An Investigation on the Mechanical and physical Properties of AL6061/SiCp/Gr Metal Matrix Composites

S.S.Mohamed, Sayed.A.Abdallah, Hamdan k.h.Alazemi

***Abstract*— In the present work, using stir casting technique Al 6061 matrix was reinforced with graphite particles and silicon carbide particles to study the effect of graphite and silicon carbide reinforcement using mechanical testing and wear behaviour. Different volume fractions of silicon carbide viz. 5%, 10% 15% are incorporated into the alloy, maintaining the volume fraction of graphite as 3% for all proportions.**

Mechanical properties such as Micro-Vickers hardness test and compression strength are determined and tribological behaviour of the composite is studied using wear test. With 15% reinforcement of SiC particles, the hardness and ultimate strength are higher and the results of wear test demonstrates an increase in wear resistance with increase in SiC reinforcement.

***Index Terms*— Mtal matrix composites, Silicon carbide particle, Graphite, Stir casting, Hardness, and Tensile strength.**

I. Introduction

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.

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 MMCsreinforced 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. Sahin et al. [3] reported that hardness, density of the material increases with increasing the content of ceramic reinforcement and porosity decreases with increasing particles content. Xiao-Dong et al. [4] studied on 5210 Al/SiCp composite with 55 vol. % of SiCp fabricated by squeeze casting method. The bonding strength was increased as the particle size was reduced. Larger particle size produces larger flaws with more defects and decreases the strength of the material.

Saravanan et al. [5] studied on composites A356-10 vol. % SiCp with excess addition of 0.4% magnesium. The hardness and Young's modulus of the material increase with addition of SiC particles. Addition of extra magnesium to the composite slurry, increases the wettability. Akhlaghi et al. [6] reported that, as the particle size increases it lead to slight increase in tensile strength over the unreinforced aluminum.

Seah et al. [7] studied on mechanical properties of zinc-aluminium alloy/graphite particles. Ductility, ultimate tensile strength (UTS), compressive strength and Young's modulus increased and significant decrease in hardness of the composite material was observed. Lin et al. [8] reported that increase in graphite content in aluminium matrix material, reduces the UTS, Young's modulus and elongation of composite. This is due to cracking of the matrix/particulate interface, reduces the percentage elongation with addition of graphite particle. The mechanical and physical properties were increased by increasing the content of SiCp to the aluminium matrix alloy but decrease in machining property of the material. To maintain the high mechanical and improve the machining property of the material addition of graphite content in Al/SiCp composite material results in Al/SiCp/Gr hybrid composites..

The composites were fabricated by liquid metallurgy route. Stir cast method is practically easy, cost is less, and uniform distribution of the reinforcement into matrix alloy is possible. Stirring was carried out at semi solid condition and all the particles were easier to incorporate in matrix alloy. At volume percentage of SiCp higher than 20% in matrix alloy the wettability decreases and agglomeration and settling tendencies increases [9, 11].

Aqida et al. [12] studied on various stirring speeds and pre-heating the particles to avoid porosity. Naher et al. [13] studied on liquid and semi-solid stir casting technique to produce an Al-SiCp composite. The stirring speed from 200 to 500 rpm of slurry in semi-solid state produced uniform distribution in matrix without addition of any wetting agent. Al-Si constituent alloys used as major alloying element as it produces excellent castability [14-17].

In the present work attempt has been made to study the influence of Graphitep/SiCp addition on the microstructure,

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micro-hardness, and mechanical and wear behavior of 6061Al-alloy. Mechanical properties were evaluated as per the standards using computerized universal testing machine and wear properties were evaluated using pinon-disc wear testing machine.

II. EXPERIMENTAL DETAILS

Materials

2.1 Aluminium 6061

The metal matrix of the composite produced in this work was Al 6061 alloy and the SiCp was fabricated by liquid metallurgy method, used as reinforcement material had a diameter of (0 – 45 µm). The chemical composition of 6061 aluminum alloy plates used in the present study as delivered by the Misr Aluminum Company is given in table(1) .It's nonhardenable solid solution and dispersoid strengthened.

Table 1. Chemical Composition of Al6061 by Weight percentage.

Chemical Composition	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Al6061	0.62	0.23	0.22	0.03	0.84	0.22	0.1	0.1	Bal

2.2 Silicon Carbide

Silicon carbide (SiC) can be utilized as reinforcement in the form of particulates, whiskers or fibers to enhance the properties of the composite. SiC certainly improves the overall strength of the composite along with corrosion and wear resistance. The wear resistance of carbides is very high, therefore the wear resistance of material obtained is high. Also, the hardness of the composites will increase. SiC are very hard as compared with Aluminium metals. If we add SiC in aluminium then they will increases the stiffness of the material.

2.3 Graphite

Graphite is a crystalline form of carbon having a layered structure with basal parts planes or sheets of close packed carbon atoms. Consequently, graphite is a week when sheared along the layers. This characteristic, in turn gives graphite its low frictional properties as a solid lubricant. However, its frictional properties are low only in an environment of air or moisture, in vacuum graphite is abrasive and a poor lubricant. Unlike in other materials, strength and stiffness of graphite increase with temperature. Also, its small absorption cross section and elevated scattering cross section for thermal neutrons make graphite suitable for nuclear applications.

III. EXPERIMENTAL APPARATUS

3.1.Fabrication of Hybrid aluminium metal matrix composites

Stir casting is utilized to fabricate the AlSiC-Gr composite specimens with 5 to 15% weight fraction of SiC particles and 3 to 5% weight fraction of Gr particles. Al6061 alloy is selected as matrix material. Silicon carbide and Graphite are utilized as reinforcement.

Aluminium alloy is made to a molten state in the furnace and then preheated reinforcement particles are added. In order to obtain uniform distribution of SiC and Gr particles in aluminium matrix alloy, stirring is continued until the composite slurry obtained. After completing mixing for few minutes, the furnace temperature is slightly raised in order to have better fluidity for the composite slurry. Finally, castings of hybrid composites are produced using a split die. The same procedure is repeated for producing other composite specimens by varying the weight fraction of SiC-Gr.

3.2. Testing

Hardness and tensile tests were carried out at ambient temperature. The hardness tests were conducted using Vickers macro hardness testing system as per ASTM E-92 standard [18]. The tests were repeated for three Vickers indents for each specimen and average values were considered. A specimen sample was ground with series of emery papers down to 600 grit size and polished with diamond paste of 1- 2 micron size. Further the specimen was polished by electrolytically and etched. Tensile tests were carried out using computerized universal tensile testing machine. Tests were repeated for six times and an average values were considered. The tensile specimens were machined according to the ASTM E8 standard shown in Fig.1.

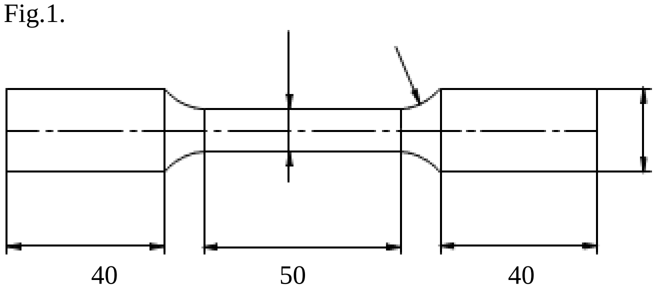

Fig. 1. Tensile Test Specimen Dimension[19].

IV. RESULTS AND DISCUSSION

4.1. Microstructures of composites

The microstructures of hybrid composites reinforced with SiC and graphite particles are shown in optical microscopy images (Fig. 1). For brevity, the microstructures of hybrid composites for a consistent reinforcement of graphite particles (10 wt.%) for each particular SiC particle size addition (45 µm and 53 µm) are presented in both optical and SEM images. The distribution of SiC and graphite particles is random with no cracks and deleterious pores in the microstructure. The measured microscopic porosities were found between 2 % – 3.5 % for produced hybrid composites. Interdendritic segregation is observed because the particles were pushed out by the solidification front and they are preferentially located in the eutectic regions during solidification. The presence of the particles in the matrix particles considerably refines the microstructure, impeding the coarsening of the dendrites of the primary phase during solidification. The SiC particles moved mostly at the primary aluminum dendrite boundaries, although some are observed within the aluminum grains. Porosity, which was revealed after slight etching of the specimens, could often be observed in the region of SiC particle clusters. Experimental observations showed that introducing graphite particles revealed similar effect with SiC addition. Increasing graphite content in the composite matrix leads grain refinement for both primary aluminum dendrites and eutectic silicon. The microstructural investigation also showed that silicon was present around the SiC particles and was located on the SiC surfaces (Fig. 1, a and c). Some of the primary silicon crystals were also found adjacent to SiC particles. Some of the primary silicon particles were heterogeneously nucleated on the SiC particles (Fig. 1, b) and equiaxed silicon particles can be seen around the large SiC dispersoid (Fig. 1, d)

4.2. ***Microstructure Analysis***

The microstructure image of the prepared specimen was observed and is shown in Fig. 2. The image shows the random distribution of an intermetallic spacing in the matrix and it also notifies about the grain orientation and distribution. It was found that the specimen contains 15% by weight as reinforcement had more randomness. It was observed that silicon carbide particles were deposited on the aluminum matrix. Silicon carbide particles has a certain attraction towards aluminum. The microstructures of the specimen are classified, where white back ground is aluminum, dark portion is graphite, light black portion is silicon and grey portion is primary silicon crystal. Hardness of the specimen increases with increase in SiC and decrease in the hardness were observed with reinforcement of Gr.

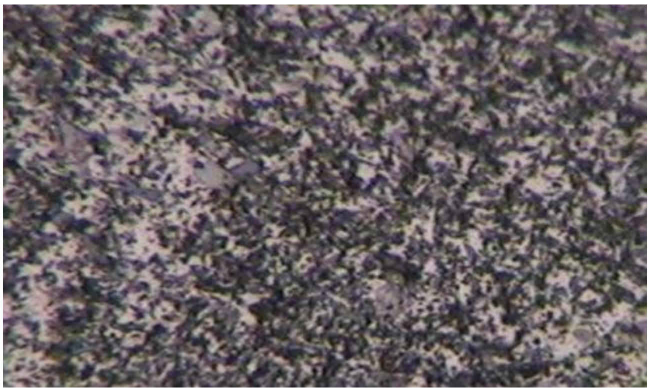

Fig. 2 Microstructure of Al-Si-SiC-Gr Composite

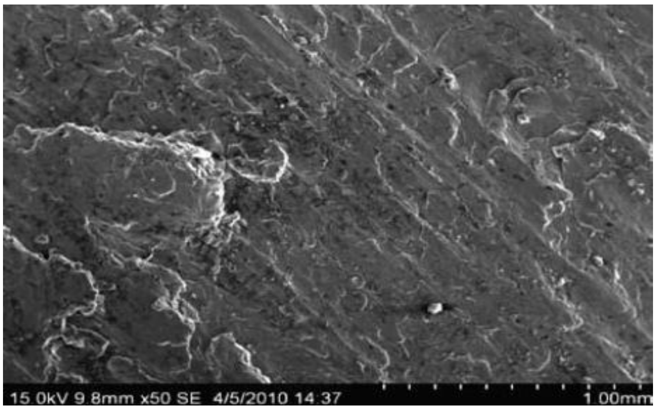

Fig. 3 SEM Image of Specimen at 50 X

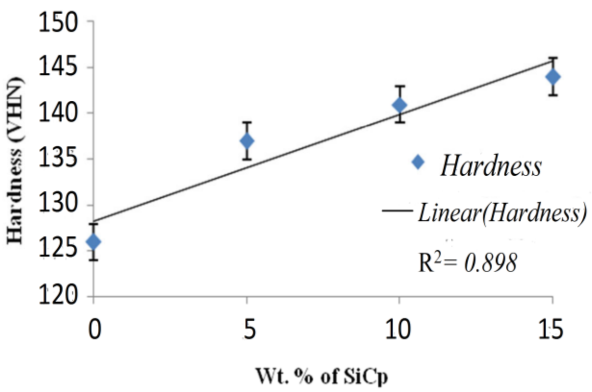

Fig. 5. Variation of Hardness with Increases in SiCp.

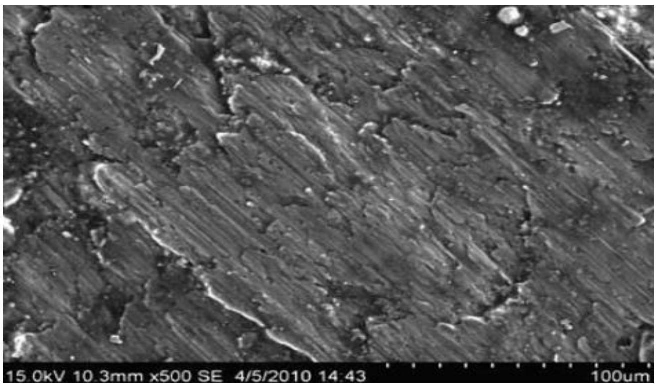

Fig.4 SEM Image of Specimen at 500 X

4-2 Characterization using SEM

The characterization of the specimen was carried out through SEM analysis on the worn surface of composite under load of 30N. The various SEM images of the prepared composite specimen are shown in the following Fig. 3 and Fig. 4. From the following SEM images it was observed that the material removal rate of the prepared specimen was occurred through micro cutting and micro chipping process only. Wide range of ploughing or abrasion marks were seen on the surface of the prepared composite and no deeper cuts occurred during the wear process.

4.3. Macro hardness

The hardness of the composite material is shown in Fig. 5 which increased with increasing the SiCp. In hybrid composites hard SiCp acts as a load bearing member, it enhances the mechanical property of the material. The hardness of the composite increased about 15 percent as the reinforcement content of SiC and graphite particles were varied from 0 to 5 wt%. The hard silicon particles are present along the flow lines and act as barriers to the movement of dislocations within the matrix. It increases the volume fraction of hard particle which increases the hardness of the material. Figure 3 show similar results were observed for A356/SiC [20] and Al-Si/SiC [21] by earlier researchers.

4.4. Tensile strength

The tensile strength of the composite increased with increase in SiCp particles shown in Fig. 6. The tensile strength of the composite material improved by 5%, with an addition of 3 wt% of SiC and graphite particles. The reinforcement of the particle in alloy plays a significant role in overall strength of the composite. The increase in strength of the matrix enhances the mechanical properties of the composites. The presence of reinforcement in the alloy generates dislocation across the span of lattice. Dislocation motion is controlled by either the dislocation interactions, direct dislocation particulate interaction with the matrix structure. The generation of dislocation as a result of heavy pile up of dislocations at the grain boundary as well as the particle-matrix interface which causes the increase in strength of the composites.

The increase in tensile strength was due to SiC particles acting as barriers to dislocations. This dislocation motion increases the dislocation density, which positively contribute the strengthening of the A356SiC/Gr composite. The inter particulate distance between the reinforcements increases the resistance to dislocation motion as reinforcement content increased. During deformation, the matrix material has to push the reinforcement's particles further during the process the dislocation piles up. This will restrict to plastic flow in the matrix provides good strengthening of the composites. Tensile strength increases up to 10 wt. % of SiCp and decreases with 15 wt. %. This is due to the inadequate bond between particles and matrix material when the percentage is increased [25].

Figure 7 shows the variation of elongation with increase in SiCp leads to decrease in the percentage elongation of the hybrid composite material. The SiCp gets oriented in the rolling direction. The alignment of SiCp aids in the better flow of the matrix, compared with the base alloy.

The effect of inclusions on tensile properties of A6061 alloy influence on tensile properties, as it reduces the property of the material that can be overcome by degassing. As degassing is very effective in removing the inclusions, it results in improvement in tensile and maintains the high percentage elongation of the material [22].

The yield strength and elastic constant was increased due to addition of SiCp in A6061 matrix material compared with alloy. When external load is applied on composite material, it produces strong internal stress between SiCp and matrix material. These types of stresses protect from slip behavior and increase the strain hardening rate. The SiCp and Si particle were found along the dendrite boundaries that act as barriers and increases the strength of the material [23].

The increase in volume fraction and particle size of graphite, reduces the tensile strength and elastic modulus. The tensile strength of SiC/Al material decreases with addition of graphite particles. It is mainly due to lower strength of graphite as compared with matrix alloy and SiCp. The Al/SiC material failed in ductile and Al/Gr failed in brittle manner. Graphite particles in composite material parallel to the basal plane produce weak Van der Waals forces, resulting in weak bond interface between Al/Gr materials. It produces a crack source and propagates rapidly along Al/Gr interface. Al/SiC material produces a plastic deformation with increasing volume fraction graphite particles, crack sources increases and hence decreases the tensile strength of the composite material [24].

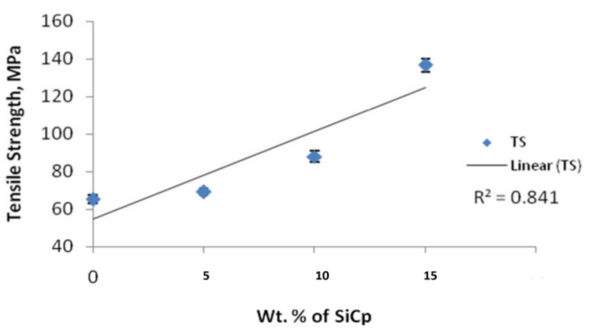

Fig. 6. Variation of tensile strength with increases in SiCp

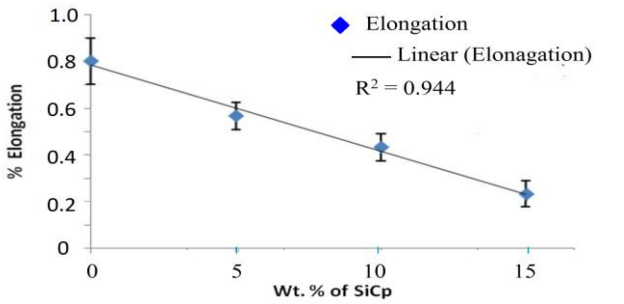

Fig. 7. Variation of Elongation with Increasing in SiCp.

4.5.Wear

Wear is a process of removal of material from one or both of two solid surfaces in solid state contact, occurring when two solid surfaces are in sliding or rolling motion together.

Dry sliding wear study

The wear tests are conducted by using pin-on Disc wear testing machine. The wear rate of specimen was found by weight loss method. The sliding distance was found by dividing the weight lost for known distance. Wear testing was carried out at a different sliding velocity with different normal loads. A cylindrical pin of size 8 mm diameter and 30mm length, prepared from composite casting, was loaded through a vertical specimen holder against horizontal rotating disc. The rotating disc was made of carbon steel of diameter 1200 mm and hardness of 60 HRC. The weights were measured before and after each test segment to determine the abrasive wear loss of each sample.

Table 2: Technical specifications of pin-on disc wear testing machine

Rotational Speed	Up to 2000 rpm
Track Diameter	50mm to 120mm
Load range	Up to 200N
Disc Size Dia	120mm * Thickness 8mm
Pin Size	6mm to 12 mm
Wear or Displacement	+2000 microns to -2000 microns
Frictional Force	Up to 200N

In this test we made an attempt of finding the wear rate by keeping load and sliding distance constant [i.e. load =20N ,sliding distance =2000m] then the result values of wear rate in microns get compared between the various compositions of composite and hybrid composites. That can be plotted by bar chart.

Wear rate is calculated by the formulae given in Equ. 1.

$$Wear\,Rate = \Delta w / 2\pi rNt \;\; gm/cm \qquad (1)$$

where Δw : is the difference in weight before and after wear test

$w_1 - w_2$ (gm.), $2\pi rNt$: is the sliding distance (cm), N: is the rotational speed of the disc (800 rpm), t: is the time period of wear test (10 min).

V. Conclusions

From the experimental investigation the following conclusions were drawn on the mechanical properties SiCp and graphite particles reinforced A6061 aluminium alloy composites

- A6061 hybrid composites have been successfully fabricated by liquid metallurgy route with uniform dispersion of SiCp and Gr particles
- The hardness of composites increased significantly with addition of SiCp, while maximum hardness was obtained for 15% of SiCp.
- The addition of low weight percentage of SiCp to A6061 leads to increase in tensile strength and decrease in percentage elongation.

• 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 5 wt% but there after tends to increase.

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