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Some Studies on Wear and Corrosion Properties of Al5083/Al_2O_3/Graphite Hybrid Composites

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ABSTRACT

Advanced technology has put an increasing demand on the composite materials, particularly more in the areas of dynamic structures. Among the several types of aluminum alloys being used, Al5000 series are widely used in marine and aerospace applications due to their superior corrosion resistance, excellent formability and good welding characteristics. Al5083, a non-heat treatable high Mg-Al wrought alloy, is extensively used for the marine applications. Hence, an attempt has been made in the proposed work to study the effects of Graphite (Gr) and Aluminium oxide (Al_2O_3) on aluminum hybrid composites involving both hard and soft reinforcements on wear and corrosion properties. The synthesis of hybrid metal matrix composite used in the present study has been carried out by stir casting method. The effects of reinforcement, time duration and particle size on prepared samples of composites have been studied on slurry erosive wear. The static and accelerated corrosion tests have been performed and the microhardness of the developed composites was also investigated. The experimental results on Al5083-Al_2O_3-Gr hybrid composites revealed that the addition of reinforcement improves the hardness and reduces corrosion and wear rates.

Keywords: Al5083-Al_2O_3-Gr Hybrid Composites; Microhardness; Slurry Erosive Wear; Corrosion

1. Introduction

Aluminum based metal matrix composites (AMCs) are of lightweight high performance material systems. Among the several types of aluminum alloys being used, Al5000 series are extensively used in marine and aerospace applications because of their superior corrosion resistance, excellent formability and good welding characteristics. Al5000 series are broadly used for the construction of ship buildings/structures; however due to low strength and poor wear resistance the application of this series is limited. The addition of reinforcement to aluminum matrix drastically alters mechanical, tribological and corrosion properties. The reinforcement in AMCs could be in the form of continuous/discontinuous fibers, whiskers or particulates. The hybrid composites have been prepared by incorporating different types of fibers into a single matrix. Due to two or more fibers in the hybrid composite, the advantages of one type of fiber could complement with what are lacking in the other. The properties of hybrid composite primarily depend upon fiber content, length of individual fibers, orientation, extent of intermingling of fibers, fiber to matrix bonding and arrangement of the fibers.

Several authors have reported on slurry erosive wear and corrosion behavior of metal matrix composites. The slurry erosion can be defined as a type of wear or loss of material experienced by a component, when exposed to high velocity stream of slurry mixture of solid particles in a liquid [1], which is a serious problem in many engineering applications. When the components are entrained in such environments, the design life of the component is significantly reduced, resulting in huge economic losses. The areas in which components suffering from this problem include, mining machinery components, hydraulic transport of solids in pipelines, marine, oil gas and power generation industries [2-5].

Caron *et al.* [6] studied the slurry erosive wear behavior of 5083-Al_2O_3 composites and found that slurry erosive wear of composites increases with increase in aluminium oxide (Al_2O_3) content in the matrix material. Ramachandra and Radhakrishna [7] reported that the slurry erosive wear resistance increases with increased silicon carbide (SiC) content in Al/SiC composites. It was observed that the formation of passive layers on sur-

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face of slurry erosive specimens decreases wear loss by forming protective layers against the impact of slurry. Ramachandra and Radhakrishna also [8] analyzed the slurry erosive wear behavior of Al-12wt%Si alloy reinforced with fly ash composites and it was noticed that the flyash enhanced the slurry erosion wear resistance of the developed composites. Li *et al.* [9] have investigated the effect of time duration on slurry erosive wear of aluminum alloy and found that the wear rate increases with increase in test time duration.

Setsuo *et al.* [10] discussed the effect of impact velocity and sand concentration on erosive wear of eutectic alloys and observed that increase in sand concentration and impact velocity increases the wear rate. Candan and Bilgic [11] in their study reported that the addition of SiC particles to Al-4wt%Mg could improve the corrosion resistance of the composites over that of the base alloy in 3.5 wt% NaCl solution. On the other hand, Kiourtsidis and Skolianos [12] noted that although SiC is not directly responsible for the enhanced pitting corrosion of aluminum AA2024 composites in 3.5 wt% NaCl solutions, intermetallic phases surrounding the particles initiated pitting attack of the material.

Saxena *et al.* [13] explained the inferior seawater corrosion resistance behaviour of a 4xx.x cast aluminum alloy (LM-13 alloy), containing 3 wt% graphite particles, to galvanic corrosion between the cathodic graphite particles and active aluminum matrix. However, the 4xx.x cast aluminum-graphite composites displayed excellent corrosion resistance in SAE-40 engine oil at 150˚C. Nath and Namboodhiri [14] observed that Al-Mg and Al-Cu composites exhibit superior corrosion resistance than the composites reinforced with mica particles. The inferior corrosion resistance of the mica-reinforced composites was attributed to the distortion of the passive protective films and provision of pit nucleation sites by the mica particles. Nunes and Ramanathan [15] studied the corrosion behaviour of alumina-aluminium and SiC-Al in sodium chloride solution. Immersion and anodic polarization corrosion tests have been carried out and these composites exhibit lower corrosion resistance when compared to matrix alloy. The formations of pits in the matrix near the particle matrix interface have been observed by Paciej and Agarwala [16], which lead to the pull out of the particle.

Mclnyre *et al.* [17] in their research reported that the precipitation behavior and consequently the pitting susceptibility of heat treatable matrix alloys vary in the presence of SiC particles. Ahmad and Aleem [18] described the corrosion behavior of aluminum metal matrix composites in salt water. Al6013-20%SiC composite showed good resistance to corrosion in salt spray tests. It was reported by Greene and Mansfield [19] that casting defects, the particle size of the reinforcing phase, the processing route, the amount of alloying element present in the matrix alloy are the factors which determine the pitting corrosion behavior of MMCs. Tazaskoma *et al.* [20] found that the pitting susceptibility was same for the composite and the matrix alloy except for the 2024 alloy. The general corrosion of these alloys was affected more by the presence of oxygen than by the silicon carbide phase.

Although there are several studies reported in the literatures on wear behavior of aluminum metal matrix composites, no published work has been seen on the effect of reinforcement on erosive wear of Al5000 series MMCs. Hence, the present research work has been undertaken, with an objective to explore the use of aluminium oxide (Al_2O_3) with graphite (Gr) as reinforcing materials in Al5083 alloy.

2. Experimental Details

The base matrix is used in the present investigation is Al5083 alloy; the chemical composition is presented in **Table 1**. The base alloy was melted in the electric furnace and different castings were taken. Aluminium oxide (Al_2O_3) and graphite (Gr) are used as reinforcing materials in Al5083 alloy. Aluminium oxide is chosen as reinforcement owing to its high hardness and low co-efficient of thermal expansion, highly wear resistant, good mechanical properties, high temperature strength and thermal shock resistance. Graphite is a solid lubricant, which permits high corrosion resistance and almost reduces the friction coefficient, disintegrates the wear products, accelerates heat abstraction and increases seizure resistance. The properties of aluminium oxide (Al_2O_3) and graphite (Gr) are summarized in **Tables 2** and **3** respectively. The different types of hybrid composites have been prepared with three different compositions. The designations of the proposed composites are given in **Table 4**. The reinforcements aluminium oxide (Al_2O_3) and graphite (Gr) of partical size in the range of 20 - 60 µm are varied in the range of 3 wt% to 6 wt% of base alloy.

The synthesis of hybrid metal matrix composites used in the present study has been carried out by stir casting method. Al5083 alloys in the form of ingots were used for the preparation of specimens. The cleaned metal ingots were then melted to the desired super heating temperature of 800˚C in the graphite crucibles under a cover of flux layer in order to minimize the oxidation of molten metal. A three-phase electrical resistance furnace with temperature controlling device was used for the melting purpose. The graphite (Gr) and aluminum oxide (Al_2O_3) particulates preheated to around 500˚C and added to molten metal and then stirred continuously by a mechanical stirrer at 720˚C. The stirring time maintained in

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Table 1. Chemical composition of base metal Al5083 (weight percentage).

Si	Cu	Fe	Mg	Mn	Zn	Ti	Cr	Al
0.4%	0.1%	0.4%	4.0% - 4.9%	0.4% - 1.0%	0.25%	0.15%	0.05% - 0.25%	Balance

Table 2. Properties of aluminium oxide.

Density (g/cm^3)	Modulus of elasticity (GPa)	Poisson's ratio	Tensile strength (MPa)	Fracture toughness (MPa$\sqrt{m}$)	Coefficient of thermal expansion (10^{-6}(˚C)$^{-1}$)	Thermal conductivity (W/m-k)
3.9	380	0.22	282 - 551	4.2 - 5.9	7.4	39

Table 3. Properties of graphite.

Bulk density	1.3 - 1.95 g/cc
Porosity	0.7% - 53%
Modulus of elasticity	8 - 15 GPa
Compressive strength	20 - 200 MPa
Coefficient of thermal expansion	1.2 - 8.2 × 10^{-6} C
Thermal conductivity	25 - 470 W/m˚K
Specific heat capacity	710 - 8130 J/m˚K
Electrical resistivity	5 × 10^{-6} - 30 × 10^{-6} Ω·m

Table 4. Designation of hybrid composites.

Composites	Composition
C1	Al5083 + 3wt%Al_2O_3 + 3wt%Gr
C2	Al5083 + 6wt%Al_2O_3 + 3wt%Gr
C3	Al5083 + 3wt%Al_2O_3 + 6wt%Gr

between 5 and 8 minutes and the impeller speed was kept constant at 250 rpm. The melt with the reinforced particulates was poured into the dried, coated, cylindrical permanent metallic mould of 80 mm in diameter and 175 mm height and the pouring temperature was maintained around 680˚C. The melt was then allowed to solidify in the moulds. For the purpose of comparison, the base alloy was cast under similar processing conditions.

The hardness, slurry erosive wear and corrosion resistance tests of the prepared cast matrix and the hybrid composite were carried out as per ASTM standards. The hardness measurements were made using Vickers micro hardness tester. The slurry erosive behavior of Al5083 base alloy and the developed hybrid composites was studied using slurry wear tester. The slurry was prepared by adding 20 liters of normal water with 700 gms of sodium chloride (NaCl). The sand particles of size up to 650 µm were added in the slurry at the rate of 100 gms/ltr. The specimens were cleaned with acetone before and after testing and the corresponding loss of weight was measured using a digital weight balance (0.001 gm accuracy). The immersion tests were carried out for base alloy as well as developed hybrid composites as per ASTM G31 test procedure. The polished samples of Al5083 matrix alloy and its hybrid composites were immersed in 3.5% NaCl solution for duration of 60 days. The polarization studies were conducted and the standard reference was calomel electrode while the working electrode was the cast composite prepared as per ASTM standard G 69 - 81. The potentiodynamic measurements were made at room temperature. The salt spray test was conducted in salt spray chamber. The specimens were subjected to salt spray test for 20 hours. The weight loss was measured for every four hours. At the end of the test, the specimens were taken out of the chamber, rinsed thoroughly and then dried. The dried specimens were then weighed.

3. Results and Discussion

Figure 1 shows the scanning electron micrograph (SEM) photographs of Al_2O_3 and graphite as reinforcements. Al_2O_3 particles are found to be uniform and spherical in shape with size ranges from 10 - 30 µm. On the other hand, the graphite particles are angular in shape with sharp edges. The largest particle size appears to be around 50 - 60 µm. The graphite powder appears to have a flaky morphology as depicted in **Figure 1**. **Figure 2** illustrates the optical micrographs of Al5083 base alloy and Al5083-Gr-Al_2O_3 hybrid composites. It is observed that the distribution of Gr and Al_2O_3 particles in base matrix alloy is fairly uniform. The microphotographs also reveal an excellent bond between the matrix alloy and the reinforcement particles. The microstructure showed the fine particles dispersed along the grain boundary in the matrix of aluminium solution and for alloy it has fine precipitates of alloying elements uniformly dispersed in Al solid solution. The analysis of the results and the influence of various parameters on the properties are summarized in the following sections.

3.1. Microhardness Test

The experimental results of microhardness are presented

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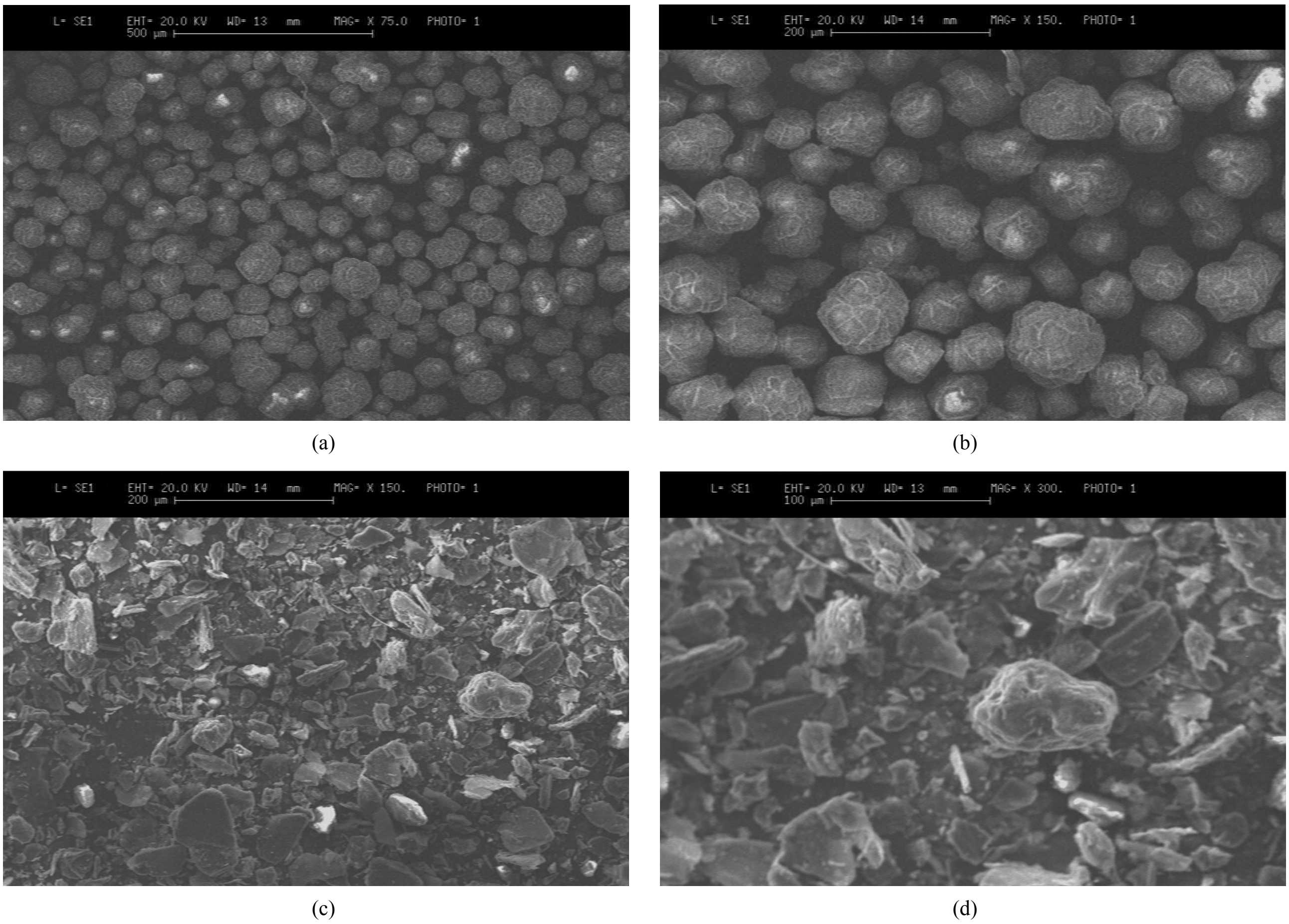

Figure 1. Scanning electron micrographs of Al_2O_3 (a) and (b) and graphite (c) and (d).

in **Figure 3**. It is observed that there is a significant improvement in microhardness with addition of graphite (Gr) and aluminium oxide (Al_2O_3) particles in matrix alloy. An improvement of hardness is noticed in Al5083 + 3%Gr + 6%Al_2O_3, Al5083 + 6%Gr + 3%Al_2O_3 and Al5083 + 3%Gr + 3%Al_2O_3 hybrid composites. Further, there is a large difference in co-efficient of thermal expansion of Al5083 alloy and reinforcement particles leading to thermal mismatch between matrix alloy and reinforcement. This factor increases the density of dislocations in the material resulting in higher hardness value. The higher hardness is always associated with lower porosity of metal matrix composites.

3.2. Slurry Erosive Wear Analysis

The effect of reinforcement on slurry erosive wear resistance of developed hybrid composites is shown in **Figure 4**. There is a significant reduction in the slurry erosive wear rate of the developed composites with increased percentage weight of reinforcement. This can be attributed to the higher hardness and excellent corrosion and wear resistance of the composite. In general, higher the hardness better the erosive wear resistance of the materials. The results revealed that a slurry wear resistance increases with both Al_2O_3 and Gr content. When compared to base metal, the composite with 3%Al_2O_3 + 6%Gr show less weight loss. The presence of Gr particles effectively improves the wear resistance. The decrease in weight loss may be due to the formation of a passive layer on the surface of the specimen acts as a protective layer. This passive layer, as long as it is not broken, protects the matrix from direct contact with the slurry and lowers the rate of weight loss.

Figure 5 illustrates the effect of impinging particle size on developed composites. As the particle size increases, the wear rate of composites also increases. Increased mass loss with increase in silica sand concentration in slurry is because, the small sized particles tend to deviate near the surface of the target material due to their lower mass and lower impact energy. Further, at constant slurry concentration, the number of particles available at the surface of the target material is higher in case of small sized particles when compared to large sized particles because of retardation after impact and inters collision among them.

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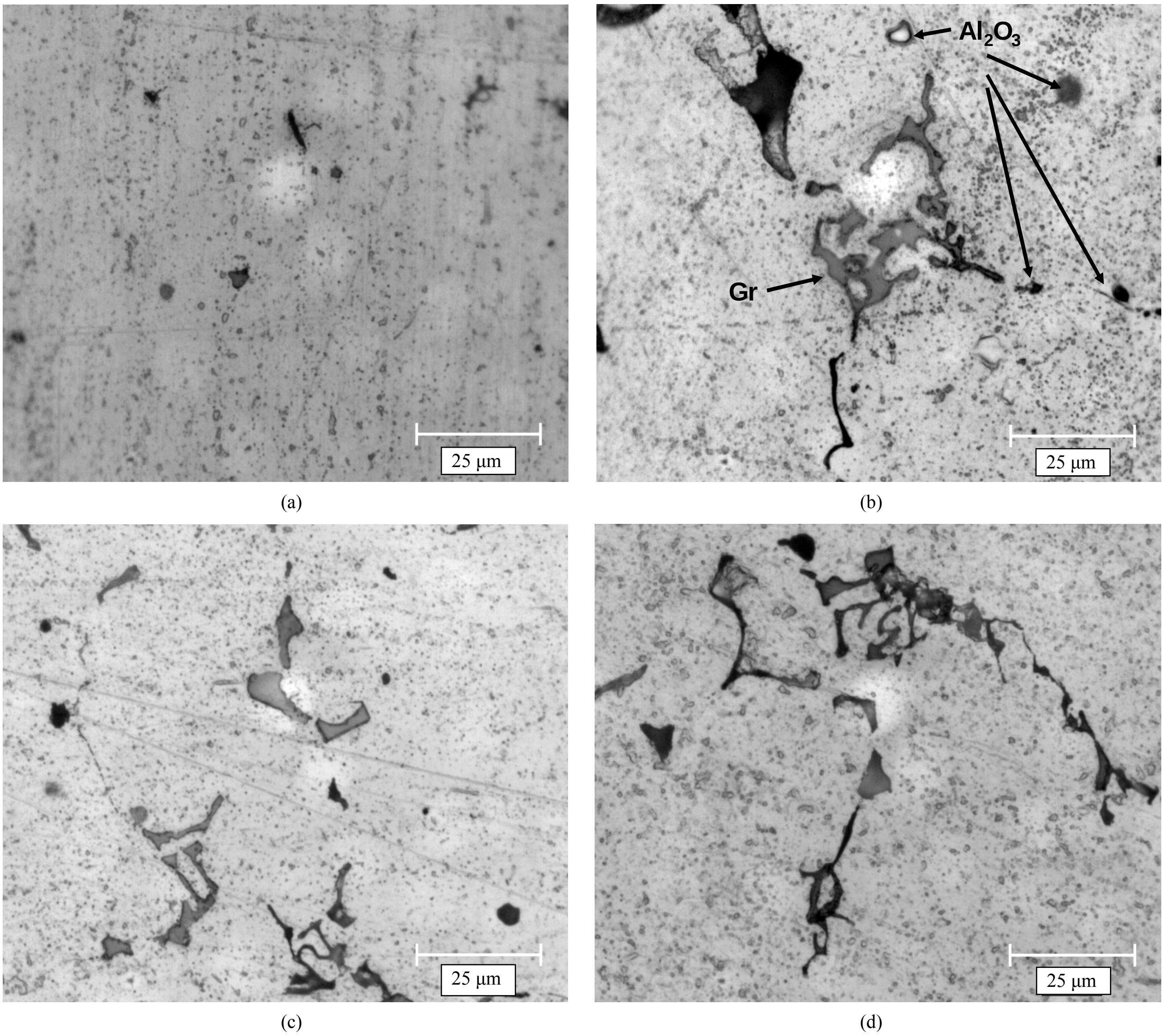

Figure 2. Optical microstructure of composites. (a) Al5083 alloy; (b) Al5083 + 3%Gr + 3%Al_2O_3; (c) Al5083 + 6%Gr + 3%Al_2O_3; (d) Al5083 + 3%Gr + 6%Al_2O_3.

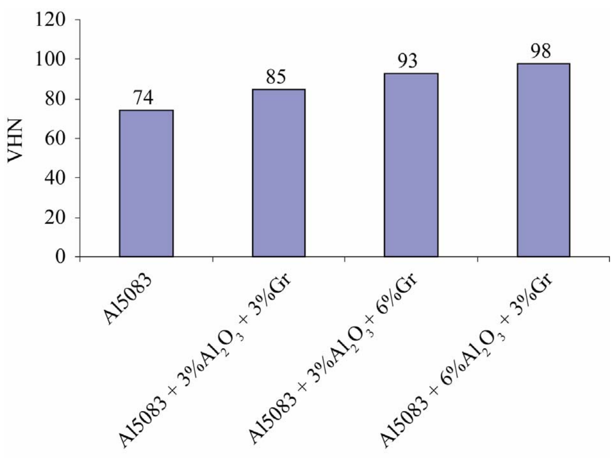

Figure 3. Microhardness of composites.

The slurry erosive wear of developed hybrid composites with different time duration at constant slurry rotation of 900 rpm is exhibited in **Figure 6**. As can be seen from **Figure 6**, the sample with 3%Al_2O_3 + 6%Gr shows the minimum mass loss. It is observed that increased time duration results an increased slurry erosive wear for both base alloy and composites studied. However, increased content of reinforcement in matrix alloy reduces the slurry erosive wear for all the time duration. This is because of the higher hardness of composites when compared with matrix alloy.

3.3. Immersion Test

Figure 7 shows the variation of mass loss of Al5083 matrix alloy and its hybrid composites. It is observed that

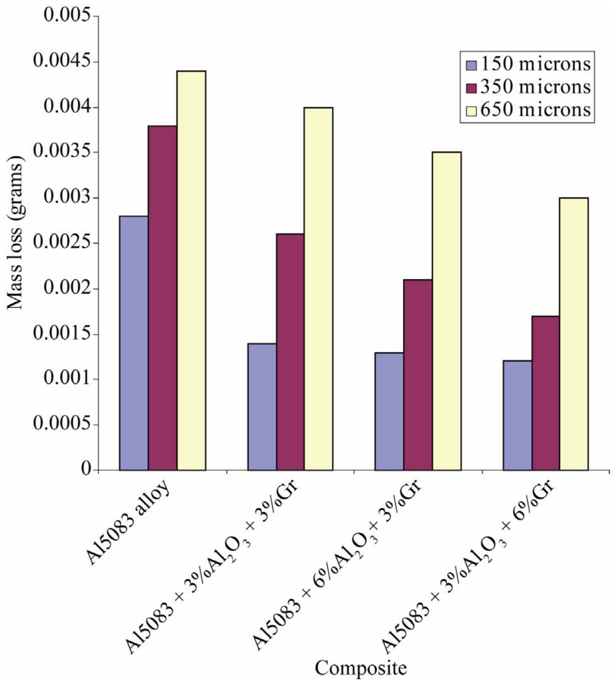

Figure 4. Effect of reinforcement of composites on slurry wear.

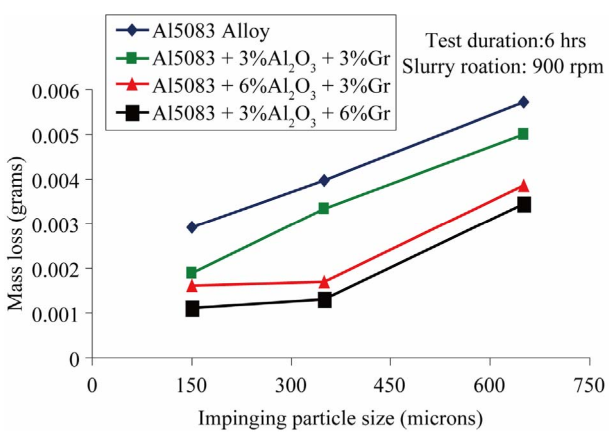

Figure 5. Effect of impinging particle size on slurry wear.

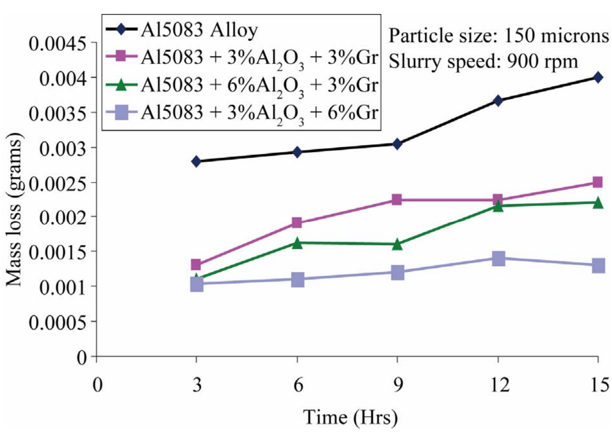

Figure 6. Effect of test duration on slurry wear.

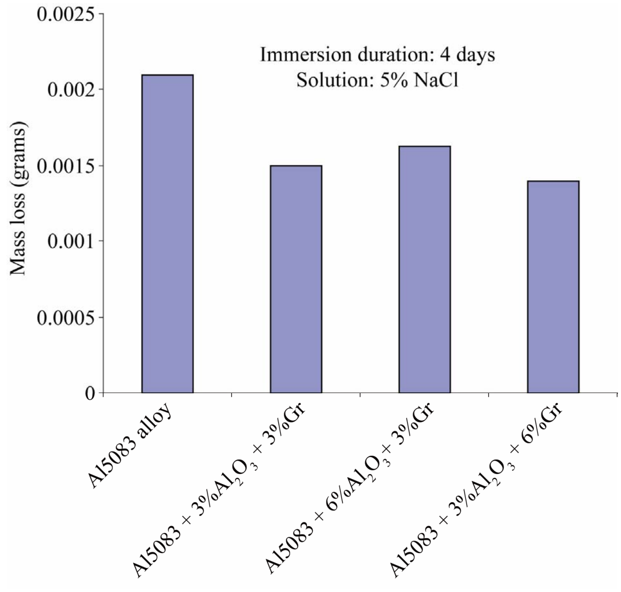

Figure 7. Effect of reinforcement in immersion test.

increased content of reinforcement in the matrix alloy decreases the mass loss during immersion test. The decrease in the mass loss with increased content of reinforcement is due to the fact that an increased content of reinforcement decreases the exposure of matrix area to the corrosive solution. Further, both Gr and Al_2O_3 exhibit excellent corrosion resistance, which decreases the mass loss with increase in their content in the matrix alloy.

The effect of immersion duration on mass loss of Al5083 alloy and developed hybrid composites is displayed in **Figure 8**. It is observed that initially mass loss increases with increase in immersion and then becomes stable. This can be attributed to the formation of a stable passive layer of $Al(OH)_3$, which is formed over the aluminum alloy and the $Al(OH)_3$ protective oxides formation of such oxides results in less corrosion reaction over a period of time. The saturation of solution with anodic ions and also formation of relatively more stable passive oxide layer, a steady state condition is arrived after few days irrespective of the materials. Further, in all the cases studied when compared with the matrix alloy the developed hybrid composites shows a decrease in the weight loss.

3.4. Salt Spray Test

The inspections of the samples were placed in the chamber for an interval of every four hours. The white corrosion product (white rust) and red corrosion product (red rust) have been observed. Initially, the white rust appears on the surface and as and when time progresses the red rust appears. The formation of Al_2O_3 oxide layer resists the white rust formation and this oxide layer slowly vanishes due to corrosion pits. As seen form **Figure 9**, the

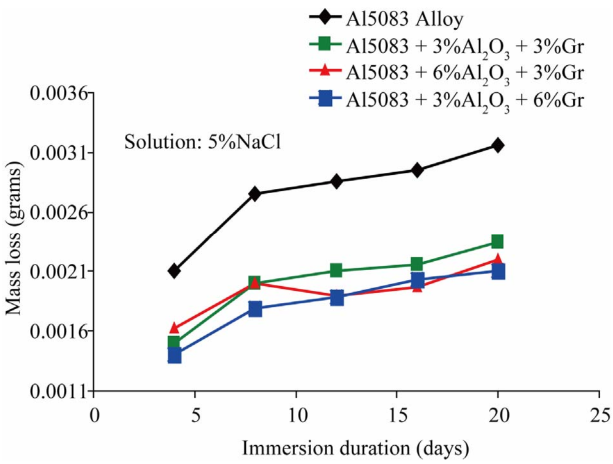

Figure 8. Effect of immersion duration.

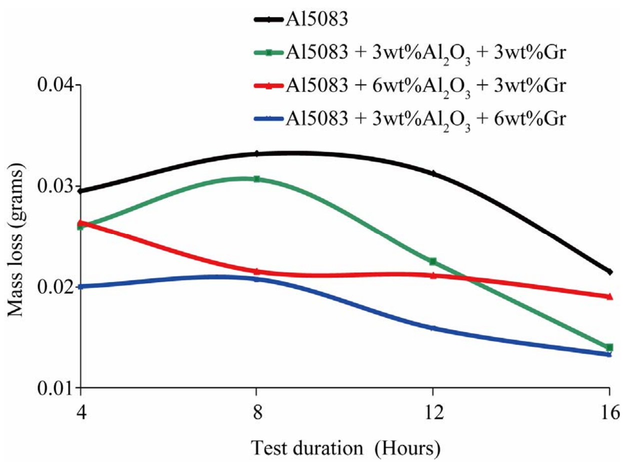

Figure 9. Effect of test duration in salt spray test.

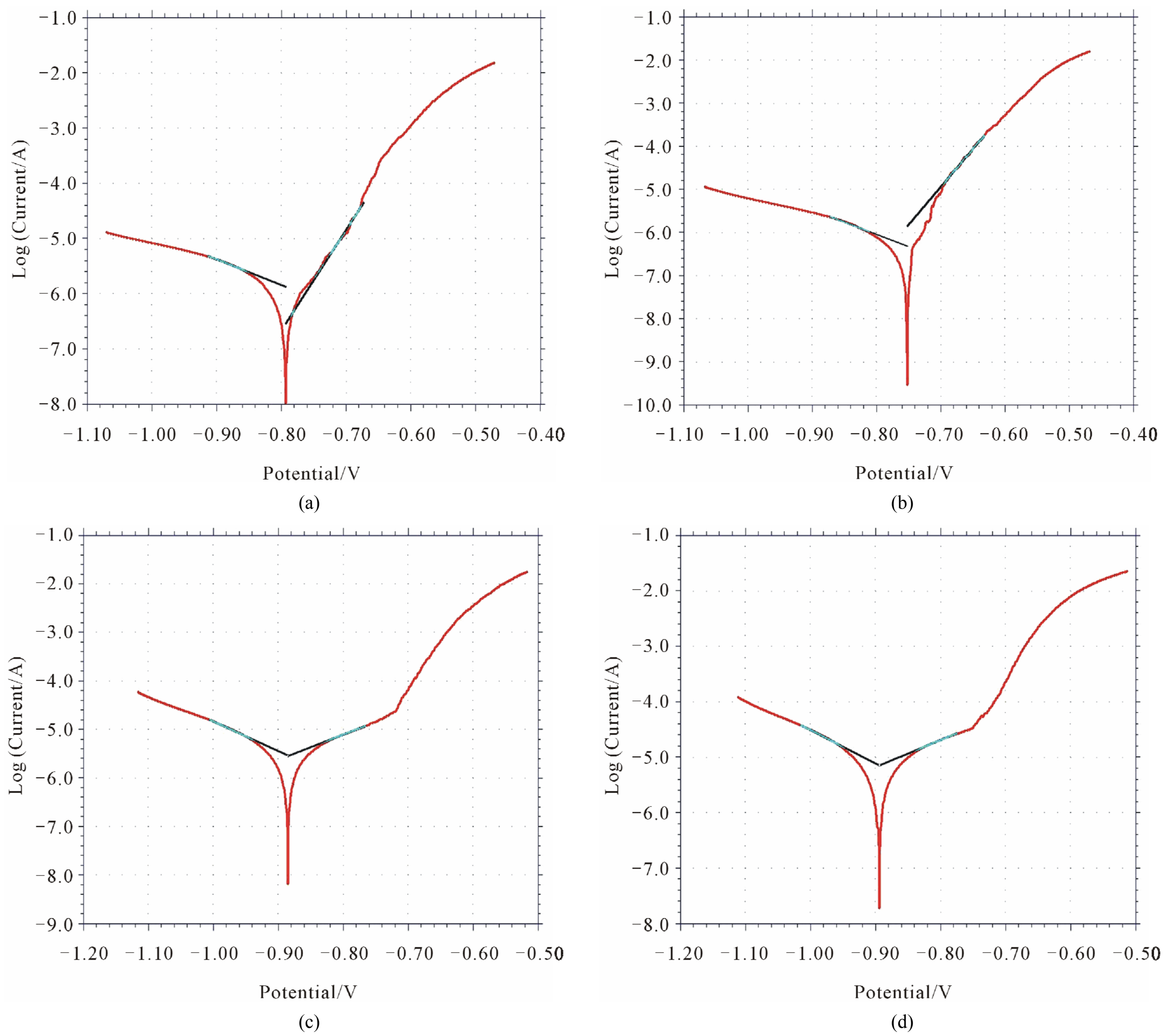

Figure 10. Polarization scan generated in potentiostat. (a) Al5083 Alloy; (b) Al5083 + 3%Al_2O_3 + 3%Gr; (c) Al5083 + 3%Al_2O_3 + 6%Gr; (d) Al5083 + 6%Al_2O_3 + 3%Gr.

sample having 6%Gr content shows much resistance to corrosion.

3.5. Polarization Studies

The polarization scan generated through potentiostat is shown in **Figure 10**, which indicates the corrosion potential of prepared composites. **Figure 11** gives the effect of corrosion density on developed hybrid composites. It is observed that corrosion density, which is an indication of the extent of corrosion of material increases gradually with increased content of percentage of reinforcement in the matrix alloy, resulting in material removal. It is evident that the composites reinforced with maximum percentage of graphite have exhibited reduced corrosion current density when compared with the alumina reinforced composites. The corrosion density increases with increase in percentage of reinforcement, which indicates the improvement in the corrosion resistance of the composites. From, **Figure 12** it is also evident that in case of the composites reinforced with 6% of Graphite, the maximum corrosion resistance is observed.

4. Conclusions

The experimental investigations of wear and corrosion behaviour of Al5083-Al_2O_3-Gr hybrid composites led to the following conclusions:

- The metallographic studies clearly revealed the uniformity in the distribution of reinforcements and excellent bond between the matrix and the reinforcement.
- The microhardness of hybrid composites are higher when compared to matrix alloy. An increased content of hard reinforcement in the hybrid composites leads to the enhancement in microhardness of hybrid composites.
- The slurry erosive wear of hybrid composites is less when compared to unreinforced matrix alloy. An increased content of reinforcement leads to improvement in the slurry erosive wear and improves the resistance of hybrid composites.
- The immersion test on developed hybrid composites indicated that addition of graphite and Al_2O_3 in to the matrix have reduced mass loss under identical test conditions.
- The salt spray test shows the formation of white and red rust formation; the red rust appears due to formation of pit in aluminium matrix. Increased graphite particles reduce the corrosion rate under identical test conditions.
- The hybrid composites possess marginally inferior corrosion resistance in 3.5% NaCl medium when compared with matrix alloy.

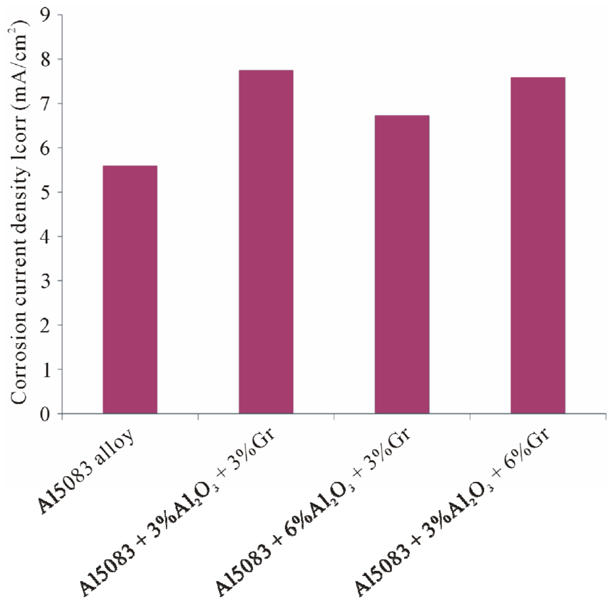

Figure 11. Effect of corrosion density on samples prepared.

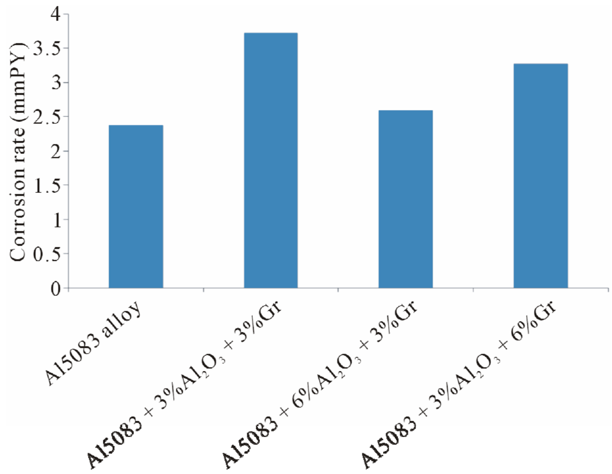

Figure 12. Effect of corrosion rate on samples prepared.

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