



Fracture toughness investigations of Al6061-Graphite particulate composite using compact specimens

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ABSTRACT. The objective of this research work is to study the fracture behavior of Al6061 with graphite particulate composite produced by the stir casting technique. For the study different composition of the particulate metal matrix composite used is Al6061 with 3, 6, 9, & 12% of graphite particles. Compact Tension (CT) specimens were utilized to determine fracture toughness for different compositions of Al6061-graphite particulate metal matrix composite. Specimens with different composition will be prepared for different crack length to width (a/w) ratios according to the ASTM E-399 standard testing procedure. The maximum fracture toughness was found for Al6061-9%Gr for $a/w = 0.45$ and the value is $16.74 \text{ MPa} \sqrt{\text{m}}$.

KEYWORDS. Fracture toughness; Al6061-Graphite Composites; Compact Tension specimens



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INTRODUCTION

All structural materials do not have theoretically calculated strength because of imperfections like inclusions, flaws, cracks and manufacturing defects, etc. The fracture based design approach is better compared to the conventional design. In conventional design, limiting strength approach is adopted. In actual service, the components will fail before reaching its limiting strength.

“The resistance to fracture of a material is known as fracture toughness.” Generally it depends upon the material composition, environment, temperature, loading rate, microstructure and geometrical parameters of the component, etc. Fracture toughness is a material property which expresses the capacity of a material having a crack to oppose fracture. For many design applications, fracture toughness is the most important property of a material. Linear elastic fracture toughness (LEFM) of a material is calculated from the stress intensity factor (SIF) at which a thin crack in the material begins to grow catastrophically. Fracture toughness is represented by K_{Ic} . Its unit in SI is $\text{MPa} \sqrt{\text{m}}$. In K_{Ic} , subscript Ic represents first mode crack opening under tensile loading at right angles to the crack. Fracture toughness could be a



quantitative approach of stating a material's resistance to brittle fracture once a crack is present. If materials have high fracture toughness, it will possibly experience a ductile fracture whereas materials having low fracture toughness will possibly undergo brittle fracture.

After studying the early work of Inglis, Griffith, and others, Irwin, head of the fracture mechanics research group at the Naval Research Laboratory, concluded that the basic tools needed to analyze fracture were already available [1]. Irwin's initial major contribution was to reinforce the Griffith approach to metals as well as the energy dissipated by native plastic flow. Griffith, Irwin and others who worked on the conceptualization of fracture mechanics, studied the behavior of cracks in brittle materials.

To investigate the fracture toughness, there are different methods. Basically an American Society for Testing and Materials (ASTM) Standard and recent advances in fracture toughness testing methods are used for testing of aluminium alloys and some of aluminium matrix particulate reinforced composites.

ASTM standard testing methods include Fracture toughness testing by Single Edge Notch Bend (SENB) Specimen and Compact Tension (CT) Specimen. Other testing methods which are getting popular for their ease include Fracture toughness by Round Bar, Indentation techniques, Circumferential Notched Tensile (CNT) specimens [2].

Metal matrix composites (MMCs) are used in automobile and aerospace applications where they are required for weight savings, wear resistance, thermal management, etc. MMCs may be of continuously and discontinuously reinforced types [1]. By far the most commonly used MMCs are based on aluminum alloys reinforced with alumina (Al_2O_3), silicon carbide (SiCp), Titanium carbide, graphite etc.

Discontinuously reinforced MMCs are a great deal more affordable to fabricate than continuously reinforced composites. Discontinuously reinforced composites have isotropic properties [3], whereas continuous aligned reinforcements have highly anisotropic properties. In applications requiring isotropic properties, discontinuously reinforced composites can do better than continuous fiber reinforced composites.

The literature survey presents a review of the published material available on the effect of various reinforcement types, their size and volume fraction, ageing behavior with Aluminium based Metal Matrix Composites (MMCs) [3] being a combination of two constituents, matrix and the reinforcement.

Mechanical characterization such as tensile strength and elongation experiments by using Universal Testing Machine [4, 5] (UTM) of Al/SiC has been reported for a varying mass fraction of SiCp with Aluminium. Fracture toughness [6], tensile fracture behavior [7, 8, 9] on Circumferential Notched Tensile (CNT) specimens and Compact Tension (CT) test [10, 11] specimen of Al alloy with different reinforcements, fracture toughness by indentation techniques [12, 13] were studied by different researchers. Most of them compared their results with the unreinforced aluminium alloy.

From the literature, it is identified that more work has been done on tensile and fracture characteristics of Al/SiC particulate [14, 15, 16, 17] MMCs. Research has to be carried on the aluminium matrix composites reinforced with graphite particles in the area of fracture and fatigue in order to improve the strength and fracture characteristics of the material to avoid cracking. The study of the tensile and fracture characteristics of aluminium matrix composites reinforced with graphite particles at varied weight fractions is here reported.

PROCESSING

Processing of MMCs was done by the stir casting technique [8]. Aluminium 6061-graphite specimens were prepared at varied weight fractions of graphite (3%, 6%, 9%, and 12%) using stir casting method. The aluminium blocks were melted in the furnace. After melting, molten aluminium was super-heated to desired temperature (about 750°C). The required amounts of graphite particles were added to the aluminium melts while stirring with stirrer at a speed of 550 RPM. The molten aluminium-graphite was poured into a split type permanent mould and it was allowed to solidify. The aluminium-graphite alloy bars were taken out from the mould. The specimens were prepared from as-cast alloys for determination of required properties.

FRACTURE TOUGHNESS TESTING

Fracture toughness of the aluminum-graphite particulate MMCs at varied weight fractions of graphite (3%, 6%, 9%, and 12%) was determined using a universal testing machine (UTM) as per ASTM E399 standard [10] testing procedure. In this method compact tension (CT) specimens are used as shown in Fig. 1. Compact tension (CT) specimens of various weight fractions of aluminium graphite are tested for their fracture toughness values. The specimen

preparation and experiments were carried out according to ASTM-E 399 standard for three different crack length to width (a/w) ratios i.e., 0.45, 0.47 & 0.50.

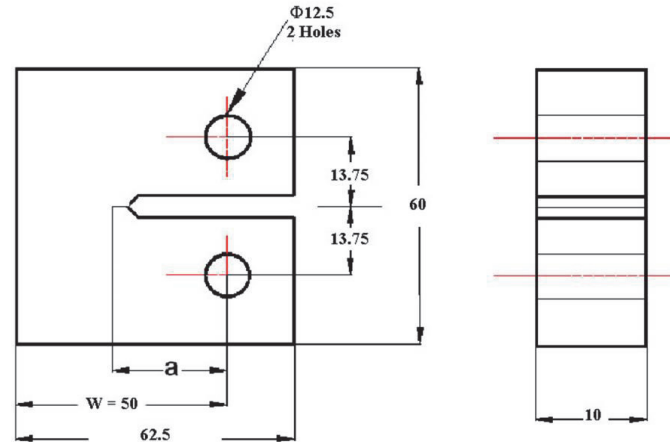


Figure 1: Dimensions of cast CT Specimens (All dimensions are in mm).

The load-displacement data are analyzed to find out fracture toughness (K_{Ic}) of the Al6061-graphite particulate MMCs. The value of K_{Ic} is determined by crack length and critical load (P_Q). The value of P_Q is determined by plotting a secant slope on the load and displacement record. Typical [10] load-versus-displacement record for the two types of K_{Ic} testing is shown in Fig. 2. The calculation for P_Q engages representing the loading slope of the load versus displacement record. A slope of 5% less than the available slope, referred as secant slope, is then drawn. In Type I, monotonically rising load, the P_Q is taken where the 5% secant incline meets the load-versus displacement curve [10]. In Type II or Type III, instability or other maximum load is reached before the 5% secant. The maximum load reached up to and including the likely intersection of the 5% secant is the P_Q .

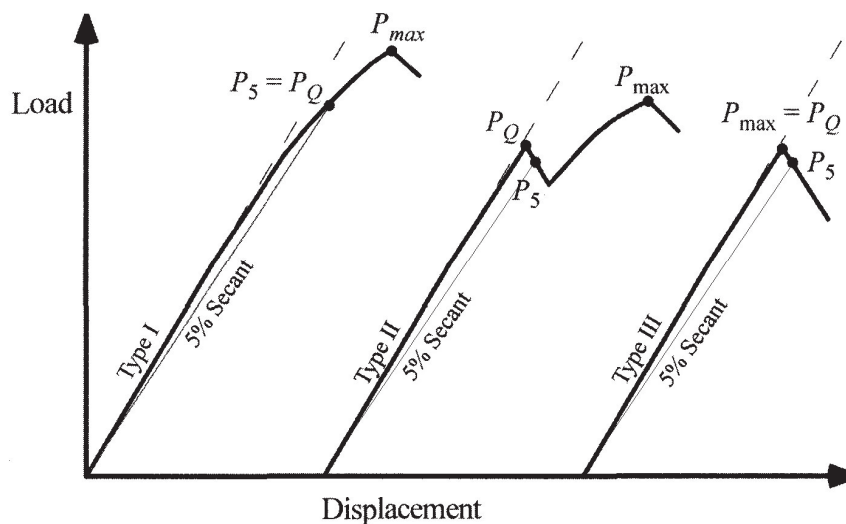


Figure 2: Three types of load-displacement behavior in a K_{Ic} test. Source: T.L. Anderson [1].

In the case of slope of the load-versus-displacement record of Al6061-graphite, the curve obtained was Type III curve as shown in Fig. 3. The maximum value of the load itself will be the critical load (P_Q). This corresponds to about 2% ductile crack extension [18]; this may be an effective crack extension linked to plastic zone development. K_{Ic} values were determined from the P_q values as prescribed in ASTM E399 Standard [10].

Experiments were carried out and results of the experiment are listed in Table 1. Fig. 3 shows the load-displacement curves of Al6061-graphite obtained using CT specimens for different crack length to width ratios.

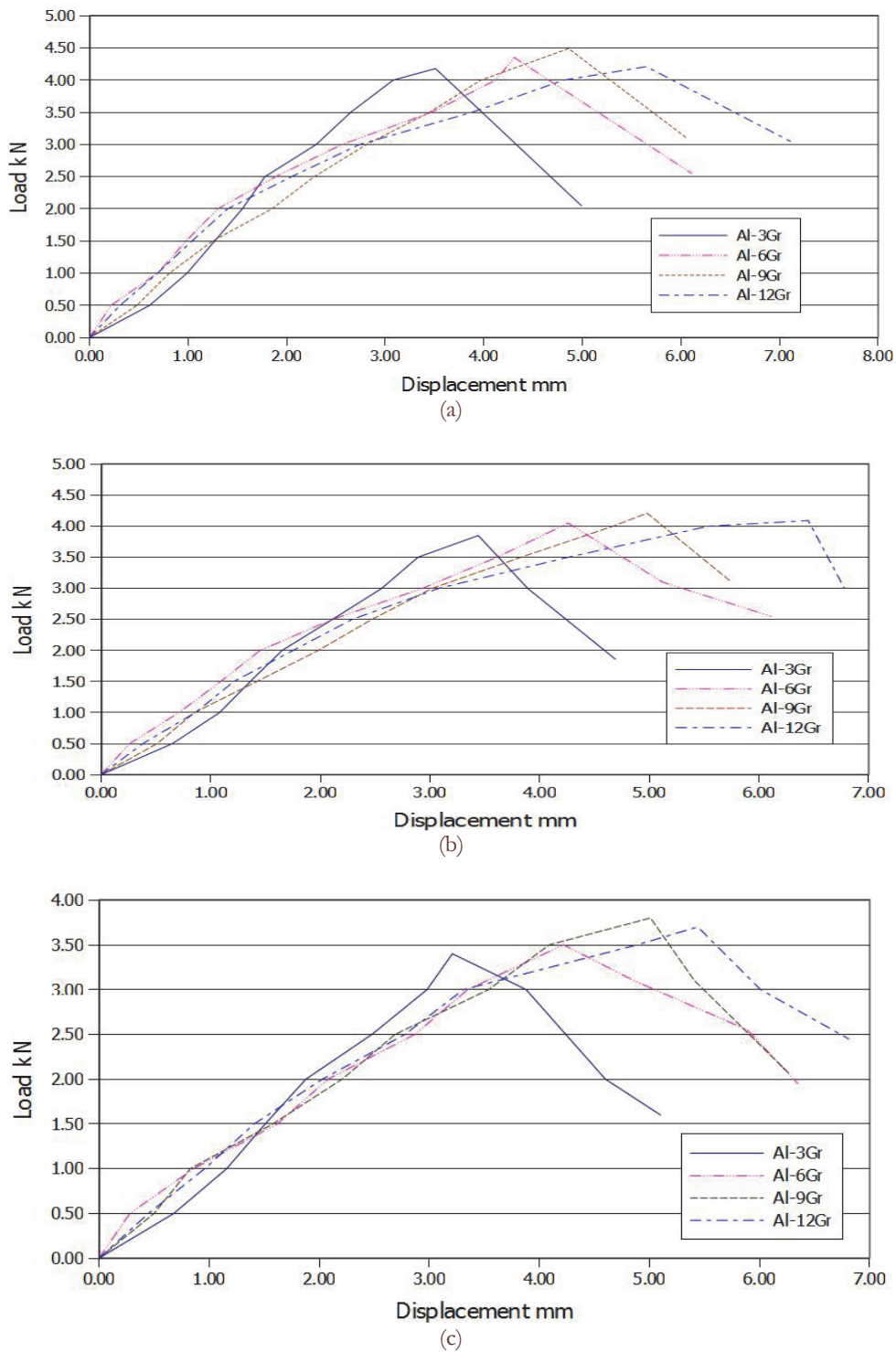


Figure 3: Load v/s Displacement graphs for different compositions: (a) $a/w = 0.45$; (b) $a/w = 0.47$; (c) $a/w = 0.50$.

From Fig. 3 it is clear that as the load increases displacement increases for $a/w = 0.45, 0.47$ and 0.50 of Al6061-graphite. For all the a/w ratios increase of load bearing capacity of Al6061-graphite has been observed. At 12% graphite there is a decrement in load carrying capacity of the material has been observed. This decrement may be due to clustering of graphite particles in the surrounding matrix.

Specimen	For a/w=0.45		For a/w=0.47		For a/w=0.50	
	Fracture Load (P _Q) kN	K _{Ic} MPa√m	Fracture load (P _Q) kN	K _{Ic} MPa√m	Fracture load (P _Q) kN	K _{Ic} MPa√m
Al-3%Gr	4.18	15.59	3.85	15.20	3.40	14.68
Al-6%Gr	4.35	16.22	4.05	15.99	3.50	15.11
Al-9%Gr	4.49	16.74	4.21	16.62	3.80	16.41
Al-12%Gr	4.21	15.70	4.09	16.15	3.70	15.98

Table 1: Fracture toughness of Al6061-graphite MMC for different a/w ratios.

For increase in graphite content fracture toughness of Al6061-graphite for a/w = 0.45, 0.47 and 0.50 has been drawn as shown in Fig 4. From the outcomes it is found that the fracture toughness results assessed from the compact tension (CT) specimens were significant. Fracture toughness of particulate metal matrix composites is depending on particle size, interfacial strength levels and the ductility of the surrounding substance and strengthening materials.

Fracture toughness testing was done using CT specimens. From the results it can be found that with increase in graphite content fracture toughness of Al6061-graphite was increased. This increment is due to the effect of increased graphite particulates which block the initiation of internal cracks in the microstructure. This increment in K_{Ic} is consistent with the trend in most as-cast Al based particulate reinforced composites [7, 8, 12, 14]. The decrement of fracture toughness at 12% graphite may be an effect of increased graphite particles which causes particle clustering in the surrounding matrix. The decrease in fracture toughness may be due to particle debonding, interfacial cracking or particulate cracking.

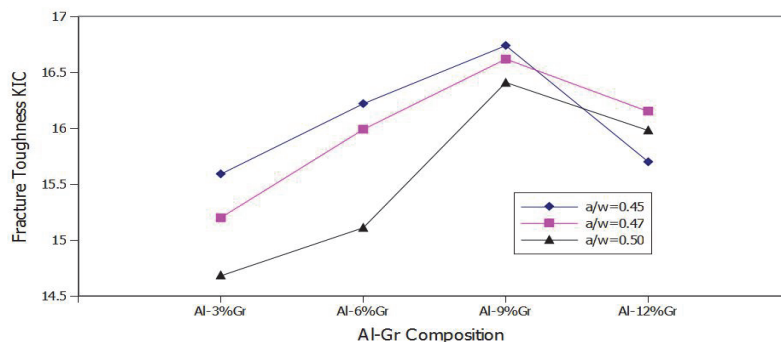


Figure 4: Fracture toughness of Al6061-graphite MMC

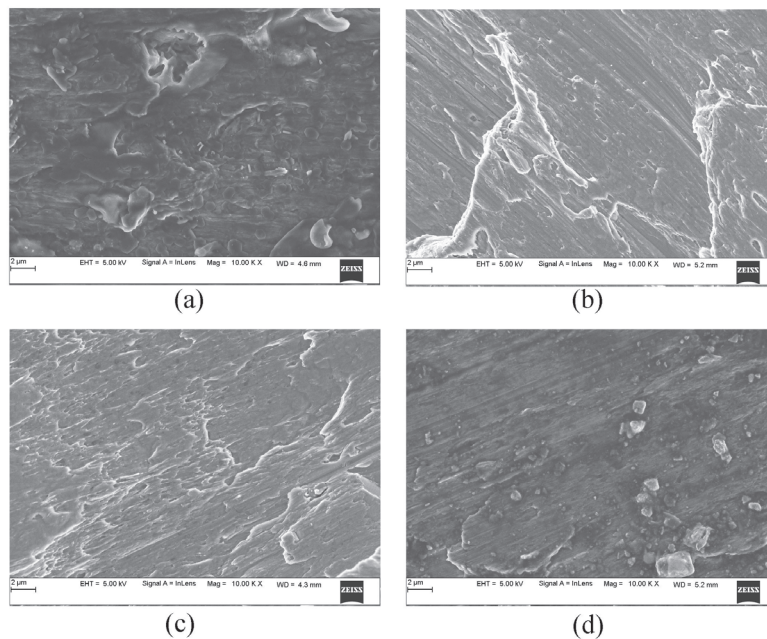


Figure 5: SEM Micrographs (a) 3% graphite (b) 6% graphite (c) 9% graphite (d) 12% graphite.



The micrographs from SEM of Al6061-graphite for different composition are shown in Figs. 5 (a-d). A strong uniform microstructure between the matrix and reinforcement facilitates in the load interchange from the reinforcement to the surrounding matrix. Accordingly, crack propagation takes place in the composite via the reinforcement and not along the interface. A solid particle/matrix interface helps the graphite particles establish themselves into the matrix logically, enhancing the crack resistance.

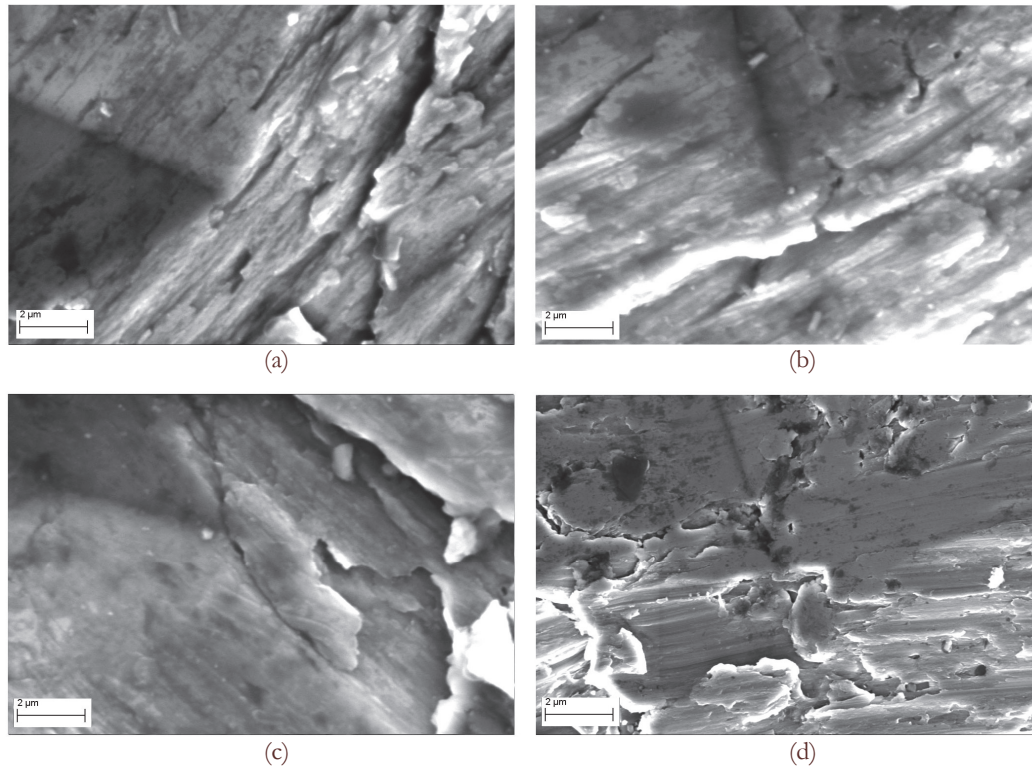


Figure 6: SEM fractographs showing dimples/voids and micro cracks propagate through the matrix and reinforcement (a) 3% graphite (b) 6% graphite (c) 9% graphite (d) 12% graphite.

The fractographic image of fracture surface is shown in Fig. 6 (a-d). Higher permissible magnification of scanning electron micrographs of a fractured surface clearly exposes voids of different sizes combines with dents of different size and shape. As a result of it the void initiation will take place within the matrix that successively causes debonding of matrix and reinforcement interfaces.

The direct tensile load on the composite, the microscopic voids looked as if it would have undergone restricted crack growth validating an encouraging involvement from graphite particles. Reinforcing graphite particulates in aluminum matrix force the constraints in plastic deformation. The simultaneous growth of a triaxial state of stress at the 'local' level assists in restricting the flow stress of the MMC. The plastic restrictions at the aluminium and graphite interfaces are mainly essential for (i) the larger graphite particulates, and (ii) clusters of the graphite particles, during failure of the composite microstructure.

Investigation of the fractured surface unveils the confined destruction to be gathered at the reinforcing graphite particulates by the method of cracked particulate and decohesion at aluminium and graphite interfaces.

CONCLUSIONS

The experimental study of the fracture toughness of the Al6061-graphite was conducted. From the results of this study investigation, the following conclusions are made: The maximum fracture toughness was found for Al6061-9%Gr for $a/w = 0.45$ and the value is $16.74 \text{ MPa } \sqrt{\text{m}}$. Significant improvement in the strength of the Al (6061) matrix composites is achieved when 9% and 12 % of graphite is used as reinforcement. Overall, Al6061 alloy can be considered as a suitable matrix for the development of graphite reinforced Aluminium based composites.



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