



## Flexural behavior and Microstructure of hybrid Metal Matrix Composites

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- ✓ flexural strength,
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### Abstract

This research work analyzed the influence of reinforcement on microstructure and flexural strength of AA6063/Al<sub>2</sub>O<sub>3</sub>/Gr<sub>p</sub> hybrid composite. The AA6063 reinforced with X wt.% Al<sub>2</sub>O<sub>3</sub> (x = 0, 3, 6, 9, 12) and 1 wt.% graphite (Gr) hybrid composites were fabricated using stir casting method. The *microstructure* of the hybrid composites were examined by means of optical microscope and scanning electron microscope. The *flexural strength* and *fracture morphology* were studied. The *flexural strength* of the fabricated composite at room temperature was estimated through a three point bending test. Result reveals that 6 wt.% Al<sub>2</sub>O<sub>3</sub> particles reinforced Aluminium matrix composite exhibit better *flexural strength* compared to other compositions considered in this study.

## 1. Introduction

Aluminium alloys are highperformance materials owing to their high specific strength and stiffness, which have been used in aerospace, automobile, chemical, and transportation industries [1]. Aluminium matrix composite (AMCs) is hypothetically necessary material for tribological applications [2]. Yusof Abdullah et al. considered the fracture behavior of Al-Si/ SiC composites and reported that hardness, tensile strength, flexural strength improved with increasing the volume fraction of the composites and stated that smaller particle size of reinforcement increased the fracture strength [3].

Baradeswaran and Elayaperumal investigated the mechanical characteristics and wear properties of AA7075/Al<sub>2</sub>O<sub>3</sub>/graphite hybrid composite. The brittleness of the Al<sub>2</sub>O<sub>3</sub> particles together with the interface between graphite and matrix leads to the increase in the flexural strength of the composite, and it was greater than that of the base alloy [4]. Fracture in Aluminium matrix composite is controlled by three techniques; (i) interfacial de-cohesion, (ii) fracture of reinforced particles and (iii) void nucleation and its growth [5]. The interfacial de-cohesion is caused by the formation of undesired interfacial reaction of the products. These intermetallic material encourage voids nucleation on the particles reinforcement interface [6]. Hwu et al. [7] found that dislocations generated due to the thermal disparity between the reinforcements and the matrix through quenching after the solution treatment which may promote the establishment of precipitates.

Generally used reinforcements are particulates, whiskers and fibers. The advantages of particulate reinforced composite above others are their fabrication with cost benefit [8]. Among the various of manufacturing methods available for particle reinforced AMCs, the stir casting routine is well known approaches utilized to generate a homogeneous distribution of the reinforcements in the matrix [9]. The porosity level, the wettability between the reinforcement and oxidation on cast AMCs should be reduced and also chemical reaction between reinforcements and the matrix should be avoided [10]. To increase wettability and particle homogeneousness during casting, several methods used by increasing the temperature of liquid and stirring of molten material for an sufficient time period. [11].

The impending of aluminium based alloy hybrid MMCs has been recognized in many industries from automotive to aerospace recently. In this view of potential applications in automotive parts, aerospace

applications, and powertrain, it is essential to understand the wear and mechanical properties of these hybrid composites. The prepared composite samples have been investigated for flexural strength at normal temperature with different weight percentage of reinforcement for diverse heat treated environments.

## 2. Experimental Methods

### 2.1. Materials and Methods

The Al6063-Al<sub>2</sub>O<sub>3</sub>-1%Gr reinforced composites were produced with alumina particles as 0- 12 wt.% insteps of 3 wt. % to base material by stir casting. The chemical compositions of AA6063 are given in Table 1. The primary reinforcing material selected was Al<sub>2</sub>O<sub>3</sub> of particle size of 20µm and graphite particle used as second phase of reinforcement with constant weight fraction of 1%.

**Table:1** Chemical configuration of AA6063 by percentage of weight

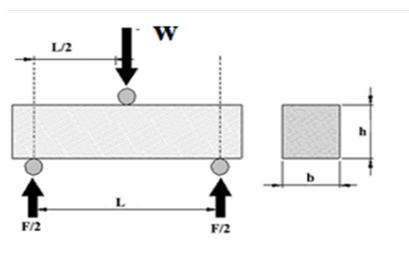
Mg	Si	Mn	Fe	Cu	Zn	Ti	Cr	Al
0.43	0.43	0.02	0.27	0.015	0.0024	0.008	0.005	98.4

Stir casting was carried out to melt an Aluminium alloy at a temperature of 800°C in graphite crucible by means of induction type electric resistance furnace. After completing the melting process the degassing agent, Hexa-Chloroethane (C<sub>2</sub>Cl<sub>6</sub>) tablet was added in order to remove the gasses from the molten alloy. The stirrer is operated at 600 rpm for 20 min. The dipping depth of the stirrer is retained at about 2/3 on the depth of the molten material. Both Al<sub>2</sub>O<sub>3</sub> and Gr were preheated for 30 min at a temperature of 400-450°C. During the stirring process, the preheated reinforcement particles Al<sub>2</sub>O<sub>3</sub> and Gr at different weight fractions was mixed in the vortex formed. Once the whole inclusion of the reinforcement particles to the molten material is done, the liquid composite material is tilted and poured into the preheated permanent steel mold and it was kept in the atmosphere for cooling. The specimen is then separated from the mold. One set of the sample is reserved without heat treatment to test in as-cast condition. The second sample was hardened at 550°C for 1 hr followed by quenching in water. The third sample of composites was hardened and then followed by aging at 170 °C for 6 hr in order to develop the mechanical characteristics.

### 2.2. Three-point bend test

The three-point bending test was conducted with Universal Testing Machine in a view to calculate the flexural strength of the hybrid composites at various conditions. The specimens with the size of 56x10x6mm<sup>3</sup> were performed on compression testing machine at room temperature as per ASTM C1161 standard. In order to study the fracture morphology the fractured samples, SEM test was carried out. The Figure 1 shows the principle of three-point bending test and a photograph of three point bend test specimens. The flexural strength was calculated using the below formula.

$$\begin{aligned} \text{Bending stress, } & \sigma = M/I * Y \\ \text{Moment of inertia, } & I = bh^3/12 \\ \text{Bending moment, } & M = WL/4 \\ \text{Deflection, } & \delta = WL^3/48EI \\ \text{Where, } & E - \text{Young's modulus} \\ & L - \text{Span length} \end{aligned}$$



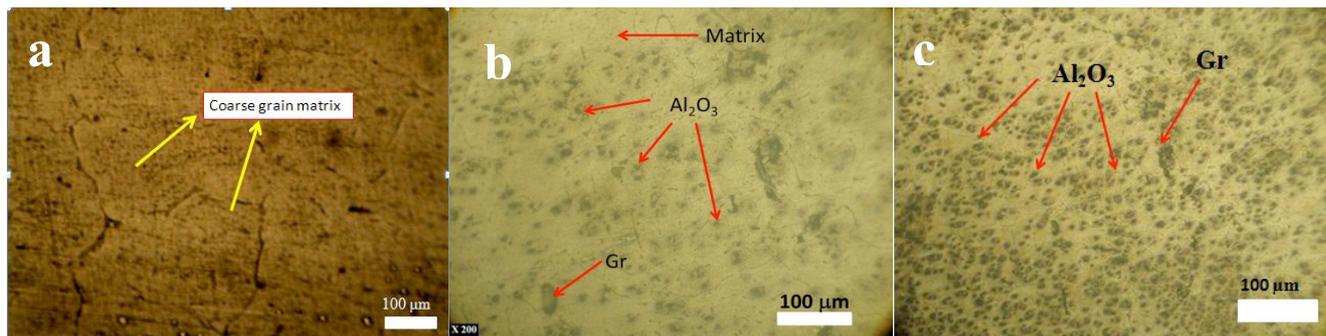
**Figure1:** systematic diagram of three point bend test and three point bend test sample

## 3. Results and discussion

### 3.1 Microstructure

Fig.2 demonstrates the optical micrographs of the polished surfaces AA6063-xAl<sub>2</sub>O<sub>3</sub> [x=0, 6 and 12] wt.%- 1% Gr composite in as-cast condition. The Fig.2 (a) evidently shows that coarse grain matrix with average grain size of 100 µm. From the fig.2 (b) it was observed that homogeneous distribution of

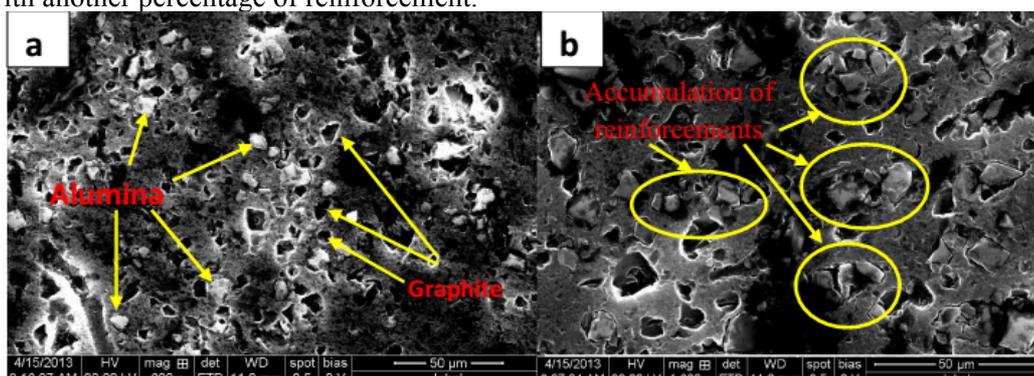
Al<sub>2</sub>O<sub>3</sub> particles found all over the matrix. Moreover, it contains coarse grain matrix with an average grain size of 70 μm. From fig.2(C) it was observed that there is an agglomeration of Al<sub>2</sub>O<sub>3</sub> particles with the matrix grain size of 60 μm.



**Figure 2:** Microstructure at as cast condition (a) Al (b) Al- 6%Al<sub>2</sub>O<sub>3</sub> -1%Gr (c) Al-12% Al<sub>2</sub>O<sub>3</sub> -1%Gr

### 3.2 SEM analysis

The hybrid composite namely AA6063-x Al<sub>2</sub>O<sub>3</sub> [x= 3, 6, 9 and 12] wt.%- 1% Gr were characterized using SEM analysis. In order to identify the dissemination of reinforcements in the matrix SEM analysis was performed. The Fig.3(a) evidently illustrates the uniform distribution of Al<sub>2</sub>O<sub>3</sub> particles and graphite all over the matrix [12]. It is expected to have better mechanical properties due to homogeneous distribution of reinforcements. From the Figure 3 (b) it was observed that there was an accumulation of reinforcement due to increase in volume fraction of Al<sub>2</sub>O<sub>3</sub> particles. From the observation, it was expected that there was a lag of bonding strength between reinforcement and matrix due to clustering which is already discussed by Saravanakumar et al.(12). Further, they analyzed the mechanical characteristics in terms of hardness, impact strength and compressive strength of hybrid composites, in that 6% Al<sub>2</sub>O<sub>3</sub> particles reinforced hybrid composite shows enhanced properties when compared with another percentage of reinforcement.



**Figure 3:** SEM analysis for (a) Al6063- 6 %Al<sub>2</sub>O<sub>3</sub> -1%Gr (b) Al6063-12% Al<sub>2</sub>O<sub>3</sub>-1% Gr

### 3.3 Flexural strength

The three point bend tests were executed to find the fracture behavior of the AA6063-Al<sub>2</sub>O<sub>3</sub>-Gr composites with increasing of the Al<sub>2</sub>O<sub>3</sub> particle. Figure 4 indicates that the flexural strength increased with the addition of Al<sub>2</sub>O<sub>3</sub>. Akhlaghi et al.[13] investigated the fracture behavior of Gr particle reinforced with aluminium 2024 alloy under three point bend test. They indicated that while increasing volume percentage of Gr, there is a decrease in the flexural strength as well as hardness and ductility of the material. At the same time, the addition of Al<sub>2</sub>O<sub>3</sub> to the matrix enhances the mechanical properties of composites.

For all reinforcement levels, 6% ceramic particles reinforced composite showed superior characteristics when compared to another percentage of reinforcement. The heat treatment supports in homogenizing the structure and minimizes the separation of alloying element in casting. This naturally initiates the enhancement in hardness and fracture strength of the composite. The fracture behavior of the aged samples possesses higher than as cast condition. From the micrograph Fig.3(a) it was observed that the average matrix grain size of 0.75μm. This has attributed to rise in the fracture strength. The spacing between particles is condensed when the size of particle is fine. The ultrafine particle restricts the plastic deformation. This ultimately leads to increasing the modulus or rupture. The decrease in fracture strength beyond the addition of 6 wt-%Al<sub>2</sub>O<sub>3</sub> particles is due to agglomeration of reinforcement. The SEM photograph of composites was illustrated in Fig.3 (b).

From the fractography, (Fig.6a) it was clear that the base alloy has numerous dimples. It represents the ductile fracture. Also, the failure occurs as the crack propagates along the matrix grains boundaries. However, in

contrast to the Fig.6(c), the dimple formation was less. It indicates the brittle fracture. Also, it was observed that the crack propagates between reinforcements and matrix interface. While applying the load, interfacial strength was not sufficient to carry the load. Also during fracture, the ceramic particles were pulled out from the matrix.

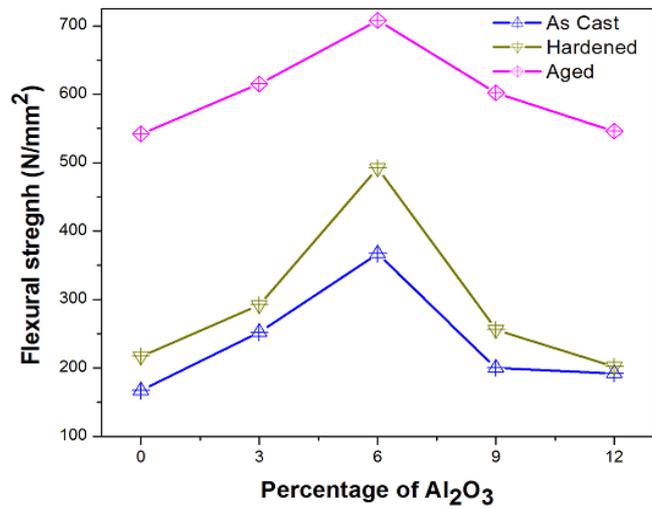


Figure 4: Comparison of flexural strength at various conditions

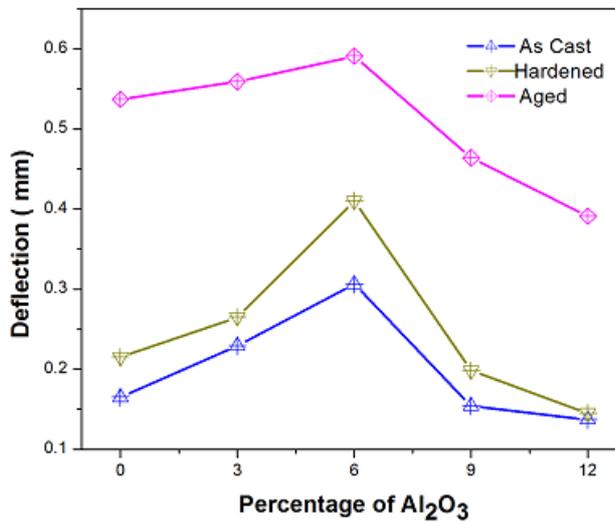


Figure 5: Deflection at various conditions

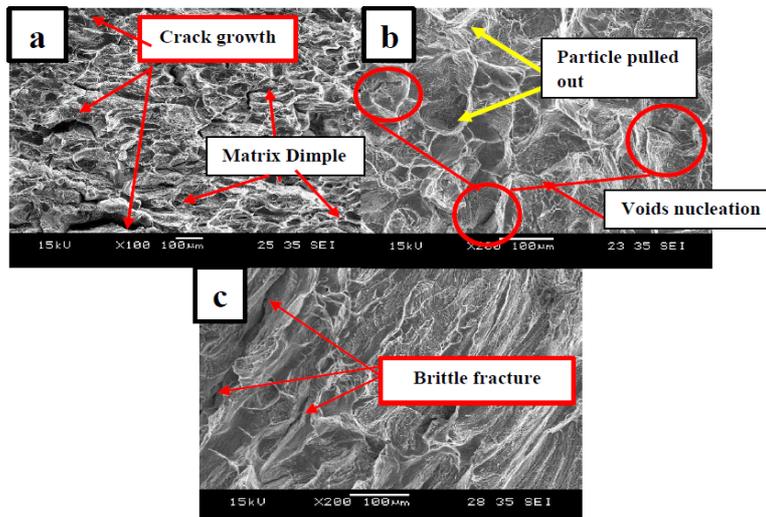


Figure 6: SEM analysis for fractured surface  
 (a) AA 6063 (b) AA6063/6% Al<sub>2</sub>O<sub>3</sub>/1% Gr (c) AA6063/12% Al<sub>2</sub>O<sub>3</sub>/1% Gr

From the Fig.6(c) it was observed that the particle fracture mainly occurred at the cluster of particles. At the region of the cluster due to the presence of porosity as well as the non-homogeneous mechanical properties, it tends to fail under low-stress conditions. Razaghian et al. (1998) examined the fracture characteristics of SiC particle reinforced AA7075 with uniaxial tensile loading condition. Enormous particles and areas of gathered particles were found to be the locations prone to harm the composite at normal temperature [14,15]. Further Saravanakumar and Sasikumar [16] confirmed the compounds presence in the fabricated composites with EDS analysis.

From the fractography, flexural strength depends on interfacial bonding strength and porosity presence in the composites. The 6% reinforced samples contain particles of finer in size providing additional interface zone which helps as the nucleation sites of grain establishment. Vice versa, the larger reinforcement particle will distribute more loads to the matrix. So the local stress acting upon the particular particle was so high. It will cause the failure. The fine particles employ more constraint on plastic flow during distortion that will lead to enhance the strength. So compared to other three conditions 6% reinforced samples possess higher flexural strength.

## Conclusion

Based on the studies on the AA6063 alloy by inclusion of Al<sub>2</sub>O<sub>3</sub> and Graphite, the subsequent findings were made:

- From the micrographs and SEM photographs, the AA6063-6% of Al<sub>2</sub>O<sub>3</sub>-1% of Gr composite obviously confirms the homogeneous distribution of reinforcement all over the matrix. That is the specific reason for higher flexural strength in 6% of Al<sub>2</sub>O<sub>3</sub> reinforced composite compared to other samples.
- There is a stable enhance in flexural strength of AA6063 alloy with an increase in the proportion of Al<sub>2</sub>O<sub>3</sub> in the mixture up to 6% owing to dispersion strengthening of Al<sub>2</sub>O<sub>3</sub>.
- The addition of Al<sub>2</sub>O<sub>3</sub> particles beyond 6% causes decreases in fracture strength due to agglomeration of reinforcement which is shown clearly in SEM analysis.
- Ductile fracture is observed in 6% of Al<sub>2</sub>O<sub>3</sub> beyond which brittle fracture occurs.

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