

Wear Characteristics in Al-SiC Particulate Composites and the Al-Si Piston Alloy

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ABSTRACT:

The Al-Si alloy with near eutectic composition has been conventionally used as a piston material for automobile applications. It is required to possess high abrasive wear resistance for enhanced life of the engine. The alloy is known to have fairly good wear resistance due to increased percentage of silicon present in fine form. In the present investigation, Al-SiC particulate composites have been studied for their wear resistance against emery paper (400 grit SiC particles) counterface and a comparison has been made with existing piston alloy i.e. Al-Si alloy.

The Al-SiC composites have been prepared using Liquid Metallurgy technique employing 2124 Al-alloy as the base material with 10 and 20 % SiC particulates by weight. The abrasive wear study has been conducted on a Pin on Disc machine. The wear rate in terms of weight loss per unit sliding distance as well as the volumetric wear rate have been obtained for the Al-SiC composites. The characteristics of worn surface were investigated using SEM. The composites are found to possess very high wear resistance as compared to Al-Si piston alloy. The results have been discussed and important conclusions are outlined.

Key words: Composite Material, Wear, SEM.

1. INTRODUCTION

There are more than 50,000 materials available for engineers to the design and manufacturing of products for various applications. These materials range from ordinary materials (e.g., copper, cast iron, brass), which have been available for several hundred years, to the advanced materials e.g., composites, ceramics and high-performance steels etc.

The life of automobile depends on its engine having piston and cylinder made from suitable alloys. The Al-based composites have found extensive applications in automobile industries due to their increased stiffness, strength and wear resistance properties. A number of particulate

phases have been employed in the Al-alloy matrix [1]. For example, particulates of graphite [2], mica [3], zirconia, alumina[4], zircon[5], silicon-carbide[6], silica [7] etc. have been employed in a suitable Al-alloy matrix. The introduction of the above particulate phases in the aluminium matrix provides a good wear resistance and antifriction properties. The strength, ductility and stiffness are the other important properties. The choice of an optimum volume fraction of the particulate phase in the composite is therefore essential to obtain an improved combination of properties.

The present investigation is based on the study of Al-SiC cast composites with particular reference to the study of the effect of particulate phase on the wear characteristics of the composites.

2. MATERIALS AND METHODS

2.1 Composite Preparation

For the present investigation four types of materials have been selected as follows

- (i) Al-alloy (2124 type)
- (ii) Al-alloy – 10% SiC (wt%) composite
- (iii) Al-alloy – 20% SiC (wt%) composite
- (iv) Al-Si piston alloy

The composites as well as Al alloy (2124 type) plates were obtained from the Regional Research Laboratory (RRL) Thiruvananthapuram (India). The 2124 Al-alloy has been used as the base alloy for the composite. The composition of the above alloy is given in **Table 1**. The composites were prepared using liquid metallurgy technique. During the preparation of composite, addition of 0.5 wt% Mg, 0.005 wt% Be and 0.07 wt % TiB were made along with the SiC particulates. The SiC particles were lying in the size range of 23 - 40 μm . The TiB is used for the grain refinement whereas Be is added for improved castability. For the improvement of interfacial bonding of SiC particles, the surface of the latter is oxidized. This is performed by preheating of the SiC particles in the temperature range of 700- 900 $^{\circ}\text{C}$. Proper stirring and mixing of particles are done to ensure uniform distribution of SiC particles. The addition of Be is also known to improve the distribution of SiC particles by minimizing the agglomerations of particles.

The plates were cast using split moulds and employing bottom pouring technique. After casting the composite plates were obtained in the dimensions of 250 mm (length) x 225 mm (width) x 40 mm (thickness).

2.2 Processing of Composites

The cast plates of the base alloy as well as the composites were soaked in a furnace for 2 to 3 hrs in the temperature range of 480 - 500 $^{\circ}\text{C}$. The plates were forged in the above temperature range using hydraulic press of 3000 Ton capacity. The final reduction after forging resulted in the plate thickness of 15-17 mm from the original 40 mm thickness.

2.3 Aluminium –Silicon Alloy

In the present investigation an Al-Si eutectic alloy has been employed for comparison of its wear behaviour with the wear behaviour of Al-SiC composites. The composition of the alloy is given in Table 1. The alloy was phosphorous (P) modified by using 70-80 ppm of P. The piston had been made by gravity die casting followed by artificial aging heat treatment. The heat treatment involved solution treatment at 505 °C for 2 ½ hours, then water quenching at 65°C and subsequently aging at 205 °C for 5 hours. The above heat treatment was known to result in optimum properties. After the above heat treatment following properties were obtained: Proof stress- 205-225 MPa, Tensile Strength - 300 MPa, %Elongation - 0.3 to 1.5 %, Hardness - 65 HRB.

TABLE 1. Chemical Composition of the Base Al-Alloy

Element	Cu	Zn	Mn	Fe	Mg	Si	Ti	Sn	Pb	Ni	Al
Base Al-alloy (Wt %)	5.10	1.13	0.592	0.565	0.454	4.09	0.112	0.015	0.044	-	Rest
Al-Si piston alloy (Wt %)	1.1	-	0.2	0.3	1.1	12.5	-	-	-	0.9	Rest

3. WEAR EXPERIMENTATION

The wear studies were conducted using a pin on disc machine (Linear Abrasive Wear Rig) [8]. The maximum loading capacity was 200 N and maximum speed of 5 m/ minute. The specimens for wear studies were cut from the base Al- alloy, composite plates and the Al-Si piston alloy in cross section of 10 mm x 10 mm with a thickness of 8 mm. The top and bottom surfaces were made planer by polishing against emery paper. The specimen was fixed on the specimen holder which in turn was mounted to the machine. The disc was provided with 400 grit emery paper to be used as the counter facing surface. For the wear test, the total travel distance covered was 100 m which was divided into 5 equal parts. The movement of specimen on the disc was continued along the same path for the distance of 20 mm in reciprocating manner. The dry sliding wear test was conducted in this study. After the coverage of each 20 m distance, the path was changed and a fresh path was used. The distance of 20 m was covered by 40 cycles of travel in a reciprocating manner as because the travel step was of 250 mm length. A travel speed of 3m/min was used during the test.

The specimen was weighed initially using an electronic balance of 0.0001 gm accuracy and the maximum capacity of 320 gm. After a travel distance of 20 mm on the disc, the sample was taken out, cleaned and weighed carefully. This was continued for entire travel distance of 100 m. The wear studies were conducted at 3 different load levels i.e. 20 N, 30 N and 50 N.

3.1 Wear Surface Study

The samples for wear surface study were sectioned carefully to appropriate sizes. They were cleaned using ultrasonic cleaner and examined under SEM (Zeiss EVO-50) at suitable

magnifications. The wear surface of each specimen was examined after completing its final applied load.

4 RESULTS

4.1 Effect of Load and Disc Surface on Weight Loss

The effect of load employed during wear test is presented in Fig. 1 on various materials i.e. Al base alloy, 10% SiC Composite, 20% SiC composite and Al-Si piston alloy. In the above figure the weight loss from the four materials is presented for loads 20 N, 30 N and 50 N in Figs. 1(a), 1(b) and 1(c) respectively for 400 grit emery paper used as the disc surface.

Following observations may be made from Fig. 1:

- With increasing load the weight loss increases in all the four materials.
- With increasing travel distance the weight loss increases in all the materials at a given load.
- For a given load and distance travelled the, weight loss is found to be maximum in the Al-Si piston alloy and minimum in the Al- 20% SiC composite. The Al-base alloy shows greater weight loss as compared to both the composites for a given load and travel distance.

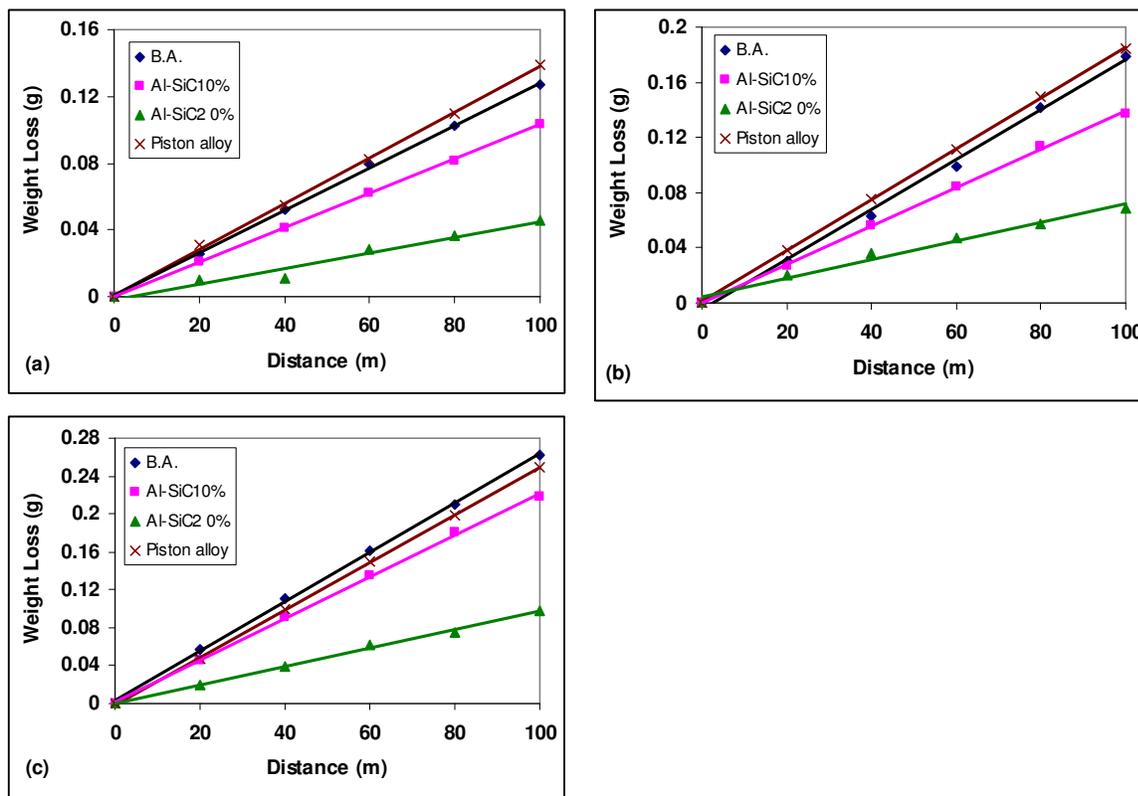


Fig.1 Weight loss as a function of sliding distance for 400 emery paper
(a) 20 N (b) 30 N (c) 50N

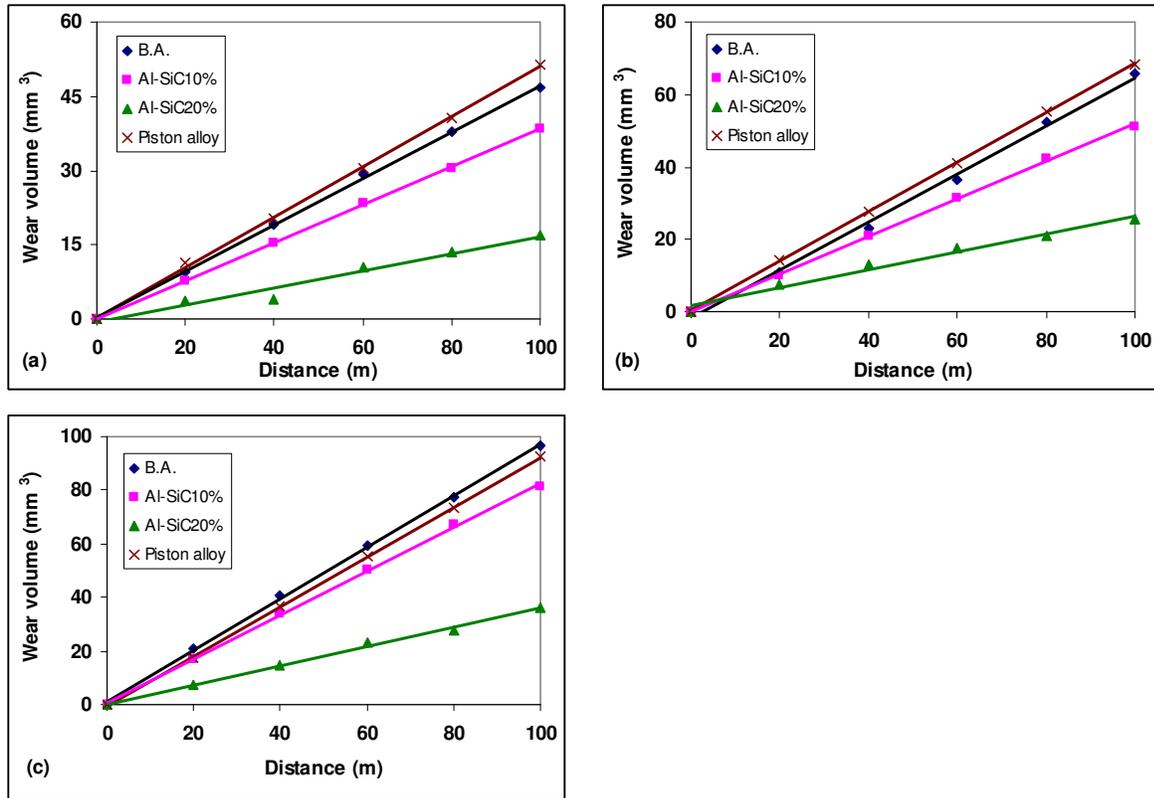


Fig.2 Wear volume as a function of sliding distance for 400 emery paper
 (a) 20 N (b) 30 N (c) 50N

4.2. Effect of Load and Disc Surface on the Wear Volume

The wear volume was calculated as follows.

$$\text{Wear Volume} = \frac{\text{Cumulative weight loss}}{\text{Density}}$$

The calculated wear volumes were plotted against the sliding distance for the materials investigated at different loads. Fig. 2 presents the wear volume vs sliding distance diagrams for 400 grit emery paper at 20 N, 30 N and 50 N of loads.

From the above diagrams following observations may be made.

- The wear volume in all the situations is the minimum for the Al-20% SiC composite.
- The maximum wear volume is noticed either for the Al-Si piston alloy or the Al-base alloy.
- The performance of Al-10% SiC composite almost lies in between the maximum and the minimum wear volume.
- With increasing load there is consistent increase in the wear volume.

5. WEAR SURFACE STUDIES USING SEM

For the wear study following wear test specimens were selected

- (a) Al-10% SiC composite at 50 N load
- (b) Al-20% SiC composite at 50 N load

Representative SEM diagrams from the wear surfaces of Al-10% SiC composite against 400 emery paper are presented in Fig. 3. The Fig.3 (a) provides overall view of wear pattern at 2000 X. Fig. 3(b) provides an enlarged view of material removal from the surface at 4500 X. The wear surface features from Al-20% SiC composite are shown in Figs 4 (a) and (b). Fig 4(b) provides details of wear track and process of materials removal.

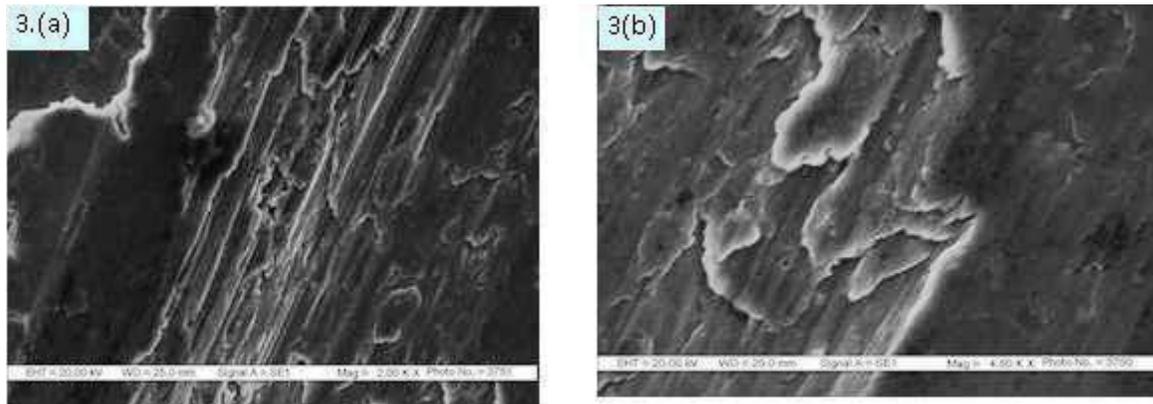


Fig. 3(a-b) Wear surface characteristics (SEM) of Al- 10 % SiC Composite (400 emery, P = 50 N)

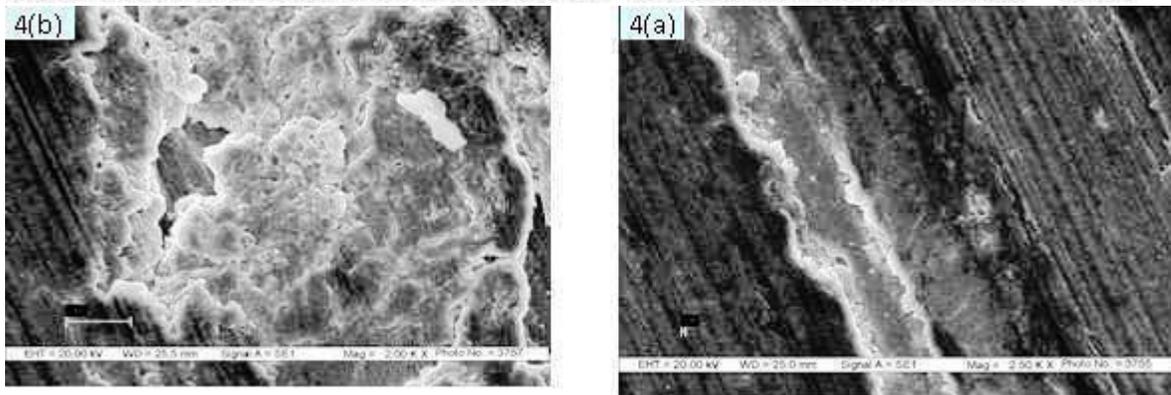


Fig. 4(a-b) Wear surface characteristics (SEM) of Al- 20 % SiC Composite (400 emery, P = 50 N)

6. DISCUSSION AND CONCLUSIONS

1. The dry sliding wear behavior in the base alloy and composites were investigated against emery papers of 400 grit. The SiC particulate phase is found to reduce the wear rate (expressed in terms of gm/m, mm³/m etc) significantly in the composites. The volumetric wear rate (mm³/m) in 20 % SiC composite is reduced by 62-66% for 400 emery sliding with respect to the base alloy. In case of 10% SiC composite the corresponding reduction in the wear rate is 15-25%.

2. The wear rate is found to increase with load in all the materials studied. The increase in wear rate with load is steeper in the base alloy as compared to that of the composites. The increasing load is known to produce heating effect leading to thermal softening and seizure. Also it brings more area into sliding contact and thereby causes enhanced wear.
3. With increasing size of the abrasive particles (in the emery paper) the wear rate of the materials investigated has been increased. The effect of increasing abrasive particle size from 15 μm to 38 μm has been studied. The increase in wear rate of the base alloy is more significant due to cutting and plowing action by large abrasive particles. In case of composites (especially 20 % SiC composite) the effect of abrasive particles size on the wear rate is less significant as reported by other investigators also [9]. However at higher load the effect of abrasive particle size on the wear rate of composites is more significant.
4. The micromechanism of wear against the coarse abrasive emery paper was found to be characterized by deep wear tracks along with fragmented SiC particulates in the 10 % SiC composite. Fine cracks were also noticed. In 20 % SiC composite wear was followed by limited extent of cutting and plowing marks keeping the overall surface smooth.
5. The wear rate in the Al-Si piston alloy is found to be significantly higher than that of the composites. The volumetric wear rate in this alloy is closer to the same as in the Al- base alloy [10].

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