Experimental Investigation and Processing of Aluminum with Silicon Carbide and Graphite Particulates

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***Abstract* - Metal matrix composites (MMCs) are materials made composed of a metallic matrix and a ceramic phase in the form of particles and platelets, whiskers, short fibres, and continuous linked fibres.**

In most cases, it is weight savings. The purpose of this research is to investigate the fracture toughness and hardness of Aluminum matrix composites containing Silicon Carbide (4%) and Graphite (8%) at a single weight fraction. Processing of hybrid composite is done by the stir casting technique. Specimens are cut according to the ASTM standard E399 [18] by using EDM wire cut machine.

From the fracture toughness, we understand that increase in the thickness of the material the behavior of the material changes. From the hardness test we understand that compared to base material hardness, adding reinforcement the hardness of the material increases.

Keywords: Metal matrix composites, Fracture Toughness, Hardness.

I. INTRODUCTION

Metal matrix composites (MMC's) are a broad range of materials made up of metallic matrix particles, short fibres, platelets, continuous aligned fibres. MMC are usually used in applications such as structure application. Which increased resistance properties, superior thermal characteristics and in most situations weight reduction.

MMc's are reinforced by both continuously and discontinuously [1] are employed. The addition of the reinforcement boosts the matrix's stiffness and strength. The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous [6]. However, the improvements in stiffness and strength generally come at the expense of ductility and fracture resistance. The addition of hard particle reinforcement to composites prevents them from becoming too soft [8].

Continuously reinforced composites are substantially more expensive to manufacture than discontinuously reinforced MMCs. As a result, when compared to aligned reinforcements, discontinuous reinforcements provide better matrix performance at lower additional costs. Manufacturing Particulate Reinforced MMCs is less expensive than reinforced composites. As a result, particle reinforcements cost less than fibre aligned reinforcements when it comes to improving matrix performance. Furthermore, particle reinforced composites have isotropic properties, but composites with fibre aligned reinforcements have significantly anisotropic properties [1].As a result, particle reinforced composites can outperform fibre reinforced composites in applications demanding isotropic characteristics. Because of faults such as inclusions, flaws, and cracks, all structural materials do not have theoretically determined strength.

II. MATERIAL & PROCESSING

<u>Aluminium (6061):</u>

The precipitation hardening aluminum alloy is referred to as Al6061, containing main alloying elements such as silicon and magnesium. It is a standout amongst the most well-known alloys of aluminum for common purpose use. It generally exists in pre-tempered grades (solutionized 6061-0) and tempered grades (6061-T6 and 6061-T651).

Al6061 is generally used for the construction of wings and fuselages in aircraft structures, generally in homebuilt aircraft than commercial or military aircraft.

Fig 1 Aluminium (6061) Bar

Graphite particulates:

Graphite is naturally available as one of the gigantic covalent structures. Graphite is usually denoted by the symbol 'C' is an allotrope of the carbon. In particle form, graphite as a low density, high strength material. Graphite structure has a planar and layered, called graphene. Carbon atoms, in each graphene, are organized in a honeycomb lattice and bonded covalently. Out of four possible bonding sites, only three are fulfilled. The fourth is allowed to move in the plane, making graphite electrically conductive.

Fig 2 Graphite Powder

Silicon Carbide:

The SiC has good mechanical properties such as (i) good lubricating effect which in turn reduces the noise and vibrations throughout the relative motion, (ii) low thermal expansion coefficient (iii) better heat conduction. With these SiC is utilized in ceramics, refractories, abrasive products, and much high performance application. SiC also find application in an electrical conductor and has been used in flame igniters, resistance heating, electronic component etc. The pentagonal atoms of silicon and carbon in SiC have a strong connection in the crystal lattice, resulting in extremely hard material.

The following are among the important features of silicon carbide that have been used in this project. Particle size= 100µm Density=3.1g/cc, melting point 2730°Cmolecular mass=40.10g/mol

Fig 3 Silicon Carbide Powder

Processing

The Al6061-graphite/SiC particulate metal matrix composites were prepared using the induction furnace hand stir casting with a graphite weight fraction of 8% and SiC weight fraction of 4%.Fig 4 shows in the manual stir casting induction furnace, the Al6061 blocks were allowed to melt. The molten aluminium was superheated to over 720 degrees Celsius. Hexachloroethane (C_2Cl_6) to remove nitrogen and degasifier to remove slag, followed by cover flux to remove air from the working area and gases from the molten aluminium.Slag, an impurity in molten aluminium, is also removed. Separately, the required amount of graphite and SiC particles were added into the molten Al6061 while stirring with a hand.

To prevent gas and electrons from entering the molten metal, cover flux zirconium (4 percent NaCl+45 percent KCl+10 percent NaF) was added before pouring into the mould. The molten composite was put into the graphite mould and allowed to harden there. The essential qualities of composite bars were determined using casted blocks that were removed from moulds.

Fig 4 Induction Furnace

III. SPECIMEN PREPARATION

The casted composite block was used to make the compact tension (CT) specimens. The wire cut EDM is used to prepare the specimens for the different thickness. The Wire cut EDM and prepared specimens are shown in the Fig.5

Fig 5 Wire Cut EDM Machine

Compact Tension (CT) Specimens

Engineering materials are not only isotropic and homogeneous but also composites which are maybe isotropic, orthotropic etc. In such materials, microstructures and mechanical properties are different in different directions. This parameter is particularly considered in the measurement of fracture toughness. This may be due to the microstructure and the chosen orientation contains the planes of shortcoming in which crack propagation generally occurs. For the same ASTM has implemented the details of specimen orientation as this will be the important variable in fracture toughness measurements.

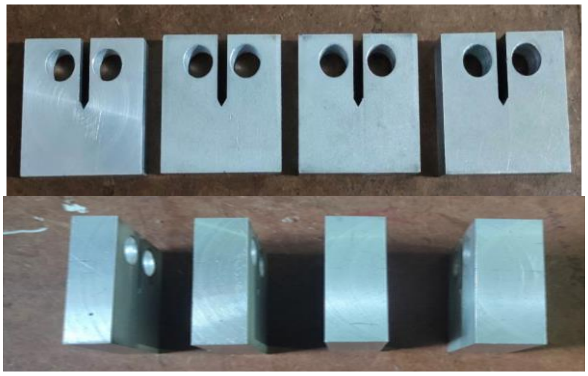

Fig 6 Compact Test Specimens

Fig 6 shows the prepared specimens for the thickness 10mm, 12mm, 14mm and 16mm. The fracture length to width ratio was kept at 0.45 during specimen processing. The width of the specimen considered is 50mm as shown in Fig.6

Fracture Toughness

"Fracture toughness refers to a material's resistance to fracture. The material composition, environment, temperature, loading rate, microstructure, and geometrical properties of the component all have a role.

Fracture toughness is a material property that describes a material's ability to resist fracture because it has a crack. For many design purposes, a material's fracture toughness is the most important property. The stress intensity factor (SIF) at which a small crack in the material begins to propagate is used to determine linear elastic fracture toughness (LEFM).K_{IC} is a measurement of fracture toughness. MPa m is the SI unit for it. The first mode crack opening under tensile load at right angles to the crack is represented by the subscript IC in K_{IC}.

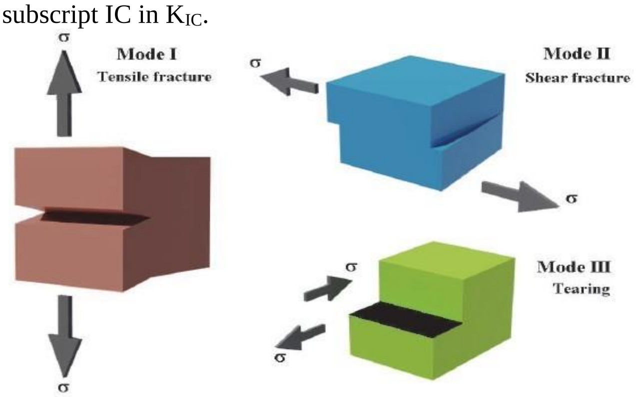

Fig 7 Fracture Modes

1. **Mode or Tearing Mode:** In the plane of the crack, shearing action is parallel to the crack edge.
2. **Mode or Shearing Mode:** In the crack plane, shearing action is normal to the crack edge...
3. **Mode or Opening Mode:** This term refers to the regular separation of fracture faces caused by tensile loads, which is by far the most common in practice.

IV. RESULTS AND DISCUSSIONS

The Compact Tension specimens prepared are tested to find the fracture toughness. From the experiment, the load and the crack opening displacements are noted. The formula used to note the fracture toughness is mentioned below.

$$K_q = \left(\frac{P_Q}{B\sqrt{W}}\right) f\left(\frac{a}{W}\right) \quad (1)$$

Where,

$$f\left(\frac{a}{W}\right) = \frac{\left(2+\frac{a}{W}\right)\left(0.886+4.64\frac{a}{W} - 13.32\frac{a^2}{W^2} + 14.72\frac{a^3}{W} - 5.6\frac{a^4}{W^4}\right)}{\left(1-\frac{a}{W}\right)^{\frac{3}{4}}} \quad (2)$$

Where

K_{Ic} = Fracture toughness.
P_q = Critical load.
a/w = Crack length to width ratio.
W= width of the specimen.
T= thickness of the specimen.
a = crack length.

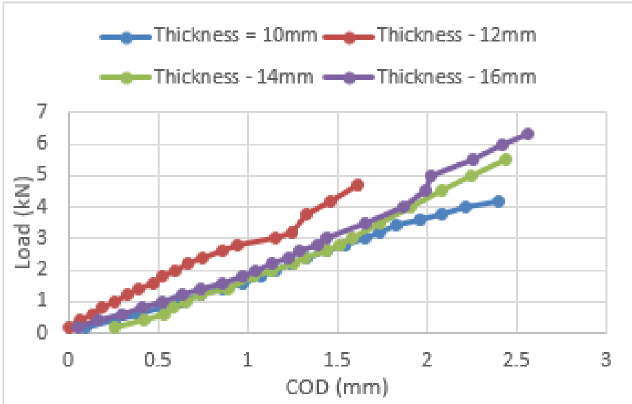

Fig 8 Load-crack opening displacement (COD) curves for various B/W ratios

The experimental CT specimens tested has a/W ratio 0.45, Width of the specimen is 40mm, fracture load obtained for 10mm specimen is 4.2 KN, for 12mm specimen = 4.7 KN, for 14mm specimen = 5.5 KN and for 16mm specimen = 6.3 KN.

Table 1 K_q of Al6061-SiC/graphite for different specimen thickness

Thickness m	a/W ratio	Fracture Load kN	width mm	f(a/W)	K_{Ic} MPa. $\sqrt{m}$
0.01	0.45	4.2	40	8.34	17.51
0.012	0.45	4.7	40	8.34	16.33
0.014	0.45	5.5	40	8.34	16.38
0.016	0.45	6.3	40	8.34	16.42

The fracture toughness of Al6061-graphite/SiC composites for varying thickness is shown in Table 1 of CT specimens. Fig 8 shows effect of specimen thickness on the fracture toughness of the Al6061-graphite/SiC composites.

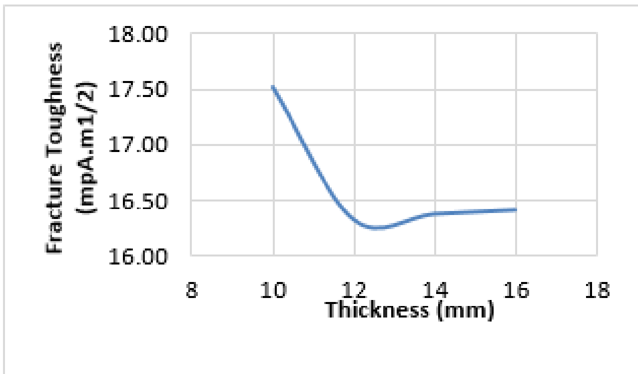

Fig 9 Effect of specimen thickness on fracture toughness

The stress state at the crack tip is addressed as stress intensity (K_I) whereas the highest estimation of K_I that a material can withstand without fracture below certain conditions represents the fracture toughness (K_{Ic}). As the crack advances to some critical level under loading, stress intensity (K_I) factor reaches the K_{Ic} value, unstable fracture occurs. To determine the critical fracture toughness K_{Ic} for Al6061-graphite/SiC MMCs, all CT specimens of various thicknesses are investigated. In Table 1.9, the computed fracture toughness of Al6061-graphite/SiC MMCs for various specimen thicknesses is reported. The maximum value is 17.51 MPa√m found at a thickness (A) = 10mm.

Hardness Test

Fig 10 Rockwell Hardness Machine

The depth of penetration is measured by applying a specific load to the indenter of a Wilson tester. The indenter (also known as a brale) can be a steel ball or a spherical diamond-tipped cone with a 120° angle and 0.2 mm tip radius. A light weight of 10 kg is imposed initially, creating a slight indentation. This is done to seat the indenter and eliminate any imperfections.

The major load is then applied once the dial is reset. After eliminating the large weight but maintaining the minor load, the depth of penetration is measured. The scales are used to read the hardness number. For particularly hard materials, a The hardness is assessed on the 'B' scale using a brale with a load of 100 kg. For most materials, a solid metal indenter is used.

Hardness testing is defined as "a test to measure a material's resistance to permanent damage by penetration of a harder material."

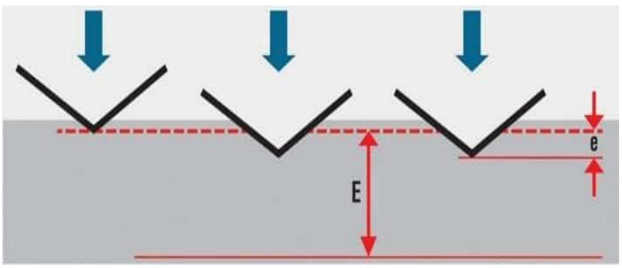

Fig 11 Measuring the Depth of Indentation

As illustrated in fig. 11, when the ball indenters on the specimen with the Rockwell hardness, the ball moves towards the specimen due to the load applied, and then record the reading shown in the non-ferrous indicator, also known as the black indicator, make trials, and average them. As illustrated in fig 11 for the reinforcing material matrix composite materials, the load vs. the diameter of the ball. The load carrying capacity of the described hybrid composite appears to increase as the thickness increases. The load carrying capacity of the specimen is obviously increased by increasing the thickness below the load, and the diameter of the ball indenter is 1/16th and the load is 100kg.

Table 2: Trails of material

Trails
35
59
432
Average =53 RHN

V. CONCLUSION

From the result of fracture toughness and hardness testing in and Rockwell hardness testing machine we came to know that the fracture toughness of the reinforcement matrix material of size 10mm is 4.2 KN, for 12mm specimen = 4.7 KN, for 14mm specimen = 5.5 KN and for 16mm specimen = 6.3 KN.

The plain Strain fracture toughness value for Al6061-SiC/graphite MMCs is 16.33MPa√m found at a thickness (B) = 12mm.

A good load distribution and good toughness of aluminum and sic/graphite in aluminum matrix have a direct impact on mechanical behavior also the hardness number is about 53 RHN of the composites

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