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# Mechanical and Wear Properties of SiC/Graphite Reinforced Al359 Alloy-based Metal Matrix Composite

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**ABSTRACT**

Al359 alloy was reinforced with Silicon Carbide and Silicon Carbide/Graphite particles using stir casting process. Thereafter their mechanical and wear properties were investigated. It was found that the hardness of the Al359-Silicon Carbide composite is better than Al359-Silicon Carbide-Graphite composite. The Silicon Carbide/Graphite reinforced composite exhibits a superior ultimate tensile strength against Silicon Carbide reinforced composite. The wear test was conducted at different loading, sliding velocities and sliding distances conditions. Results showed that the wear resistance of Al359 alloy increased with the reinforcement of Silicon Carbide/Graphite material for higher loading, sliding velocities and sliding distance conditions. SEM images of the worn surface of the pin were examined to study their wear mechanism.

**Keywords:** Metal matrix composite, wear, hardness, tensile strength, scanning electron microscopy

## 1. INTRODUCTION

Aluminium and its alloys are widely used in engineering applications due to their high specific strength, high corrosion resistance, ease of fabrication, and low cost. Al359 is one such alloy with its number of applications in automobiles, aerospace, and electronics industries[1]. A number of researchers have worked to enhance the mechanical and wear properties of various aluminium alloys using different hard particulate reinforcements.

Silicon Carbide particulates were mostly used for reinforcing the various aluminium alloys[2-5]. The tensile and flexural strength improved up to 10 wt.% of SiCp, beyond which the strength decreased due to agglomeration of SiCp particulates[6]. Shin[7], *et al.* studied that the strength of the Al-6061alloy reinforced with SiC depends on the temperature. The beneficial effect on strength was till temperature of 200 °C, beyond which there was no effect on strength. Sahin[8] found from the worm surface that the small particle sizes of SiC composite exhibits more wear as compared to large particle size of reinforcement.

Researchers have even added different particles to Al-SiC composite for improving the properties. The addition of graphite in Al or Al-SiC gave superior wear properties as compared to matrix material[9,10]. The resistance to wear improved in Al-Gr with increase in speed due to the presence of the supporting tribo layer in between the worm surface and the disc. Wear decreases with increase in load and sliding distance due to the reduction in tribolayer[11]. Kumar[12], *et al.* observed that the mechanical properties were improved in Al-7Si/$TiB_2$ composite as compared to Al-Si composite. It was also found from the analysis of the worn surfaces that ploughing and adhesion were predominant at lower load and delamination was more at higher load. Kaur and Pandey[13] studied the behaviour of Al-SiC alloy with Zircon reinforcement. The composite was developed using spray forming technique. It was found that the Zn reinforced composite exhibits lesser wear as compared to Al-SiC composite under different load condition due to abrasive, adhesive and oxidative wear mechanism.

Researchers have even tried reinforcements other than SiC for improvements in properties. Torres[14], *et al.* studied the behaviour of mechanical properties of 2124 aluminum alloy reinforced with 15 vol. % of $MoSi_2$, $Ni_3Al$, $Cr_3Si$, NiAl prepared by powder metallurgy. It was found that 2124 aluminum alloy reinforced with $MoSi_2$ had better mechanical properties as compared to other reinforced materials. Seah[15], *et al.* studied the behaviour of the Al/quartz particulate composite cast with the metallic (cast iron, copper, steel) and non-metallic (silicon carbide) chills. The ultimate tensile strength and toughness of the cast specimen were improved with increase in weight of quartz up to 6%, beyond which these two mechanical properties reduced. It was found that the tensile strength and hardness were improved with the addition of nano-$Al_2O_3$ particles in aluminium matrix[16,17,18]. Ahlatic[19], *et al.* found that the addition of Mg content in aluminium matrix facilitated the increased wear resistance of metal due to formation of Fe rich transfer layer. It was also stated that the addition of Mg content results in increase in matrix hardness and decrease in the porosity of the reinforced composite.Nemati[20], *et al.* presented that the resistance to wear of nano size TiC reinforcement composite was more than the micro size TiC reinforcement composite. It was also found that the worn surfaces of composites were smoother, grooves were finer and total depths of deformation were smaller than the unreinforced aluminium alloy composites.

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Zhu[21],*et al.* observed that the wear rate of reinforcement composite ($Al_3$Zrpa-$Al_2O_3$)/Al increases with increase in sliding speed. The increase was up to 0.6 m/s, beyond which the wear rate decreases gradually. But, with the increase in test temperature, the increase in sliding velocity decreases the wear rate. It was found that with the increase of applied loads and test temperatures, the abrasive wear, oxidation wear and adhesive wear were the main modes in the wear mechanism of the composite.Farahani[22], *et al.* found that there was mixed type of wear mechanism *i.e.*, delamination, adhesive, and abrasive at higher applied load for Al-5Ti-1B and Al-15Zr alloy. It was also found that the wear resistance of SC free 7042 alloy increased with applied pressure due to friction heat which softened the composite during sliding.

Researchers have even explored the effect of coatings and casting techniques for their effects on different properties. Apachitei and Duszczyk[23], found that there was improvement in wear and hardness of the aluminium 6061 with lesser thickness of phosphorous coating as compared to that of phosphorous amorphous coating. Hemanth[24], observed that the wear resistance was highly dependent on the rate of chilling during casting.

It can be seen from the literature review that number of researchers has worked on the mechanical and wear properties of various aluminium alloys reinforced with different materials. Very few work is reported on enhancement of mechanical and wear properties of Al359 alloy. It can also be seen from the literature review that SiC is commonly used as reinforcement of aluminium alloys. But SiC being hard material can adversely affect the mechanical properties of the base alloy. So the present work is to study the mechanical and wear behaviour of Al359 alloy with the addition of SiC and Gr particles.

## 2. EXPERIMENTATION

In the present work, Al359 was used as the matrix material with SiC or SiC/Gr as reinforcement material. The detail of chemical composition of Al359 is given in Table 1.

The weight percentage variation of Al359 alloy, SiC and Gr for the preparation of the specimen are given in Table 2.

**Table 1. Chemical composition of Al359 alloy (in wt%)**

| *Al* | *Si* | *Fe* | *Mn* | *Zn* | *Cu* | *Ti* | *Mg* |
|---|---|---|---|---|---|---|---|
| 86.97 | 10.22 | 1.39 | 0.47 | 0.38 | 0.30 | 0.17 | 0.11 |

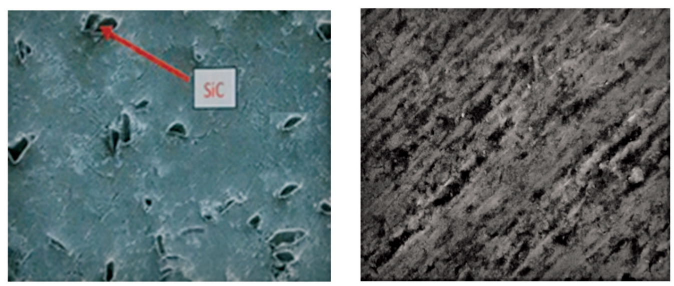
**Table 2. Wt. % variation of Al359 alloy, SiC and graphite**

| Al | SiC | Gr |
|---|---|---|
| 100% | 0% | 0% |
| 90% | 10% | 0% |
| 90% | 7.5% | 2.5% |

Among the variety of processing techniques available for particulate-or-discontinuous reinforced metal matrix composites, stir casting was one of the methods adopted for preparing the aluminum composites. It was attractive because of simplicity, near net shaping, flexibility and economical for large size components to be fabricated. Al359 alloy was heated in a furnace at about 830 °C, which is above the melting point temperature of aluminium. The calculated quantity of SiC or SiC and Gr powder was preheated at temperature of 300 °C in a separate furnace. After melting the Al359 alloy in the furnace, the preheat reinforcement powder was fed at a constant rate. To achieve the desired mechanical properties, mixture was stirred at a constant speed of 600 rpm for 10 min to disperse the SiC and Gr particles into molten metal.  Thereafter molten metal was poured into moulds to prepare the specimen. The cast were prepared of the size 520 mm x 140 mm x 8 mm for the tensile test and 30 mm diameter, 100 mm length for wear test. SEM images, shown in Fig. 1, were taken to ensure the uniform dispersion of the reinforced particles in Al359 alloy.

Hardness, tensile and wear tests were performed on the different specimens to investigate the effect of SiC and Gr particles in Al359 alloy.

The micro hardness test was performed on Vickers hardness (Mitutoyo) machine. The micro hardness of polished samples was measured at different location using a load of 100 gm for 10 s.




(a) (b)

**Figure 1. SEM images of: (a) Al359 with 10 wt. % of SiC, (b) Al359 with 7.5 wt. % of SiC and 2.5wt. % of Gr.**

The tensile test was conducted on prepared samples, shown in Fig. 2, according to ASTM E8-04 standard, using Universal Testing Machine (H-1000A). The test was performed at room temperature with a cross head velocity of 1 mm/min.

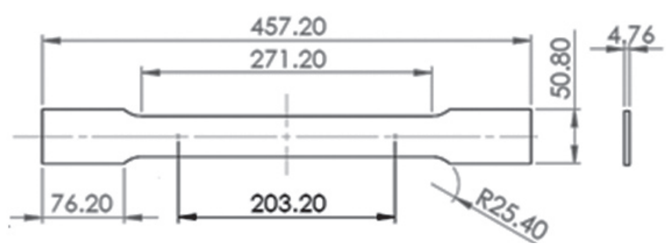



**Figure 2. Tensile test specimen.**

The wear characteristics of prepared composite material were studied using pin and disc type of apparatus, shown in Fig. 3. The tests were conducted as per the ASTM G99 standard. The test specimens in the form of pin with diameter 10 mm was prepared. The end faces of the specimens were polished with abrasive paper of 800 grit. The specimens were cleaned with acetone before and after each run of the wear test. The wear test was conducted at the loading of 1 N, 3 N, and 5 N; with the velocity of 1 m/s, 1.5 m/s, 2 m/s, and 2.5 m/s and with the sliding distance of 2000 m and 2500 m. The weight loss was measured using electronic weighting machine with

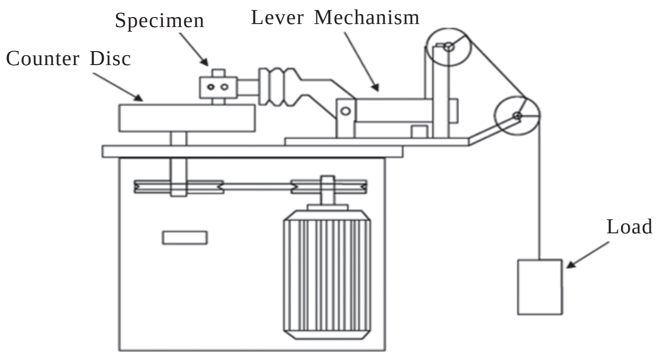



**Figure 3. Pin and disc type of apparatus.**

resolution of ± 0.1 mg. SEM images were used to study the behaviour of the worm surfaces of pin.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Hardness

The Vickers indentation tester was used for measuring the micro indentation hardness. Figure 4 shows the variation of micro-hardness with change in the weight percentage of reinforcement materials. Figure 4 shows that the hardness of reinforced composites was higher than the base material alloy. It can also be seen from the figure that the micro hardness of SiC reinforced composite is higher than the SiC/Gr hybrid composite. It is due to the fact that the addition of graphite softens the material along with acting as a lubricant.

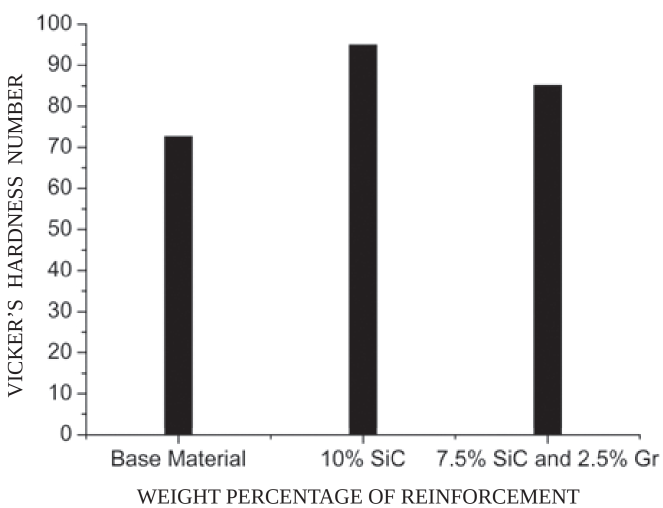



**Figure 4. Variation of micro hardness with respect to change in reinforcement composition.**

### 3.2 Tensile Strength

Figure 5(a) and 5(b) shows the variation of ultimate tensile strength and percentage elongation with respect to reinforcement composition in Al359 alloy. Figure 5(a) shows that the ultimate tensile strength of the SiC or SiC/Gr reinforcement is more as compared to the base material alloy. The tensile strength of SiC/Gr hybrid reinforced composite is more as compared to SiC reinforcement. It is due to the fact that SiC and Gr reinforcement exhibits a good bonding with Al359 alloy and also with each other which helps in withstanding more load as compared to Al359 alloy. Figure 5(b) shows that the ductility of

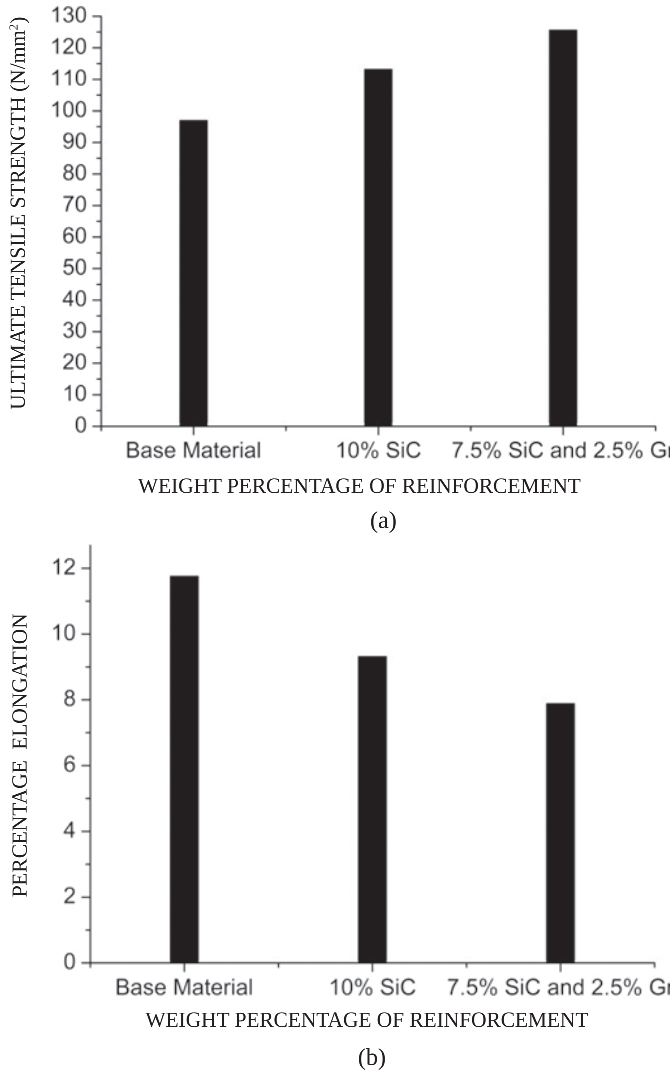



**Figure 5. (a) Ultimate tensile strength wrt change in reinforcement and (b) Percentage elongation wrt change in reinforcement.**

the composite decreases continuous and significantly with the addition of the SiC or SiC/Gr reinforcement in matrix material. The reduction in ductility is due to the presence of hard phase of ceramics that is responsible for the localized crack initiation and increased embrittlement effect on the composite due to local stress concentration at the interface of reinforcement and matrix material.

### 3.3 Wear Rate

Figures 6-9 represents the variation of wear rate with different sliding distances at different loads. The sliding velocity of the wear test varies from 1 m/s to 2.5 m/s.

Figure 6 shows the wear rate at sliding distance of 2000 m and 2500 m with velocity of 1m/s. Figure 6 shows that the wear rate of base material and composite are almost similar at low load condition but at higher load the wear rate of Al359-SiC composite is less as compare to Al359-SiC-Gr and matrix alloy. But for higher sliding distance and higher loads Al359-SiC-Gr has lesser wear rate as compared to Al359-SiC. The good interfacial bonding of the reinforcements with the matrix material result in lesser wear rate.

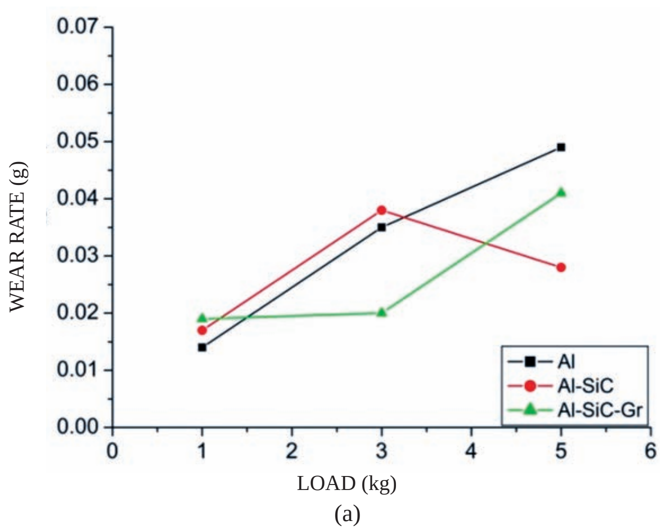
Figure 7 shows the comparison of wear rate at sliding distance of 2000 m and 2500 m with velocity 1.5 m/s. The load varies from 1 to 5 kg. Figure 7(a) shows that at lower load the wear rate of Al359-SiC-Gr exhibits the minimum wear. At higher load, the wear rate of Al359-SiC is minimum. With the increase in sliding distance, Al359-SiC exhibits a better wear properties for higher loading conditions, shown in Fig. 7(b).

Figure 8 shows the comparison of wear rate at sliding distance of 2000 m and 2500 m with the velocity of 2 m/s. Figure 8(a) shows that the wear rate of Al359-SiC-Gr composite is minimum at higher load as compared to other composites. Figure 8(b) shows that the wear rate of the composites increased with increase in load while the minimum wear rate was observed for Al359-SiC-Gr composite at higher load as compared to matrix alloy and Al359-SiC Composite.

Figure 9 shows the comparison of wear rate at sliding distance of 2000 m and 2500 m with velocity of 2.5 m/s. The minimum wear rate was observed for Al359-SiC-Gr composite for higher load at higher sliding velocities.

There are non-monotonic trends in wear behaviour shown in Figs. 6(a), 7(a), 8(a), and 9(a) for Al359-SiC-Gr. It is due to the fact that at low sliding velocities and higher loads, the wear rate of Al359-SiC is less as compared to Al359-SiC-Gr. There is a formation of tribo layer in between the worn surface and the pin due to the addition of Gr. With the increase in speed and load, the layer stabilises which causes the wear rate to reduce for Al359-SiC-Gr composites.

It can be concluded that the addition of the SiC and Gr to the Al359 alloy improve the properties of the composite which exhibits the less wear as compare to the Al359 alloys. The addition of appropriate graphite content improves the wear properties of Al359 due to the formation of tribo layer which reduces the wear for higher sliding distances and higher sliding velocities. The SiC particles refine the eutectic silicon and provide excellent wear resistance whereas the Gr particle provides the good lubrication property.



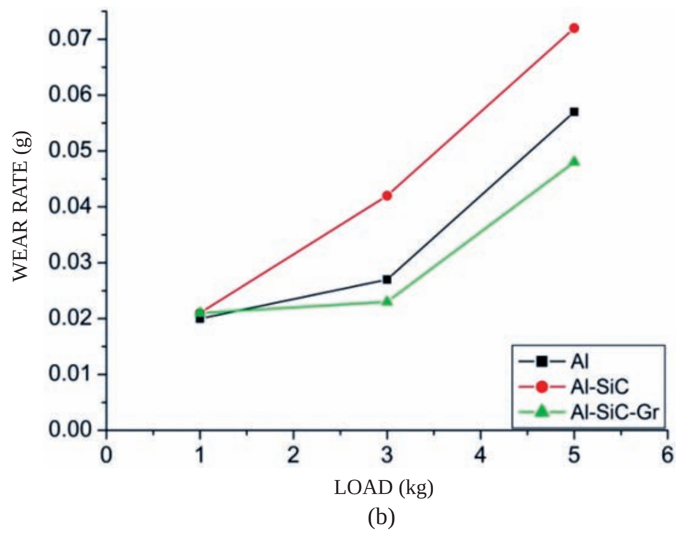
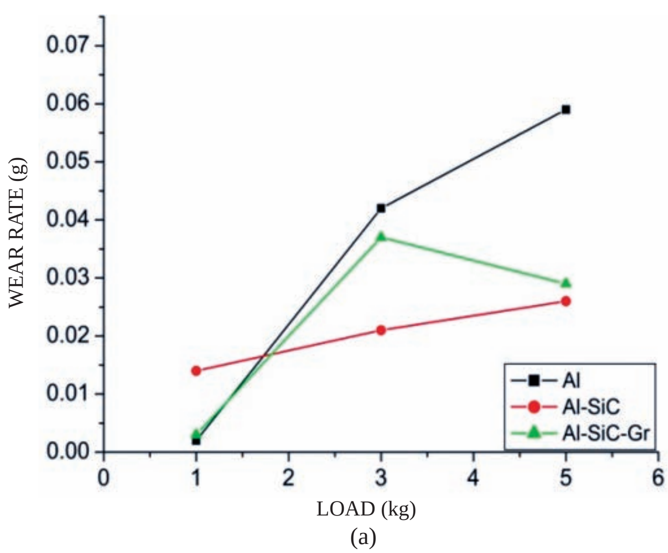




**Figure 6. Variation of wear rate of different composites at sliding velocity of 1 m/s with different sliding distances: (a) 2000 m, (b) 2500 m.**



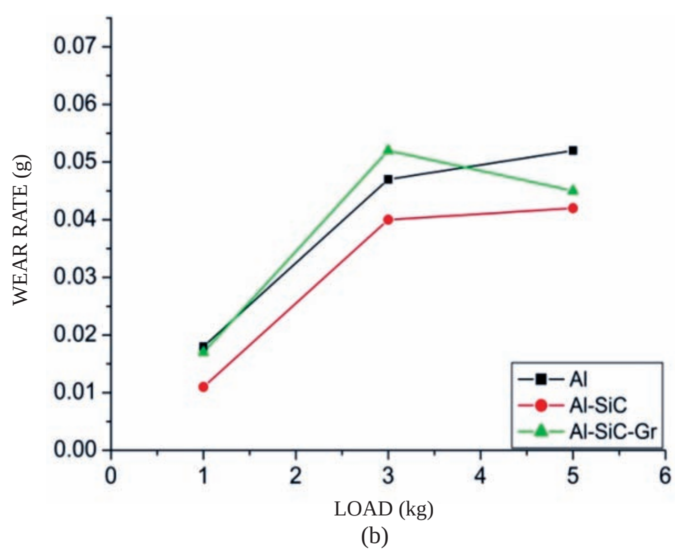
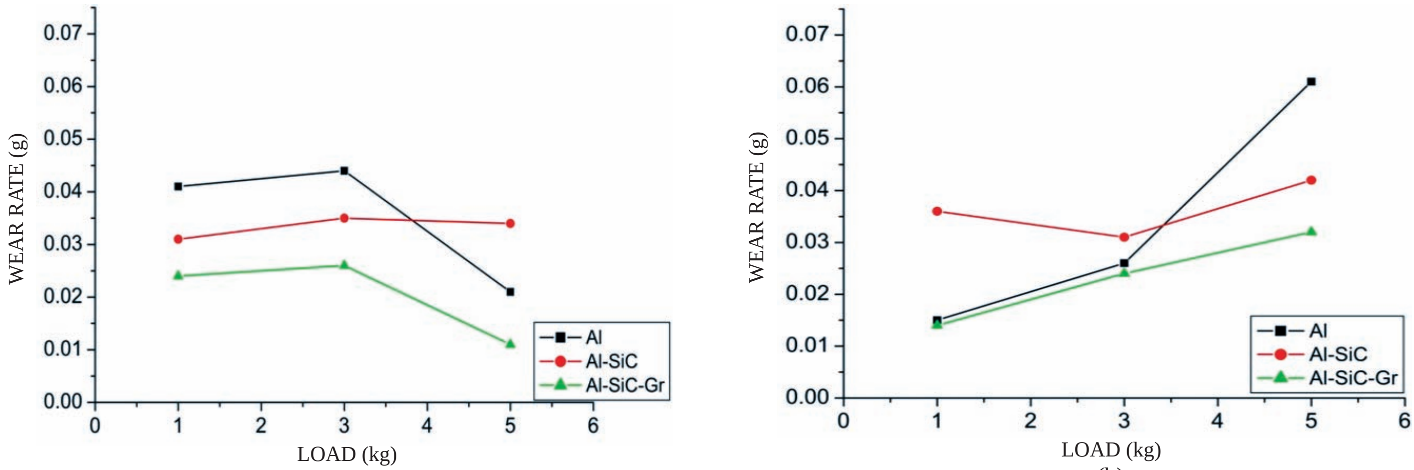
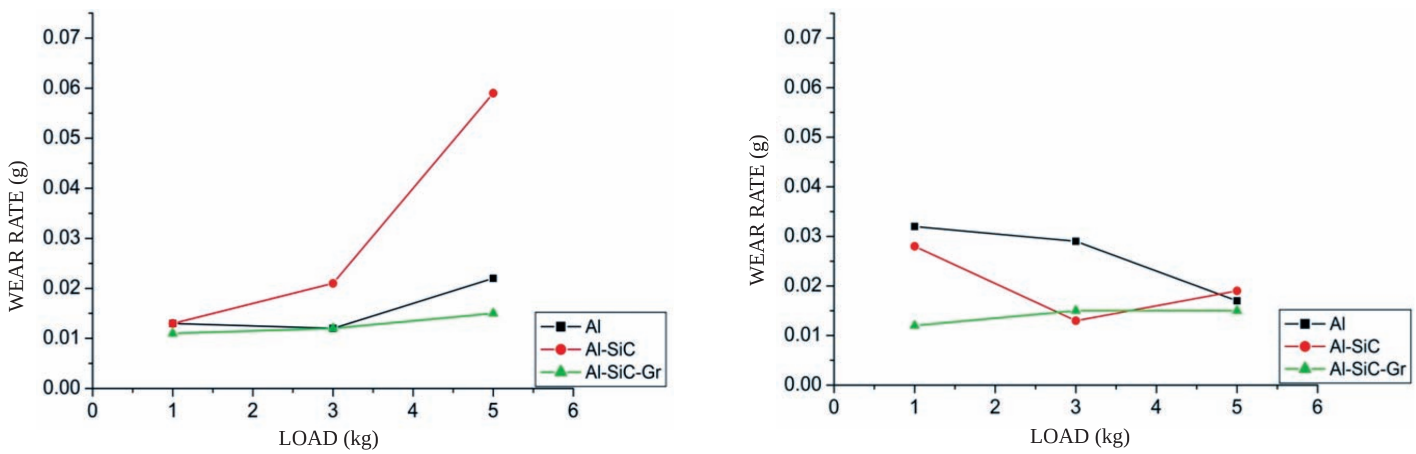




**Figure 7. Variation of wear rate of different composites at sliding velocity of 1.5 m/s with different sliding distances: (a) 2000 m, (b) 2500 m.**




(a) (b)

**Figure 8. Variation of wear rate of different composites at sliding velocity of 2 m/s with different sliding distances: (a) 2000 m, (b) 2500 m.**




(a) (b)

**Figure 9. Variation of wear rate of different composites at sliding velocity of 2.5 m/s with different sliding distances: (a) 2000 m, (b) 2500 m.**

### *3.3.1 Morphological Analysis of Worm Surfaces*

The morphologies of worm out surface of pin offer the clues to wear mechanism involved during sliding of the sample with a given load. SEM images were taken which helped to understand the mechanism.

Figures 10 and 11 show the SEM images of Al359-SiC and Al359-SiC-Gr materials at different sliding distance, velocity and load. Figure 10(a) shows that there is plastic deformation of asperities during the wear test which forms the abrasive and adhesive wear. The images also suggest the excessive material removal and cracks on the worm surface of the composite.

As the sliding distance increases, the material loss is in the form of craters which grows in the sliding direction, shown in Fig. 10(b). The material loss due to delamination and several micro cracks are also observed along the sliding direction. Crack propagation occurs due to Al359 matrix material. But the SiC and Gr reinforcement materials shows the good bonding characteristics.

At higher load, the ploughing action of the reinforcement followed by the plastic deformation is the result of wavy pattern shown in Fig. 10(c). The ploughing marks on the worm surfaces are deeper and cause in the form of cracks and grooves.

With the increase in speed and load, ploughing marks with speckle are formed on the worm pin surface. This is shown as wavy pattern in Fig. 10(c). With further increase in velocity, the ploughing marks grow deeper, shown in Fig. 10(d).The deeper ploughing marks on the worm surfaces cause the formation of cracks and grooves.

With the velocity of 2.5 m/s, the images in Fig. 10(e) shows the rippled pattern of grooves which are formed due to plastic deformation followed by the ploughing action of particles. The small particles are formed at the interface of the specimen and disc due to the crushing and grinding action.

Figure 10(f) shows the generation of cracks in the form of ploughing marks due to delamination of matrix material. Voids are also clearly seen on the surface of the composite. These voids will help the micro cracks to propagate. This occurs at high velocity and high sliding distances.

Figure 11 shows the SEM image of Al359-SiC-Gr composite for 3 kg load at different velocities and sliding distance. Images in Fig. 11(a) shows the wider and longer cracks along the sliding direction at the velocity of 1 m/s. The cracks grow in size due to the successive removal of the material. With the increase in sliding distance there are grooves

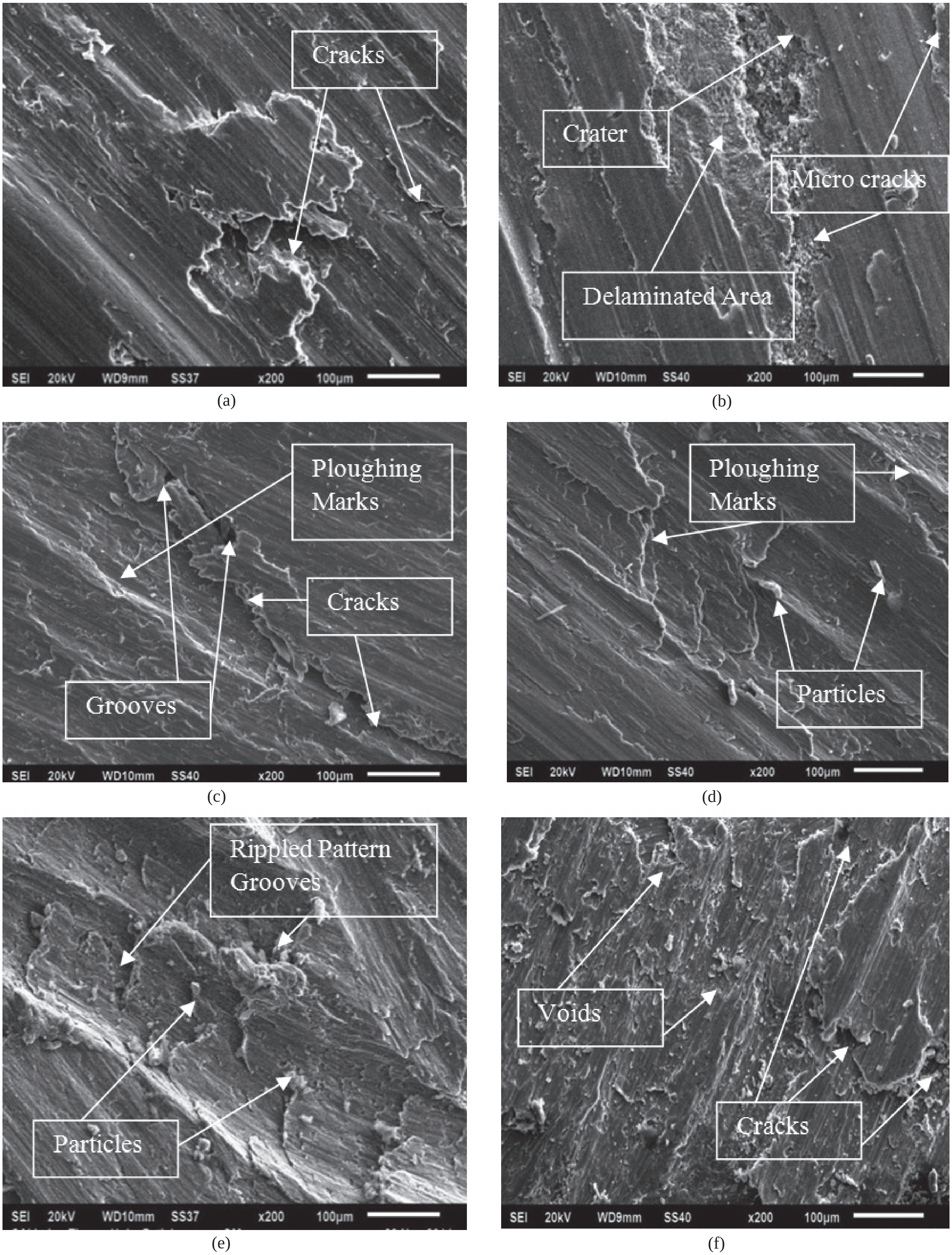



**Figure 10.** **SEM Image of worm pin surface of composite Al359-SiC at load 3kg for different velocities and sliding distances: (a) 1 m/s and 2000 m, (b) 1 m/s and 2500 m, (c) 1.5 m/s and 2500 m, (d) 2 m/s and 2500 m, (e) 2.5 m/s and 2000 m, and (f) 2.5 m/s and 2500 m.**

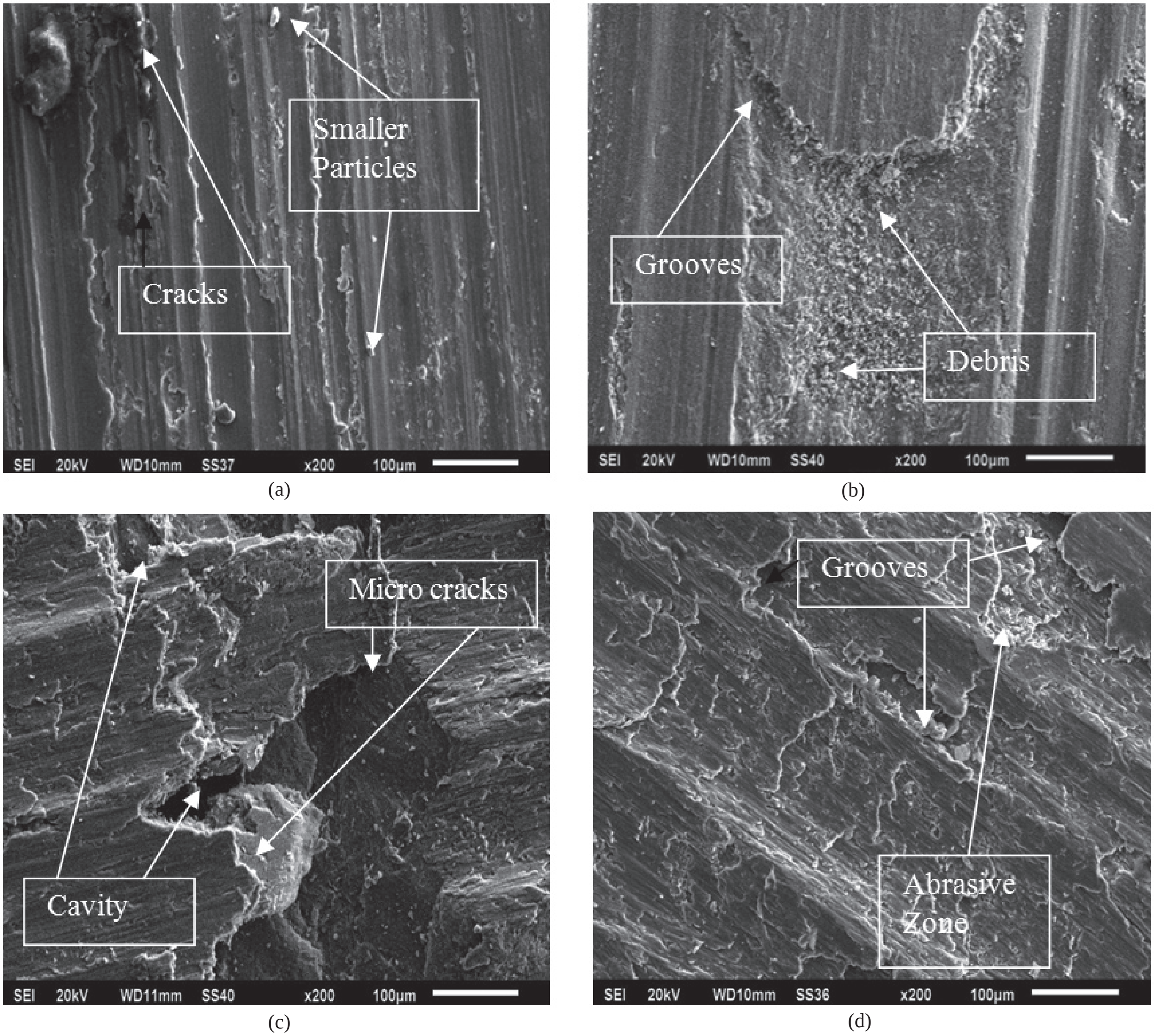



**Figure 11. SEM Image of worm pin surface of composite Al359-SiC-Gr at load 3kg for different velocities and sliding distances: (a) 1 m/s and 2000 m, (b) 1 m/s and 2500 m, (c) 2.5 m/s and 2000 m, and (d) 2.5 m/s and 2500 m.**

and debris formed on the surface, shown in Fig. 11(b). The worm surface revels that the grooves are finer at lower load as compared to higher load.

With an increase in velocity to 2.5 m/s, images in Fig. 11(c) shows the cavities and microcracks along the sliding direction due to tearing and delamination of surface material. With an increase in sliding distance at velocity of 2.5 m/s, images in Fig. 11 (d) shows the finer grooves and abrasive zones, which take place due to increase in temperature at the interface of pin and disc. The size of the grooves is larger at higher temperatures. The continuous formations of the grooves parallel to the sliding direction on the worm surface is probably due to the ploughing action.

## 4. CONCLUSIONS

The effect of silicon carbide and graphite reinforcements on the mechanical and wear properties of Al359 alloy were investigated in the present work.

i. The hardness of the aluminum metal matrix composite was improved with the addition of SiC and Gr particles in Al359 alloy. The hardness of the Al359-SiC composite is better than Al359-SiC-Gr composite as the addition of graphite material softens the composite.
ii. The ultimate tensile strength of the reinforced composite is better as compared to the base alloy. The SiC/Gr reinforced composite exhibits a superior ultimate tensile strength against SiC reinforced composite, because of good bonding of SiC/Gr with Al359 alloy which helps to withstand the higher load. The percentage elongation decreases continuously with the addition of the SiC or SiC/Gr reinforcement in matrix material. The reduction in ductility in SiC/Gr composite is due to the localized crack initiation and increased embrittlement effect on the composite due to local stress concentration.

iii. The addition of the SiC and Gr to the Al359 alloy improve the wear properties of the Al359 alloy. The wear of the Al359-SiC composite is considerably decreased with increase in load and speed upto 1.5 m/s at 2000 m sliding distance. Beyond the speed of 1.5 m/s, the wear of Al359-SiC composite increases. However, for higher loadings, sliding distances and velocities the wear rate of Al359-SiC-Gr composites is lesser as compared to Al359-SiC composites. It is due to the fact that the addition of graphite in the metal matrix acts as lubricant which reduces the wear rate at higher values.

iv. The SEM images of Al359-SiC and Al359-SiC-Gr composites found that there are larger size cracks, ploughing marks, grooves and voids present on the worn surfaces of component prepared from Al359-SiC composite material as compared to Al359-SiC-Gr material. The cavities, grooves and micro cracks are very fine in components prepared from Al359-SiC-Gr material.

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In the current study Shubhranshu Bansal was involved in the preparation of the specimens from metal matrix composite (MMC) casted sheets as per ASTM standards for tensile test and wear test. Thereafter the experiments were performed to investigate hardness, tensile and wear properties.

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In the current study J.S. Saini was involved in the literature review, material selection, purchasing and preparation of the metal matrix composite (MMC). Thereafter the sample sheets were casted using the prepared MMC.