

Fabrication and characterization of the Al6063/5%ZrO₂/5%Al₂O₃ composite

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Abstract. Metal matrix composites (MMCs) combine the desirable characteristics of metals (thermal conductivity and ductility) and ceramics (high stiffness, high hardness, and low thermal conductivity). Aluminium hybrid composites are new generations of metal matrix composites that have the potential to satisfy the recent demands of advanced engineering applications. In the present study, Al-MMC has been fabricated by mixing the 5wt% ZrO₂ and Al₂O₃ reinforcement into the Al6063 aluminium alloy matrix. Stir casting method has been adopted for the fabrication of MMC. The prepared casted MMC has been characterized by scanning electron microscope (SEM), X-ray diffraction (XRD) analysis. The physical property (density) and mechanical property (hardness, tensile test, bend test, compression test) have been measured for the fabricated MMC. The fracture surface has been studied. The fracture of Al-MMC is found brittle in nature.

Keywords: Al6063 aluminium alloy; metal matrix composite; stir casting; mechanical property; physical property.

1. Introduction

Metal matrix composite consists of greater properties such as high strength, high elastic modules, high stiffness, high electrical and thermal conductivity, high corrosion resistance, oxidation and wear compared to conventional material. Aluminium alloy based metal matrix composites (AMMCs) are extensively used in various engineering field due to their low weight to density ratio. Al-MMC reinforced with particles and whiskers are widely used for high-performance appliances such as automotive, aerospace, military, and electricity industry because of their enhanced physical and mechanical properties [1]. The manufacturing of Al-MMC can be categorized into three types. They are solid phase processes viz. diffusion bonding and powder metallurgy, semi-solid process viz. spray, compo casting and rheo casting and liquid phase process viz. stir casting [2]. Stir casting or vortex is most commonly used method out of all the available method for metal matrix composites production and allow a very large size component to be manufactured [3]. Carbon (C), boron nitride (BN), silicon carbide (SiC), titanium carbide (TiC), aluminium oxide (Al₂O₃), Zirconia (ZrO₂) are most popular reinforcements used for fabricating metal matrix composite.

Two types of MMC have been developed for the last few decades: fiber reinforced MMCs and particle reinforced MMCs [4, 5]. Baghchesara et al. [6] have fabricated Al-ZrO₂ composites by using vortex method using ZrO₂ powder and studied the fracture surface of the fabricated MMCs. Kumar et al. [7] have adopted the liquid metallurgy technique and successfully prepare the Al6061-SiC and Al7075-Al₂O₃ composites. They have found the significance improvement of the physical and mechanical properties than their base material. Gautam et al. [8] have prepared Al-Al₂O₃ composite by the mechanical alloying method and studied the physical and mechanical behavior of the composite. Unlu [9] has made Al/Al₂O₃/SiC composite by casting and P/M method and studied the mechanical and tribological properties for both the method.

In this present study, Al6063 aluminium alloy composite has been fabricated by mixing ZrO₂ and Al₂O₃ reinforcement particle into the matrix. MMC has been characterized by scanning electron microscope, X-ray diffraction analysis. The physical property such as density and mechanical property like hardness,



tensile test, bend test, compression test have been measured. The fracture surface has been studied using SEM.

2. Experimental details

The major raw materials used in this study are aluminium alloy, ZrO_2 and Al_2O_3 powder. Al6063 is taken as a matrix of the composite. Figure 1(a) and (b) shows the SEM image of Al_2O_3 and ZrO_2 which have used as reinforcement.

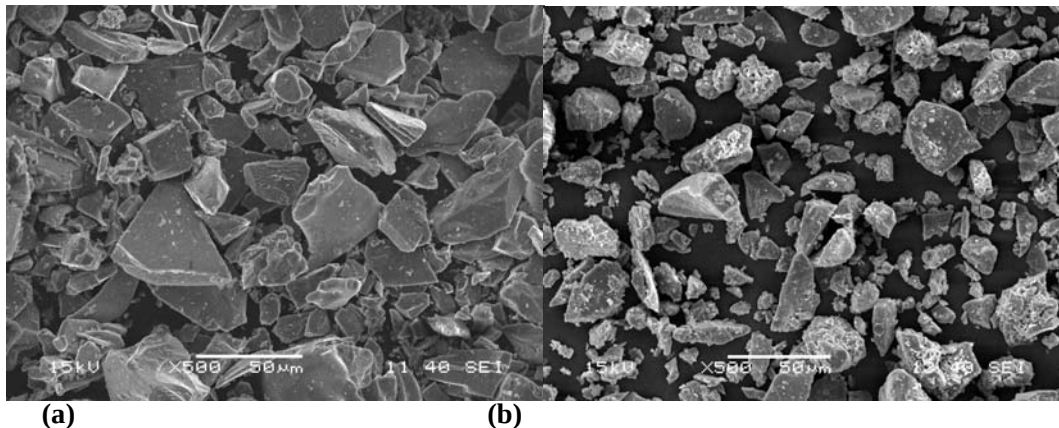


Figure 1. SEM image of the as-received powders: (a) Al_2O_3 (b) ZrO_2

2.1 Fabrication of $\text{Al6063}/\text{ZrO}_2/\text{Al}_2\text{O}_3$ MMC

For fabrication of hybrid metal matrix composite (h-MMC), stir casting technique was adopted. For fabrication commercially available Aluminium alloy (Al6063) was used as a matrix material and ZrO_2 (~20 μm) and Al_2O_3 (~30 μm) were used as reinforced material.

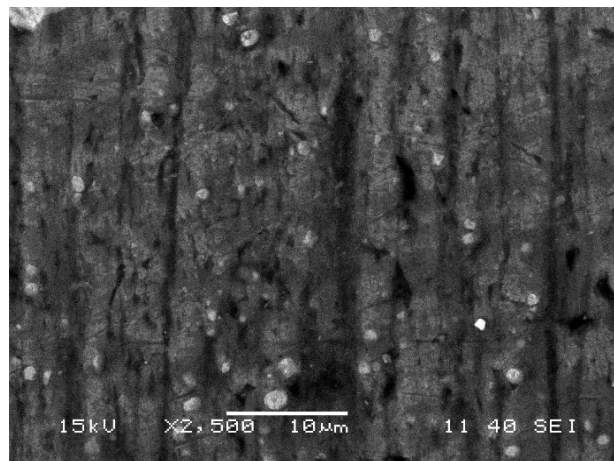


Figure 2. SEM image of fabricated Al-MMC

During stir casting route the matrix material was melted at 850°C in a graphite crucible under the controlled argon environment in the resistance heated furnace. The specific amount of Al_2O_3 and ZrO_2 particles equal to 5wt% preheated upto 300°C and 1200°C and then mixed into the molten bath of Al6063. Reinforced particles were stirred by a stirrer at 700rpm. After complete stirring, the material mixture was again reheated into the furnace and then poured into the mold at 750°C to 850°C . The material was

allowed to cool in open atmosphere. After cooling the casting material was machined to a required shape. Figure 2 shows the SEM image of Al-MMC fabricated by stir casting.

3. Result and discussion

3.1 X-ray diffraction (XRD) analysis

Figure 3 represents the XRD pattern obtained from the Al-MMC. Al, Al_2O_3 , ZrO_2 are clearly identified as the main phase of the composite. Al_3Zr_4 , Al_3Zr and $\text{Ti}_9\text{Al}_{23}$ are also observed as a secondary phase.

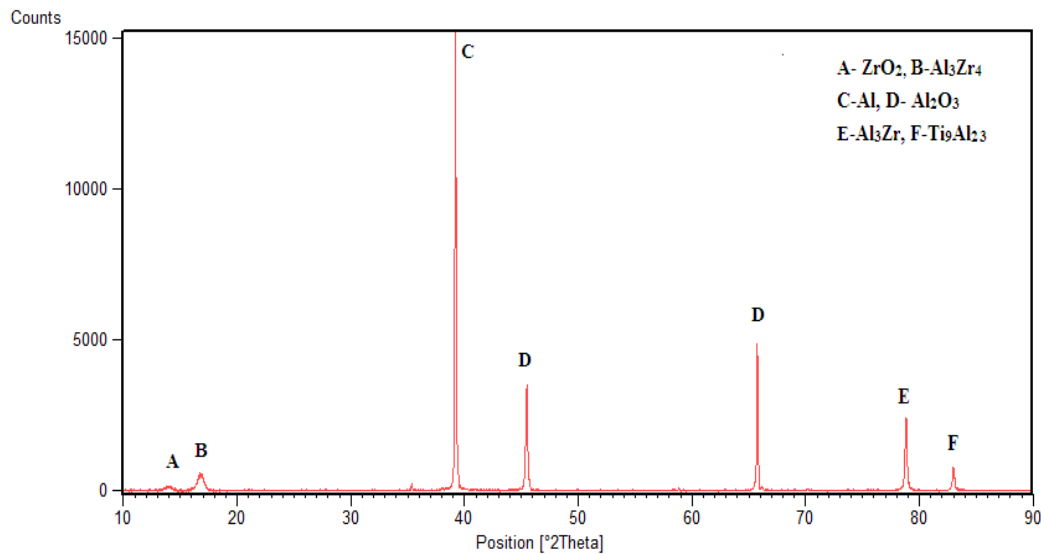


Figure 3.X-ray diffraction pattern of fabricated Al-MMC

3.2 Physical property

3.2.1Density

The fabricated composite specimen was considered for density measurement. The actual density was determined by Archimedes principle at room temperature and theoretical density was calculated by using “Rule of Mixture” formula. The theoretical and actual density obtained from the calculation are 2.89gm/cm^3 and 2.71gm/cm^3 respectively. The relative density is 93.36% for this fabricated composite.

3.3 Mechanical property

3.3.1Hardness

The hardness of the Al-MMC was measured by Vickers hardness tester (LecoMicrohardness tester LM248AT). Before testing the sample was polished to a scratch free surface. During testing, the load was kept constant at 50gf for a dwell time of 5 seconds. A minimum five reading was taken for determining the mean micro-hardness value. The hardness was found 91.1 HV for the Al-MMC.

3.3.2Tensile test

The tensile strength of the specimen was investigated using Instron, UK/SATEC 600KN. The tensile specimen was grounded according to the ASTM B557. The maximum tensile strength has been found out 78.51MPa. Figure 4 shows the load vs. extension curve for the tensile test. The brittle phase of Al_2O_3 and ZrO_2 is the reason behind the low tensile strength.

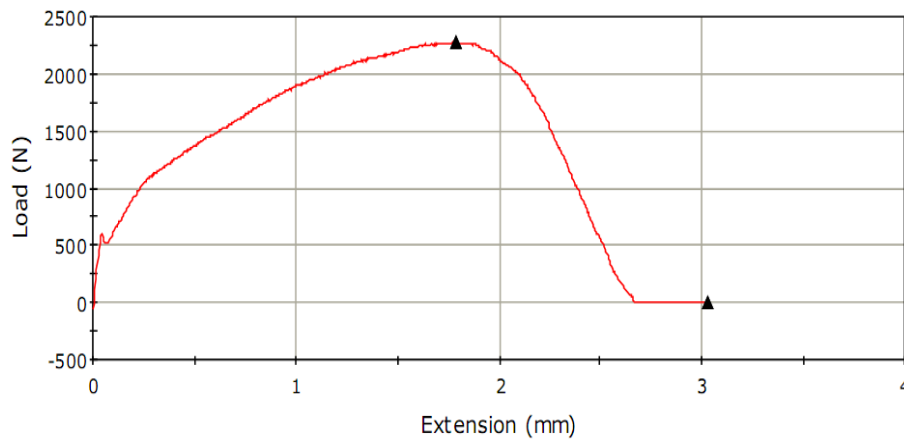


Figure 4. Tensile test of Al-MMC

3.3.3 Compression test

Compression test was performed by universal testing machine (INSTRON/SATEC 600KN). Specimen dimension 10mm of diameter and 8mm height was taken according to ASTM Standard E9-89. The experiment was performed under 28°C, 50% humidity and at 1 mm/min strain rate. Compressive strength has been found 685 MPa for Al-MMC. Figure 5 shows the load vs. extension curve for the compression test.

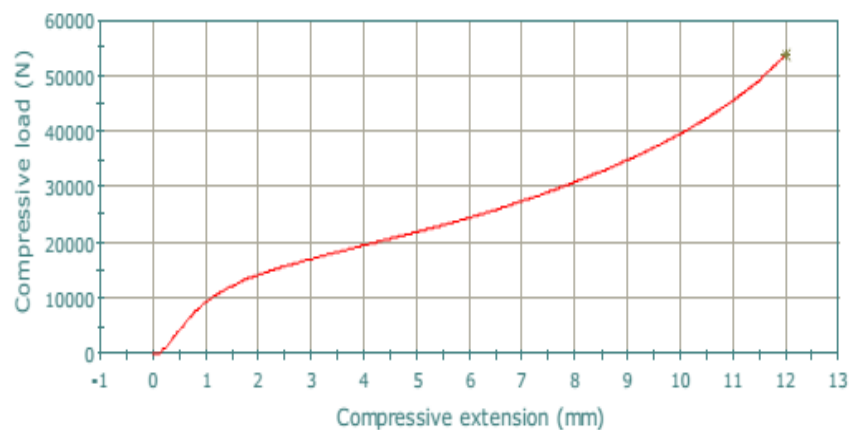


Figure 5. Compression testing of Al-MMC

The fabricated composite shows low strength under tensile mode compared to compressive mode. This may cause because of the presence of ceramic reinforcement in the metal matrix. The effects of elastic property of reinforcement inhibit the plastic deformation of aluminium matrix resulting increase in compressive strength [10].

3.3.4 3-point bend test

The flexural test is a combination of both tensile and compressive tests. Bend test was performed by universal testing machine (INSTRON 5967). In this test a rectangular cross section is placed on two supporting pins. The loading force is applied to the middle portion using loading pin. Fig.6 depicts the details of the bending test.

The flexural stress is calculated by the Eq. 1.

$$\sigma_f = \frac{3PL}{2bd^2} \quad (1)$$

Where, σ_f is stress in outer surface at midpoint (MPa)

P is load at a given point (N), L is supported span (mm), b is the width of test beam (mm), and d is the depth of tested beam.

Specimen dimension is $30 \times 10 \times 5 \text{ mm}^3$. ASTM standard B925-08 was taken for this test. The flexural test was carried out in the universal testing machine (INSTRON-5967) maintaining crosshead velocity of 0.2 mm/min and a span length of 24 mm during the test. Figure 6 depicts the flexural test of Al-MMC.

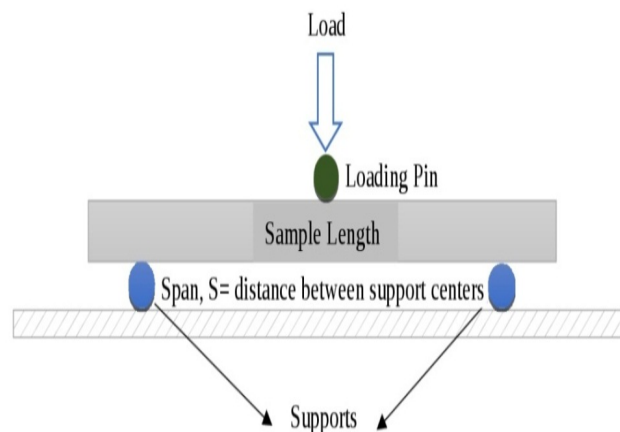


Figure 6. Details of bending test

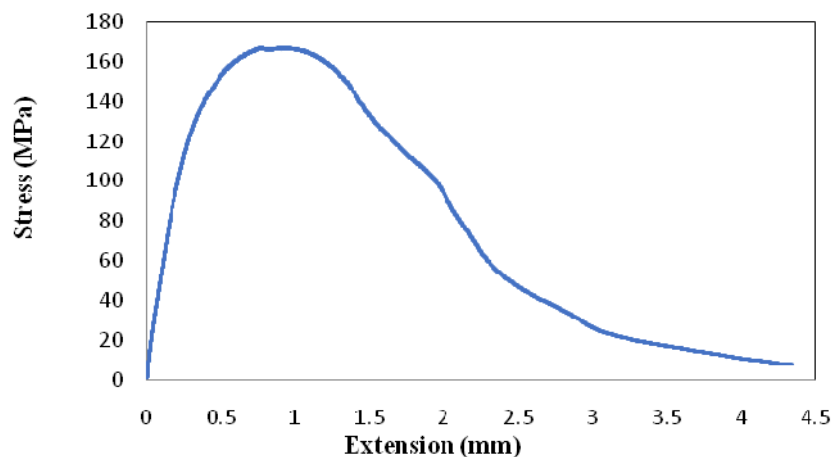


Figure 7. Flexural testing of Al-MMC

From Figure 7, it is observed that the maximum flexural stress is 167 MPa at 1.16 kN flexural break load.

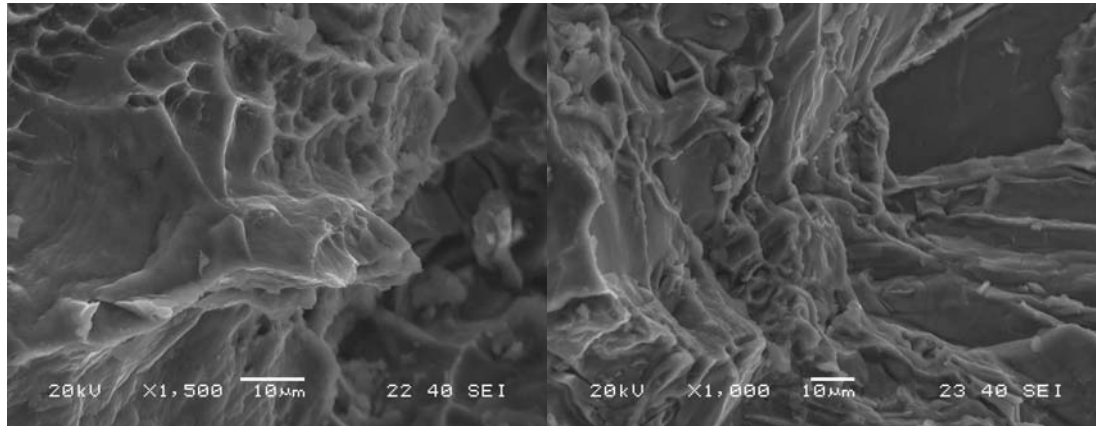
3.3.5 Fracture surface

To understand the unusual mechanical behavior of this composite the fractography was performed on the specimen (Figure 8). Figure 8 (a) and (b) shows the SEM micrographs of fracture surfaces of the specimen containing 5% ZrO_2 and 5% Al_2O_3 produced by stir casting.

Fracture normally occurs as a result of one or the combination of the following mechanism

1. Fracture of reinforcing particle [11]
2. Partial debonding of reinforcement-matrix interface and nucleation of voids [12]
3. Development of the voids and ignition of cracks in the matrix [13]

Various types of factors are responsible for the composite fracture. They are the processing method, the applied stress, the post heat treatment, reinforcement distribution and morphology of the reinforcing particle, etc.



(a) (b)
Figure 8. Topography images of the fracture surface of the specimen

Figure 8 reveals the presence of dimple with tear ridges, while eutectic phases are mostly present. The incoherency of matrix-particle interface has been observed extensively. Relatively rough fracture surface and presence of porosity have been observed. The reinforcement size is also responsible for the failure. The presence of hard and brittle ZrO_2 and Al_2O_3 particles in the ductile aluminium matrix exerts constraints on the plastic flow of the matrix. When powder concentration and triaxiality of stress combine in the clustered particle regions, the composite undergoes brittle fracture [14]. This indicates the brittle mode of failure of the Al-composite. Fracture of Al composite initiates from the matrix. In other words, composite fracture is directed by matrix fracture [15, 16].

4. Conclusions

Al6063 aluminium alloy reinforced with ZrO_2 , Al_2O_3 powders is successfully fabricated by stir casting method. The mechanical (hardness, tensile test, bend test, compression test) and physical (density) properties have been studied for the Al-MMC. The relative density is found 93.36% for the fabricated MMC. The composite shows low strength under tensile load compared to compressive load. The topographic observation of the fracture surface revealed that the fracture of Al-MMC is brittle in nature, and the matrix-fracture is dominant.

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