Wear Behavior of Al-SiC Metal Matrix Composite under various Corrosive Environments

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Abstract - This paper investigates the wear behavior under corrosive environments of LM6 based metal matrix composite reinforced with 5 wt% SiC prepared through the stir casting method. The experiments are carried out in a pin-on-disk tribotester varying five levels of normal load and sliding speed. The duration of each experiment is fixed for 30 minutes. Three environments viz. dry, deionised and dilute acid environments are considered to carry out the tribological tests. The composite exhibits slightly good wear resistance under low load and speed condition but weight loss increases as these parameters increases in all three environments. Maximum weight loss occurs in case of acid environment as it is more corrosive than dry and deionised environment. The wear surface of the composite is examined through the scanning electron microscopic (SEM) and energy dispersive x-ray analysis (EDX).

Keywords: Al-SiC MMCs, Corrosive Environments, Wear

1. Introduction

High performance in tribological application is one of the major needs for developing aluminium based metal matrix composites (MMCs). The MMCs acquire many advantages in comparison to monolithic materials regarding the resistance to corrosion, coefficient of thermal expansion and thermal conductivity. In general, the composites are used in many engineering applications especially in automobile industries, space, aircraft etc. [1-4]. The presences of hard reinforcement phases in the form of particulates, fibers or whiskers have enabled these matrix composites with excellent friction and wear resistance characteristics. The commonly used metallic matrixes are aluminium, magnesium, titanium and their alloys but the aluminium metal matrix composites are extensively used for many engineering situations where sliding contact is occurring and light weight is considered. Deuis et al. [5] have reviewed the wear characteristics of aluminium based composites under unlubricated (dry) condition. The effect of applied load, sliding speed and percentages of reinforcement phases are considered in their review in detail. The wear of SiC reinforced MMCs have been broadly investigated by different researchers [6-16]. From the literature study [17-19], it is found that wear resistance of MMCs basically depends on the particle size and volume fraction of SiC reinforcement. The reinforcing particle in an aluminium metal matrix composite increases the wear resistance [20-23] and...
decreases the friction coefficient. Many reinforcements materials are used but out of them silicon carbide, aluminium oxide and graphite are widely used [24-25]. Al-Rubaie et al. [26] have investigated two bodies abrasive wear of an aluminium matrix composite reinforced with 5, 10 and 20 vol. percentage of SiC particulate using a pin-on-disk experiment. Their results show that SiC particles improve the abrasion resistance and these increases with an increase in the volume fraction and size of SiC particle reinforcement. It is also shown that the value of abrasion resistance decreases with an increase in abrasive penetration depth. Lim et al. [27] have considered the tribological properties of Al-Cu metal matrix composite reinforced with a 13 vol. % SiC manufactured by rheocasting method. Rheocast samples exhibit a better wear resistance at higher loads compared to the other metal matrix composites of same composition prepared by powder metallurgy method. Ghosh et al. [28] have studied the wear behavior of Al-SiC metal matrix composite manufactured by the liquid metallurgy route by varying the weight percentage of SiC in the range of 5% - 10%. The wear tests are conducted in a multiribotester using block on roller configuration by considering the factors like weight percentage of reinforcement, applied load, sliding speed and sliding duration. From the experiment, it is concluded that SiC content, sliding speed and normal load are the important factors influencing the sliding wear in dry condition. Kalkanli and Yilmaz [29] have synthesised and characterized the aluminum alloy 7075 reinforced with silicon carbide particulates of weight fraction 10%, 15%, 20% and 30%. The composites are fabricated by vertical pressure/squeeze casting machine. From the experiment, it is concluded that the 10 wt% SiC aluminium matrix composite shows the maximum flexural strength both for the cast and heat treated samples. Mindivan et al. [30] have investigated the wear and friction behavior of squeeze cast aluminium alloy (2618, 6082, 7012 and 7075) matrix composites reinforced with 50 vol% of SiC particle. The experiment is conducted with the help of a reciprocating wear tester by rubbing a 10 mm diameter Al₂O₃ ball on the composite surfaces under dry and water condition. It is revealed that tribological properties like friction and wear are not affected by the properties of the matrix alloy under low load condition (≤3 N) but at high load (≥4.5 N) alloy matrix superiorly influences the tribological performance.

Al-SiC metal matrix composites may be used in different applications where different corrosive environments are present. From the literature review, it is seen that researchers have studied the tribological behavior of metal matrix composite mainly in dry (unlubricated) condition. In this regard, the tribological behavior under corrosive environments needs to be further explored to study the suitability of the material in the said applications. In this context, the present work aims to investigate the wear behavior of Al-SiC metal matrix composite and compare their results with dry and deionised environments. Also, attempts are made to study the micro-structure of the worn out samples.

2. Experimental details

2.1. Material
The metal matrix used in this investigation is an alloy of aluminium, LM 6 which contains 10-13 wt.% Si, 0.1 wt.% Cu, 0.1 wt.% Mg, 0.6 wt.% Fe, 0.5 wt.% Mn, 0.1 wt.% Ni, 0.1 wt.% Zn, 0.1 wt.% Pb, 0.05 wt.% Sb, 0.2 wt.% Ti and rest Al. The Silicon carbide particle with a 400 mesh size is used as the reinforcement phase, at a nominal composition of 5 wt.% Specimens are manufactured by melting the small ingots of LM6 in a clay graphite crucible using an electric resistance furnace. The SiC reinforcement is preheated to 900 °C for 2-3 hours in a box furnace before adding with molten metal. Mg is added by 3 wt. % to the mixture of molten metal in order to get the strong bonding and is stirred with the help of the mild steel impeller. When the reinforcement incorporates into the metal properly, then it is poured into a green sand mould at a temperature of 720 °C. The castings are cut and machined to prepare the desired specification of sample.

2.2. Experimental procedure
Sliding wear tests are conducted using a pin-on-disk type tribotester (TR-208-M2, Ducom, India) as shown in Figure 1 and Figure 2. The pin specimen of dimension 6 × 6 × 6 mm is fitted into the sample
holder and it slides against the alumina disk. The loads are applied to the pin through the loading lever. The friction force is measured through the sensor attached to the lever and that value is displayed on the monitor connected with the experimental set up. The tribological tests are carried out under three environments viz. dry, deionised water and acid environments (1M of sulphuric acid). Each experiment is conducted for 30 minutes. The details of the tribotester parameters along with their levels are shown in Table 1.

| Level | Load (N) | Speed (RPM) | Time (MIN) |
|-------|----------|-------------|------------|
| 1     | 10       | 20          |            |
| 2     | 30       | 60          |            |
| 3     | 50       | 100         | 30         |
| 4     | 70       | 140         |            |
| 5     | 90       | 180         |            |

3. Result and Discussions

3.1. Wear Behavior

Tribological tests are carried out under three environments viz. dry, deionised water and sulphuric acid for Al-5% SiC composites considering the different combinations of process parameters. The sliding duration is fixed for 30 minutes to conduct the experiment. The effects of weight loss with applied normal load and sliding speed are discussed in this investigation.

Variations of wear with process parameters for the Al-SiC MMC in three different environments are shown in Figure 3-7. From Figure 3, it is observed that at low speed (0.04 m/s) weight loss increases up to 30 N and after that it remains stable for dry condition. In case of the dry condition, the debris particles produce rolling effect and that may reduce the weight loss. For deionised water environment, in general wear loss increases continuously as load increases for all speed conditions. Also, in sulphuric acid medium, wear loss increases as the the applied normal load increases for all speeds.

It is observed that the wear rate increases as the load increases for all the environments. Since the applied normal load increases, it is expected that the weight loss will also be increased. But out of
In three environments, the sulphuric acid environment has the maximum weight loss. This is because the acid environment produces corrosive effects at the contact surface. This may be explained by the fact that corrosion resistance in the case of Al-SiC MMC depends on the presence of transfer layers at its interacting surfaces. These layers may consist of a few atoms of thickness, resulting from the interaction between contacting surfaces and surrounding corrosive environments. It forms oxides, solid precipitates, absorbed layers or passive surface films. Basically, the thick oxide layer and transfer films act as a protective layer by isolating the two contact surfaces. This may be the main reason for dry condition showing the low weight loss. But in case of acid environment, both mechanical action and chemical effect break the oxide layer continuously which may be the reason of maximum weight loss.

Figure 3. Weight loss in different environment with increase in load at 0.04 m/s sliding speed.

Figure 4. Variation of weight loss w.r.t normal load in different environment at 0.12 m/s sliding speed.

Figure 5. Weight loss in different environment with increase in load at 0.2 m/s sliding speed.

Figure 6. Variation of weight loss w.r.t normal load in different environment at 0.28 m/s sliding speed.
Figure 7. Variations of weight loss w.r.t normal load in different environment at 0.36 m/s sliding speed.

Figure 8. SEM image and corresponding EDX in dry condition under 50 N load and 0.2 m/s

3.2 Micro structural characterization of wear surface

The microstructure of pin sample has been analyzed by taking SEM and EDX images of worn surfaces. The microscopic study as shown in Figure 8, Figure 9 and Figure 10, suggests that SiC shows a good wear resistance in case of dry and deionised water environment, but it fails to resist wear when it comes in contact with corrosive environment. From Figure 10 (EDX image), the oxygen weight percentage is 24.34 while in Figure 8 and Figure 9, the oxygen weight percentage is much higher than this value. So it reveals that an oxide layer is formed in case of dry and deionised environment which protects the material loss. But the chemical actions of acid environment cleanse the oxide layer from the contact surface which may be the key reason for a maximum material loss for this environment. So from the SEM and EDX analysis, it can be concluded that a higher material loss occurs due to the combined effect of mechanical action and chemical reaction in the case of the corrosive environment.
Figure 9. SEM image and corresponding EDX in deionised water environment under 50 N load and 0.2 m/s

Figure 10: SEM image and corresponding EDX in acid environment under 50 N load and 0.2 m/s

4. Conclusion:
In the present study Al-5%SiC metal metal matric composite materials are prepared and the wear characteristics of the composite under three mediums viz. dry, deionized and sulphuric acid are evaluated. Also, the results of wear in sulphuric acid environment are compared with the dry and deionised water results. From the results, it can be concluded that as load increases, the weight loss increases for all mediums. Comparing three environments, in the sulphuric acid environment, wear loss is the maximum followed by deionised water and dry condition. From the EDX analysis, it can be concluded that an oxide layer plays the key role in wear loss which acts as a protective layer in case of dry and deionized water environments but fails to protect in sulphuric acid environment. From the microstructure study by the scanning electron microscopy of the worn surfaces, it reveals that both adhesive and abrasive wears are encountered.

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