Experimental Investigation and Processing of Aluminium with Silicon Carbide and Graphite Particulate

A M Rajesh, Saleemsab Doddamani, M S Manoj, P B Bharath,
G S Prabhuswamy, S P Shivakumar and M Mithunvenkatesh

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[1]Dr.Rajesh.A.M, [2]Dr.Saleemsab Doddamani, [3]Manoj.M.S, [4]Dr.P B Bharath,
[5]Prabhuswamy G S, [6]S P Shivakumar [7]Mithunvenkatesh.M

[1]Associate Professor, Department of Mechanical Engineering, SJM Institute of Technology, Chitradurga

[2]Post Doctoral Fellow, Department of Mechanical Engineering, National Institute of Technology, Surathkal

[3] Department of Mechanical Engineering, SJM Institute of Technology, Chitradurga

[4]Professor, Department of Mechanical Engineering, SJM Institute of Technology, Chitradurga

[5]Assistant Professor, Department of Mechanical Engineering, SJM Institute of Technology, Chitradurga

[6]Professor, Department of Mechanical Engineering, SJM Institute of Technology, Chitradurga

[7]Department of Mechanical Engineering, SJM Institute of Technology, Chitradurga

Abstract

Metal matrix composites (MMCs) are a differing group of materials that comprise of metallic matrix normally reinforced with a ceramic phase as particles, platelets, whiskers, short fibers, and continuously allied fibers. MMCs are utilized as a part of structural applications and in applications requiring increased wear resistance, better thermal properties, and most of the cases in weight savings.

In this work, it is intended to study the fracture toughness and hardness of aluminum matrix composites reinforced with Silicon Carbide (4%) and Graphite (8%) at single weight fraction. Processing of hybrid composite is done by the stir casting technique. Specimens are cut according to ASTM standard by using EDM wire cut machine.

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

Introduction

Metal matrix composites (MMCs) are a differing group of materials that comprise of metallic matrix normally reinforced with a ceramic phase as particles, platelets, whiskers, short fibers, and continuously allied fibers. MMCs are utilized as a part of structural applications and in applications requiring increased wear resistance, better thermal properties, and most of the cases in weight savings.

Both continuously and discontinuously reinforced MMCs [1] are used in structural applications. The incorporation of the reinforcement increases the stiffness and strength of the matrix. However, the improvements in stiffness and strength generally come at the expense of ductility and fracture resistance.

Discontinuously reinforced MMCs are much less expensive to fabricate than continuously reinforced composites. Consequently, performance enhancement of the matrix comes at lower additional costs with discontinuous reinforcements compared with aligned reinforcements. Particulate reinforced MMCs are not expensive to manufacture than reinforced composites. Accordingly, performance improvement of the matrix comes at lesser expenses with particulate reinforcements compared with fiber aligned reinforcements. In addition, particulate reinforced composites exhibit the isotropic properties [1], whereas the properties of composites with fiber aligned reinforcements are highly anisotropic. Thus, in applications requiring isotropic properties, less expensive, particulate reinforced composites can do better than fiber reinforced composites

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.

MATERIALS AND PROCESSING

Aluminium (6061):

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-O) 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 1.1

Graphite particulates:

Graphite is naturally available as one of the gigantic covalent structure. Graphite is usually denoted by the symbol 'C' is an allotrope of the carbon. Graphite has been acknowledged as superior strength and low-density material in particulate form. 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 1.2

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 properties of ceramic, they are utilized in producing the hybrid MMC.
SiC is utilized in ceramics, refractories, abrasive products, and much high performance application. SiC also find the application in an electrical conductor and has been used in flame igniters, resistance heating, and electronic component etc. SiC has a tetrahedral atom of silicon and carbon having strong bond in the crystal lattice which gives very hard and strong materials.

The SiC material is a blend of silicon and carbon, outstanding abrasive material. Now a day, the SiC material is formed into a technical grade better quality ceramic with excellent mechanical/physical properties. Some of the key properties of silicon carbide utilized here are Density – 3.1 g/cc, melting point – 2730oC, molecular mass – 40.10 g/mol, particle size=100 µm,, Appearance –Black in color.

Fig 1.3

Processing

Hand Stir casting method was utilized to prepare the Al6061-graphite/SiC particulate metal matrix composites for weight fraction of graphite (8%) and SiC (4%). Fig 1.4 shows the Al6061 blocks were allowed to melt in the hand stir casting furnace. The molten aluminum was super-heated to the temperature about 720^0C. hexachloroethane (C_2Cl_6) to remove nitrogen & degasifier to remove slag next cover flux to remove air present in working area to the molten aluminum to take away the gases. Impurity in the molten aluminum that is slag also removed. The requisite quantity of graphite and SiC particles was poured to the molten Al6061 separately while stirring with a hand.
Before pouring into the mold cover flux zirconium (4%NaCl+45%KCl+10%NaF) has been added to avoid the gas & electrons to enter the molten metal. In the graphite mold, molten composite was poured and it was kept in the mold to solidify. The casted blocks are removed out from molds were utilized for determining required properties of composite bars.

Fig 1.4

Specimen Preparation

The compact tension (CT) specimens were prepared using the casted composite block. 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. 1.5

Fig 1.5

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.

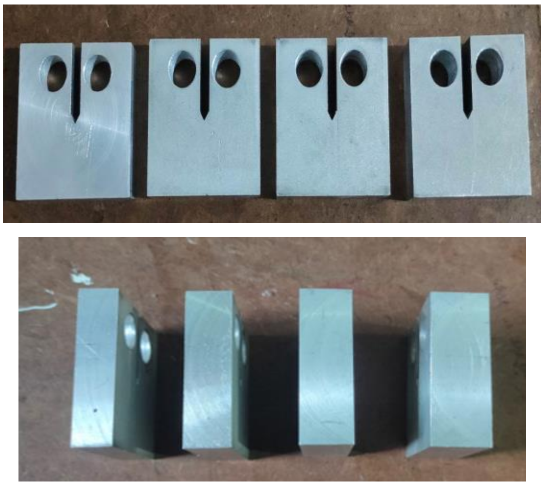

Fig 1.6

Fig 1.6 shows the prepared specimens for the thickness 10mm, 12mm, 14mm and 16mm. While the specimen preparation the crack length to width ratio maintained is 0.45. The width of the specimen considered is 50mm as shown in Fig.1.6

Fracture Toughness

"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.

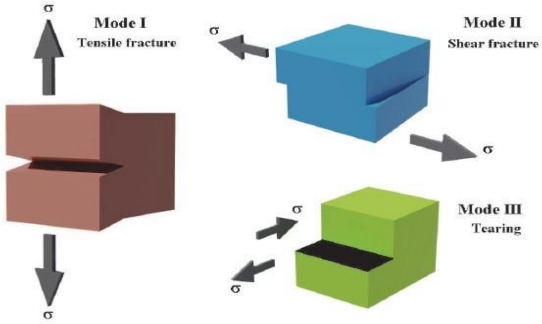

Fig 1.7

The capacity of a material having a crack to oppose fracture is referred to as fracture toughness which is a material property. Fracture toughness of a material is the most essential property required for many design applications. Linear elastic fracture toughness (LEFM) of a material is calculated from the stress intensity factor (SIF) at which a small crack in the material started to propagate. Fracture toughness is represented by K_{IC}. Its unit in SI is MPa √m. In K_{IC}, subscript I_C represents first mode crack opening under tensile loading at right angles to the crack.

1. **Mode or Tearing Mode:** Shearing action is parallel to the crack front in the plane of the crack.
2. **Mode or Shearing Mode:** Shearing action is normal to the crack front in the plane of the crack.
3. **Mode or Opening Mode:** Corresponds to the normal separation of the crack faces under the action of tensile stresses, which is by far the most widely encountered in practice

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.

$$K_Q = \left(\frac{P_q}{B\sqrt{w}}\right) f\left(\frac{a}{w}\right)$$

$$\text{Where, } f\left(\frac{a}{w}\right) = \frac{\left(2+\frac{a}{w}\right)\left(0.886+4.64\frac{a}{w}-13.32\frac{a^2}{w^2}+14.72\frac{a^3}{w^3}-5.6\frac{a^4}{w^4}\right)}{\left(1-\frac{a}{w}\right)^{3/2}}$$

Where

K_Q = 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.

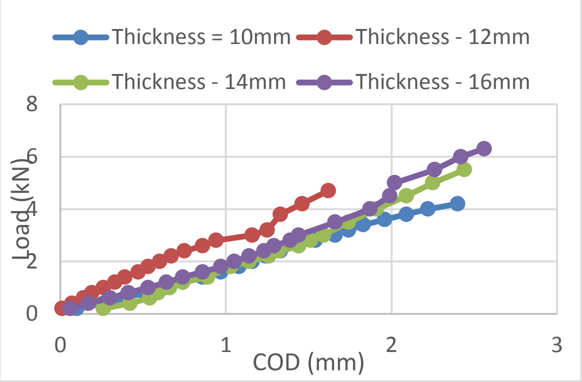

Fig 1.8

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.

Thickness m	a/W ratio	Load kN	width mm	f(a/W)	K_{Ic} MPa.m1/2
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

Table 1.9

Table 1.9 shows the fracture toughness of the Al6061-graphite/SiC composites for different thickness of CT specimens. Fig 1.7 shows effect of specimen thickness on the fracture toughness of the Al6061-graphite/SiC composites.

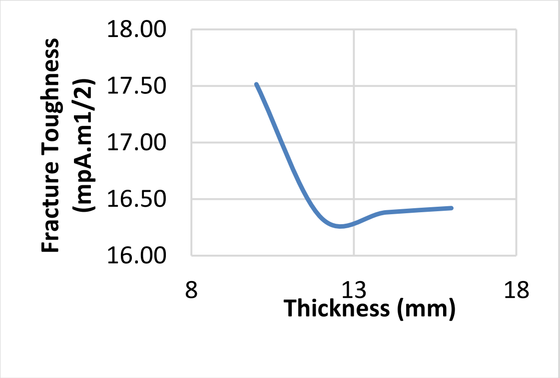

Fig 1.10

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. All the CT specimens of different thickness are tested to find the critical fracture toughness KIc for Al6061-graphite/SiC MMCs. The calculated value of fracture toughness of the Al6061-graphite/SiC MMCs for different specimen thickness has been listed in Table 1.9 The maximum value is 17.51 MPa√m found at a thickness (A) = 10mm.

Hardness Test

The hardness of a material usually is considered resistance to permanent indentation. In general, an indenter is pressed into the surface of the metal to be tested under a specific load for a definite time interval, and a measurement is made of the size or depth of the indentation.

Hardness may be defined as the ability of a material to resist plastic deformation caused by penetrating forces. The Rockwell hardness scale is based on the indentation hardness of a material, which is simply the resistance offered by a material to indentation.

Fig 1.11

Specific load is applied on the indenter of a Wilson tester and the depth of the penetration is measured. The indenter may be a steel ball or a spherical diamond-tipped cone of 120° angle and 0.2 mm tip radius (called a brale). A minor load of 10 kg is applied first, which causes a minor indentation. This is done in order to seat the indenter and also remove any surface irregularities.

Then the dial is reset and the major load is applied. The depth of penetration is measured after removing the major load but retaining the minor load. The hardness number is read directly from the scales. A brale with a load of 100 kg is used for very hard materials and the hardness is read on the 'B' scale. For most materials, a steel ball indenter is used.

The definition of hardness testing is 'a test to determine the resistance a material exhibits to permanent deformation by penetration of another harder material.

Hardness is not a fundamental property of a material, but rather defined as "the resistance the material exhibits to permanent deformation by penetration of another harder material." The principal purpose of the hardness test is to determine the suitability of a material, or the particular treatment to which the material has been subjected. The quantitative value of hardness should always be evaluated in relation to:

- The type of indenter and its geometry
- The given load on the indenter
- A specific loading time profile and a specific load duration

Calculated by measuring the depth of an indent, after an indenter has been forced into the specimen material at a given load.

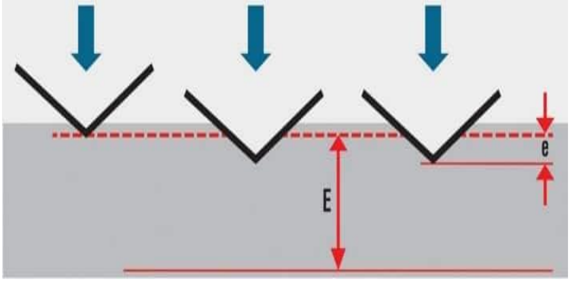

Fig 1.12

As shown in the above fig 1.12 when the ball indenters on the specimen with the Rockwell hardness due to the load applied the ball goes towards the specimen and then note down the reading shown in the non-ferrous indicator or formally called as black indicator make trials and take the average of them.

As shown in the above fig 1.12 the load vs diameter of the ball for the reinforcement material matrix composite materials. It is observed that as the thickness increases the load carrying capacity of the said hybrid composite increase. It is obvious that the thickness under the load increases the load carrying capacity of the specimen and the diameter of the ball indenter is 1/16th and the load is 100kg.

Trails
35
59
432
Average =53

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.

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 of the composites.

Reference

1. ASM Handbook, “Composites”, ASM International, 21 (2001).
1. T .L Anderson “Fracture Mechanics-Fundamentals and Applications”. 3rd Edition, Taylor & Francis Group, New York, (2013).
2. ASM International, “Mechanical Testing and Evaluation”, ASM Handbook, Volume 8, 2000, 1302-1326.
3. N. Balaje Krishna, Parvathy Unnikrishnan, S. Ilangovan, “Synthesis and Characterization of Zircon/Graphite and Flyash/Graphite Reinforced Aluminium7075 Alloy: A Comparative Study”, Journal of Materials and Environmental Sciences, 9, (1), 2018, Page 26-31.
4. Schunk Ho"mann Carbon Technology, Austria, Aluminium Graphite Composites, 2013.
1. A. Chennakesava Reddy, “Mechanical Properties And Fracture Behavior Of 6061/Sicp Metal Matrix Composites Cast By Low Pressure Die Casting Process”, Journal of Manufacturing Technology Research, 1, (3/4), 2009, pp.273-286.
2. Manoj Singla, D. Deepak Dwivedi, Lakhvir Singh, Vikas Chawla,

"Development of aluminium based silicon carbide particulate metal matrix composite", Journal of Minerals & Materials Characterization & Engineering, Vol. 8, No.6, 2009, pp 455-467.

3. A. Brotzu et al, "Effects of the manufacturing process on fracture behavior of cast TiAl intermetallic alloys", Frattura ed Integrità Strutturale, 27 (2014) pp 66-73.
4. B. C. Pai, P. K. Rohatgi, "Production of cast aluminium-graphite particle composites using a pellet method", Journal of Materials Science, 13 (1978) pp 329-335.
5. A.I. Selmy, F. Shehata, A. Fathy, E. Gewfiel, "Fabrication and Characterization of Aluminum graphite Composites", fifth Assiut University Int. Conf. on Mech. Eng. Advanced Tech. For Indus. Prod, 2011, pp 93-100.
6. Aravind Appanna K E, K. S Keerthiprasad, "Characterization of Al-Graphite Composite Developed by Powder Metallurgy Technique", International Journal of Research in Engineering and Technology, 4, (10), 2015, pp 119-121.
7. N. Barekar, S. Tzamtzis, B.K. Dhindaw, J. Patel, N. Hari Babu, and Z. Fan, "Processing of Aluminum-Graphite Particulate Metal Matrix Composites by Advanced Shear Technology", Journal of Materials Engineering and Performance, ASM International, DOI: 10.1007/s11665-009-9362-5 Feb 2009.
8. ASTM Standards, "Standard Test Method for measurement of Fracture Toughness", ASTM International, E 1820-18, (2018).
9. ASTM Standards, "Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials", ASTM International, E 399-17, (2017).
10. Xian-Kui Zhu, "Review of fracture toughness (G, K, J, CTOD, CTOA) testing and standardization", Engineering Fracture Mechanics, 85 (2012) pp 1–46.