Comparison of the mechanical and wear behaviour of aluminium alloy with homogeneous and functionally graded silicon nitride composites

1 Introduction

The development of metal matrix composites (MMCs) for lightweight materials with high strength, stiffness and heat resistance is a great deal in industrial applications. In MMCs, the composite materials reinforced with particles have received much attention and are characterised by improved mechanical properties and significant wear resistance compared to the monolithic alloys [1, 2]. The properties of such composites mainly depend on their reinforcement material, size and shape of the particles, their distribution and the interaction among them. The mechanical properties of the composite, like strength and stiffness, are found to be improved with the varying volume fraction of reinforcement content and particle size [3–5]. An increasing trend of hardness and impact strength with an increase in reinforcement content of silicon carbide (SiC) has also been observed [6]. Particulate-reinforced aluminium (Al) MMCs also exhibit a lower wear rate compared to Al alloys [7, 8]. Wahab et al. [9] investigated the characteristics of Al/aluminium nitride (AlN) MMCs and found that the distribution of AlN particles surrounding the Si phase has improved the hardness and wear properties of the composites. Al alloys reinforced with alumina (Al2O3) particles are prepared by the stir casting process, and it was found that increasing the particle volume fraction improved the wear resistance of the composite compared to the monolithic alloy [10]. The worn surfaces of Al composites reinforced with different weight percentages of aluminium diboride (AlB2) were examined by scanning electron microscopy to determine probable wear mechanisms [11].

Functionally graded Al MMCs have emerged as an advanced material for automotive and aerospace applications, as these materials can be tailored to meet specific applications due to their non-homogenous structural properties. The fabrication technique of functionally graded materials (FGMs) is a very important criterion, and various processing methods have been developed, such as powder metallurgy, laser cladding, vapour deposition and centrifugal casting [12, 13]. It is noted that centrifugal casting is the most commonly employed technique due to
its controlled compositional and microstructural gradient across its thickness [14]. The advantages of centrifugal casting for the production of structural components have been discussed, and it has been found that the centrifugal effect is useful in producing components with different specifications in different locations of the component [15]. Process parameters such as mold temperature, mold speed and melt stirring influence the gradient in the composites [16]. Al/SiC FGM fabricated at a low centrifugal speed (1500 rpm) results in a smooth gradient on the particle distribution, whereas FGM produced at a higher centrifugal speed (2000 rpm) shows a sharper gradient on the distribution of the particles [17]. The microstructural and mechanical properties and fracture behaviour of Al2O3 particle-reinforced FGM synthesised by the centrifugal process revealed a particle-rich external zone under the centrifugal force and segregation of some low bulk density Al2O3 particles at the inner zone of the cylinder. Mechanical properties are increased with increasing Al2O3 particles and the fracture surface showed a brittle nature at the outer zone [18]. Al/AlB2 functionally graded composites produced by centrifugal casting resulted in enhanced hardness of the external casting zones due to a greater volume fraction of reinforcement particle segregation [19]. In the fabrication of Al/SiC functionally graded MMCs, the particles are segregated as a gradient towards the outer periphery of the casting, enhancing high strength, hardness and wear resistance [20–22]. Analysis of variance is also done to investigate the significant parameter that affects the wear behaviour of those composites, and the results reveals that the particle-rich zone has a major effect on the dry sliding wear followed by the applied load.

Based on the above literature, it is observed that a large number of studies report the wear behaviour of homogeneous MMCs, but only very limited studies are available on the wear behaviour of such materials when fabricated as FGM. Therefore, it is significant to examine the wear characteristics of functionally graded composites. Hence, the purpose of the present work is to synthesise functionally graded Al/silicon nitride (Si3N4) MMCs and to compare its mechanical and three-body abrasive wear properties with unreinforced alloy and homogenous composite.

2 Synthesis of the alloy and the composites

The unreinforced Al alloy, homogeneous composite and the functionally graded composite are produced through conventional casting, liquid metallurgy and centrifugal casting methods, respectively. The LM25 Al alloy is chosen as the matrix as it has vast automotive applications, particularly in cylinder blocks and heads. Si3N4 particles also have many automotive applications due to their excellent wear resistance and, thus, are preferred as the reinforcement (10 wt %), with an average size of 40 μm. The alloy and reinforcement densities are 2.68 g cm−3 and 3.44 g cm−3, respectively. The Al alloy is taken in the graphite crucible and placed in the furnace (NVS plasto heaters and panels, Coimbatore, India) (Figure 1A) to melt in an inert argon gas atmosphere. The inert gas atmosphere provides degassing in the melting chamber which avoids oxide layer formation during melting of the Al alloy. Then, the molten metal is poured conventionally into the metallic die with dimensions 80 mm × 30 mm × 20 mm to obtain the unreinforced Al cast specimens.

The homogeneous composite is fabricated by incorporating the Si3N4 particles into the Al matrix. During melting of the Al alloy, the Si3N4 particles are preheated (300°C) simultaneously to remove the moisture content which promotes wettability between the molten metal and the reinforcement particles. These particles are added to the molten metal through the hopper made in the furnace. Then, these particles are stirred into the molten metal in a mechanical way through the stirrer at 250 rpm for 10 min with the aid of bevel gear transmission. Then, this liquid metal is poured into the die (80 mm × 30 mm × 20 mm) and allowed to solidify to obtain the homogeneous composite.

The functionally graded composite is fabricated through the liquid metallurgy process followed by the centrifugal casting process. On attaining the homogeneous molten metal from the liquid metallurgy process, the centrifugal casting die (NVS plasto heaters and panels, Coimbatore, India) (Figure 1B) is simultaneously preheated (350°C) to reduce the temperature difference between the molten metal and the inner surface of the die. On continuous rotation of the die at 1250 rpm with the help of a motor through belt and pulley transmission, the molten metal is poured into the die. Due to the rotation of the die, centrifugal and gravitational forces act on the molten metal containing the particles. The centrifugal force pushes the particles in the molten metal towards the wall. This centrifugal force is calculated using the equation $F_c = \frac{m \omega^2 r}{2}$ and the gravitational force is given by $mg$. The ratio of the centrifugal force to the gravitational force gives the gravitational coefficient ($G$) or $G$ number and is given by Equation (1)

$$G = \frac{\omega^2 r}{g},$$

where $\omega$ is the mold rotation rate (rad s−1), $r$ is the radius of the cast cylinder taken (m) and $g$ is the acceleration.
due to gravity (m s\(^{-2}\)). From this, it is known that the centrifugal force is \(G\) times higher than the gravitational force and, thus, the gravitational force is negligible. This clearly denotes that the \(G\) value increases as the centrifugal force increases. After pouring, the die is allowed to rotate until solidification is completed. Thus, a hollow cylindrical FGM with dimensions of 150 mm outer diameter, 150 mm length and 17 mm thickness is obtained (Figure 1C). The obtained alloy, homogeneous and FGM cast parts are subjected to machining for further investigation.

3 Microstructural characterisation

The machined specimens from the unreinforced alloy, homogeneous composite and FGM are subjected to microstructural investigation in a Zeiss Axiovert inverted metallurgical microscope (Carl Zeiss Axiovert25, Jena, Germany). In FGM, the outer, middle and inner surfaces that are at distances of 1 mm, 7 mm and 13 mm from the outer periphery are considered for structure evaluation. At all surfaces considered for examination, polishing is done using a linisher polisher and by emery sheets. The disc polisher is utilised for attaining a good surface finish on the specimen surfaces in the presence of diluted Al\(_2\)O\(_3\). Keller’s reagent is employed for etching the specimens before the examination.

4 Hardness and tensile test

The surfaces of the alloy, homogeneous composite and FGM are subject to a hardness test in Vickers hardness tester (Mitutoyo MVK-H11, New Delhi, India). In the FGM, the surfaces are taken as a function of radial distance from the outer periphery to measure the hardness imparted by the graded reinforcement particles across the thickness of the matrix, and, hence, the surfaces at distances of 1 mm, 7 mm and 13 mm from the outer periphery are considered for evaluation. Emery sheets are utilised for polishing all the specimen surfaces prior to testing to remove the scratches. The specimen is fixed over the base plate and indentation is produced using an indenter. A load of 100 gf is made on a certain point and applied for a time of 15 seconds. The indenter is released from its position and the diagonal length of the indentation is measured to obtain the hardness value. Five repeatability tests are performed on the same surface and the average value is taken as the hardness value.

The tensile (Tinius Olsen) specimens of the unreinforced alloy, homogeneous composite and sections (outer 1–7 mm and inner 7–13 mm) of FGM are machined as per ASTM standards and subjected to testing in the universal testing machine (UTM). The specimens are fixed in the pulling jaws of the tester and a load is applied on the specimens at a constant speed of 1 mm/min. The specimens fracture by the pulling action of the jaws and the observed tensile strength is noted. The specimens obtained after...
the tensile test are further subjected to fractural surface analysis to study the resulting failure modes.

5 Abrasive wear test

The surfaces of the alloy, homogeneous composite and FGM are studied for its abrasive wear performance using a dry abrasion tester (DUCOM instruments, Karnataka, India), shown in Figure 2A. The specimen before and after the abrasive wear test is shown in Figure 2B. As the FGM has particle gradation on the thickness of the casting, the three surfaces, such as outer, middle and inner, which are at distances of 1 mm, 7 mm and 13 mm from the outer periphery, respectively, are taken for abrasive wear test. The abrasion tester comprises a chlorobutyl rubber wheel with a diameter of 228 mm that acts as counter face against the specimen. The abrasive medium of silica sand AFS 50/70 (Figure 3) is loaded in the hopper and falls continuously at the rate of 354 g min⁻¹ between the specimen and the rubber wheel, that is used for making abrasions on the specimen surfaces. The abrasive medium that falls down after abrading the specimen is received in the collector placed at the bottom of the dry abrasion tester. Prior to the test, all the specimens (75 mm × 25 mm × 12 mm) are measured for their mass, utilising an electronic weighing balance with an accuracy of 0.1 mg. The specimen to be tested is fixed in the specimen holder and the load is applied through the lever mechanism to keep the specimen in continuous contact with the rubber wheel. The required weights are placed on the loading pan hanging on the lever. The initial load that acts by the lever without any weights placed on the loading pan is 2.2 kg. The lever ratio is 1:2.4 and, therefore, the total load that acts on the specimen for placing 1 kg is 2.2 + 1 × 2.4 = 4.6 kg. The load impresses the specimen towards the rotating rubber wheel and against the abrasive medium. The specimens are tested at different loads (33, 45, 57, 68 and 80 N) at a constant speed of 200 rpm to study the significance of load on wear behaviour; the speeds (100, 125, 150, 175 and 200 rpm) are also varied for the specimens at constant load to study the effect of speed on the abrasive wear rate. All the tests are performed for a constant time of 7 min. After the test, the specimens are again measured for their mass to determine the mass loss, and the abrasion wear rate is computed using Equation (2).

\[ W_a = \frac{\Delta G}{dMS}, \]  

where \( W_a \) is the abrasion wear rate (mm³ Nm⁻¹), \( \Delta G \) is mass loss (g), \( d \) is density (g mm⁻³), \( M \) is the applied load (N) and \( S \) is the sliding distance (m).

6 Results and discussion

These sections detail the microstructural investigation, hardness, tensile behaviour, wear performance of the alloy, homogeneous composite and functionally graded composite.
6.1 Microstructural investigation of the alloy and composites

The Si₃N₄ particles used for the fabrication of homogeneous composite and FGM are observed using a scanning electron microscope (SEM), and are shown in Figure 4.

The observed microstructures of the alloy, homogeneous composite and the FGM (outer, middle and inner surfaces) are shown in Figure 5A–E. The microstructure of the unreinforced Al alloy (Figure 5A) reveals a continuous matrix network. The homogenous composite (Figure 5B) displays the uniform dispersion of the Si₃N₄ particles in the matrix, and this is due to mechanical stirring of the reinforcement particles in the molten metal during the liquid metallurgy process. The microstructure of the outer surface of the FGM (Figure 5C) is observed with a particle-enriched zone due to the centrifugal effect which takes place during the casting process. The centrifugal force involved in the process causes the reinforcement particles to move away from the axis of rotation and forms a particle-rich region at the exterior areas of the casting.

Figure 4: SEM micrograph of Si₃N₄ particles.

Figure 5: Microstructures of (A) unreinforced Al alloy (B) homogeneous composite (C) FGM – outer surface (D) FGM – middle surface and (E) FGM – inner surface.
This surface reveals no voids and discontinuities in the surface which is evidence that good bonding has occurred between the matrix and the reinforcement, and the same behaviour is observed [23]. The middle surface (Figure 5D) of the FGM shows the less-reinforced region compared to the exterior particle-rich region, and the inner region (Figure 5E) is particle-depleted compared to the middle region. Thus, it is observed that particle segregation is reduced towards the axis of rotation under the action of the centrifugal force and fewer particles occupy the inner surface. The reinforcement particles which are advancing towards the exterior regions under the centrifugal force are restricted by a few gaseous bubbles formed during the casting process. Thus, a few particles are carried and deposited on the inner region by the gas bubbles and this might be the reason for observing very few reinforcement particles, forming a particle-depleted region, and the same phenomenon is observed [24].

6.2 Hardness of the alloy and composites

The hardness of the unreinforced alloy, homogeneous composite and the surfaces (outer, middle and inner) of the FGM are presented in Figure 6. This hardness test is performed to know the hardness that has been imparted by the reinforcement particles to the composite. The hardness of the Al alloy is found to be the lowest (86 HV) and this is due to the softer matrix surface which is unable to resist the deformation caused by the indenter. The inner surface of the FGM shows higher hardness (103 HV) than the unreinforced alloy as this is due to the concentration of a few Si₃N₄ particles. The middle surface of the FGM has a higher concentration of reinforcement than the inner surface and, hence, higher hardness (128 HV) is achieved at this surface. The homogeneous composite exhibits better hardness (137 HV) than the aforesaid three surfaces, as this is due to the uniform distribution of reinforcement particles in the surface. These particles resist crack formation due to good bonding and, therefore, higher hardness is obtained. The exterior area of the FGM is found to be harder (146 HV) among all the surfaces tested, which show that hard Si₃N₄ particle segregation is more at this region. These hard, protruded particles diminish the matrix contact area with the indenter and, therefore, exhibit less indentation, which results in higher hardness. From the hardness results, it is understood that the hard Si₃N₄ particles strengthens the matrix and reduce the deformation to a greater extent, and the same mechanism is observed [25].

6.3 Tensile strength and fractural surface analysis of the alloy and composites

The tensile behaviour of the alloy, homogeneous composite and the FGM (outer and inner sections) are shown in Figure 7. The homogeneous composite exhibits higher tensile strength (212 MPa) among all the specimens tested and this is due to the uniformly distributed Si₃N₄ particles in the matrix. These particles avoid the dislocation motion and the initiation of cracks due to good interfacial bonding between the matrix and the reinforcement, while the same behaviour is observed [26]. The load acting in the tensile test is transferred from the matrix alloy to the reinforcement particles, which act as the load-bearing elements, and delays the breaking of the specimen. The outer section of the FGM shows a decrease in tensile strength (198 MPa) because this section has a gradation of the reinforcement particles across the thickness of the casting. The outer section contains a particle-rich region and a particle-transition zone. Thus, this section cannot bear the load uniformly like the homogeneous composite and, therefore, the deformation of the specimen takes place non-uniformly, which results in reduced tensile strength. The inner section of the FGM is further reduced in its

![Figure 6: Hardness of the alloy and the composite surfaces.](image1)

![Figure 7: Tensile strength of the alloy and the composites.](image2)
N. Radhika: Comparison of the mechanical and wear behaviour of aluminium alloy

6.4 Effect of load on the abrasive behaviour of the alloy and composite

The change in load (from 33 N to 80 N) at constant speed of 200 rpm for a time of 7 min shows an increase in the wear rate on the surfaces of the alloy, homogeneous composite and FGM (Figure 9). During the abrasive wear test, the sand particles that flow continuously between the rubber wheel and the specimen are indented to abrade the specimen surface at different conditions. The three zones involved in the abrasion test are the entrance zone,

![Figure 8: Fractographs of tensile specimens (A) unreinforced alloy (B) homogeneous composite (C) FGM – outer section and (D) FGM – inner section.](image)

![Figure 9: Effect of load on the alloy and composite surfaces at a constant speed of 200 rpm.](image)
the middle zone and the exit zone. The action of a low load (33 N) on all the surfaces shows a low wear rate as this is due to less interacting pressure of the rubber wheel with the specimen. The abrasive particles are free to slide and roll between the surfaces, which result in a reduced effect of producing ploughing action on the specimen. On increasing the load to 45 N, the abrasive sand particles’ behaviour varies as the physical pressure increases at the interface. Therefore, these sand particles experience a crushing effect at the middle zone where the pressure is the maximum between the specimen and the counter face rubber wheel. This crushing effect produces cutting and ploughing actions on the specimen surface. When the load is increased to 57 N, the abrasive particles are crushed at the entrance zone and produce the ploughing effect earlier, which causes the material to deteriorate further. On further increasing the load to 68 N, more interfacial pressure causes the abrasive medium to reduce in its size and utilises more of its energy in producing deeper ploughing and grooving actions on the surfaces. When a high load of 80 N is introduced, the tribosystem starts vibrating and causes large uncertainties in the specimen surface; meanwhile, the abrading action of the compressed sand particles gets severe and produces more material removal. Thus, it is observed that the wear rate increases with an increase in load on all the surfaces due to the increased physical contact of the specimen with the rubber wheel and the abrasive particles, and the same behaviour is observed [29]. This allows more abrasive particles to penetrate on the surface of the specimen, resulting in more material loss.

Even though the wear rate is found to be increased at all the surfaces for an increase in load, the unreinforced alloy shows a higher order of wear rate and the outer surface of the FGM shows a lower order of wear rate. All the surfaces responded uniquely to the abrasion depending upon their surface properties and the concentration of Si₃N₄ reinforcement particles. The Al alloy carries a softer matrix region which tends to abrade easily by the abrasive medium and, therefore, more material removal is observed at all load conditions. The inner surface of the FGM with the particle-depleted region shows a wear rate nearer and lesser to the unreinforced Al alloy. This surface gets affected by the abrading action as this surface also contains a major portion of the softer matrix alloy. The middle surface of the FGM shows some improved wear resistance than the inner surface, which is evident as this surface is particle-rich than the inner region. Thus, the severity of abrasion is reduced at this surface which results in a lower order of wear rate. The homogeneous composite exhibits less wear rate than the unreinforced alloy and the surfaces (middle and inner) of FGM. The uniformly distributed reinforcement particles strengthen the matrix surface and limit the matrix contact area with the rubber wheel and the abrasive particles. Thus, the reinforcement particles protect the matrix from severe wear and result in a lower wear rate. The outer surface of the FGM shows higher wear resistance and less material removal due to its harder surface. This is owing to more reinforcement particle formation at the surface which protects the matrix area, and these protruded reinforcement particles deflect the moving abrasive sand particles towards the soft rubber wheel. The non-removal of the reinforcement particles from the matrix reveals that there is good interfacial bonding at the interface between the matrix and reinforcement which results in minimum wear rate.

### 6.5 Effect of speed on the abrasive wear behaviour of the alloy and composite

The increase in speed on the alloy, composite and FGM surfaces causes a decrease in the wear rate (Figure 10). At a low speed of 100 rpm, the rotating rubber wheel makes more surface contact against the abrasive medium and the specimen surface. Meanwhile, the abrading action of the compressed sand particles gets severe and produces more material removal. Thus, it is observed that the wear rate increases with an increase in load on all the surfaces due to the increased physical contact of the specimen with the rubber wheel and the abrasive particles, and the same behaviour is observed [29]. This allows more abrasive particles to penetrate on the surface of the specimen, resulting in more material loss.

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FIGURE 10: Effect of speed on the alloy and composite surfaces at a constant load of 57 N.

![Figure 10: Effect of speed on the alloy and composite surfaces at a constant load of 57 N.](image-url)
with the abrasive medium and a reduced ploughing effect of the sand particles results in decreased wear rate. The abrasive wear rate decreases with respect to an increase in the speed of the rubber wheel and is also related to the contact time of the rubber wheel with the specimen when the speed changes. Thus it is concluded that surfaces at different distances of the FGM and the homogenous composite show less wear rate than the unreinforced alloy at all speed conditions at constant load.

6.6 Scanning electron microscopy analysis

The worn-out surfaces obtained from the abrasion wear test are subjected to SEM analysis (Figures 11A–E and 12A–E) to observe the wear mechanisms caused by the abrasive medium. The surfaces worn at different loads (Figure 11A–E) are examined due to their significance on the wear behaviour of the alloy and the composites. The particle-rich outer surface, which is at the distance of 1 mm from the outer periphery of the FGM abraded at different loads, is shown in Figure 11A–C. The surface worn at a low load of 33 N (Figure 11A) reveals fine scratches with less material removal due to low physical pressure. The surface worn at a load of 57 N (Figure 11B) reveals long shallow grooves with slightly more material removal due to the increased pressure developed at the interface. On the high load (80 N) condition (Figure 11C), cutting action of the abrasive medium is observed in fewer regions because this particle-rich zone obstructs the abrading action of the silica sand particles and exhibits high wear resistance even at the high load condition, and the same trend is attained [31]. When this high load (80 N) is acting on the homogeneous composite surface (Figure 11D), pitting action of the sand medium and more material removal is observed. This homogeneous composite is composed of both the softer matrix region and the harder reinforcement region. Thus, sand particles abrade the softer matrix area when it contacts with it and are deflected towards the rubber wheel when contacting with the reinforcement particles. Therefore, more material removal is observed compared to the particle-enriched outer region of the

![Figure 11: SEM micrographs of (A) outer FGM – 33 N (B) outer FGM – 57 N (C) outer FGM – 80 N (D) homogeneous composite at 80 N and (E) unreinforced alloy at 80 N.](image-url)
FGM at this load condition. When the unreinforced alloy is subjected to the same load of 80 N (Figure 11E), severe abrasion with deeper grooves is observed as a result of easy penetration of the sliding abrasive particles on this surface. The sand particles which penetrate the surface contact with the rotating rubber wheel, and on rotation, these particles tend to slide on the surface of the specimen and produce continuous grooves on the surface.

The surfaces abraded at different speeds are also considered for SEM examination (Figure 12A–E) to study the effect of speeds on the wear resistance of the unreinforced alloy and the composites. The middle surface, which is at the distance of 7 mm from the outer periphery of the FGM and abraded at different speeds of 100 rpm, 150 rpm and 200 rpm, is shown in Figure 12A–C. The effect of the low speed rotating rubber wheel (Figure 12A) enables the silica sand particles to embed and produce repeated contact with the specimen, which results in eroding the surface further. In this condition, the specimen surface has more time to interact with the rubber wheel and sand particles and, therefore, more material removal is observed. As the speed is increased to 150 rpm on this surface (Figure 12B), eroding action is substantially reduced due to less embedding of the silica sand particles on the rubber wheel and to less surface contact. This surface reveals less ploughing and cutting actions of the sand particles. When the wheel is rotated at a high speed of 200 rpm (Figure 12C), the sand particles experience centrifugal force and do not interact much with the specimen. Thus, the surface reveals fewer cutting and pitting actions and results in less material removal. At the same speed (200 rpm), the homogeneous composite surface (Figure 12D) reveals less surface damage with less pitting, and this is due to a larger portion of the matrix covered by the uniformly distributed reinforcement particles. Thus, the reinforcement particles decrease the matrix and rubber wheel contact, which eventually reduces the wear rate. The unreinforced alloy (Figure 12E) reveals greater surface damage than the middle surface of

Figure 12: SEM micrographs of (A) middle FGM – 100 rpm (B) middle FGM – 150 rpm (C) middle FGM – 200 rpm (D) homogeneous composite at 200 rpm and (E) unreinforced alloy at 200 rpm.
the FGM and the surface of the homogeneous composite at the same speed of 200 rpm. Due to the throwing effect of the rubber wheel at this speed, a lower number of particles are involved in the abrading action and that causes severe wear on the softer unreinforced alloy surface and results in the formation of many grooves.

7 Conclusion

The unreinforced alloy, homogeneous composite and functionally graded composite have successfully been fabricated. The homogeneous composite is observed with uniformly distributed Si₃N₄ particles and the functionally graded composite is observed with a particle-enriched outer region and a particle-depleted inner region. The outer surface of the FGM is found to have higher hardness, followed by the homogeneous composite, middle and inner surfaces of the FGM, and the unreinforced alloy. Tensile strength is seen to be high in the homogeneous composite due to its uniform deformation. The increase in load significantly increases the abrasive wear rate and the increase in speed declines the wear rate on all the specimen surfaces. The outer surface of the particle-enriched functionally graded composite exhibits higher wear resistance, followed by the surface of the homogeneous composite, among all the surfaces. Scanning electron microscopy analysis shows a few scratches with less material removal on the outer region of the functionally graded composite even under high load conditions. The outer surface of functionally graded composite is observed with overall better performance than the homogeneous composite and the unreinforced Al alloy. Therefore, these FGMs can be used as a potential alternative for the replacement of Al alloy, Al homogenous composites and other alloy-made components in several automotive and other fields which lack in their mechanical and wear performances.

Acknowledgments: The authors are truly thankful to the Department of Science and Technology for funding (Grant No. SR/S3/MERC/0116/2012).

References


