uniform dispersion of nano-sized ceramic particles in liquid metals due to high viscosity, poor wettability in the metal matrix and the increase of specific surface area caused by the reduction of particle size which induces agglomeration and clustering [4, 5, 6].

Hybrid powders are useful and they have been employed in reinforcing metals as the nano particles improve the strength of the composite while the micron particles enhance the wear resistance of the composite[7, 8, 9, 10]. Components reinforced in this way can thus be useful in applications where superior wear properties are required. The object of this study was to evaluate tribological properties of A356 alloy reinforced with wide range SiC particulate sizes from 100 nm to 3.0 µm, so called Metal Matrix Hybrid Composites (MMHC).

2. Experimental Procedure

The production of the MMHC was composed of two steps, grinding of micron size SiC particles to produce the hybrid nano-micron particle size distribution followed by mixing of the hybrid particles with aluminium alloy.

Hybrid particulate SiC was achieved by milling micron (3-5 µm) size SiC powder. The procedure for milling and compocasting is detailed on the study preceding the current one [7]. Castings with 15 Vol. % milled hybrid SiC particulate in A356 were produced.

Two-body abrasive pin on disk wear was carried out on automatic grinding/polishing machine. A Buehler Alpha 2 Speed Grinder-Polisher with a Vector Power Head was used to carry out the abrasive wear test. SSM HPDC A356 aluminium alloy in the as cast condition, as cast (F) MMHC and T6 heat treated MMHC, were machined into pins with a length and diameter of 20 and 8 mm respectively. The head of the pin that was to make contact with the mild steel counter-face was machined into a ball shape. Mild steel plates with a diameter and thickness of 250 and 2 mm respectively and a hardness of 135 HV10 were used for the disk. The steel plates magnetically stuck on the machine base and were further held in position by a set of steel clips to ensure they do not move during the experiments. The pin was fitted in a sample holder that was mounted on the Vector Power Head. The pin was set to rotate complimentary to the rotation of the disc. The disc speed was set to 250 rpm while the rotational speed of the pin was 60 rpm. A constant 20N load was applied pneumatically. Three samples of the A356, MMHC in F condition and MMHC in T6 conditions were tested for 5, 15 and 30 minutes, uninterrupted. There was no addition of any lubricant during the wear. A fresh plate of steel was used for each individual test.

Mass differences were measured to the fourth decimal using a Sartorious extend balance. The worn surfaces of the pins were viewed under a Stereo and Scanning Electron Microscopes.

3. Results and discussion

3.1. Mass loss

Mass losses recorded on A356 in the F condition as well as 15 % MMHC in the F and T6 conditions are shown in figure 1. Inspection of figure 1 reveals that the MMHC exhibits higher wear resistance than A356 upon wear for 5, 15 and 30 minutes. Reinforcement with 15% micron and nano sized SiC powder resulted in more than four times improvement in wear after 15 minutes while an improvement of more than 3 times is witnessed after 30 minutes. The F and T6 MMHC show a slight difference in mass losses after 5 minutes while they show the same wear resistance after 15 and 30 minutes. This may suggest that upon contact with the steel surface the heat generated on the aluminium pin surface during dry sliding wear results in over-aging of the T6 heat-treated samples.

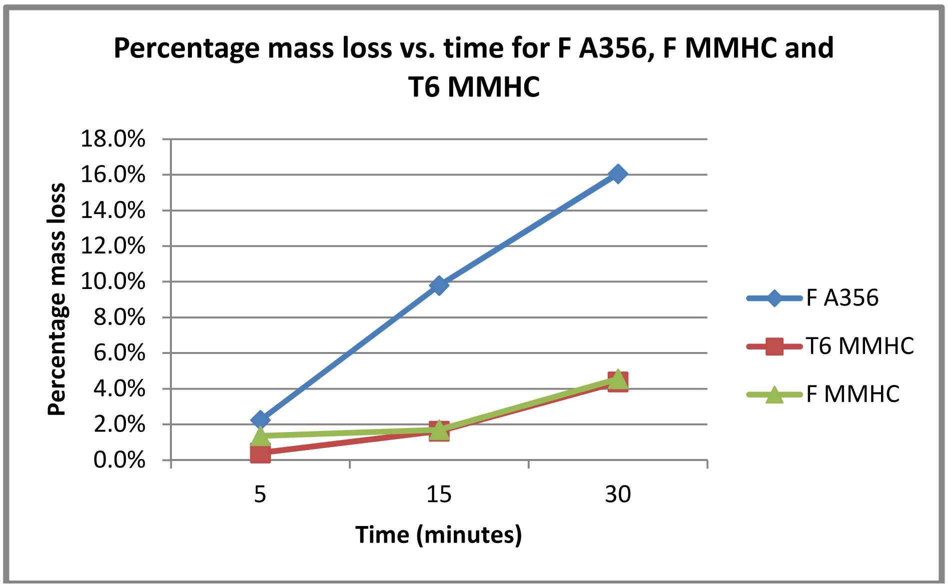

Fig. 1: Percentage mass losses for F A356, F MMHC and T6 MMHC after 5, 15 and 30 minutes of wear.

3.2 Wear Mechanism

During the wear testing experiments it was observed that during the early stages (~90 seconds) of contact between the moving pin and steel counter-face, pieces of aluminium fractured and fell off at regular intervals. This behaviour reduced as the test continued. This is not necessarily the transition between severe and mild wear. It is a combination of 2 factors, namely: smearing of aluminium onto the steel track as well as the higher force on the small surface area as the first part of the pin that makes contact with the steel is only the tip of the pin.

From the observation of smearing as well as the combination of the wearing pair (steel and aluminium) the type of wear observed is sliding adhesive wear [11]. During the test aluminium locally adheres to steel. No steel fragments are observed in the wear debris. Fragmented aluminium pieces come loose from steel, but new material fills the impression again. This effect of smearing was more pronounced for the unreinforced A356 which is more ductile than the MMHC. Stereo images (SI) (figure 2A and B) revealing the topographical features show a more ductile failure for unreinforced A356. Broader slip bands and material that constantly becomes loose with new material constantly filling is observed. For the MMHC it can be seen that the slip bands are finer and sharper resembling a less ductile mode of failure.

The presence of SiC in MMHC means that the wear mechanism will be slightly different to that of the unreinforced A356. Ceramic materials are brittle and do not undergo plastic deformation. During the wear testing ceramic debris get loose and some get crushed and get reabsorbed very firmly as a transfer film. This has an effect of reducing the ware rate significantly [11]. The removal and reattachment of SiC on the sliding pin tends to cause scarring on the worn surface as can be seen on the SEM image (figure 3A) of the T6 heat treated sample worn for 30 minutes.

The MMHC contains only 15 Vol. % SiC and therefore is still expected to undergo some plastic deformation during wear. Under cyclic deformation, a large number of dislocations gets accumulated and form a series of closely spaced slip bands also known as persistent slip bands (PSB). PSB's are zones of high cyclic slip activity [12]. Nucleation of microcracks occurs preferentially on the PSB's and during a large number of cycles these microcracks coalescence to form macrocracks which leads to spalling of the material from the interface. Microcracks are revealed as a topographical feature on the T6 heat treated sample worn for 15 minutes, figure 3B.

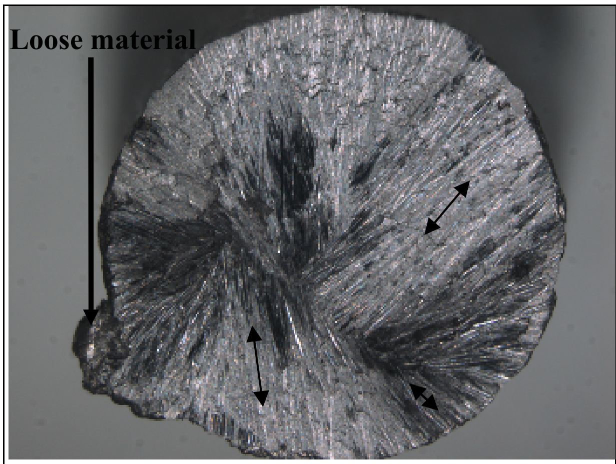

Fig.2A: Stereo image showing topographical features of the unreinforced A356 15 minute worn surface with broad slip bands in different directions (double pointed arrows) loose material.

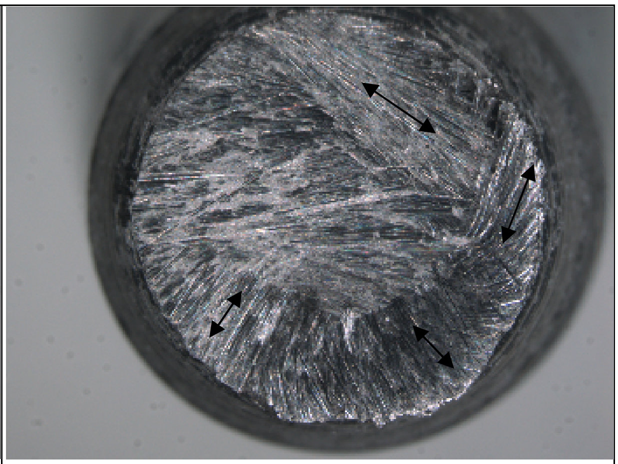

Fig. 2B: Stereo image showing topographical features of the F MMHC 15 minute worn surface with loose a number of fine slip bands (double pointed arrows) in different directions.

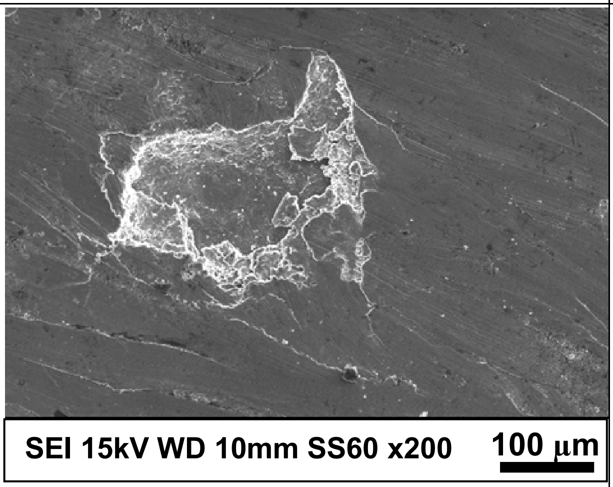

Fig. 3A: SEM image showing topographical features of T6 MMHC 30 minute worn surface with scarring of material.

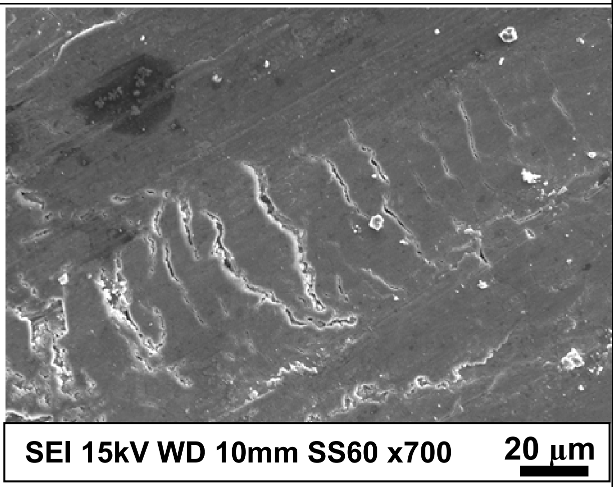

Fig. 3B: SEM image showing topographical features of T6 MMHC 15 minute worn surface with a coalescence of microcracks which will lead to spalling of material.

4. Conclusions

- 15 % Vol. SiC in A356 composite results in significantly improved wear than unreinforced A356.
- The T6 heat treatment has an impact on the wear properties only in the early stages but if the material is exposed to extended uninterrupted wear over a longer period there is no influence.
- Sliding and Adhesive type of wear was the wear mechanism between A356 and mild steel.

5. References

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