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Research Paper

PREPARATION AND EVALUATION OF MECHANICAL AND WEAR PROPERTIES OF Al6061 REINFORCED WITH GRAPHITE AND SiC PARTICULATE METAL MATRIX COMPOSITES

Prashant S N[1]*, Madev Nagaral[1] and V Auradi[1]

Corresponding Author:* ***Prashant S N,* ✉ *prashant.064@gmail.com*

Aluminium alloy materials found to the best alternative with its unique capacity of designing the materials to give required properties. Aluminium alloy Metal Matrix Composites (MMCs) are gaining wide spread acceptance for automobile, industrial, and aerospace applications because of their low density, high strength and good structural rigidity. In the present work, an attempt is made to prepare and compare the mechanical and wear properties of Al6061-Graphite and Al6061-SiC composites. The composites were prepared using stir casting method in which amount of reinforcement is varied from 6-12% in steps of 3wt%. The prepared composites of Al6061-Graphite and Al6061-SiC are characterized by microstructural studies and hardness, density, and mechanical, tribological properties were evaluated as per the standards. The microphotographs of the composites revealed fairly uniform distribution of the particles in both Al6061-Graphite and Al6061-SiC composites with clustering at few places. The experimental densities were found to be lower than theoretical densities in all the composites. Micro-hardness of the Al6061-SiC composite found increased with increased filler content and where as Al6061-Graphite composite found decreased with increased filler content are found to be 98-151VHN and 98-76VHN respectively. The dispersed Graphite and SiC in Al6061 alloy contributed in enhancing the tensile strength of the composites. The wear resistance of the Al6061-SiC composite found decreased with increased filler content where as the wear resistance of the Al6061-Graphite composite found to decrease up to 6wt% but thereafter tends to increase.

Keywords: Al6061, SiC, Graphite, Metal matrix composites, Mechanical properties

INTRODUCTION

Metal Matrix Composites (MMCs) are increasingly becoming attractive materials for advanced aerospace applications because their properties can be tailored through the addition of selected reinforcements (Christy

[1] Department of Mechanical Engineering, Siddaganga Institute of Technology, Tumkur 560010, India.

et al., 2010; and Swamy *et al.*, 2011). In particular, particulate reinforced MMCs have recently found special interest because of their specific strength and specific stiffness at room or elevated temperatures (Ramesh *et al.*, 2010). The various reinforcements that have been tried out to develop aluminium matrix composites(AMCs) are graphite, silicon carbide, titanium carbide, tungsten, boron, Al203, flyash, Zr, TiB2. Addition of hard reinforcements such as silicon carbide, alumina, and titanium carbide improves hardness, strength and wear resistance of the composites (Christy *et al.*, 2010; and Ramesh *et al.*, 2010). Aluminium-based Metal Matrix Composites (MMCs) have received increasing attention in recent decades as engineering materials. The introduction of a ceramic material into a metal matrix produces a composite material that results in an attractive combination of physical and mechanical properties which cannot be obtained with monolithic alloys (Manocha and Bunsell, 1980). The particulate reinforced MMCs is mainly used due to easy availability of particles and economic processing technique adopted for producing the particulate-reinforced MMCs. Aluminium alloy-based particulate-reinforced composites have a large potential for a number of engineering applications. Interest in reinforcing Al alloy matrices with ceramic particles is mainly due to the low density, low coefficient of thermal expansion and high strength of the reinforcements and also due to their wide availability. Among the various useful aluminium alloys, Aluminium alloy 6061 is typically characterized by properties such as fluidity, castability, corrosion resistance and high strength-weight ratio. This alloy has been commonly used as a base metal for MMCs reinforced with a variety of fibres, particles and whiskers (Berghezan, 1966; Pandey, 2004; and Karthigeyan *et al.*, 2012). Amongst different kinds of the recently developed composites, particle-reinforced metal matrix composites and, in particular, aluminium base materials have already emerged as candidates for industrial applications.

In the present work attempt has been made to study the influence of Graphite$_p$/SiC$_p$ addition on the microstructure, micro-hardness, and mechanical and wear behavior of 6061Al-alloy. For this purpose 6 wt%, 9 wt% and 12 wt% of Graphite$_p$/SiC$_p$ addition was used. Mechanical properties were evaluated as per the standards using computerized universal testing machine and wear properties were evaluated using pin-on-disc wear testing machine.

EXPERIMENTAL DETAILS

The following section highlights the materials used its properties and method of composite preparation and evaluation of mechanical and wear properties.

Materials Used

The matrix material for present study is Al6061. Table 1 gives the chemical composition of Al6061. Table 2 gives the details of the physical and mechanical properties of Al6061. The reinforcing material selected was Graphite and SiC of particle size 125 µm. Table 3 gives the details of the physical and mechanical properties of graphite.

Preparation and Testing of Composites

The 6061 Aluminium alloy is used in this experiment as the matrix. The conventional casting technique was used for this composite material. Stir casting method has been

Table 1: Shows the Chemical Composition of Al6061 Alloy Used in the Present Study

Si	Cu	Fe	Mn	Mg
0.62	0.23	0.22	0.03	0.84
Zn	**Pb**	**Ti**	**Sn**	**Al**
0.22	0.10	0.01	0.01	BAL

Table 2: Shows the Physical and Mechanical Properties of Al6061 Alloy Used in the Present Study

Elastic Modulus (GPa)	Density (g/cc)	Poisson's Ratio	Hardness (HB500)	Tensile Strength (MPa)
70-80	2.7	0.33	30	115

Table 3: Shows the Physical and Mechanical Properties of Graphite and Silicon Carbide Particulates

Rein-forcement	Elastic Modulus (GPa)	Density (g/cc)	Poisson's Ratio	Hardness (HB500)
Graphite	8-15	2.09	0.14	1.7 mohs scale
SiC	410	3.10	0.14	2800

adopted to prepare Al6061-Graphite and Al6061-SiC composites. Preheated Graphite or SiC powdered particulates of laboratory grade purity of particle size 125 µm were introduced into the vortex of the molten alloy after effective degassing. Mechanical stirring of the molten alloy for duration of 10 min was achieved by using ceramic-coated steel impeller. Speed of the steel impeller was maintained at 400 rpm. A pouring temperature of 730 °C was adopted and the molten composite was poured into permanent cast iron mould. The extent of incorporation of $Graphite_p$ or SiC_p in the matrix alloy was varied from 6 to 12 wt% in steps of 3 wt%. Thus composites containing particles were obtained in the form of cylinders of diameter 12.5 mm and length of 125 mm.

The prepared Al6061-Graphite, Al6061-SiC composites and the castings of the base alloys are characterized by microstructural studies. Hardness measurement of the base alloy and composites were carried out using Z-wick Micro-Vickers hardness testing machine. Hardness is measured at 30 different locations on each specimen and value reported is average of 100 readings. Further, the mechanical, wear properties were evaluated as per the standards. For each test, three test specimens were used and the value reported is average of three tests.

RESULTS AND DISCUSSION

The test results of Al6061 and its composites containing Graphite and SiC particulates with various weight percentages are presented in these sections.

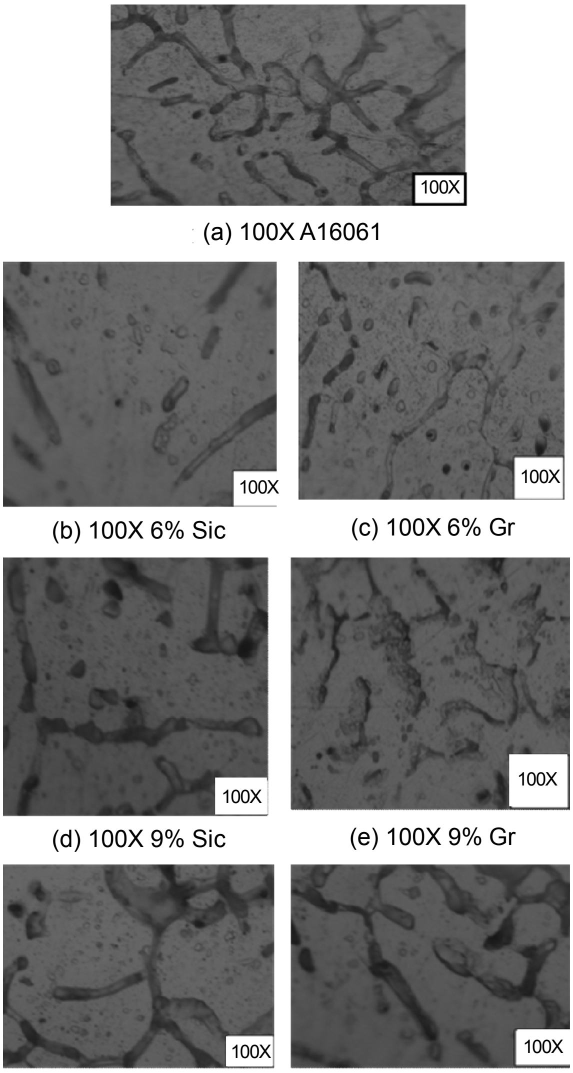
Microstructure

Figure 1a shows the microstructure of Al6061 base alloy, which consists of -Al dendrites and eutectic Si which are distributed at grain boundaries. Figures 1b-1f reveals the microphotographs of Al6061 reinforced with Graphite and SiC particulates. From figure it is clear that, the distribution of reinforcing particulates in both the composites is fairly uniform in all the compositions studied while clustering of the particles were seen at few locations.

Density Measurements

Table 4 shows the comparison between the theoretical and experimental density measurements of the prepared composites. Theoretical density is found using rule of mixture while experimental density is evaluated based on Archimedes principle. From the table it can

Figure 1: Showing the Optical Microphotographs of (a) 6061Al Alloy and (b-f) with Different wt% of SiC and Graphite Particulates Taken at 100X



(a) 100X A16061

(b) 100X 6% Sic (c) 100X 6% Gr

(d) 100X 9% Sic (e) 100X 9% Gr

(f) 100X 12% Sic (g) 100X 12% Gr

be concluded that the theoretical density values are slightly higher than experimental densities for all compositions and can be attributed to the presence of porosities. Further the density increases with increased percentage of filler content in the composites. The higher density of Al6061-SiC composites over Al6061-Graphite and can reasoned for the higher density values of SiC.

Table 4: Comparison of Theorectical and Experiment Densities of Al6061-SiC and Al6061-Graphite Composites

Material	Density (g/cc)	Weight % Reinforcement			
		0	6	9	12
Al6061-SiC	Theoretical Density	2.70	2.72	2.73	2.75
	Experimental Density	2.65	2.67	2.68	2.74
Al6061-Graphite	Theoretical Density	2.70	2.67	2.66	2.64
	Experimental Density	2.65	2.58	2.53	2.58

Hardness

Hardness measurements were carried out on both the composites as well as on the base matrix using Zwick hardness testing machine at a load of 2N for a time of 10 seconds. The value reported is average of 100 readings taken at 30 different locations and are presented in Figure 2. It is observed that the hardness of Al6061-SiC composite increases with increased wt% of reinforcement while in Al6061-Graphite composite the hardness decreases with increasing wt% of reinforcement.

The increase in hardness of Al6061-SiC composite with increasing SiC content could be due to the fact that the reinforcement material is much harder than that of the matrix material for SiC and also could be due to better wettability of SiC by 6061 matrix which leads to good bonding between the matrix and reinforcement. However, decrease in hardness of Al6061-graphite composites is possibly due to poor wetting characteristics of Graphite by 6061Al.

Tensile Properties

Tensile properties of the both SiC/Graphite reinforced alloy and unreinforced Al6061 alloy

Figure 2: Comparisons of Hardness with Different wt% of Reinforcement

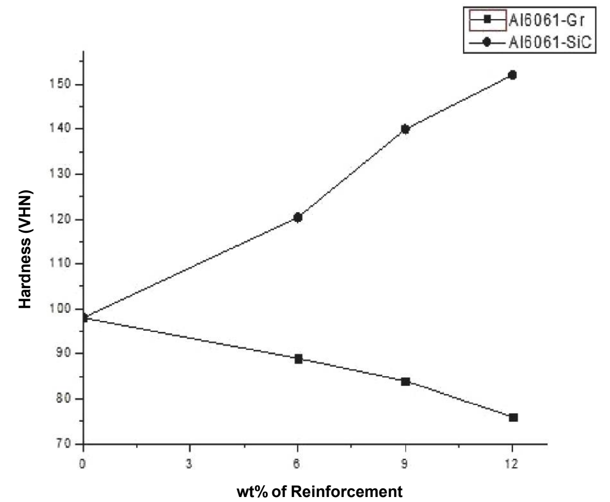
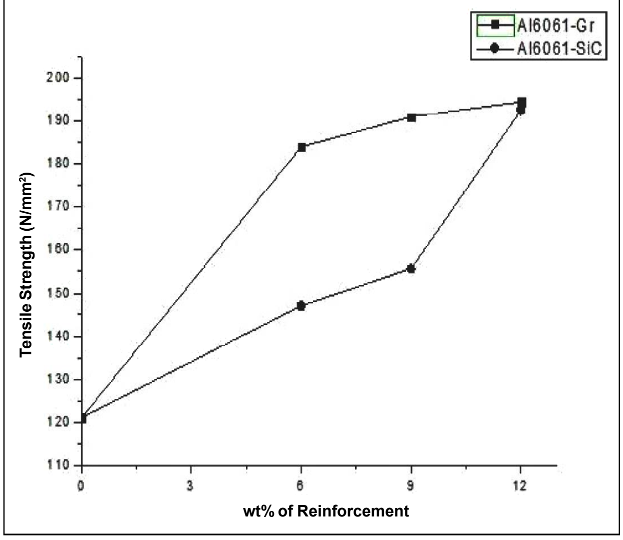


Figure 3: Comparision of Tensile Strength of Al6061-Graphite and Al6061-SiC with Different wt% of Reinforcement



were evaluated using computerized universal testing machine. For each composition three specimens were tested and the value reported is average of three readings which is shown in Figure 3. From the Figure 3 it can be seen that the tensile strength of composites is higher than the unreinforced matrix. However, with increasing wt% of Graphite/SiC particulates tensile strength of the composite increases. Also from the figure it can be observed that the tensile strength of the Al6061-Graphite composites is higher than that of the composites of Al6061-SiC. This improvement in tensile strength of the composites may be attributed to the fact that the fuller graphite possesses higher strength when compared to SiC. Further, at 12wt% the tensile strength value of Al6061-Graphite composite remain identical to that of Al6061-SiC composites which could be attributed poor wetting characteristics of Graphite by the matrix.

Wear Test

Wear is a process of material removal phenomenon. The as cast Al6061 alloy and Al6061alloy with varying weight percentage of Graphite and SiC particles are subjected to wear test under dry sliding conditions using pin-on-disc wear test machine (Model ED-201). The test were conducted on 8 mm diameter, 30 mm long cylindrical specimens against a rotating EN-32 steel disc (count face) having hardness 63Rc. The tangential frictional force and wear rate were monitored with help of electronic sensors. Both these parameters were measured as a function of load and sliding distance. For each type of material, tests were conducted at three different nominal loads (10N, 30N and 50N) keeping the sliding distance at 1.6 m/sec fixed at 400 rpm. Wear tests were carried out at room temperature without lubrication for 15 min.

From the Figures 4, 5 and 6 it can be concluded that the wear rate of SiC composites decreases with increasing content of SiC in the matrix for all three loads and at constant sliding speed of 1.6 m/sec. However, in case of Al6061-Graphite composites a decrease in wear rate was observed only with 6 wt% of Graphite, while increasing Graphite wt% has resulted increase in wear rate. Probably due to poor bonding between particles and matrix and during wear this has resulted in dislodging of graphite particles hence, more wear rate. Therefore, evaluating SiC and Graphite composites it can be seen that SiC reinforced composites exhibits better wear resistance properties than that of Graphite reinforced composites.

Figure 4: Comparison of Wear Rate Results of Graphite and SiC for Load of 10N-400 rpm

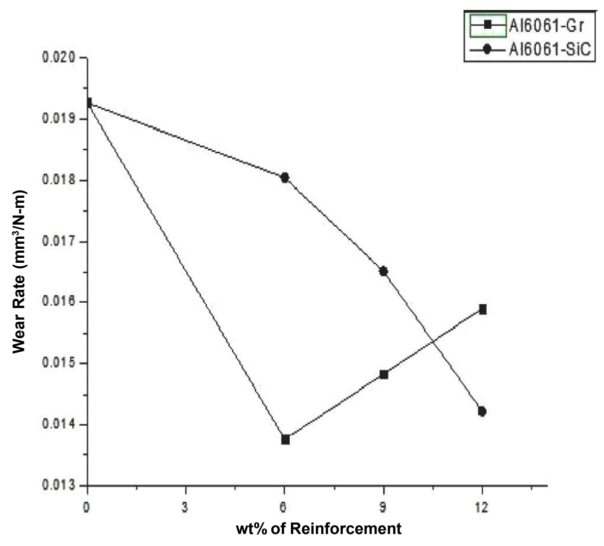


Figure 5: Comparison of Wear Rate Results of Graphite and SiC for Load of 30N-400 rpm

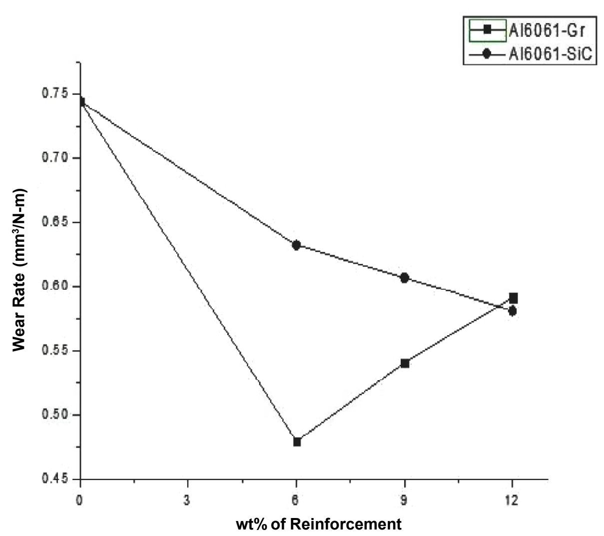
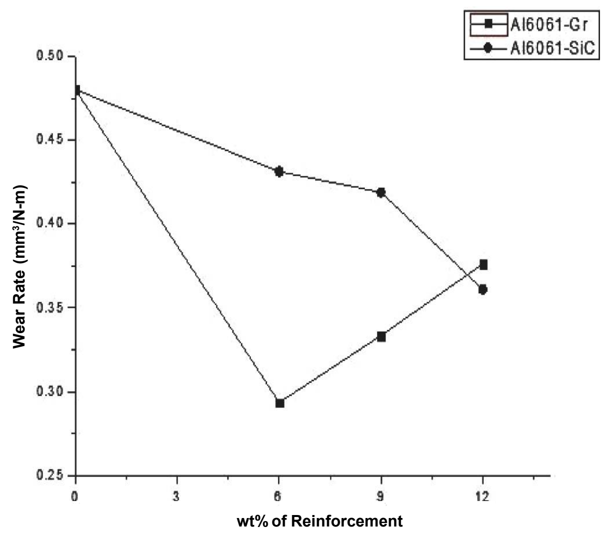


Figure 6: Comparison of Wear Rate Results of Graphite and SiC for Load of 50N-400 rpm



CONCLUSION

The conclusions based on the present work on Al6061-SiC and Al6061-Graphite metal matrix composites are as follows.

- Al6061-SiC and Al6061-Graphite composites are successfully prepared using stir casting method with filler contents up to 12 wt%.
- The microstructural studies revealed the fairly uniform distribution of the particles in both Al6061-SiC and Al6061-Graphite composites.
- Higher value of Hardness was observed in composites when compared to matrix alone. Further, hardness of the Al6061-SiC composite increases with increasing amount of reinforcement and where as in Al6061-Graphite composite increasing amount of Graphite has resulted in decrease of hardness.

- The addition of SiC/Graphite has resulted in increase in tensile strength of Al6061 alloy when compared to unreinforced alloy. The tensile strength is a function of volume fraction of reinforcement. As volume fraction of reinforcement increases tensile strength of composite increases.
- The wear rate of the Al6061-SiC composite found decreased with increasing SiC content where as the wear rate of the Al6061-Graphite composite found to decrease up to 6 wt% but thereafter tends to increase.

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