EVALUATION OF WEAR BEHAVIOR OF Al-Si ALLOY USING SiC AS THE REINFORCEMENT

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Resume

The current study investigates the wear behavior of the SiC particles reinforced Al-Si alloy composites developed using the stir casting process. The results were obtained from the wear tests of the cast Al-Si alloy and prepared SiC reinforcement composites containing 3 % wt and 9 % wt using fine and coarse size SiC particles. The wear test of all the developed composites were done at different testing conditions with varying loads. The analysis of wear traces, as well as the wear debris, was done at every composition but at higher loads. It was observed that the wear resistance was improved with increasing the amount as well as decreasing the size of the SiC particles. However, the wear rate of the composites increases with increasing the applied load. From the microstructural study of specimen after the wear test one can conclude that both adhesive and abrasive wear mechanisms contribute for wear of SiC particle composites.

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1. Introduction

The investigation of friction and wear caught the attention of many scientists during the course of the last few decades, however, consistent and sustained scientific investigation into friction and wear is a relatively recent phenomenon. The concept of developing special materials and coatings to overcome friction and wear problems is becoming a reality. Composites are the class of material that evolved with the existence of nature. Nature inspires the today's composite advancement in the field of aeronautical, aerospace, automotive and structural sector. Composites are engineered materials that have been designed to provide significantly higher specific stiffness and specific strength i.e. higher structural efficiency relative to previously available structural materials. As a common practical definition, composite materials may be restricted to emphasize those materials that contain a continuous matrix constituent that binds together and provides form to an array of a stronger, stiffer reinforcement constituent. The resulting composite material has a balance of structural properties that is superior to either constituent material alone [1]. Reinforced concrete is an excellent example of a composite structure in which the concrete and steel still retain their identities.

Das et al. [2] proposed that some of the aluminum alloys exhibit wide range of properties but lacks in tribological properties, which limits its use to certain applications. Das et al. [3] have developed an aluminum matrix composite with reinforcement of hard particles that is the widely used option for enhancing tribological properties as compared to other techniques, in terms of ease and economics involved along with the achievement of desired properties.

2. Experimentation

In the present work, aluminum alloy was chosen as the matrix material due to its light

Table 1

Nominal (NCC) and actual (ACC) chemical composition of the aluminum alloy.

Elements	Si	Fe	Cu	Mn	Mg	Zn	Ni	Al
NCC	10-12	1	0.7-1.4	0.5	0.8-1.5	0.2-0.5	1.0-1.5	Bal.
ACC	11.8	0.6	1.1	---	1.3	0.2	1.3	Bal.

weight with good corrosion resistance. SiC has been used as the reinforcement material because of high hardness, high modulus of elasticity with good thermal stability. The chemical composition of the aluminum alloy is presented in Table 1.

Effect of the reinforced SiC particle size on the wear behavior of the composites is monitored in the present work. For this purpose two ranges of sizes were selected for the reinforcement: fine size and coarse size.

In the present investigation, stir casting technique is used for the development of the composite. This process involves the mixing of the particles into aluminum melt with the help of the stirrer and then allows the material to solidify in the mold at the normal environmental conditions [4]. Afterwards, the melt was transferred to the metal mold of cast iron of dimension 0.1×0.1×0.05 m and then allowed to solidify at room temperature. The samples were prepared by using SiC reinforcement of 3 %, and 9 % (by weight) with fine and coarse particles.

3. Characterization

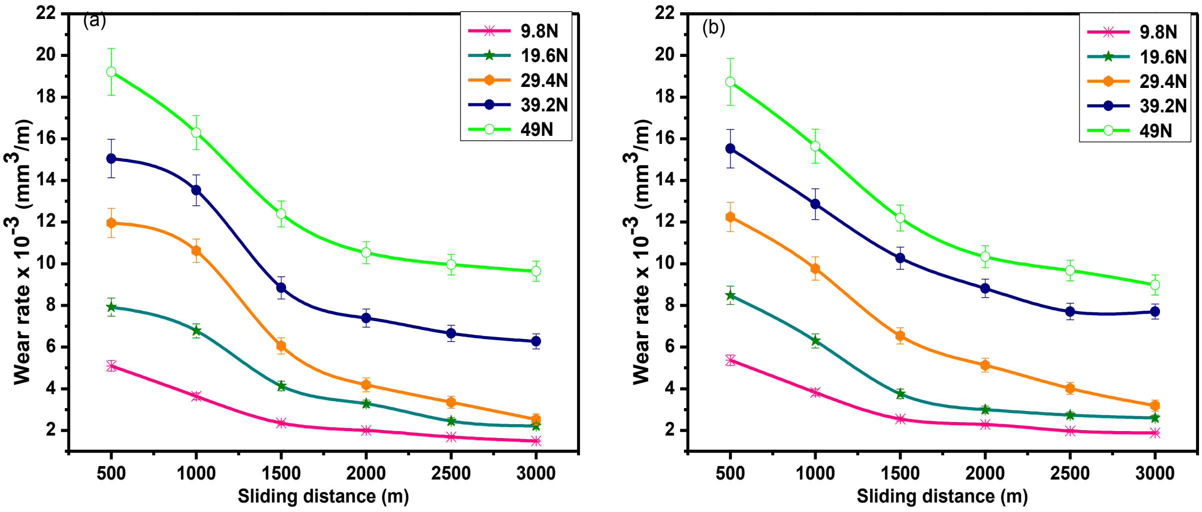
The dry sliding wear test, using the pin-on-disc method, was done to study the wear behavior of the prepared composite. The samples of the cast composite were machined to 8 mm diameter cylindrical pins and the wear tests were performed on pin on disc under the dry sliding conditions in ambient air at controlled temperature. The wear tests were conducted at different loads (9.8 N, 19.6 N, 29.4 N, 39.2 N and 49 N). All the aluminum composite samples were tested against EN32 steel disc having 65HRC hardness. Average value of the wear rate was calculated bases on three observations by taking run three times. Before each test, the track was properly cleaned with acetone. All the wear tests were conducted on the new wear tracks in order to get similar test conditions. A constant sliding velocity of 1.75 m s^{-1} was maintained throughout the experiment and sliding distance covered during the experiment was about 3000 meters.

4. Results and Discussion

4.1 Effect of load on the wear behavior

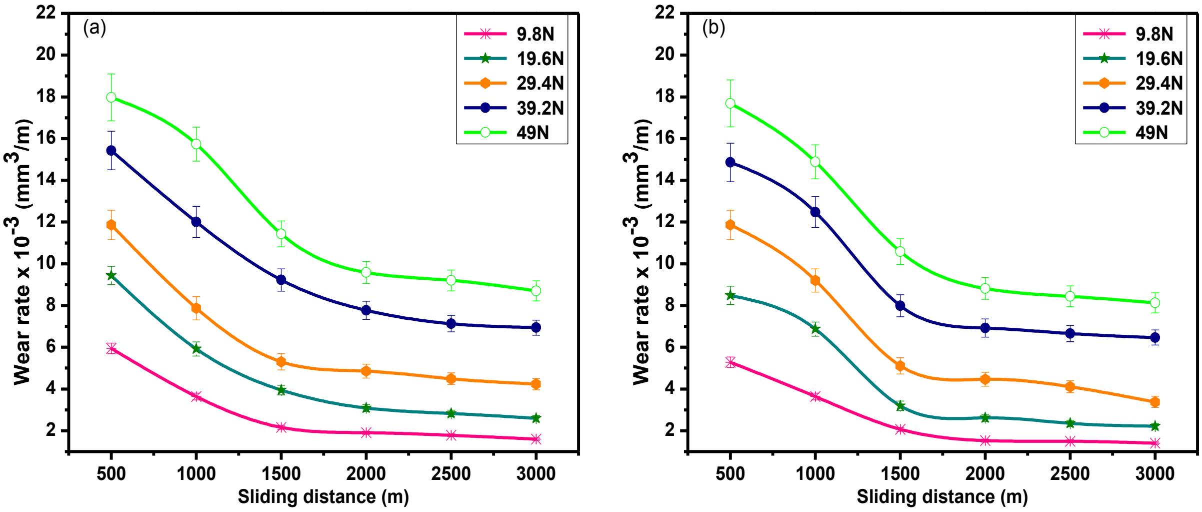
Figs. 1 and 2 shows the variation of wear rate with sliding distance at different applied loads for the composites having 3 and 9 wt. % of fine and coarse size SiC particles, respectively. The wear rate of 3 wt. % fine and coarse size reinforced composite, as a function of sliding distance at variable loads from 9.8 N to 49 N is shown in Fig. 1a-b. The wear rate in the composites is observed to increase with increasing load. However, the 3 wt. % fine size reinforced composite (Fig. 1a) shows a minimum wear rate. In the initial stages of run, the abrasive wear between the two surfaces in relative motion is dominant. The abrasive wear is controlled by the asperity to asperity contact of the two surfaces. The pin specimen of the composite and the hard steel counter surface contains large asperities of different height, shape and sharpness [5].

Some of the protruded asperities of the hard surface may penetrate into the softer pin. Subsequent sliding due to the reciprocating motion leads to the removal of material. The abrasive wear is accompanied by the formation of thin and shallow grooves on the specimen. So the initial stages of run have shown very heavy wear loss due to the statistical fluctuations in wear. The continuous grinding of these abrasive particles while sliding reduces the sharpness of the asperities. These blunt



a) fine size reinforced *b) coarse size reinforced*

Fig. 1. The wear rate of composites against sliding distance at different loads for 3 wt. %.
(full colour version available online)



a) fine size reinforced *b) coarse size reinforced*

Fig. 2. The wear rate of composites against sliding distance at different loads for 9 wt. %.
(full colour version available online)

shaped smooth abrasives cause fall in the wear loss and the steady state is attained. The similar type of wear behavior is also observed by Chaudhary et al. [6] and Onat [7]. The continuous increase in the wear rate isobserved in all the composites with the increase in load from 9.8 N to 49 N. Application of the high load causes huge removal of material, which may be explained based on plastic deformation. The oxide film, which acts as a cover envelope to the metal surface, breaks during the dry sliding, thus bringing the surfaces in contact.

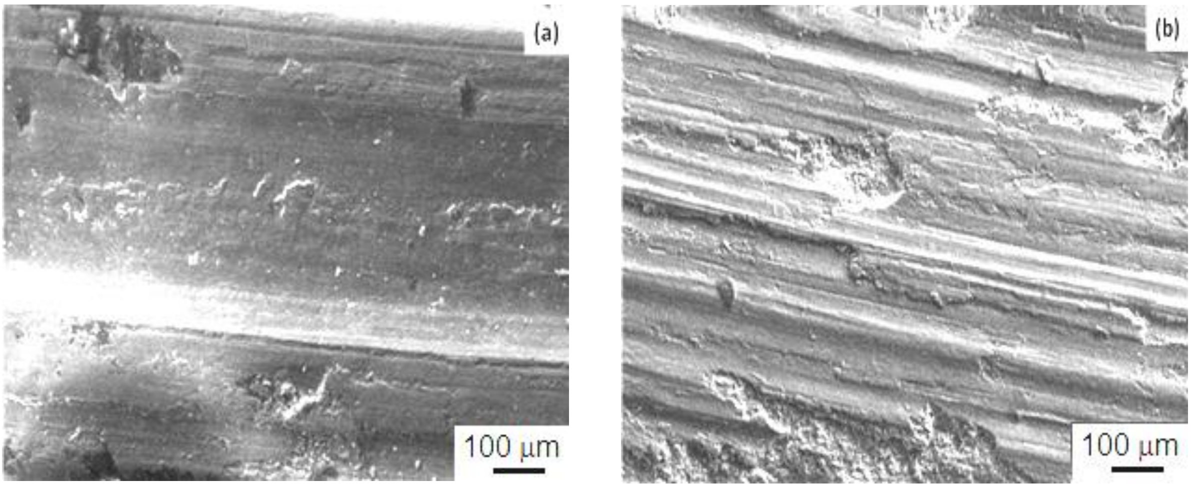
On increasing the amount of SiC particles in the composite from 3 to 9 wt. % further reduction in wear rate is observed as shown in Fig. 2a-b. Improvement of the wear resistance with increasing the amount of SiC particles from 3 wt. % to 9 wt. % was observed at all applied loads.

The high wear rate of the material during the run in wear stage was observed for the 9 wt. % coarse size SiC particles composite because the coarse size SiC particles have smaller surface area as compared to the fine size SiC particle inside the composites. The large surface area of fine size SiC particles increases the interfacial area [5]. This, in turn, increases the brittleness and enhances the hardness of the 9 wt. % SiC particles composite. The improvement in wear resistance can be attributed to the increased hard SiC particle addition, which restricts the damage from the abrasives of the counter surface, which is evident from the graph even at higher applied loads of 49 N.

4.2 Analysis of wear traces at applied peak loads

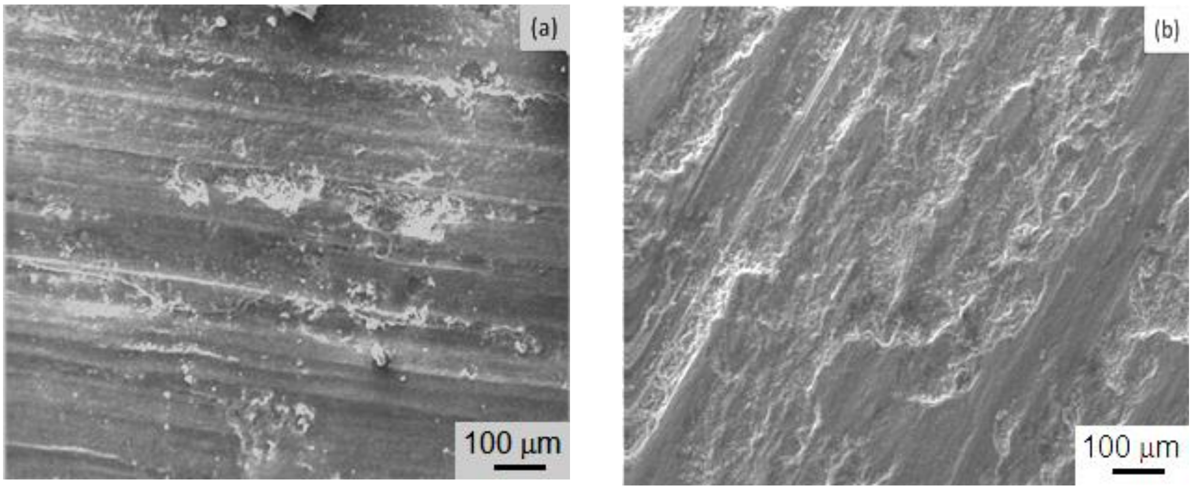
The removal of the material from the contacting surface during the dry sliding conditions leaves numerous permanent impressions on the surface of the composites. A careful investigation of the wear traces and the wear debris help to understand the wear mechanism. The particular type of wear which is responsible for the wear loss depends upon the various factors like the sliding speed, sliding distance, applied load and frictional temperature at which wear tests are performed, [8]. The SEM micrographs of the wear traces of composites, containing different size and amount of the SiC particles, tested at 49 N loads, are presented in the Figs. 3 and 4. The scar on the sliding surfaces suggests that the abrasive wear is the dominating mechanism under these conditions. The asperities of the contacting surfaces undergo plastic deformation during sliding due to the normal stress, [9]. The high local pressure generated due to the relative motion between the contact surfaces leads to welding of asperities. As the sliding continues, breaking of bonds generates micro cavities, which further cause tiny particles abrasion. Fig. 3a shows the wear traces micrographs of the 3 wt. % fine size SiC reinforced composites at higher load (49 N); wear traces clearly show the groove formation by the abrasive action of the asperities at the point of actual contact as presented in Figs. 3a. Fig. 3b shows the wear traces micrographs of the 3 wt. % coarse size SiC reinforced composites at higher load (49 N); the increased depth and width of the grooves indicate the transition from the mild wear to severe wear. The wear traces are also covered with the thin white oxide layer, which protects the matrix, but rupturing of the oxide layer leads to transition in the wear mode, [10], which is responsible for increase of the delamination area, as shown in Fig. 3b.

Fig. 4a shows the delaminated area along with the abrasive grooves on the worn surface of the 9 wt. % fine size SiC reinforced composite. Due to the presence of SiC particles in the matrix, abrasive grooves are created on the surfaces during the continuous sliding of the materials. Some adhesive debris is present on the wear trace due to the thermal welding between the contact areas, [11]. Surface presents the view of the delaminated area as observed in the micrograph (Fig. 4a). Fig. 4b shows the worn surface of the 9 wt. % coarse size SiC reinforced composite tested at 49 N. The larger delaminated area with deeper grooves indicates the higher wear rate due to the increased depth of the grooves because of the change in shape of asperities. The plastic deformation has left more patchy scars on the surface. At 49 N load, 9 wt. % coarse size SiC reinforced composite exhibits the worn surface with much more delaminated area and some sign of chipping out of particles during the wear test, which is responsible for the higher wear rate as shown in Fig. 4b.



a) fine size reinforced *b) coarse size reinforced*

Fig. 3. The wear traces of composites at 49 N loads for 3 wt. %.



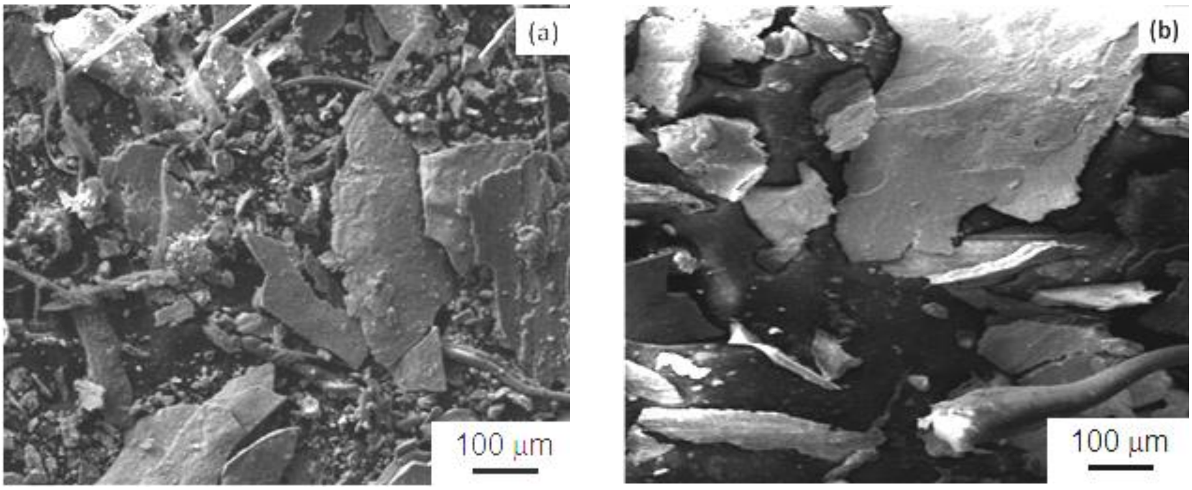
a) fine size reinforced *b) coarse size reinforced*

Fig. 4. The wear traces of composites at 49 N loads for 9 wt. %.

4.3 Analysis of wear debris at applied peak loads

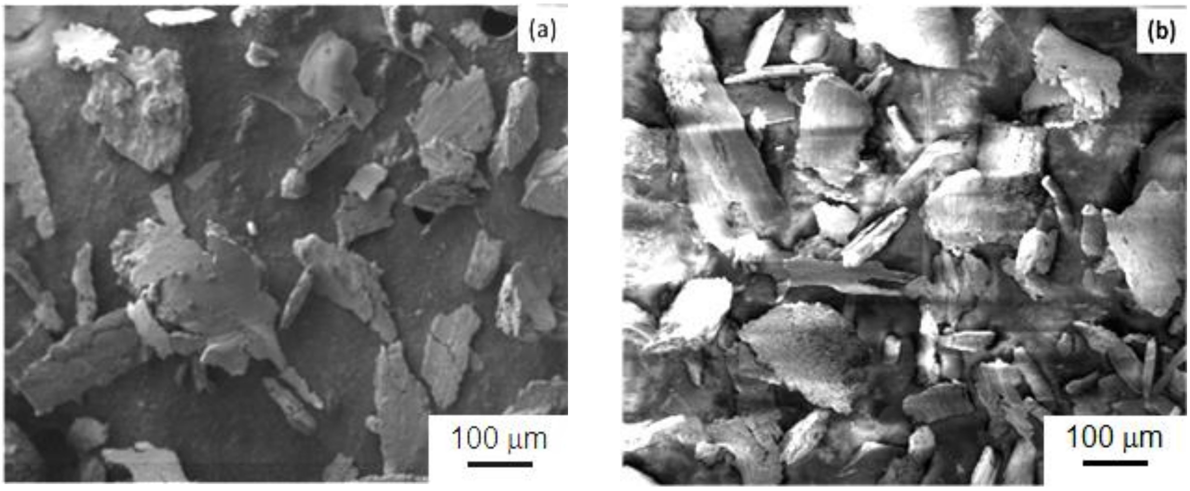
The size of debris of the 3 wt. % fine size SiC reinforced composite is smaller at higher load (49 N) as compared to 3 wt. % coarse size SiC reinforced composite. The flake type debris (Fig. 5a) gives the indication of adhesive wear due to the transfer of material from the contacting surfaces in relative motion due to the solid phase welding or localized bonding. Deep grooves along with the flake type structure formed under high stress can be easily seen on the debris in Fig. 5b, which indicates the high wear rate of the material. At the higher load (49 N) conditions, the wear loss is due to the combination of adhesion and delamination. The delamination wear is prominent at higher load because of the fragmentation of oxide layer, which covers the surface due to the accelerated oxidation of the metal surface layers in contact, [12].

Fig. 6a shows that at higher load, (49 N), larger size debris (flakes like shape is observed after the wear test and this type of wear debris indicates that the adhesive wear dominates in the sliding direction during the wear. Due to the adhesive nature at high load, metal is chipped out in the form of flakes as debris, however, the small size debris are generated by crushing of flakes at higher load, [13].



a) fine size reinforced *b) coarse size reinforced*

Fig. 5. The wear debris of composites at 49 N loads for 3 wt. %.



a) fine size reinforced *b) coarse size reinforced*

Fig. 6. The wear debris of composites at 49 N loads for 9 wt. %.

Some debris with grooves is observed in Fig. 6b, which indicates that the coarse particles have chipped out from matrix and those particles move between the contact surfaces in the sliding direction and generate grooves on the debris. Wear is governed by delamination, which gives plate-like morphology of debris with micro cracks, [8]. The large flat plate type morphology indicates the huge removal of material at higher load (49 N), which is shown in Fig. 6b. The fragmentation of debris was observed, which may be due to continuous rubbing of delaminated flakes between the contacting surfaces. The debris trapped in wear traces leads to a corrugated structure, shown in Fig. 6a.

5. Conclusion

In the present study, the particle reinforced metal matrix composite was developed by the stir casting process. To investigate the effect of SiC particles on the wear behavior of the composites, SiC particles of two sizes fine, and coarse were incorporated in two different amounts (3 and 9 wt. %). It was concluded from the study that at the higher loads more wear was noticed. From the experimental study was also observed that the wear resistance of the composite materials increases with an increase in reinforcement of SiC, although an increase the size of the reinforcement SiC does not result in an appreciable change of the wear rate.

The microstructural study of specimen after the wear test leads to the conclusion that both adhesive and abrasive wear mechanisms contribute for wear of composites.

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