IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Vol.-6, Issue-5, May 2018 E-ISSN: 2347-2693

# Experimental Investigation on mechanical properties of Al6061 Hybrid Metal Matrix Composite Reinforced with Silicon Carbide and Graphite

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**Available online at: www.ijcseonline.org**

Accepted: 16/May/2018, Published: 31/May/2018

***Abstract*** - Aluminium (Al6061) possesses excellent Castability and considered as the prominent materials widely used for various mechanical applications. Lower mechanical properties such as strength, hardness and wear resistance of the Aluminium alloy is major limitation for their use in many areas. Their limitation can be prevailed by producing hybrid metal matrix aluminium composites with appropriate selection of reinforcement material and process. In this present experimental work, Graphite is chosen as reinforcement material owing to its exceptional wear and heat resistant properties and the other reinforcement material Silicon Carbide - for its Hardness, tensile strength and enhancing yield strength characteristics. The reinforcement materials were added and by stir-casting method the cast components were produced and are subjected to various tests to find their improved Properties. Wear test was carried out using pin-on-disk wear testing machine and the microstructure analysis was studied on an Inverted optical metallurgical microscope at a magnification factor of 200X. The values obtained from the test result shows that Al6061 alloy hybrid metal matrix composite processed with addition of different weight percentage of reinforcement particles Silicon Carbide (SiC) and Graphite (Gr) in volume percentage combinations resulted in the significant improvement in mechanical properties.

***Keywords*** - *Castability, hybrid metal matrix, Stir casting, mechanical properties, wear behavior*

## 1. INTRODUCTION

Hybrid composite materials are the popular emerging materials in recent years for various engineering domain. The volume and area of applications of composite materials have developed progressively, pertaining and conquering upcoming markets persistently. Components made from cast iron with graphite or steel consisting of carbides and metallic binders comes under this cluster of composite materials. The fabrication of hybrid metal matrix composites (HMMCs) with aluminium as a matrix and SiC/MoS2 as reinforcing particles have got enormous advantages that can meet about all prospects of engineering application. The interest of this work was made use of micro graphite as well as combination of graphite and silicon carbide as the reinforcing agent for Al6061 alloy so that the end products is a combination of the desired hardness, tensile strength and wear resistance.

The intention of the work is to fabricate the metal matrix composites of A6061 alloy with silicon carbide, micro graphite and various combinations of concentrations of micro graphite and silicon carbide by stir casting process. The composition of reinforcements used in A6061 alloy and reinforcement materials include are Graphite and Silicon Carbide. To study the Tensile strength, Hardness and wear rate of the Al6061 composite using UTM, Brinell hardness equipment and disc wear machine respectively.

## 2. MATERIALS AND METHODS

Al6061 is selected as the base material due to its excellent mechanical characteristics and ductility along with good corrosion resistance. But it has low wear resistance and low strength; these problems may be overcome by proper selection of reinforcement material. Al6061 has many applications because of its low cost and improved mechanical property.

### 2.1 REINFORCEING MATERIAL

Silicon carbide (SiC) and Graphite (Gr) have been selected as the reinforcement material due to its excellent wear, corrosion resistance and warping at the elevated temperature. These particles frequently act as a third body abrasive that lead to increase in these mechanical properties. Grains of silicon carbide are bonded together by sintering to form very hard ceramics that are extensively used in various applications requiring high endurance, such as brakes, clutch system and ceramic plates in bulletproof application. Silicon carbide particles have high strength, high hardness, high thermal conductivity, high elastic modulus and excellent thermal shock resistance. It is mainly used in fixed and moving turbine components, seals and bearings, ball valve parts, hot gas stream liners and heat exchangers.

Graphite is a crystalline type of carbon, a semi metal and forms one of the allotropes of carbon. It is in stable form of carbon under standard conditions. They are generally available in the form of crystalline flake graphite, amorphous graphite and lump graphite. Graphite generally have layered and planar structure. In each layer the carbon atoms are arranged in a honeycomb lattice with the separation of 0.142 nm and the distance between planes is 0.335 nm covalent bonds exists between these molecules. Flake graphite is the most physically occurring form of graphite that is usually found as discrete flakes ranging from 50-800 micrometer in diameter and 1-150 micrometer thickness.

## 3. EXPERIMENTAL METHODOLOGY

The experimental setup for making hybrid composite by stir casting essentially consists of an electric furnace with a mechanical stirrer. The electric furnace consists of crucible with a capacity of 2kg. The maximum operating temperature of the furnace is 1000°C. The current rating of furnace is single phase 230V AC, 50Hz. The matrix material is aluminium alloy Al 6061. The reinforcements comprising of volume % of Silicon Carbide (SiC) and Graphite (Gr) with (0+0), (12+0), (13+0), (12+2), (13+2), (12+4), (13+4) volume % combinations respectively and remaining AL6061 are planned for investigating the properties of hybrid composites.

The aluminium alloy AL6061 ingots were cut in power hacksaw machine to the small slices of 10 to 15 mm thickness to feed the materials in to the crucible. The required proportion of the ingots as per experimental plan is fed in to graphite crucible and melted by heating in the induction furnace at temperature of 850°C for 2 to 3 hours and melt the ingot above its liquidus temperature to formulate it in the form of semi-liquid state (around 600°C). The Silicon carbide and graphite particles in the right proportion as per the experimental plan were preheated to a temperature of 300°C to make their surface oxidized. In order to formulate with the molten aluminum the preheating process is performed. Preheated die is heated to a temperature of 200°C for proper solidification. During the reheating process of aluminium alloy at 750°C stirring is done with the help of mechanical stirrer which rotates at a speed of 600rpm. In the furnace the reinforcement powders are added to semi liquid aluminium alloy. Potassium hexaflurotitanate flux quantity is added after preheating it for 200°C for improving the wettability. Argon gas is passed in to the molten metal to remove the soluble gases present in the liquid state metal. Stirring of molten metal is carried for 5 minutes duration. The aluminum composite material reaches absolutely liquid state at the temperature of about 750°C and the completely melted aluminum hybrid composite is poured into the permanent mold die and subjected to solidification to produce the required specimen.

### 3.1 TENSILE TESTING

The tensile test establishes the ability of a material to withstand loads before elongation and the testing is conducted using extensometer testing machine. Ultimate tensile strength is calculated to find out maximum stress that a material can with stand under tensile loading. Test specimens are prepared according to ASTM E8-82 standards with each sample having 8mm in diameter and 60mm gauge length. The samples were fixed in Universal Testing Machine and tested until the failure of the specimen occurs. Tests were conducted in the specimen with different combinations of reinforcing materials and ultimate tensile strength and ductility were measured. Standard tensile test was conducted on the specimen that has been measured for its cross-sectional area and gauge length and placed in the testing machine and the extensometer is attached. Concurrent readings of load and elongation were taken at uniform intervals of load. Uniaxial tensile test were conducted on the fabricated specimen to obtain data's regarding the behavior of a given material under gradually rising stress-strain conditions.

### 3.2 BRINELL HARDNESS TEST

Brinell hardness test are subjective by scratches on the surface and coarseness from other hardness tests. For achieving the bulk and precise measurement, micro hardness test on material particularly for those materials having heterogeneous structures are best suitable. Hardness test conducted as per ASTM E10 standard. A load of 250 kg was applied gradually on the specimen for 30 seconds using 10 mm diameter hard steel ball indenter and the indentation diameter was measured using a microscope at two direction right angles to each other and average diameter is noted for calculating the hardness. The hardness was calculated at three dissimilar locations of the specimen and the average value was obtained.

### 3.3 WEAR TESTING

Wear testing is carried out by the pin-on-disc apparatus. Pin-on-disc wear testing is a universally used method for abrasive wear of the material. As the name imply that the equipment consists of a “pin” in contact with the revolving disc. The contact surface of the pin will be flat, spherical or certainly of any suitable geometry, that of exact wear component. In pin-on-disc experimentation, the coefficient-of-friction is constantly observed for wear occurring, and the material removed is evaluated by weighing and /or measuring the contour of the ensuing wear track. Changes in the coefficient-of-friction are frequently investigative of a change in wear mechanism, even though marked variation are seen during the stages of wear tests as symmetry conditions will be established.

## 4. RESULT AND DISCUSSION

### 4.1 MICROSTRUCTURAL ANALYSIS

The micrograph investigation evidently reveals the lack of dendrite morphology in all the composites fabricated for evaluation. The dendrite structure can be tailored during casting process which is subjective by several factors such as dendrite fragmentation, restraint of dendrite growth by the particles, and thermal conductivity, disparity between the particles and melt. Dendrite fragmentation can be recognized during shearing of early dendrite by the stirring action. During process it was established that the perturbation in the solute time, owing to the occurrence of particles can alter the dendrite tip radius and tip temperature. These consequences gives increase in dendrite to cell conversion as the density of particle is improved.

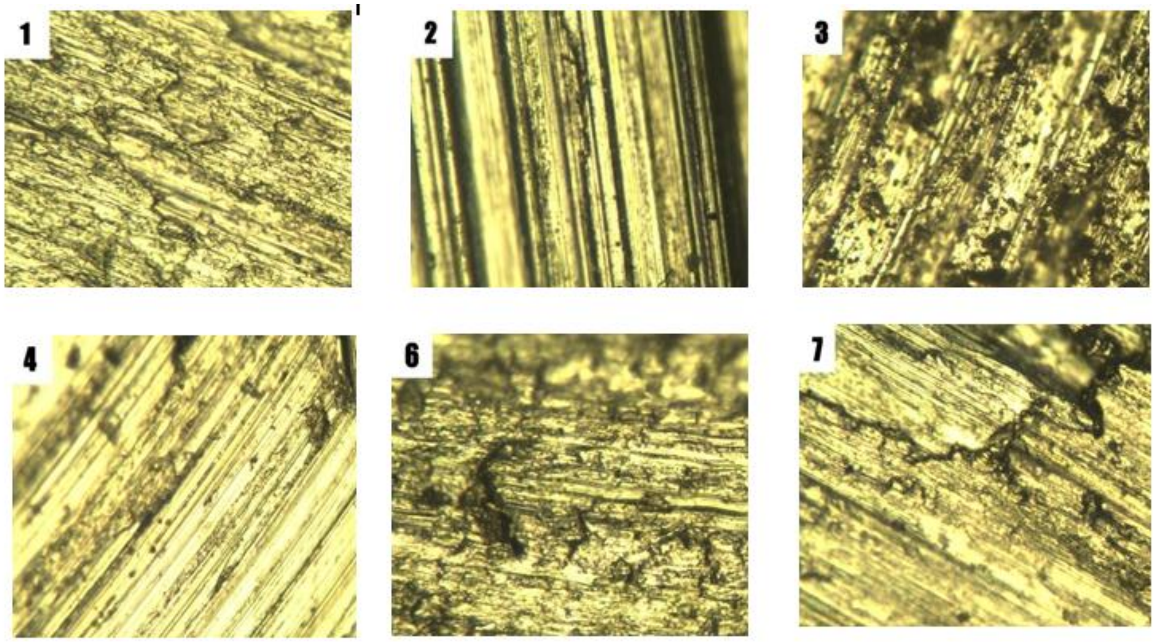


**Fig 4.1** Microstructure Analysis of all the samples

**4.2 TENSILE TEST**

The composite has superior tensile strength than Al 6061 alloy with lower ductility. The increase in tensile strength of fabricated composite contrast with the alloy, Al 6061 is due to the consistent distribution of the reinforcement phases of SiC in the matrix form. The stress value raises with response holding time up to 30 minutes and then it decreases. Hence the optimal reaction holding time of Al 6061 alloy is 30 minutes. It decreases with the reaction holding time up to 30 minutes and then it increases slightly. Compared to the Al 6061 alloys, the decrease in percentage elongation of the composite material may be due to presence of reinforcement particles in the composite material giving rise to increase in hardness.

**Fig 4.2** Tensile samples

**Table. 4.1 Tensile test results**

| Sl. No. | Reinforcement percentage | Tensile Strength (Mpa) | Yield Strength (Mpa) | Elongation (% ) |
|---|---|---|---|---|
| 1 | Al | 230 | 218 | 19.1 |
| 2 | Al/SIC-12p | 265 | 257 | 18.2 |

 

| | | | | |
|---|---|---|---|---|
| 3 | Al/SiC-12p/Gr-2p | 263 | 258 | 18.4 |
| 4 | Al/SiC-12p/Gr-4p | 260 | 256 | 18.5 |
| 5 | Al/SiC-13p | 271 | 265 | 18.0 |
| 6 | Al/Sic-13p/Gr-2p | 269 | 262 | 18.1 |
| 7 | Al/Sic-13p/Gr-4p | 268 | 260 | 18.3 |

### 4.3 BRINELL HARDNESS TEST

The hardness test conducted for the fabricated composites and their mixtures is shown in fig 4.4. From the result, an increasing tendency of hardness was examined with increase in weight fraction of SiC and relatively light decrease in hardness with the increase of Graphite. It is pointed out that the maximum hardness is observed at Al / (10% SiC+ 0% Gr), which leads to the deformation of the composite when subjected to strain. Amalgamation of fly ash particles with this composite considerably improves the hardness and also the deformation of the Aluminum matrix. It is observed that the combination of SiC with Graphite particles yields higher hardness than the aluminium. From this it concludes that the mechanical properties such as density, tensile strength, yield strength and hardness of the composites increases by increasing SiC in their mixtures and Graphite slightly decreases the Hardness, Yield strength and tensile strength value to a greater extent. While elongation the hybrid metal matrix composite decreases very much as that of the unreinforced aluminium. Adding magnesium in the composite improves the wettability between the reinforcement particles and improves the mechanical properties of the composites by solid solution strengthening. At the same, mechanical stirring at the time of semi-solid state increases the uniform distribution.

**Fig 4.3 Hardness Test – samples**

**Table 4.1 Hardness Test Results**

| Samples | Reading 1 | Reading 2 | Reading 3 | Average Hardness |
|---|---|---|---|---|
| 1 | 79.8 | 79 | 80.5 | 79.7 |
| 2 | 86.2 | 86.8 | 87.7 | 86.9 |
| 3 | 85.3 | 85.8 | 84.8 | 85.3 |
| 4 | 84.1 | 83.9 | 83.5 | 83.8 |
| 5 | 88 | 88.7 | 88.1 | 88.2 |
| 6 | 87.5 | 86.9 | 87.2 | 87.2 |
| 7 | 87.3 | 86.3 | 86.6 | 86.7 |

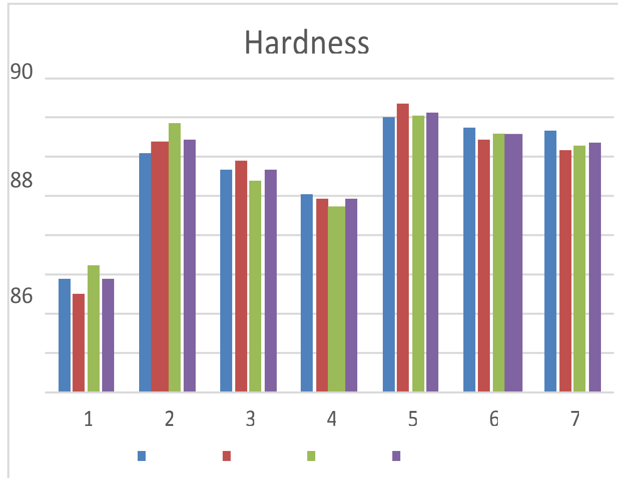


**Fig 4.4** Hardness Graph

### 4.4 WEAR TEST

The wear test for the seven samples machined as per ASTM standards were shown in Fig 5.13 have practically tested for wear and the graphical results for the wear rates and coefficient of friction for each sample has been observed and studied. From the results of the wear tests on the above 7 samples, it is evident that addition of SiC and Graphite greatly reduces the wear rate due to SiC being a very hard substance with a very high density and Graphite which being softer reduces the impact stresses on the entire metal part. Also, Graphite plays a very major role in reducing the coefficient of friction as it is smooth. This has proven to reduce the wear rate on the entire composite and the increased composition of Graphite further reduces metal wear.

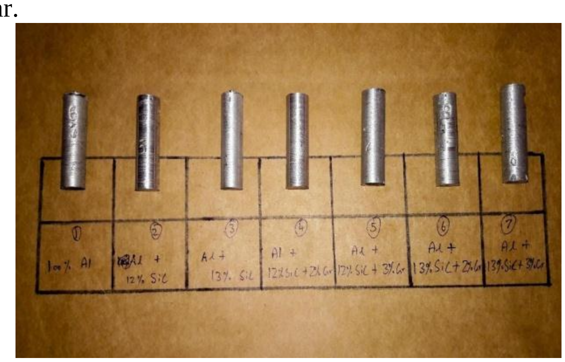

**Fig 4.5 Wear test specimen**

### 5. CONCLUSION

Graphite being a soft material reduces consequence of wear on the composite and reduced coefficient of friction. The addition of Graphite has a lower impact on material density and weight than silicon while it only negatively impacts the hardness of the composite. The addition of SiC particles in the alloy have significantly improved the hardness and wear properties of fabricated composites. The hardness value decreased (both micro and macro) as the content of Gr particles increased in the composite (Table 5.3) this may be due to low hardness of Gr compared to that of aluminum. The ultimate tensile strength decreases with increase in the content of Gr particles from 265 MPa at 0% addition of Gr particles to a minimum of 260 MPa at 4% addition of Gr particles. This decrease in ultimate tensile strength may be due to presence of Gr particulates into metal matrix, which is soft particles which acts as impurities in the molten metal and increases the porosity content due to which strength of composites decreased. Thus, the produced cast composite has the following properties:

- The composites show a 15-17% increase in tensile strength and 17-21% increase in yield strength mainly due to SiC and a maximum of 3% decrease in both properties due to the addition of Graphite.
- It shows a 5-8% increase in hardness where similarly SiC contributes to this and Graphite reduced Hardness by 1% at 4% composition.
- Wear test reveals that Graphite is successful at reducing wear by 16% in the Sample 7 (Al/SiC-13p/Gr-4p)

The conclusion is that the added Graphite in the SiC reinforced Al6061 reduces wear rate, thereby improving its life in the broad set of applications.

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