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Dry Sliding Wear Behaviour of Hybrid Metal Matrix Composites

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This investigation reveals the wear behaviour of as cast aluminium alloy, aluminium alloy reinforced with SiC particles and aluminium alloy reinforced with SiCp–Graphite. Both the composites are fabricated using liquid metallurgy route. The unlubricated pin-on disc wear tests were conducted to examine the wear behaviour of the aluminium alloy and its composites. The sliding wear tests were conducted at various loads, speeds and sliding distances. The result reveals that wear rates of the Graphitic composite is lower than that of the matrix alloy and SiCp reinforced composite. The wear rate has been increased with the increasing load and decreased with increasing speed up to 4.6 m/s and then increased. The tested samples were examined using scanning electron microscope and analyzed.
Keywords: metal matrix composites, wear, wear parameters, abrasion, delamination.

1. INTRODUCTION

Discontinuous reinforced aluminium metal matrix composites (DRAMMCs) are a class of composite materials which are having desirable properties, which include low density, high specific stiffness, high specific strength, controlled co efficient of thermal expansion, increased fatigue resistance and superior dimensional stability at elevated temperatures etc. [1, 2]. These materials have emerged as the important class of advanced materials giving engineers the opportunity to tailor the material properties according to their needs. Essentially these materials differ from the conventional engineering materials from the viewpoint of homogeneity. In composites, controlled distribution of one or more reinforcement materials in continuous metal matrix phase is possible. Large majority of these composite materials are metallic materials reinforced with high strength, high modulus and brittle ceramic phases which can be either continuous in the form of fiber, discontinuous in the form of whisker, platelets or particulate reinforcements embedded in a ductile metallic matrix. In the last two decades, wear performances of DRMMCs reinforced with various reinforcements ranging from very soft materials like Graphite, Talc etc., to high hardened ceramic particulates like SiCp, Al_2O_3 etc., [3 – 6] have been reported to be superior to their respective unreinforced alloys. A good number of works have been done on the Al/SiCp [4 – 6] and Al/Graphite [3, 7] individually. Traditionally, the external lubricant plays an important role in wear behaviour. Though the wear behaviour of Al/SiCp is good, the addition of natural lubricant like graphite enhances the self-lubricating capacity of the composites, which is essential in some of the applications where lubrication needs to be applied periodically especially for wear parts which are difficult to access. Solid lubricant contained in the composite can be released automatically during the wear process and reduces the wear. The incorporation of graphite alone will give the desired solutions but various researchers have identified both experimentally and mathematically that the incorporation of graphite will reduce the mechanical properties of the composites [7], which is undesirable for the component used in structural and high-elevated temperature applications. The wear behaviour of Al alloy reinforced with SiCp-Graphite particles has not been understood new. As a result, combination of high-hardened SiC particles and soft graphite were used in the present investigation to investigate the wear behaviour of the Al alloy reinforced with SiC and graphite particles.

2. EXPERIMENTAL

2.1 Materials and processing

Aluminium alloy Al 2219 was used as matrix material and its chemical composition is given in the Table 1.

Table 1. Composition of Al 2219 (weight %)

Element	Weight %
Si	0.20 max.
Fe	0.30 max
Cu	5.8 to 6.8
Mn	0.20 to 0.40
Mg	0.02 max
Zn	0.10 max
V	0.05 to 0.15
Ti	0.02 to 0.1
Zr	0.1to 0.25
Al	Balance

This matrix was chosen since it provides excellent combination of strength and damage tolerance at elevated and cryogenic temperatures. Both the composites are fabricated with SiCp reinforcement content of 10 weight percent and average particle size of 25 μm. A fixed quantity of 3 percent graphite by weight with an average particle size of 45 μm is added to SiCp composite. The liquid metallurgy method was used to fabricate the composites, which was used by earlier researchers [8 – 10].

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2.2. Testing of the composites

A pin- on- disc test apparatus, which is shown in Figure 1 was used to investigate the dry sliding wear characteristics of the Aluminium alloy and its composites as per ASTM G99-95 standards. The wear specimen size of 10 mm diameter and height of 40 mm was cut from as cast samples, machined and then polished metallographically. The tests were conducted with the load ranging from 10 to 40 N at a sliding speed of 1.53 m/s, 3 m/s, 4.6 m/s and 6.1 m/s with a constant sliding distance of 5000 metres.

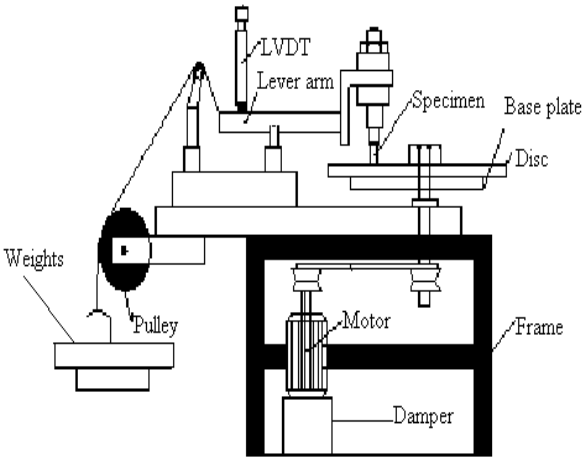

Fig. 1. The schematic view of the pin- on- disc apparatus used in this study

All these tests were conducted at room temperature. The initial weight of the specimen was measured in a single pan electronic weighing machine with a least count of 0.0001 g. During the test the pin was pressed against the counter part rotating against EN32 steel disc with hardness 65HRc by applying the load. An approximately strain–gauged friction-detecting arm holds and loads the pin specimen vertically into a rotating hardened steel disc. The frictional traction experienced by the pin during sliding is measured continuously by PC-based data-logging system for post testing analysis. After running through a fixed sliding distance, the specimen were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. The difference in the weight measured before and after the test gives the wear of the specimen. The wear rates were determined using the weight loss method. The wear of the composite was studied as a function of the sliding distance, applied load and the sliding velocity.

3. RESULTS

3.1 Wear characteristics

Fig. 2 shows the variation of volume loss with the sliding distance for Aluminium alloy 2219, SiCp reinforced and SiCp-Graphite composites in as cast condition. It can be observed from Fig. 2 that as the sliding distance increases the wear of the composites and alloy also increases. The wear of the unreinforced alloy is more than that of the composites for all sliding distances.

The wear volume loss is decreased with the addition of SiC particles and it is further decreased with the incorporation of Graphite reinforcement. At the initial phase, little change in volume loss was observed for the composites, as the sliding distance increases more change in the wear

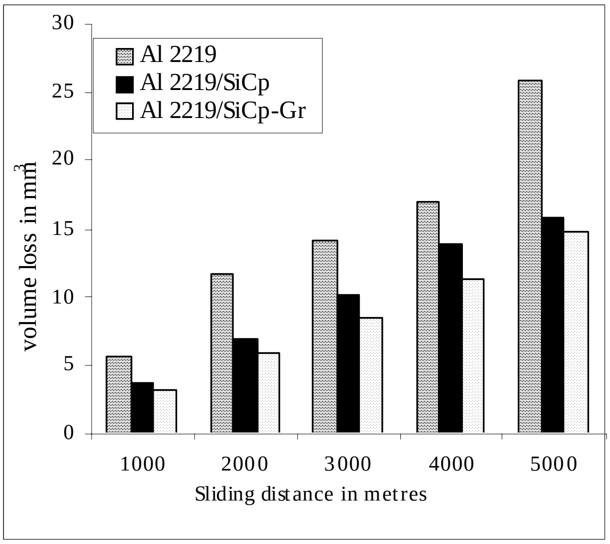

Fig. 2. Variation in volume loss with sliding distance for various composites and its alloy at a sliding speed of 1.53 m/s and at the load of 40 N

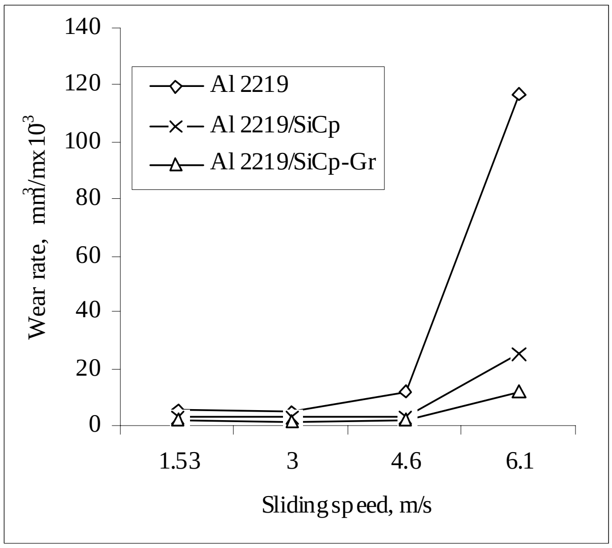

Fig. 3. Variation in wear rate with sliding speed for both composites and its alloy at fixed load of 40 N and for a sliding distance of 5000 metres

was observed. The wear resistance of the graphitic and SiCp reinforced composites is increased compared to the unreinforced alloy at all sliding distances. The drastic decrease in volume loss was observed with the addition of reinforcement content. Fig. 3 corresponds to variation in wear rate with the sliding speed for the unreinforced alloy and other two composites. The wear rate of the unreinforced alloy and composites decreased as the sliding speed increases up to 3 m/s, beyond 3 m/s the wear pattern of the unreinforced alloy changes and it increases with increasing speed, however the same trend of decreasing wear rate with increasing the speed was observed in composites. A drastic increase of wear rate was observed for unreinforced alloy when the speed is increased from 4.6 m/s to 6.1 m/s. Heavy noise and vibration was observed during the process. The effect of graphite on the wear rate can be observed from Fig. 3. It is clear from the study that as the sliding speed increases, the wear rate initially decreases and after reaching transition speed, it increases.

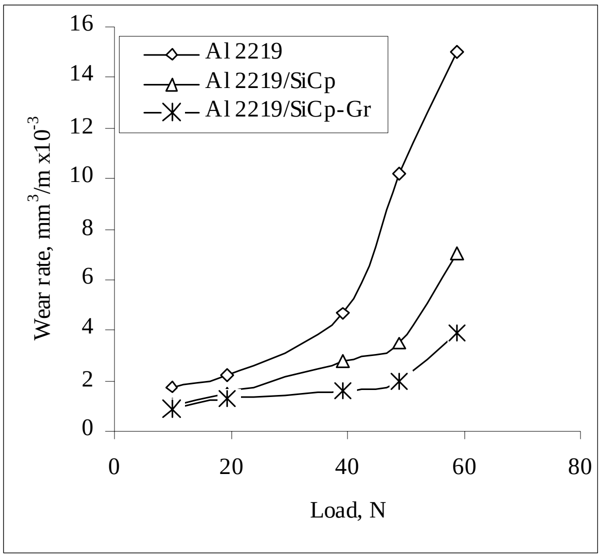

Fig. 4. Variation in wear rate with applied load for various composites and alloy for a fixed distance of 5000 metres

Fig. 4 indicates the dependence of wear rate on the applied load for fixed sliding speed of 3 m/s. The mild wear is observed at low applied load, as the load increases further the wear rate of the unreinforced alloy and the composites increases up to 20 N. At 20 N load the wear pattern changes for the unreinforced alloy, while the composite follow the same trend up to 50 N, at this load unreinforced alloy seizes. At 60 N load both the SiCp reinforced and SiCp-Graphitic composites wear rate increases steeply. The positive effect of the reinforcing silicon carbide particles and Graphite content was reflected in the Fig. 3, 4. The obtained results are inline with the other researchers [5, 11 – 13].

3.2 Examination of worn surfaces

The SEM Micrographs shown in Fig. 5 and 6 are the worn surfaces of aluminium alloy 2219 and Al 2219/10 % SiCp composites respectively. The Fig. 7 indicates the SiCp-Graphite reinforced composite tested at a load of 40 N and at a sliding speed of 3 m/s for a sliding distance of 1000 metres. For simplicity and convenience only few micrographs at the same speed and load with different materials were taken, however the same explanation holds good even for the other composites and its alloy with different sliding distances, speed and load. The large amount of plastic deformation was observed on the surface of the unreinforced alloy as shown in Fig. 5. In the case of composites Al 2219-10 % SiCp, Al 2219-10 % SiCp-3 % Gr grooves have been formed by the reinforcing particles as shown in Fig. 6, 7. As load increases to higher values, the morphology of the worn surfaces gradually changes from fine scratches to distinct grooves. The damaged spots in the form of craters have been observed in the areas where particles were pulled out. It has been seen that a layer of material has been removed as debris in the form of thin sheets from the surface. It is considered that tearing (fracture) causes formation of wear debris [14].

In some places the diversion of wear grooves is also noted. When the delamination wear, the subsurface cracks,

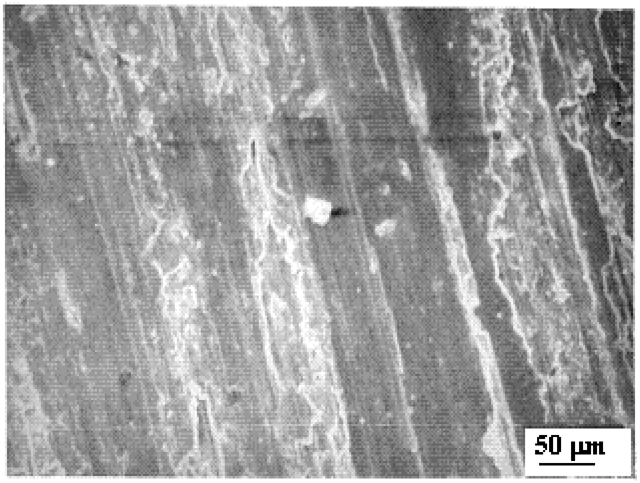

Fig. 5. Wear surface of Al 2219 alloy. Parameters: sliding speed 3 m/s, load 20 N, sliding distance 5000 m

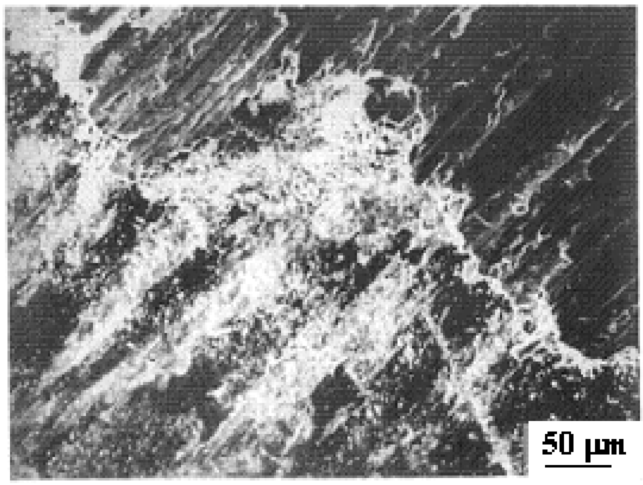

Fig. 6. SEM worn surface of Al 2219/10 % SiCp composite. Sliding distance 5000 m, load 40 N, sliding speed 3m/s

which may either exist earlier or get nucleated due to the stresses, propagate during the course of wear. When such subsurface cracks join the wear surface, delamination is the dominant wear mechanism [15]. The Graphitic composite clearly shows the interaction of SiCp particles with the surface of the hard disc and the initial formation of lubricant layer. Due to wear of the matrix, the SiCp particles are projected out and these particles are fractured as observed in Fig.7.

3.3. Discussions

It was found from Fig. 5, 6 that wear rate of SiCp, SiCp-Graphite reinforced composite specimens reduces with the increase in reinforcement content in the dry sliding wear tests. The asperities of both the pin and counter face which are in contact with each other are subjected to relative motion under the influence of applied load. Initially both the surfaces are associated with a large number of sharp asperities and contact between the two surfaces take place primarily at these points.

In the present case also, the asperities on the pin are having a large number of reinforcements. Under the

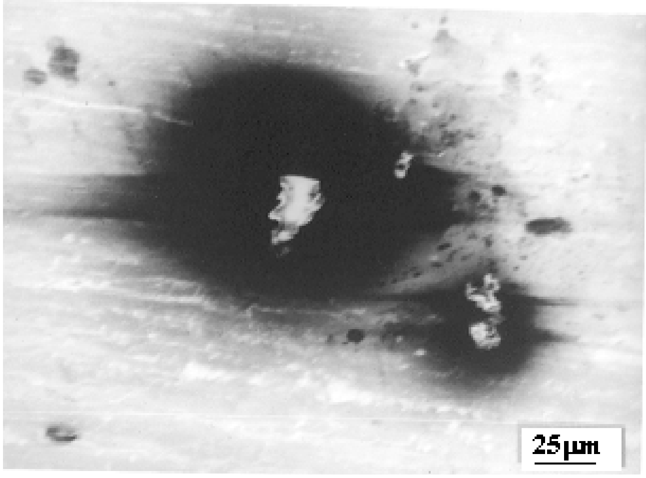

Fig. 7. SEM shows the worn surface of Al 2219/10%SiCp-3 % Gr composite at a speed 3 m/s and at a load of 40 N after running for a distance of 1000 meters

influence of applied load and speed, the asperities in each surface come in contact with each other and they are either plastically deformed or remain in elastic contact. As the asperities are very sharp in nature, the effective stress on these sharp points may be more than the elastic stress and then all these sharp asperities are plastically deformed at their contact points except the partially projected points of the reinforcement. The plastically deformed surface will fill the valley of the material both in pin and the counter face during the course of action and there is a possibility of fracturing a few asperities on both the surfaces leading to very fine debris.

The asperities of the sliding pin surface come in contact with the steel disc surface and work hardening of the matrix material takes place under the applied load and speed [16]. The SiC particles, which are very strong in compression, are pushed back in to the soft Al 2219 alloy initially instead of fracturing. During the initial run-in period in all cases, the wear rate is more because of the fact that the few of highly projected SiC broken particles from the pin will act as debris and plough the surface particularly the Al 2219 leaving the projection of SiC in the composite [17].

In the case of SiCp reinforced composites, the wear rate goes to a minimum as the speed increases up to 4.6 m/s. After this a combination of abrasive and delamination wear operates and shows severe wear at 6.1 m/s. The wear rate at the beginning is more because of the fact that the asperities of SiC particles were not projected and the entire surface is under the same amount of stress such that the asperities will be deformed easily and the fractured matrix material particles and SiC particles will plough the surface of the counter face and the pin. When the speed increases, the ploughed surface of the counter face (Fe) will react and form Fe_3O_4 and SiC particles will crush and form very minute particles [11, 18 – 20]. The Fe_3O_4, Fe and minute fractured particles of the SiC form a layer between the work hardened pin and the counter face and reduce the wear rate up to a speed 4.6 m/s. When the speed increases to 6.1 m/s the surface film will break, the sub surface which was work hardened will be under severe stress and the microscopic projections or asperities bond to the sliding surface causing a combination of abrasive and adhesive wear. The sliding forces fracture the bonds, tearing metal from the pin surface and minute projections of the Al 2219 on the counter face. This further leads to the seizer of the wear surface.

In the case of SiCp-Graphite composites the stress on the surface of the pin is almost uniform and contact between the pin and the counter face is intact, such that more surface area is in contact. The initial wear is little less than the above case, along with the protecting layer formed in SiCp composite graphite smears and forms a protecting layer such that the wear rate is still less compared to SiCp composites. The spreading of the graphite on the surface of the pin can be clearly observed from the Fig. 7. The decreasing trend of the wear rate when sliding speed is increased is due to the formation of protective oxide film (Fe_3O_4) along with the lubricating films of Graphite. At higher speed due to increase in the temperature, the surface of the material becomes smooth that promotes local yielding and the wear mechanism changes from abrasion to delamination wear. Hence the graphitic composite has lesser wear rate for a particular speed and load (40 N and 4.6 m/s) compared to all other classes of composite under study.

4. CONCLUSIONS

The following conclusions can be drawn from this work.

1. SiC particles can be used as both reinforcement material to improve the properties and as a carrier for introducing the Graphite particles in Al 2219 alloy.

2. The incorporation of graphite particles in the aluminium matrix as a second reinforcement decreases the wear rates of the composite compared to SiCp reinforced composite.

3. Wear rate decreases as the sliding speed increases up to transition speed and load, due to work hardening of the surface, formation of Iron oxide, crushing of the SiC particles and smearing of Graphite.

4. Seizure occurred for Aluminium alloy, but no seizure occurred for Al/SiCp and Graphitic composites under the study. Combination of abrasion, delamination and adhesive nature of wear was observed.

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