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EFFECT OF AGING ON WEAR BEHAVIOR OF AL-MG-SIC COMPOSITE

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ABSTRACT

The Purpose of this work is to study about the wear behavior and aging characteristics of as cast Aluminium-Magnesium-Silicon carbide composite. The Al-Mg-Si carbide alloy block is prepared in an induction heating furnace. Wear behavior of these samples was studied by conducting several wear tests on pin on-disc wear test machine by varying time, applied load, sliding speed and sliding distance. The microstructures of the damaged/worn samples and the crack morphology of the surfaces were studied using Stereoscope. Pin-on-disc wear analysis indicated that Al matrix with Mg and SiC increased the wear resistance. Profilometre studies were done to study the surface roughness. Then five samples were sliced from the main sample for the aging treatment. The composite was solution treated at a temperature of 250 °C for 1hr and then aged at four different temperatures viz. 120 °C, 150 °C, 180 °C, and 220 °C to study the aging behavior of the composite. The micro hardness was measured with the Micro-vicker's hardness testing machine. Then SEM and XRD analysis is done to get the details of the phases present.

KEYWORDS: Al-Mg-Si, Wear, Aging, Carbide Composite

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Original Article

INTRODUCTION

Metal matrix composites (MMCs) have geared up extensive research all over the world during the past decade as they are found to be suitable candidate materials for structural and mechanical applications [1-4]. The outstanding ability of MMCs to unify the reinforcement (usually ceramic material) properties (high strength and elastic modulus) with that of the metallic phase (high ductility and toughness) makes them capable of bearing higher compression and shear loadings and also sustainability at elevated temperatures. The usage of aluminum based MMCs (AMCs) is increasing in a wide variety of industries as they provide unique advantages over conventional monolithic materials in terms of more specific strength and stiffness, improved wear resistance and high temperature capabilities, adjustable coefficient of thermal expansion and resistance to thermal fatigue. The applications of AMCs includes gears and braking system in automobiles, fuel access door covers and ventral fins in automobiles, golf club shafts, bicycle frames, track shoes in military tanks, flywheels, ice hockey sticks, Cryostats, rocket turbine housing, missile nose tips, etc. AMCs with reinforcement in the form of particles are gaining importance due to their isotropic properties when compared with fiber and whisker reinforcements which exhibit anisotropic mechanical properties. These particulates reinforced metal matrix composites (PRMMCs) exhibit high strength, hardness, and wear and erosion resistance. They have superior plastic forming potential than fiber and whisker strengthened composites which in turn reduces their manufacturing cost. The properties of PRMMCs depend upon the size and properties of the reinforcing particle, interparticle spacing, and particle-matrix interface condition and shape and volume fraction of the particle [5-7].

Aluminium has several series in its nomenclature based on elements, it alloys with. For example, 3 XXX for alloying with manganese, 5XXX for alloying with magnesium and 6XXX for alloying with magnesium and silicon. Followings are the advantages of magnesium additions to Aluminium: 1) Magnesium has two thirds the weight of Aluminium, thus addition of Magnesium to Aluminium leads to decrease in the density of the alloy. 2) Magnesium has higher specific strength than Aluminium. Thus the addition of Magnesium results in increased strength of alloy as compared to Aluminium. 3) Magnesium addition leads to an increase in the strength to weight ratio. Thus the alloys are more suitable for automobile and aircraft parts as it increases the fuel efficiency. 4) Addition of magnesium to Aluminium results in precipitation and age hardening of alloy. Thus the strength is significantly increased. 5) It improves the wettability of solid ceramic reinforcement in Aluminium metal matrix composites. Better wettability would result in more homogeneous distribution of reinforcement in the matrix. 6) Magnesium also improves the formability and castability of aluminium, (7) Addition of Mg into liquid Al reduces its surface tension [8] and threreby avoids rejection of the particles from the melt, (8) Without addition of Mg, the recovery of the particles into the melt is quite low [9-11]. Hence 2-4% Mg is generally added into the Al melt before incorporation of the particles. Silicon carbide is one of the most widely used ceramic reinforcements in Aluminium metal matrix composites. SiC have high corrosion resistance, low thermal expansion coefficient, high thermal conductivity, high hardness and good refractory properties. The addition of SiC to aluminium improves its strength and other mechanical and thermal properties. SiC improves strength of the alloy and the elevated temperature hardness.

In this paper the wear behavior of the Al-3%Mg-10%SiC composite sample studied by varying various parameters i.e. Time, Applied load, Sliding speed, Sliding distance, Surface roughness. The aging behavior of Al-3% Mg-10%SiC also studied for detecting the property alteration.

EXPERIMENTAL PROCEDURE

Aluminium-3%Magnesium-10% silicon carbide alloy block of dimension 100 mm x 100 mm x 30 mm is prepared by stir casting route in an induction heating furnace. A modified stir casting technique for preparation of the Al-Mg alloy is designed using low cost scrap Mg, using a plunger for making the alloy addition. A mild steel cylinder container is coated with aluminium and used to hold the aluminium melt. A hollow spindle which has its stirrer blades attached to motor and V-belt arrangement for better stirring. The plunger rod is attached to perforated capsule which holds the magnesium. Aluminium blocks are melted in the crucible at temperature of 800 °C and stirred at 500 rpm. Magnesium turnings are added one after another through the hollow spindle. The magnesium is released after the aluminum foil coating melts and the Mg dissolves in 15 seconds. Then the reinforcement SiC particles are added in the similar manner. The melt is poured into the mould and cooled. Then samples of the required dimensions are cut for the wear and other tests. Three cylindrical samples of diameter 10 mm and a height of 30 mm were cut from the block using a highly calibrated lathe machine for the wear test. Wear behavior of these samples was studied by conducting several wear tests on computerized Ducom (DUCOM Wear and Friction Monitor, TR-20-M100, Bangalore, India) friction and wear monitor pin on-disc wear test machine. The samples were weighed at regular intervals to measure weight loss using an electronic balance having an accuracy level of 0.1 mg. It was under careful examination that the specimens wearing in the test are continuously cleaned with woolen cloth so as to avoid the snaring of wear debris and to achieve uniformity in experimential procedure. The tests were done by varying one among the below mentioned parameters and keeping the other parameters constants: time, applied load, sliding speed and sliding distance. The microstructures of the damaged/worn samples and the crack morphology of the surfaces were observed under Stereoscope. Profilometric studies were done to study the surface roughness. Then five samples were sliced from the main sample for the aging treatment. The composite was solution treated at a temperature of 250 °C for 1hr and then aged at four different temperatures viz. 120 C, 150 C, 180 C, and 220 C to study the aging behavior of the composite. The micro hardness was measured with the Microvicker's hardness testing machine. Then SEM and XRD analysis were done to get the details of the phases present.

Figure 1: Pin on Disc Wear Test Machine

RESULTS AND DISCUSSIONS

Surface Analysis of as-Casted Sample

Microstructural observation in Figure 2(a) showing the as casted Al-Mg-SiC composite at room temperature. Here Non-homogeneous distribution of rain forced particles was clearly observed. Figure 2(b) showing the XRD pattern of the as-cased Al-Mg-SiC composite surface area. In as-casted sample, the major elemental form of Al is identified at (111), (002) and (113) plane. Magnesium favorably grows in (011) plane. But SiC grows along with the Aluminum plane. Here it is clear that the homogenization and wet tability of SiC along the Aluminum is better than the magnesium [12].

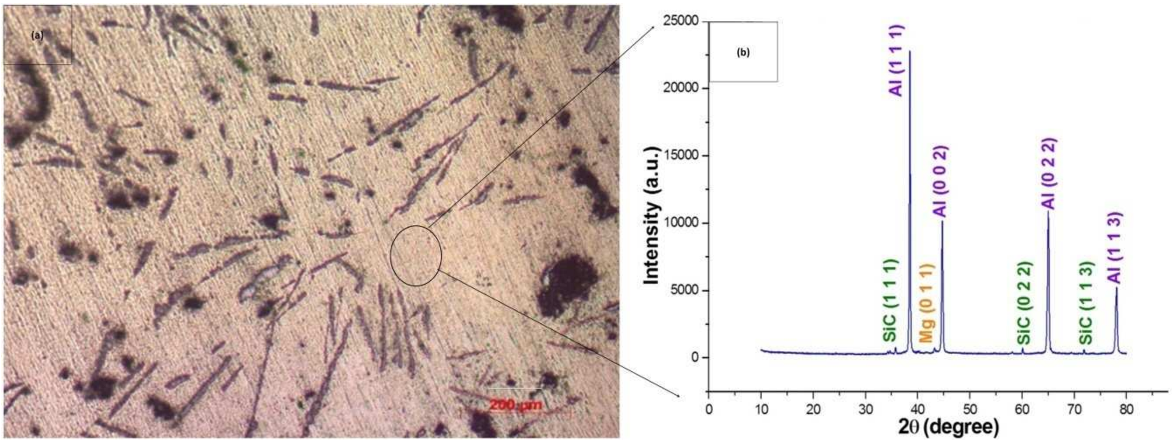

Figure 2: Optical Image of the Al-3%Mg-10%SiC Composite Sample at Room Temperature at Magnification of 10X and XRD Pattern of the Selected Area of the Composite Sample at Room Temperature

Wear Characteristic

Surface Morphology of Worn Part

Figure 3 showing the comparison of the optical microstructure of the surface of worn sample. The wear surface shows groove formation, damaged regions and crack propagation along the longitudinal and transverse directions.

The sliding directions are observed on the surface. In Figure 3a the deeper groves are present along sliding direction than that of SiC reinforced sample in Figure 3b. But for Al rainforced with SiC and Mg, the groves are not present due to increase in wear resistance. Figure 4 shows the optical Micrograph of the worn surface of Al-3%Mg-10%SiC composite at different applied loads 70N, 80N, 90N and 100N. In figure 4a, the groves are discontinued due to larger co-efficient of friction. The wear resistance is higher at this lower load. With the increase in the load (figure 4b-figure 4c), the wear resistance became lower. Then exposed SiC particulates on worn sur-face oppose further material removal. And at 100 N load (Figure 4d), the grooves are sharp, because at this load, the sample is not able to resist for the wear and larger mass reduction will occur. As the load increased, deeper grooves are created because of increased pressure and temperature and wear. But at higher loads the grooves are smooth and in dry condition; so wear rate decreases as frictional force decreases [13-14].

Figure 3: The Worn Surface of the Specimen (a) Al-Sample, (b) Al-Mg alloy and (c) Al-Mg-Si Composite

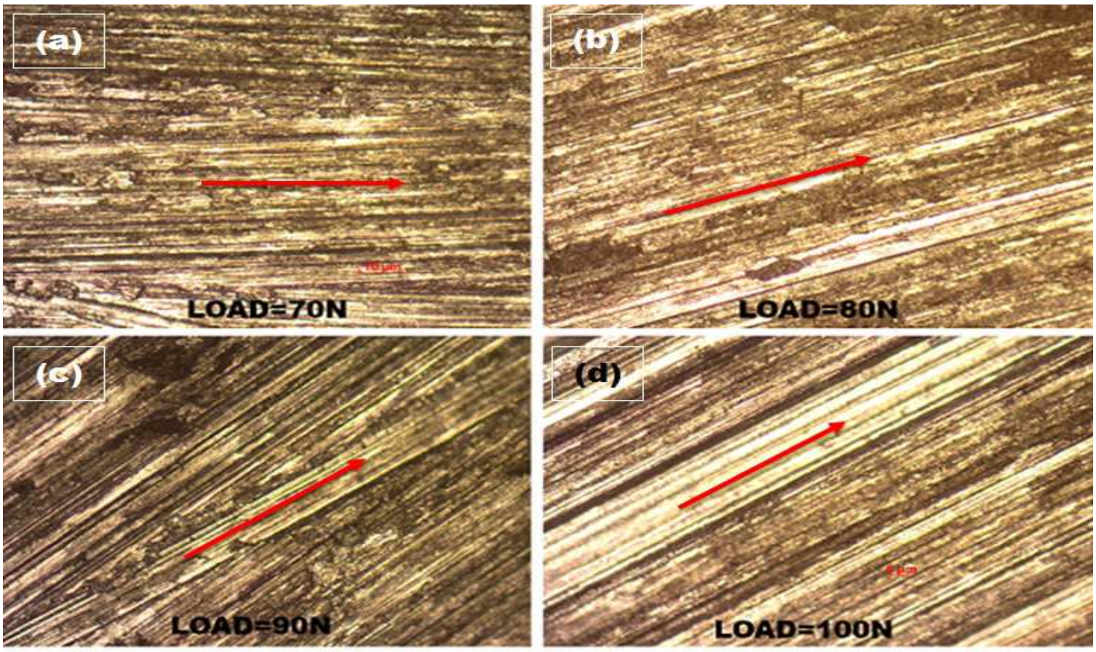

Figure 4: Optical Micrograph of the Worn Surface at Different Applied Loads Like 70N, 80N, 90N, 100N at 10X Magnification

Wear Due to Variation of Parameters

Figure 5 showing the wear behavior of the composite that investigated at room conditions at four different loads, 70 N, 80 N, 90 N, and 100 N and with varying sliding speeds like 200 rpm, 300 rpm, 400 rpm, 500 rpm, 600 rpm, and 700 rpm. The weight loss was measured and the graph plotted against wear sliding time at four different applied loads. As the sliding time increases the weight of the sample decreases constantly, which increases the cumulative weight loss. But at higher sliding time wear rate decreases. Initially the surface becomes rough, so the sliding movement occurs in very small areas at the peaks and over time the peaks break and the contact area is increased. So the flattening of the surface occurs, which leads to decrease in the co-efficient of friction and wear at the higher sliding time [15]. Thus, it is found that the wear rate is directly proportional to the sliding time. As load increases, deeper grooves are created because of increased pressure and temperature. So weight loss is more leading to higher wear at higher loads.

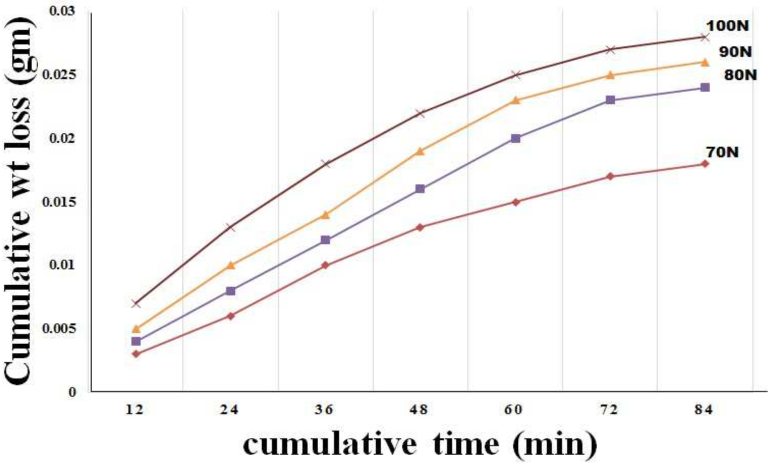

Figure 5: Graph between Cumulative Weight Loss and Cumulative Sliding Time at Different Applied Loads Like 70 N, 80 N, 90 N, 100 N

Figure 6 shows the cumulative weight loss with the variation of load. As the applied load increases the rate of weight loss decreases, leading to lower wear rate. Because at higher loads the grooves become smooth and in the dry condition which can be observed from the optical micrograph of the worn surface. So there is a decrease in co-efficient of friction leading to decrease in wear rate.

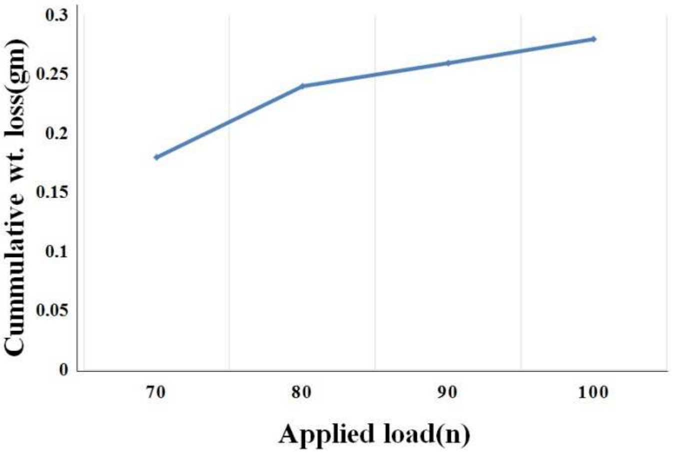

Figure 6: Graph between Cumulative Weight Loss and Applied Load Used in Wear Test

Figure 7a shows wear weight loss due to the sliding distance at different applied load. The weight loss increases with the sliding distance and the rate of weight loss increases with load. Here at 70 N and 100 N gives a linear increase in weight loss. But for 80 N and 90N, the weight loss path follow a sigmoidal function as shown in Figure 7a. Figure 7b shows the Wear due to the variation of sliding speed.

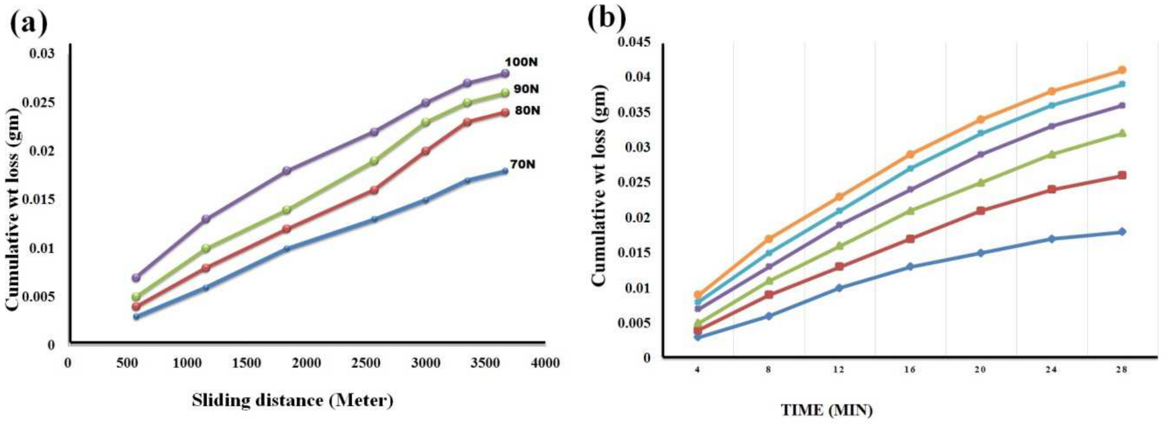

Figure 7: (a) Graph between Cumulative Weight Loss and Sliding Distance at Different Applied Loads Like 70N, 80N, 90N. 100N, (b) Graph between Cumulative Weight Loss and Sliding Time at Different rpms Like 200, 300, 400, 500, 600, 700

Figure 8 shows the wear against sliding speed. As the sliding distance and sliding speed increases, the amount of wear increases, but the wear rate decreases at higher sliding distance and sliding speed. Because sliding over long distances and at a higher sliding speeds causes hardening of the surface layer composition of the waste debris and reduces the wear rate. Higher sliding speed leads to decrease in surface roughness, Decreased surface roughness and a small quantity of wear debris decrease the co-efficient of friction. So wear rate decreases at higher sliding speeds.

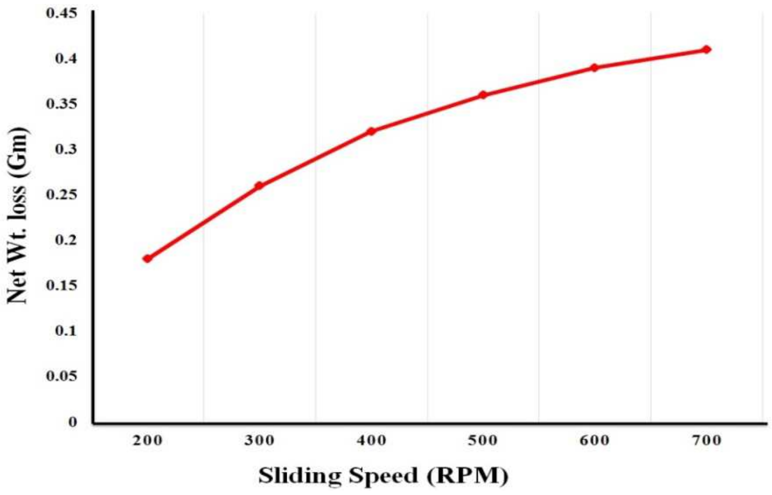

Figure 8: Graph between Cumulative Weight Loss and Sliding Speed

Surface Roughness of Wear Part

The surface roughness of the worn surface was measured by using Profilometer and the Ra value was plotted against varying applied load. The increase in load leads to higher surface roughness due to the formation of deeper grooves [16]. At higher load at 90 N and 100 N, the surface roughness nearly same.

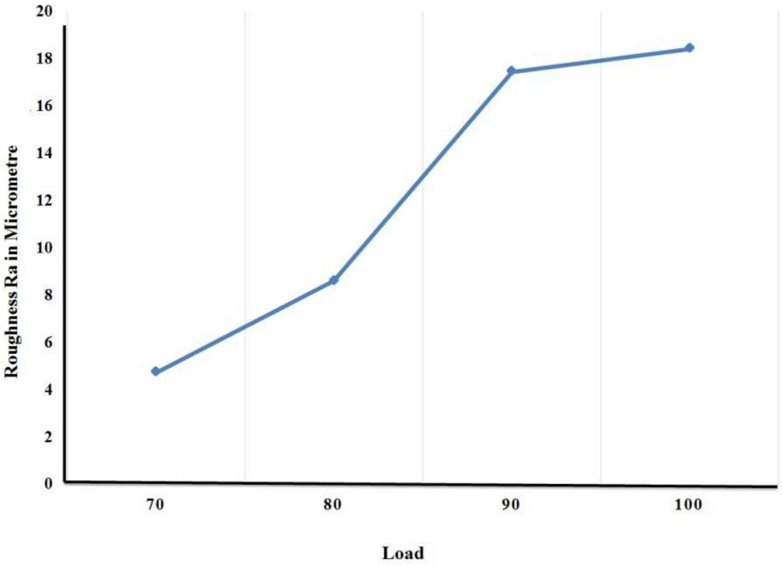

Figure 9: Graph between Surface Roughness of the Worn Sample and Applied Load

Co-Efficient of Friction During Wear

Initially the surface becomes rough, so the sliding movement occurs in very small areas at the peaks and over time the peaks break and the contact area is increased. So the flattening of the surface occurs, which leads to decrease in the co-efficient of friction [17-18].

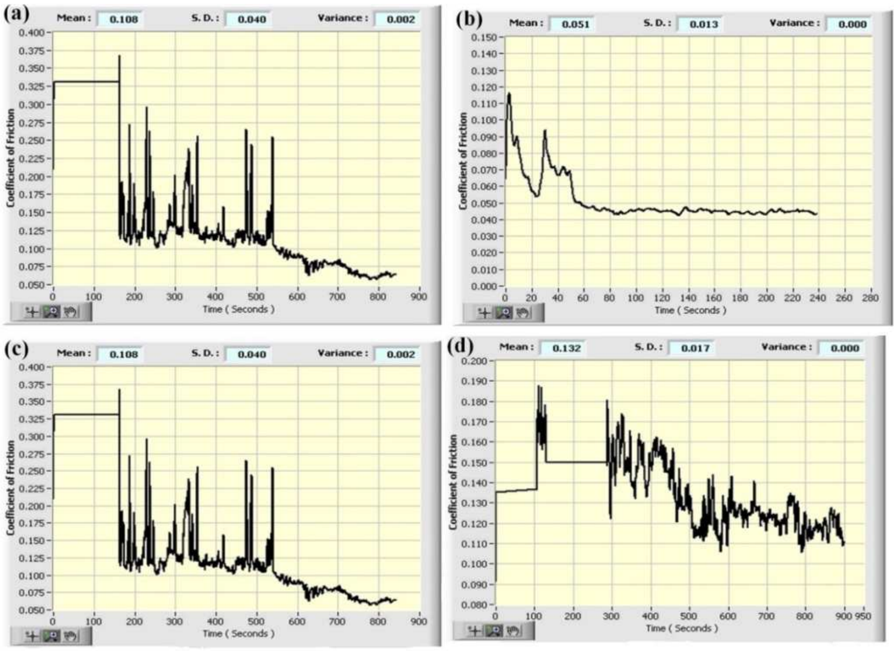

Figure 10: Graph between Co-Efficient of Friction and Sliding Time at Different Applied Loads Like (a) 70N (b) 80N (c) 90N (d) 100N

Againg Behaviour of Al-Mg-Si Sample

Microstructure Analysis of Aged Sample

Figure 11 shows the SEM surface morphology of Al-3%Mg-10%SiC composite aged at the different temperature. In figure 11a, the composite aged at 120 C having hardness 90.8 Hv (In figure 12) which is higher than the as-casted sample (67.4 HV), that confirm the presence of SiC reinforced particles. At 150 °C aged sample (Figure 11b), the surface became rough due to contraction of different reinforced phases and formation of more number of SiC phases. Here the hardness is maximized (94.3 Hv in figure 12) due to precipitation hardening [19]. Also, Mg addition to Al-MMC enhances the hardness of Al matrix and improves inter-facial bond strength. At the aging temperature of 180 °C, there is a clear vision of grain growth of SiC particles (Figure 11c) which is the prime reason of a sharp decrease in hardness value of 78.8 Hv in Figure 12. At the aging temperature of 220 °C the SiC particles start dissolving (Figure 11d). So there is a decrease in the no of SiC precipitates, which leads to a decrease in the hardness value of 82.3 Hv.

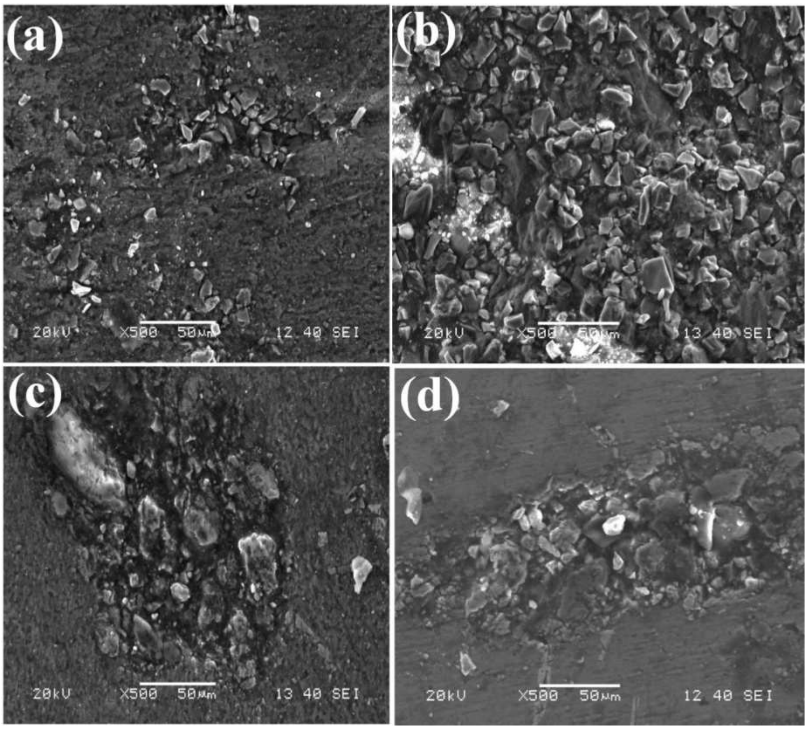

Figure 11: SEM Image of the Al-3%Mg-10%SiC Composite Sample Solution Treated at 250 C for 1hr.and Aged at Four Different Temperatures Showing Micro-Vicker's Hardness(a) Aging temp=120 C, Hardness=90.8HV, (b) Aging Temp=150 C, Hardness=94.3HV,(c)Aging Temp=180 C, Hardness=78.8HV (d) Aging Temp=220 C, Hardness=82.3HV

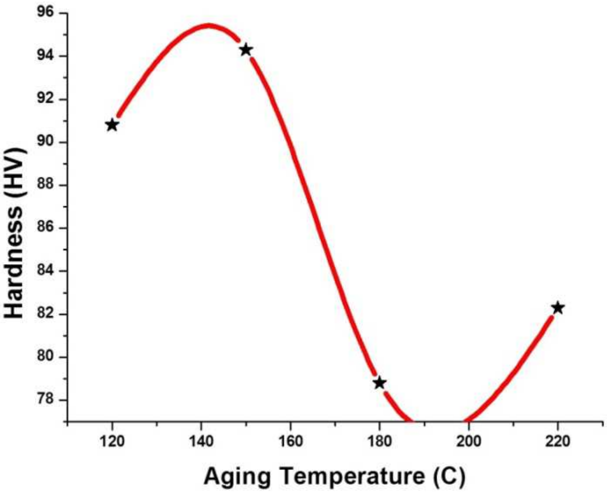

Figure 12: Variation of Hardness with Aging Temperature of Al-3%Mg-10%SiC Composite

Phase Analysis of Aged Specimen

Figure 13 shows XRD pattern of 120 °C aged sample. Here SiC grows same plane as that of the as-casted sample showed in Figure 2. But here there is no elemental peak of Al, there is a presence of Al-Mg complex phases. 150 °C aged samples (Figure 14) shows same pattern as that of 120 °C aged samples. Figure 15 shows the XRD analysis of the 180 °C aged sample and Figure 16 shows about 220 °C aged sample. In case of 180 and 220 aged sample, there is presence of elemental form of Al that indicates the precipitates are dissolved in the large Al matrix and that causes the lower hardness value of the samples.

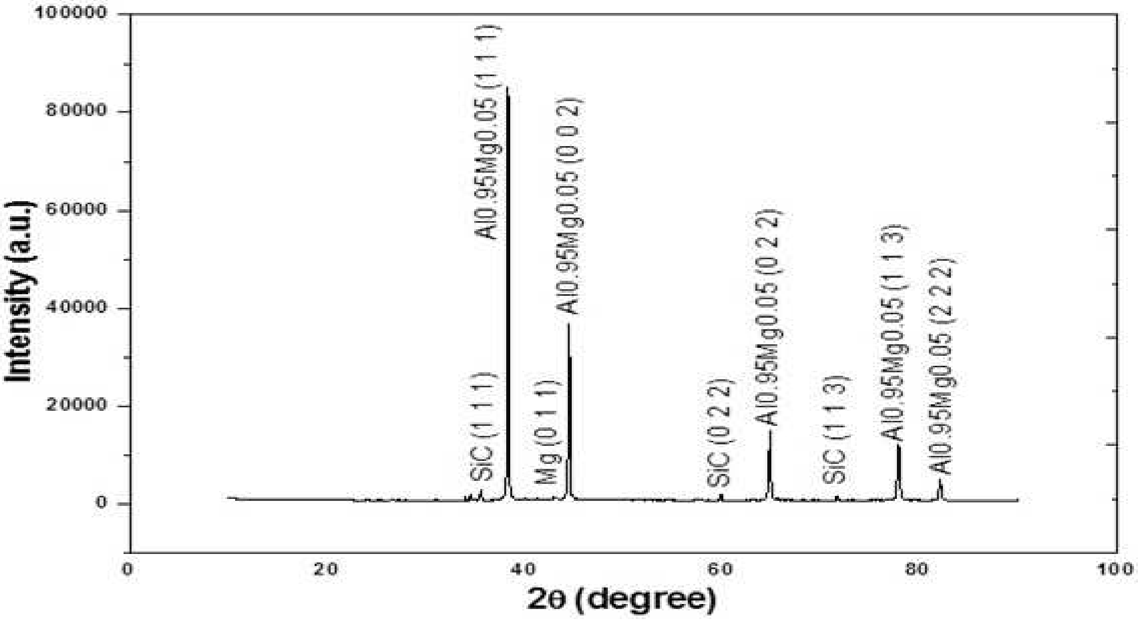

Figure 13: XRD Analysis of the Composite Solution Treated at 250 °C for 1hr. and Aged at 120 °C

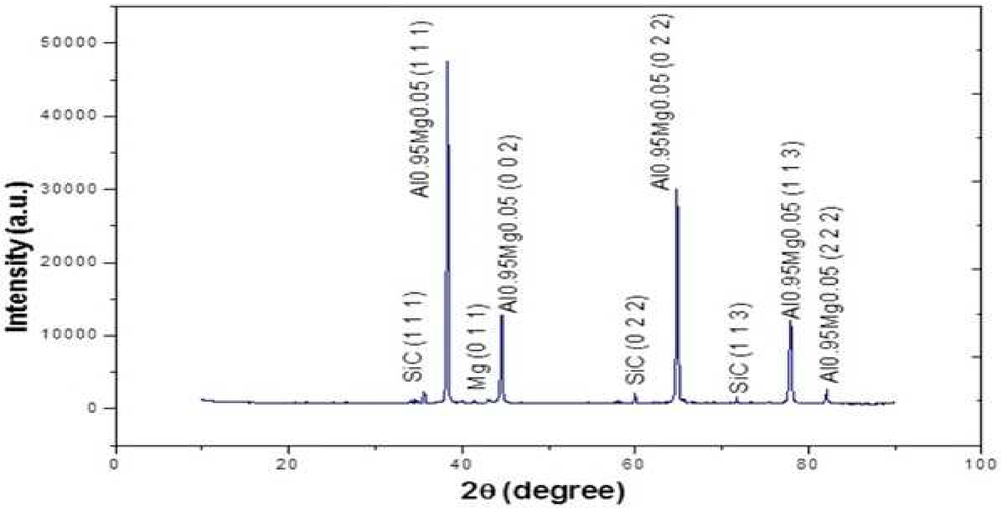

Figure 14: XRD Analysis of the Composite Solution Treated at 250 °C for 1hr. and Aged at 150 °C

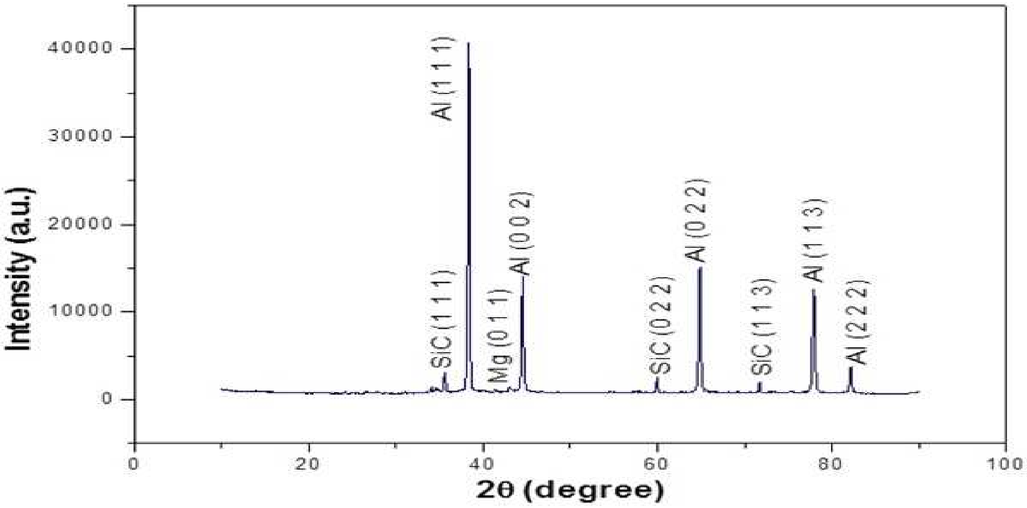

Figure 15: XRD Analysis of the Composite Solution Treated at 250 °C for 1hr. and Aged at 180 °C

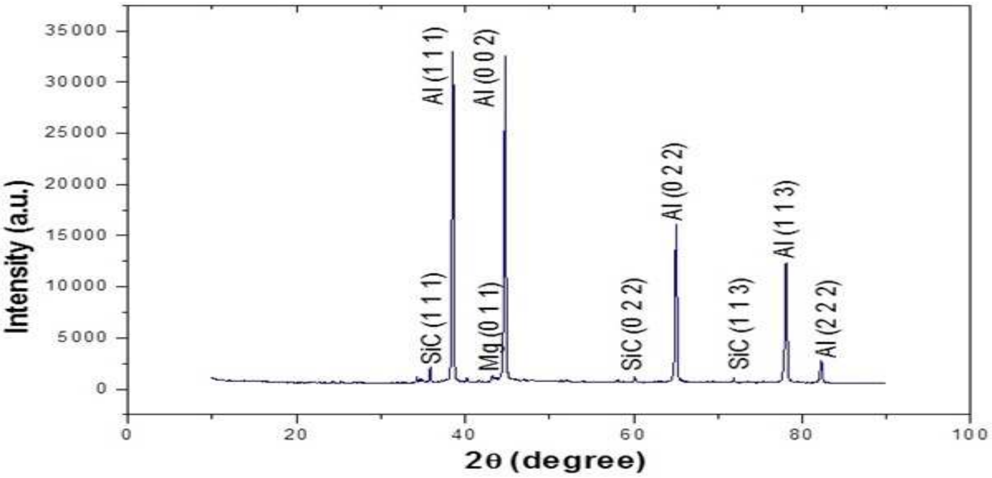

Figure 16: XRD Analysis of the Composite Solution Treated at 250 °C for 1hr. and Aged at 220 °C

CONCLUSIONS

Al-MMC reinforced with varying wt. % of SiC and Mg was successfully prepared by induction casting. The outcome of this investigation as following:

- Initially, the weight loss almost increases linearly with increasing sliding time and sliding distance, indicating a steady-state behavior.
- But sliding for long time and sliding over long distances cause hardening of the surface layer composition of the waste debris and reduces the wear rate.
- As load increases, deeper grooves are created because of increased pressure and temperature. So weight loss is more leading to higher wear at higher loads. But as the applied load increases rate of weight loss decreases leading to lower wear rate. Because at higher loads the grooves become smooth and in dry condition.
- Al-3%Mg-10%SiC composites possess improved wear resistance and hardness value as compared with unreinforced alloy during sliding. Improved wear resistance of composites can be attributed to the presence of SiC particles which reduce the ability or propensity for material flow at the surface.

- The increase in sliding time, sliding speed, loading, and sliding over long distances, reduce wear rate. Thus, maintaining appropriate sliding speed and normal load levels can reduce frictional force and wear and improve the mechanical properties.
- SiC particles in the matrix act as pinning points to hold the debris particles on the wear surface, and thus some of the debris get accumulated around these particles. All these facts lead to less wear in the Al-Mg-SiC composite as compared to the unreinforced alloy.
- Age hardening process increased the hardness of the Al-Mg-SiC composite significantly by the formation of more number of SiC precipitates.
- Peak hardness was observed at the ageing temperature of 150 °C because of the formation of maximum number of SiC precipitates on the Al-Mg matrix.
- At a temperature of 180 °C and more the sample was observed to be over aged leading to grain growth of the SiC precipitates and thus showed lower hardness value.

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