

Effects of SiC_p Reinforcement on the Abrasive Wear Properties of Al-Si Alloy

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Abstract—In the present investigation, an attempt has been made to analyze the high stress abrasive wear response of a SiC particle reinforced Al-Si alloy. The wear test were conducted on a Pin on Disc machine at linear velocity of 1.26 m/s the applied load range of 1-7 N while the abrasive platform used is 600 grit emery paper. To examine the influence of the SiC particle dispersion matrix alloy was also characterized under similar condition. The wear rate and coefficient of friction decreases with abrading distance while a reverse trend was observed. In case of frictional heating which gradually increases with the abrading distance. Incorporation of SiC improves the wear resistance of the matrix alloy and increasing the percentage of SiC increases the frictional heating and reduces the friction coefficient of the test material.

Keywords: AMMCs, SiC particulate, Stir Casting, Abrasive wear, Pin on disc machine, SEM.

I. INTRODUCTION

Aluminium alloys because of their ease of processing and light weight have wide range of applications such as aerospace, automobile and other engineering sectors. A combination of hard dispersoid is such as Al₂O₃, SiC, B₄C etc. in Al-alloys increases stiffness and strength but decrease ductility. The synthesis and characterization of aluminium matrix composites (AMCs) requires significant attention among MMCs and poor machinability is one of major disadvantage of AMCs [1-5]. Because of hard dispersoid causing great damage to the machining tools.

Various types of ceramic materials such as silicon carbide, zircon, alumina etc. have been used as dispersoid for synthesis composites [6-29] and few research has been made to natural minerals such as granite, corundum, sillimanite, etc. for making aluminium alloy & its composite, though these natural minerals have numerous capacity for using as reinforcement [30-36]. Because of excellent higher stiffness as well as wear resistance.

A lot of researches have mostly used aluminium alloys are LM2, LM6, LM13 & LM25 and other variety of series Al-1100, 2011, 2014, 2024, 2124, 6061, 7075 on two body (high stress) abrasive wear. Excluding these, within the series of aluminium alloys restricted work has been done on two body (high stress) abrasive wear [37]. During this context Al-Si alloys form a noteworthy series of the alloy system. Their composites containing hard particles are receiving importance. These materials have properties like high specific strength, high specific stiffness, better wear and seizure resistance as well as improved high temperature performance [38].

Abrasive wear is plowing of localized surface contacts by a harder material [39]. Abrasive wear mainly happens in non-metallic and metallic particles but abrasive wear mostly affected on non-metallic particles. Abrasive wear is divided into three types namely low stress (three body), high stress (two body) and gouging. Low stress abrasion has light rubbing activity of abrasive particles along with the metal surface which are the reasons of scratches and there is no work hardening. High stress abrasion is due to high stress which results in additional work hardening. Various examples of abrasion caused are in, pivots, gears, cams and rolling-contact bearings. Gouging abrasion occurs due to high stress that creates gouges or grooves on the affected surface. Some examples where it may be seen are parts of impact hammers in pulverisers, crusher liners etc.

The objective of this study was to investigate the two body abrasive wear behavior of an Al-Si alloy (BS:LM2) and its composite reinforced with 10 & 15 wt% SiC particles under the influence of varying applied loads and abrading distance.

II. EXPERIMENTAL

A. Material Preparation

Al-Si based matrix alloy and composite were prepared by liquid metallurgy route using graphite crucibles for melting. The composites were fabricated by incorporating 10 wt % and 15 wt% of 50-100µm Silicon Carbide particles on the vortex of the melt of the matrix alloy. The SiC particles were preheated in ambient air at 600°C for 2 hours prior to in the alloy melt. Mechanical stirrer rotating at a speed of 600 rpm was used for creating the Vortex. SiC particles were dispersed in the melt at 800°C while the pouring temperature was 850°C. Cast iron moulds were used for the solidifying of the alloy and composites. The moulds were also preheated to around 200°C before pouring the melts. All the castings were made in the form of finger (Length: 170 mm, diameter: 16 mm). Table 1 shows the chemical compositions of the sample materials.

B. Microstructural Examination

Microstructural studies were carried out on 15 mm thick & 10 mm diameter of samples. The samples were polished metallographically and etched suitably. Keller’s reagent was used for etching the samples of the aluminium (matrix) alloy and composite. Microstructural characterization of the samples was conducted on using scanning electron microscopy.

C. Measurement of Physical and Mechanical Property

Hardness measurements were performed on metallographically polished samples using a Vickers hardness tester. The applied load in this case was 294 N. Density of the samples was determined by water displacement technique. For weighing the samples a Mettler microbalance with a precision level of 0.01 mg was used in water and air. An average of five observation has been taken Tension test were conducted on 10 mm diameter, 50 mm G.L. specimens as per IS 1608. The tests were performed at room temperature using Instron make computerized tension testing machine. The strain rate or cross head speed used was 0.5 mm/min.

TABLE I Chemical Composition of the Test Materials

Elements	Elements, wt%							
	Si	Mn	Mg	Cu	Fe	Ni	Al	SiC
Al-Si Alloy	10.29	0.12	0.47	1.98	0.75	0.80	Balance	-
Alloy + 10wt% SiC Composite	10.29	0.12	0.47	1.98	0.75	0.80	Balance	10
Alloy + 15wt% SiC Composite	10.29	0.12	0.47	1.98	0.75	0.80	Balance	15

D. Abrasive Wear Test

High-stress abrasive wear tests will be conducted on 30mm long and 10 mm diameter cylindrical samples using a pin on-disc apparatus. Diagrammatic representations of the wear test apparatus and the test configuration are shown in fig. a & b, respectively. A polishing/emery paper having SiC abrasive particles (18µm) firmly bonded on a strong paper base will be used as abrasive medium in this study. The abrasive medium will be firmly put in position on the disc of the machine. The sample will be held against the rotating abrasive medium with the help of a specimen holder. Load on the sample applied through a cantilever mechanism with the assistance of dead weights. The traversal distance, track radius load and rotational speed of the disc was varied according to our need. The applied loads in this case were 1, 3, 5 & 7N while the track diameters adopted were 8 cm which enabled the rotational speeds of 300 to attain linear sliding velocities of 1.26 m/s. The specimens were tested for 1.20, 2.40, 4 and 5.20 minutes to cover the distance 100, 200, 300 and 400 m respectively. The samples polished metallographically, cleaned with acetone and weighed using the previously mentioned microbalance prior to testing. The tested samples were once again cleaned with acetone and weight loss taken at continuous interval. Friction force was measured using a load cell/force transducer placed to make contact with the rear end of the lever arm during the tests; the other end of the lever will be connected with the sample in the holder. The friction force was examine on a digital meter fixed with the controller and display unit of the test set up connected with the load cell. The measured friction force will be then converted into friction coefficient. Temperature at a distance of 1.5mm from the contacting surface of the specimen was also monitored during the tests by inserting a chromel–alumel thermocouple in a 1.5mm diameter hole made therein. An average of three observations will be considered in this study.

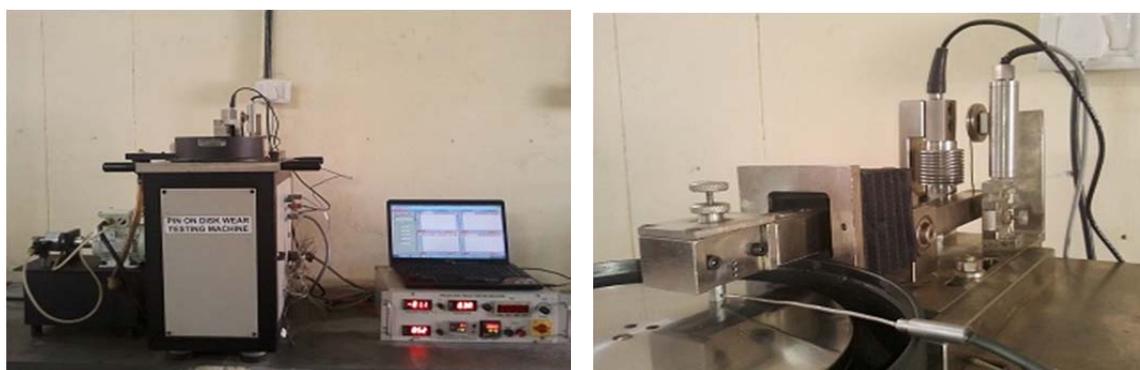


Fig. 1. (a) Schematic diagram of the wear testing machine (b) Magnified view of Pin-Disc Test Assembly

III. RESULTS

A. Microstructure

Microstructure of matrix Alloy shows aluminium dendrites and eutectic silicon solidifying in interdendritic region and around dendrites. Micrograph of 10% SiC reinforced composite shows secondary aluminium dendrites eutectic silicon in the dendritic spacing and around the dendrites and distribution of SiC particles in the matrix. Micrograph of 15% SiC reinforced composite shows interphase of SiC particle and aluminium silicon alloy matrix and segregation of eutectic silicon at the interphase. The SiC particles are noted to be uniformly distributed within the metallic matrix and these particles are trapped within the primary aluminium dendrites rather than of interdendritic region (figure 2).

B. Hardness, Density and Tensile Strength

Table 2 represents various properties of the specimens. The composites attain higher density and hardness than the matrix alloy and both the properties are increased with increase in SiC content. Further, incorporation of SiC particles in to the matrix alloy reduces their tensile strength and the rate of decrement increases with the increase in SiC content.

Table II Hardness and Density of Specimen

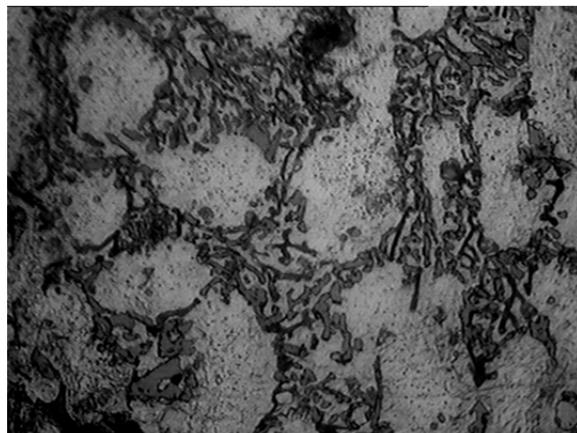
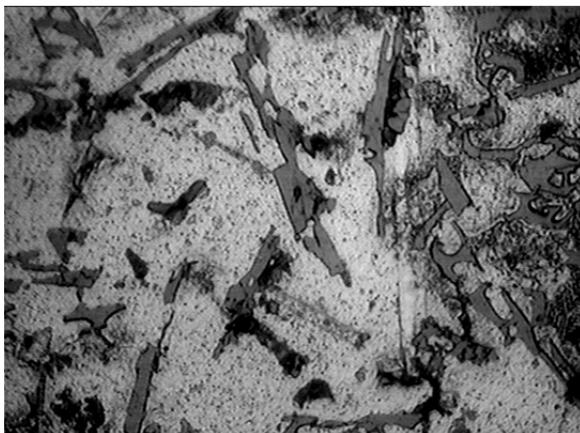
Type	Vickers Hardness (HV)	Density g/cm ³	Tensile Strength (MPa)
Matrix Alloy	92.3	2.64	152.1
Matrix Alloy + 10% SiC Composite	98.7	2.78	124.3
Matrix Alloy + 15% SiC Composite	107.1	2.79	119.7

C. Wear Behaviour

1) *Wear rate:* Wear rate of the specimens has been plotted as a function of abrading distance at an applied load of 1N and 7N for different test materials are shown in figure 3. The wear rate decreases with the increase in abrading distance for all the test materials and at all the loading conditions. It is observed that wear rate is maximum for the matrix alloy and addition of SiC into the matrix alloy reduces their rate also the rate of reduction of wear rate increases with the increase SiC content. Abrasive wear loss of the test materials plotted as a function of applied load at an abrading distance of 400 metres is shown in figure 4. Moreover the tendency of wear increases with the increase in applied load of all the test materials however the slope of increment is maximum for the base alloy and maximum for the 15% SiC reinforced composite while 10% SiC reinforced composite revealed immediate response.

2) *Frictional Heating:* Temperature near the contact surface for matrix Alloy, 10% SiC and 15% SiC composite at an applied load of 1N and 7N plotted as a function of abrading distance is shown in figure 5. The temperature rises linearly with the test duration and the maximum frictional heating is attained by 15% SiC Composite followed by 10% SiC and matrix Alloy. As far as the effect of load on the frictional heating is concerned, the temperature increases with the increase in applied load irrespective of the test material however the severity of increase is maximum for 15% SiC composite and minimum for the matrix Alloy (Figure 6).

3) *Friction coefficient:* Figure 7 represents friction coefficient for matrix Alloy, 10% SiC and 15% SiC composite as function of abrading distance at an applied load of 1N and 7N. The friction coefficient decreases with the increase in test duration for all the test material and it is observed that the friction coefficient is maximum for matrix Alloy followed by 10% SiC and 15% SiC composite, however an increase in load increases the friction coefficient and the maximum increase is obtained for matrix alloy and minimum for 15% SiC composite while 10% SiC composite revealed intermediate behaviour (Figure 8).



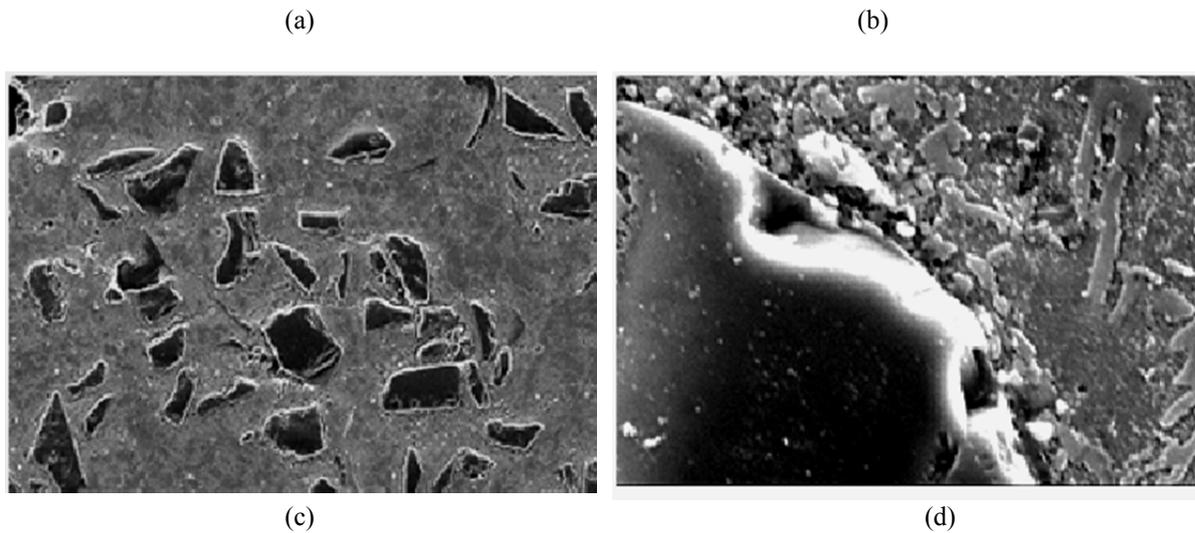


Fig. 2. Microstructure of Matrix Alloy (a), 10wt% SiC Composite (b), 15 wt% SiC composite(c) and higher magnification micrograph of 15 wt% SiC composite showing interphase of matrix alloy and SiC particle (d)

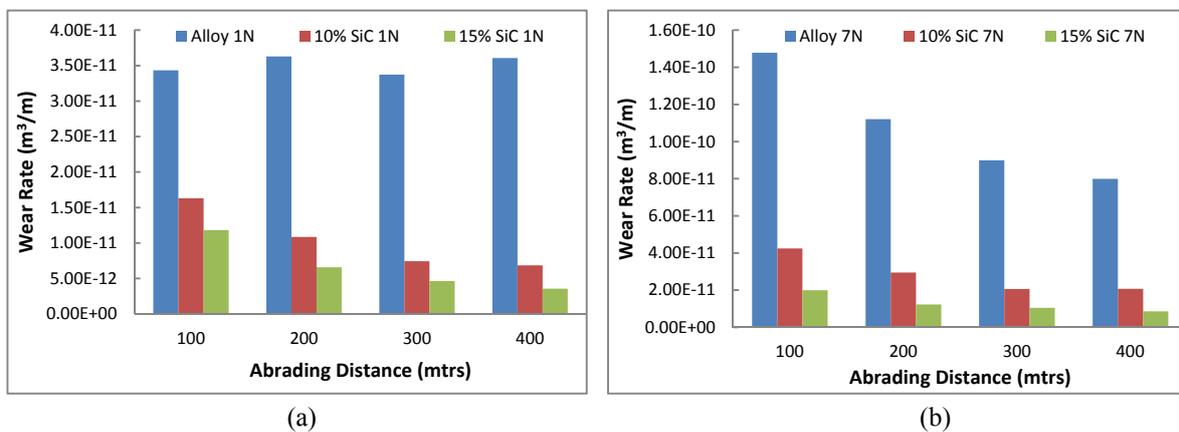


Fig. 3. Abrasive wear loss of the test materials plotted as a function of abrading distance at an applied load of 1 N (a) and 7 N (b).

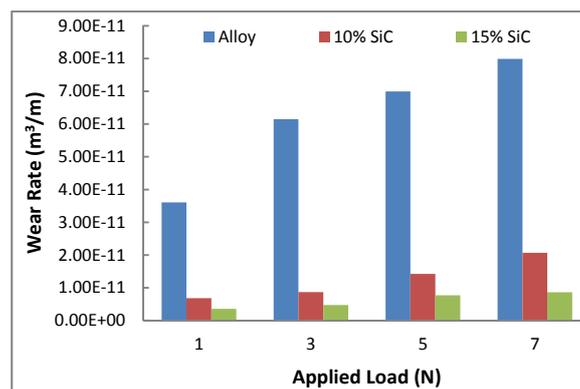


Fig. 4. Abrasive wear loss of the test materials plotted as a function of applied load at an abrading distance of 400 metres.

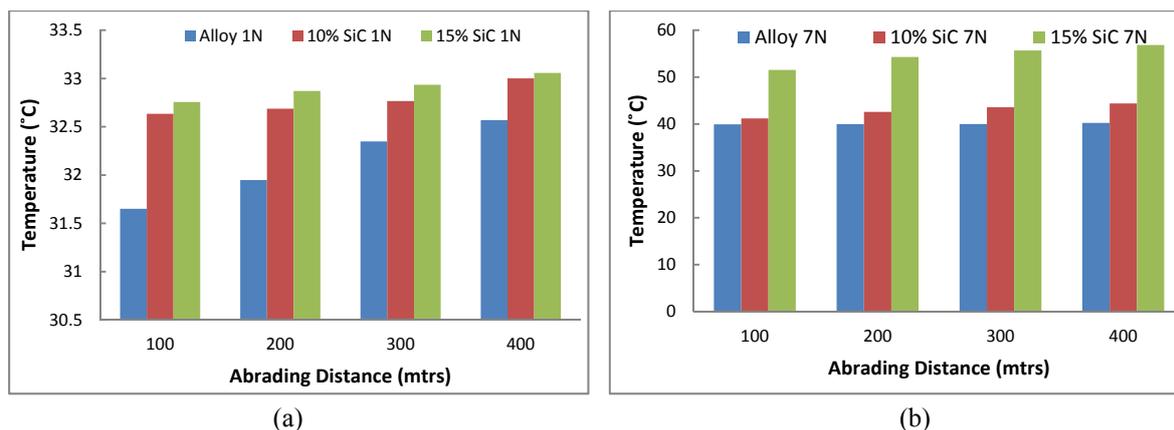


Fig. 5. Frictional Heating of the samples plotted as a function of Abrading Distance at the applied load of 1 N (a) and 7 N (b)

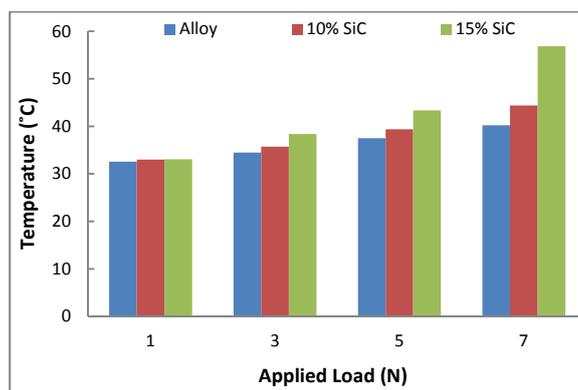


Fig. 6. Frictional Heating of the samples plotted as a function of applied load at an abrading distance of 400 metres

IV. DISCUSSION

From Microstructural point of view, the Al-Si alloy contains plate shaped eutectic silicon and the other intermetallic phases. As the ambient temperature solid solubility of Silicon in Aluminium is negligible the eutectic structure contains Aluminium and Silicon. SiC reinforced composite shows secondary Al dendrites eutectic si in the dendritic spacing and around the dendrites. The SiC particles are noted to be uniformly distributed within the metallic matrix and these particles are trapped within the primary aluminium dendrites rather than of interdendritic region.

The matrix alloys attains lower hardness and the hardness increases with increase in SiC content. This is due to the fact that the volume fraction of relatively higher harder phase increases in the matrix alloy. As far as tensile strength is concerned, the matrix alloy attains higher tensile strength and addition of SiC particles in the matrix slightly reduces the tensile strength this is because of the fact that SiC particles are generally ceramic in nature and the bonding between Si and Al is very week like vanderwall bonding. At the temperature of processing of composite materials Al and SiC does not react together and thus there is no possibility of forming interface products. During tensile stress there is decohesion at particle matrix interface and which results into void formation. The probability of void formation is high in the case of coarse particles (50-100 μm) in Aluminium matrix thereby decreasing the tensile strength in case of composite materials.

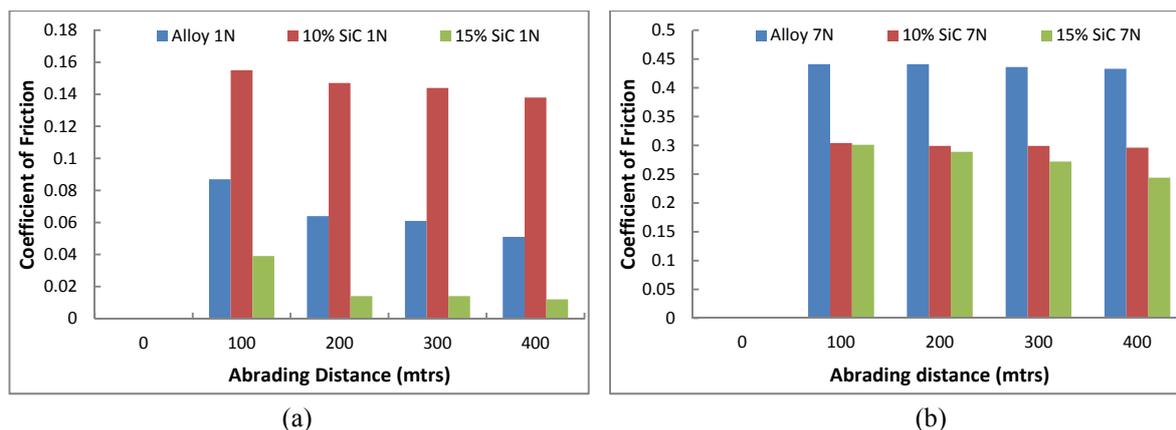


Fig. 7. Friction coefficient of the samples plotted as a function of Abrading Distance at the applied load of 1 N (a) and 7 N (b).

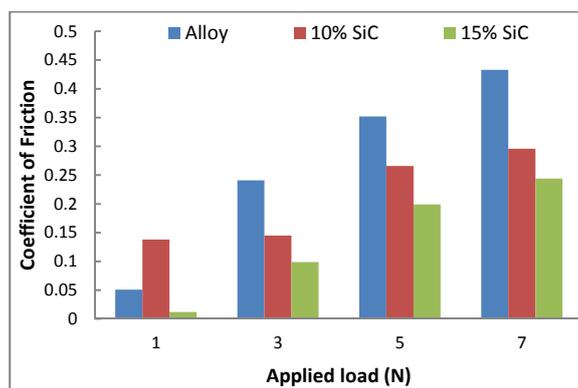


Fig. 8. Friction coefficient of the samples plotted as a function of applied load at an abrading distance of 400 metres

The abrasive wear is associated with the penetration of the hard rigid abrasives and subsequent scratching of the specimen surface by the penetrated abrasives. The scratching of the abrasives leads to the continuous groove marks. The depth of penetration (i.e., the width and the depth grooves) depends on applied load and relative hardness of the abrasive with respect to the specimen surface hardness. As the hardness of the composite is higher than that of the alloy, it is expected that the depth of penetration of the abrasive in the composite surface is less as compared to the alloy. Additionally, SiC particles on the composite surface act as protrusions, which carry the major portion of the applied load and this helps in protecting the matrix alloy from severe contact of abrasives. As a result, relatively less material is removed from the composite surface as compared to the alloy due to cutting or plowing action. The wear resistance of the composite also depends to a significant extent on the interfacial bonding between SiC and the matrix alloy and the fracturing tendency of SiC particles. It is reported by several earlier studies that the composite is superior to the alloy (as far as wear resistance is concerned) provided the bonding is strong enough to hold the particle on the wear surface intact and the hard ceramic particles are not fractured or fragmented. Important events during abrasion of the samples as far as the abrasive particles are concerned include capping, clogging, shelling and attrition. Especially attrition becomes quite effective in reducing the abrasion rate when the same abrasive comes in contact with the specimen surface in a cyclic manner. Interaction with relatively sharper abrasive particles in the starting of the tests could lead to higher rate of increase in wear rate and temperature. As the test duration increases to sufficiently dull the abrasive particles, the rate of increase is reduced.

Highest friction coefficient and frictional heating of the most ductile matrix alloy could be due to a larger depth of penetration of the abrasive particles on the samples. A reduction in the severity of penetration due to the hard SiC reinforcement in the alloy matrix caused the friction coefficient and frictional heating of the composite to decrease on the contrary to that of the matrix alloy. Higher wear rate, friction coefficient and frictional heating with increasing load may be attributed to a larger depth of penetration by the abrasive particles on the specimen surface. The friction coefficient in turn appears to have predominantly been controlled by the factors like capping, clogging, shelling and attrition of the abrasive particles leading to a decrease in their cutting efficiency/depth of penetration and hence a reduction in friction coefficient of the samples with test duration.

V. CONCLUSION

Microstructure of matrix Alloy shows aluminium dendrites and eutectic silicon solidifying in interdendritic region and around dendrites. The composite under shows similar behaviour to those of the base alloy except the additional presence of the reinforced SiC particles.

Incorporation of SiC particles reduces the density but increases the hardness of the base alloy.

The wear rate decreases with the increase in abrading distance for all the test materials and at all the loading conditions. Dispersion of SiC particles reduces the wear rate. Increment in the applied load increases the wear for all the test material however the slope of increase is maximum for the base alloy followed by 5% and 10% SiC.

The temperature rises linearly with the test duration and 10% SiC reinforced composite attained maximum frictional heating followed by 5% SiC reinforced composite and Matrix alloy. Increase in applied load increases the temperature irrespective of the test material however the severity of increase is maximum for 10% SiC composite and minimum for the Matrix Alloy.

The friction coefficient decreases with the increase in test duration for all the test material and maximum friction coefficient is observed for Matrix Alloy followed by 5% SiC and 10% SiC reinforced composite, increases in load increases the friction coefficient and the maximum increase is obtained for matrix Alloy and minimum for 10% SiC reinforced composite while 5% SiC reinforced composite revealed intermediate behaviour.

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