

Development and Characterization of Al6061-Zirconium Dioxide Reinforced Particulate Composites

Udayashankar.S¹, V.S.Ramamurthy²

¹Research Scholar, ²Research Supervisor,

^{1,2}Department of Mechanical Engineering, Don Bosco Institute of Technology, Bangalore, Karnataka, India

*Corresponding Author Email: ¹udaya_creative@yahoo.com, ²VSRamamurthy@yahoo.com

Abstract

Particulate reinforced Aluminium based metal matrix composites are widely used in aerospace, defense, marine and space applications because their excellent properties such as high strength, high stiffness, high corrosion resistance, high fatigue resistance, high wear resistance etc., In the present work Aluminum Alloy Al6061-Zirconium dioxide composites were developed by stir casting technique by varying the percentage of Zirconium dioxide in steps of 3% up to 12%. The samples were prepared as per ASTM standards for microstructure study, tensile strength and hardness properties. The microstructure studies carried using optical microscope revealed the presence of Zirconium dioxide particulates in the Aluminium matrix. Also it revealed the uniform distribution of Zirconium dioxide in the Aluminium matrix and no voids and porosity were present in the matrix. The tensile strength and hardness properties were more than the base metal aluminium alloy. The tensile strength and hardness properties were increased with the increase in percentage of Zirconium dioxide up to 9% and decreased there afterwards. The optimum value for hardness and tensile strength of the composite was obtained at 9% of Zirconium dioxide.

Keywords: Zirconium dioxide, Al 6061 ASTM, Stir Casting, Hardness.

1. Introduction

Composite Materials in general are well established engineering materials with most of them possessing higher specific weight, higher specific modulus, higher thermal stability, higher stiffness properties and higher wear resistance compared to monolithic materials. Now a day's composite materials are widely used in variety of applications such as aerospace, transportation, marine and structural components.

Metal Matrix Composites (MMC's) are considered a group of advanced materials which represent low density, high tensile strength, high modulus of elasticity, low coefficient of thermal expansion and high wear resistance. These Characteristics could not be achieved together in the monolithic materials [3].

Particulate reinforced MMCs have recently found special interest because of their higher specific strength and high specific stiffness at room and elevated temperatures. Particulate Reinforced MMC's are used in aerospace, automotive and tribological applications. In the field of automobile Particulate reinforced MMC's are used in pistons, brake drum and cylinder block because of better corrosion and wear resistance. The most commonly used particulates are silicon carbide, aluminum oxide, graphite, flyash, SiO₂ etc. The fabrication methods used for MMC's are powder metallurgy, stir casting, squeeze casting etc. Manufacturing of aluminium alloy based composite materials via stir casting is one of the prominent and ecological route for development and processing of metal matrix composites. Stir casting is one of the simplest way of

producing aluminium metal matrix composites. Stir casting method is widely used for mass production of MMC's.

Among many types of matrix materials for composites, aluminium and its alloys are the favourite material for producing metal matrix material. Aluminum alloy based composites are very attractive on account of their processing flexibility, wide range, low density and abundant availability, high wear resistance, high thermal conductivity, high heat treatment capability, improved elastic modulus, high strength, high stiffness and high dimensional stability. Applications of Aluminum-based MMC's have increased in recent years as engineering materials. The introduction of a ceramic material into a metal matrix produces a composite material that results in an attractive combination of physical and mechanical properties which cannot be obtained with monolithic alloys. Discontinuously reinforced aluminium matrix composites have emerged from the need for light weight and high stiffness materials which are desirable in many applications mainly in aerospace and automobile products such as engine piston, cylinder liner, brake disc/drum etc. The strengthening of aluminum alloys with a reinforcement of fine ceramic particulates has greatly increased their potential in wear resistance and structural applications. There is an increasing interest in the development of metalmatrix composites (MMC's) having low cost reinforcements, high strength, high stiffness and better wear resistance.

Aluminium alloys are the alloys in which aluminium is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon and zinc.

There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories such as heat treatable and non-heat treatable. Alloys

composed mostly of aluminium have been very important in aerospace manufacturing since the introduction of metal skinned aircraft. Aluminium-magnesium alloys are both lighter than other aluminium alloys and much less flammable than alloys that contain a very high percentage of magnesium [6].

Al6061 is a precipitation hardening aluminum alloy, containing magnesium and silicon as its major alloying elements. It has good mechanical properties and exhibits good weldability. It is one of the most common alloys of aluminium for general purpose. Al6061 is widely used because of its properties such as good formability, good weldability, high corrosion resistance and it is the most economical among the heat treatable aluminum alloys [1].

Among the various particulate reinforcements used, Zirconia (ZrO_2) is one of the most inexpensive, easily available reinforcement and has capacity to retain high strength at elevated temperature and having excellent mechanical and wear properties. Zirconia is having good properties like high strength, high hardness and high wear resistance. Zirconia (ZrO_2) particulates in the alloys of Aluminium have greatly enhanced mechanical and wear properties at elevated temperatures [8].

Al6061 is a medium to high strength heat treatable alloy. Zirconia is having good properties like high strength, high hardness and high wear resistance and can be combined with Al6061 [2].

It is evident that there has been no attempt to develop Al6061-Zirconia (ZrO_2) Particulate Reinforced Composites using stir casting method and to study the mechanical properties. Hence the present work is aimed at developing Al6061-Zirconia (ZrO_2) composites by stir casting method and to study the mechanical properties.

2. Experimental Details

A. Materials

Al6061 was taken as the matrix as it is easily machinable and Zirconia (ZrO_2) is selected as the reinforcement particle due to its easiest availability and its high temperature applications.

Al6061 is a medium to high strength heat treatable alloy with copper and magnesium as the alloying elements. It is used in applications requiring high strength to weight ratio, as well as good corrosion and wear resistance.

Al6061 is typically used for heavy duty structures in rail coaches, truck frames, ship building, bridges and military bridges, towers transport, boiler making and motorboats

Table 1: Chemical Composition of Aluminium Alloy (Al6061)

Component	Al	Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr
Amount (wt.%)	Balance	0.90	0.50	0.50	0.30	0.20	0.10	0.10	0.25

Zirconium dioxide is one of the most studied ceramic material. Zirconium oxide (ZrO_2), sometimes known as Zirconia is a white crystalline oxide of zirconium. Its most naturally occurring form, with a monoclinic crystalline structure, is the mineral baddeleyite. Zirconia as a pure oxide does not occur in nature but it is found in baddeleyite and zircon ($ZrSiO_4$) which form the main sources for the material. Among these two zircon is the most widespread but it is less pure and requires a significant amount of processing to yield Zirconia.

The processing of Zirconia involves the separation and removal of undesirable materials and impurities. There are several routes to the extraction of Zirconia from zircon including Chlorination, Alkali oxide decomposition, Lime fusion and Plasma dissociation. Pure Zirconia exists in the monoclinic form at room temperature. Cubic and tetragonal phases are also stable at higher temperatures. The transformation of monoclinic to cubic Zirconia occurs at 800-1000°C and is accompanied by a large change in lattice size.

Table 2: Physical Properties of Zirconium Dioxide (ZrO_2)

Molecular formula	ZrO_2
Molecular mass	123.218 g mol ⁻¹
Appearance	White
Density	4.9 g cm ⁻³
Melting point	2715°C

B. Synthesis of Al6061-Zirconium Dioxide (ZrO_2) Composites

A stir casting setup consists of an electrical arc furnace and a stirrer assembly which was used to synthesize the composite. The stirrer assembly consisted of a graphite stirrer, which was connected to a variable speed motor vertically with range of 50 to 800 rpm by means of a steel shaft. The stirrer was made by cutting and shaping a graphite block to desired shape and size manually. The stirrer consisted of four blades at an angle of 120° apart. Clay graphite crucible was placed inside the furnace. Cast iron crucible of 4 Kg capacity was placed inside the furnace.

The stir casting technique has been adopted to prepare the cast composites as described below. Initially Al6061 Alloy was charged into the graphite crucible to about 750°C till the entire alloy in the crucible alloy was melted. The reinforcement particles

(ZrO_2) were preheated to 400°C for one hour before incorporation into the melt. After the molten metal was fully melted, degassing tablets (Hexachloroethane) was added to reduce the porosity. The stirrer made of stainless steel was lowered into the melt slowly to stir the molten metal at the speed of 500-700 rpm. The preheated ZrO_2 particles of size 60 microns were added into the molten metal at a constant rate during the stirring time. The stirring was continued for another 5 minutes even after the completion of particle feeding. The mixture was poured into the mould which was also preheated to 500°C for 30 minute to obtain uniform solidification. Using this process 0, 3, 6, 9 and 12% by weight ZrO_2 particle reinforced composites were produced. The Stir casting set up is shown in the below figure .1.

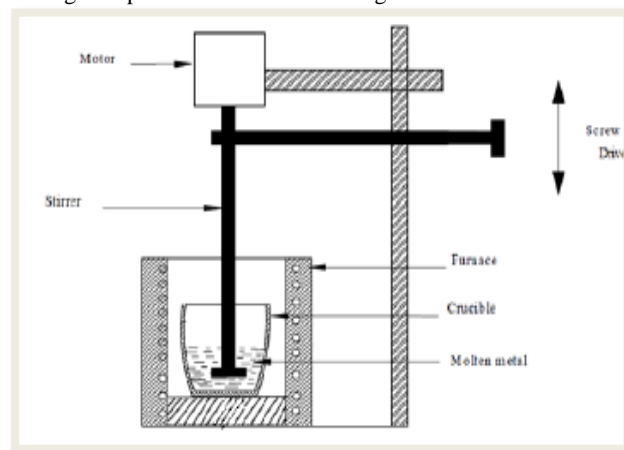


Fig. 1: Stir casting Setup



Fig. 2: Pouring of Molten Composite in to the mould



Fig. 3: Casted Specimens

3. Testing of Composites

A. Microstructure

Particles distribution was evaluated with the help of an optical microscope. Microstructure studies were carried out to confirm the presence of reinforcement in the alloy matrix.

The Al6061-ZrO₂ composite was examined under the optical microscope to determine the reinforcement pattern and cast structure. In any casted part as the composition of reinforcement increases the accumulation of reinforcement increases along the grain boundary. Microstructure was visualized with the help of optical microscope. For the specimen preparation, first of all specimen were cut down into small cuboids shapes after that the different samples were grinded on different grit size papers sequentially by 100, 220, 400, 600 and 1000. After grinding, the specimens were mechanically polished by alumina paste and then etched by kellers reagent to obtain better contrast. The specimens were visualized at magnifications of 500X to show the presence of ZrO₂ and its distribution on the Al6061 matrix. In any composites as the reinforcement increases the grain size of the base metal decreases because of the accumulation of reinforcement particles.

B. Tensile Strength

The tensile behaviour of the prepared samples was determined as per ASTM E8 M-09 standard using Instron testing machine.

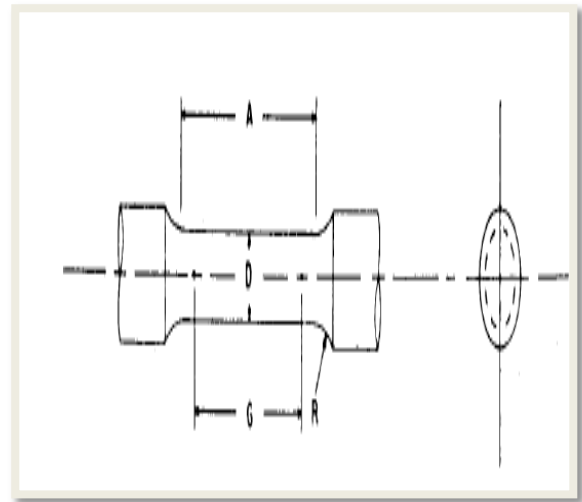


Fig. 4: Tensile Test Specimen Dimension

Table 3: Dimensions of Tensile Specimen According to ASTM E8 M-09 Standards

G-Gauge Length	30mm
D-Diameter	6mm
R-Radius of fillet	6mm
A-Length of radius	36mm



Fig. 5: Tensile.Specimen before testing



Fig. 6: Tensile.Specimen after testing

C. Hardness Test

The hardness test of the prepared samples was determined as per ASTM E standard using Brinell Hardness Tester machine. The following formula is used to calculate the Brinell hardness of Al6061-ZrO₂ Composites.

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$

Where,

P = applied force (kgf)

D = diameter of indenter (mm)

d = diameter of indentation (mm)

The ASTM sized standard specimen used for hardness testing is shown in the below figure 4.9.

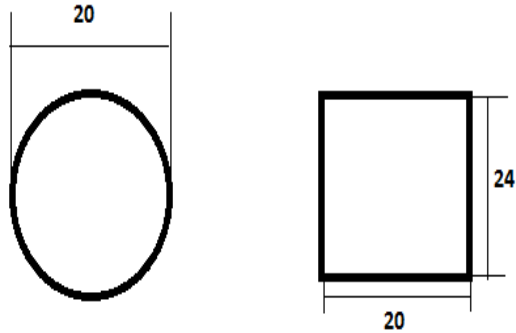


Fig. 7: Hardness Specimen Dimension



Fig. 8: Hardness. Specimen before testing



Fig. 9: Hardness. Specimen after testing

4. Results and Discussions

A. Microstructure Study

It is clear from the Figures 10, 11, 12, 13 and 14 that the distribution of ZrO_2 particles is observed in a matrix Al6061 alloys. The shape of most ZrO_2 particle is angular and sub-angular in nature. We can observe the increase in interfacial bonding of reinforcement with the Al6061 alloy. Good interfacial bonding can be obtained by pre-heating of ZrO_2 particulates before adding in the matrix material. From the microstructures shown in above figures we can say that all microstructures consists of fine precipitates of alloying elements dispersed along the grain boundary in the matrix Al6061 alloy. From the below microstructure images we can observe the uniform distribution of ZrO_2 Particulates in the matrix Al6061 at 9% Of ZrO_2 .

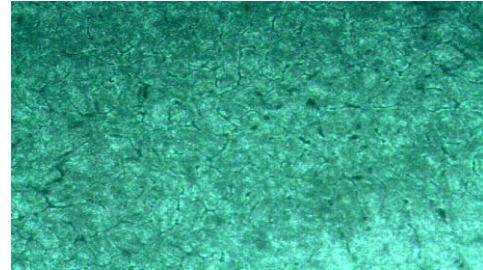


Fig. 10: Al 6061-0% ZrO_2 at 500X

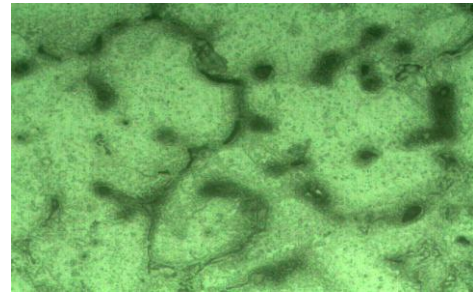


Fig. 11: Al 6061-3% ZrO_2 at 500X

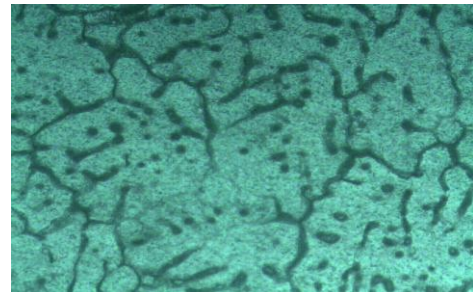


Fig. 12: Al 6061-6% ZrO_2 at 500X

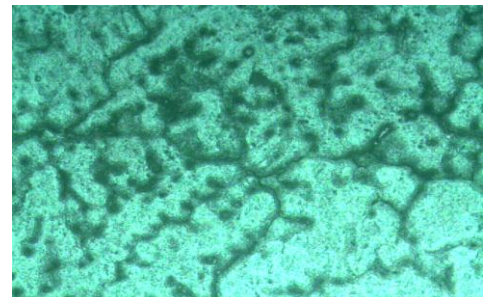


Fig. 13: Al 6061-9% ZrO_2 at 500X

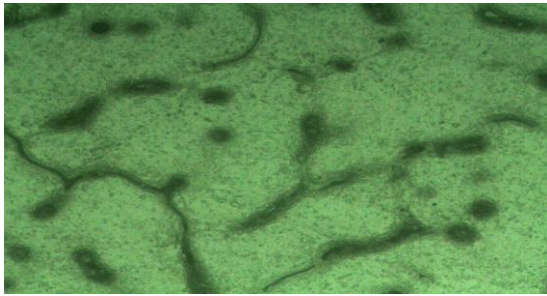


Fig. 14: Al 6061-12% ZrO₂ at 500X

B. Tensile Strength

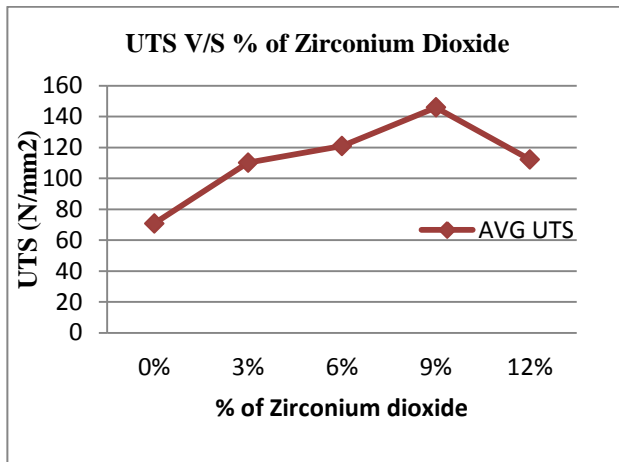


Fig. 15: UTS Variation versus % of Zirconium dioxide

The variation in ultimate tensile strength with varying percentages of Zirconia is shown in the above graph Fig. 15. From the above graph we can observe that there is an increase in the values of UTS up to 9% and decreases their afterwards due to poor wettability and poor bonding between the Al6061 alloy and Zirconia particulate. The optimum value of UTS for the composite is obtained at 9% of Zirconia.

C. Hardness Test

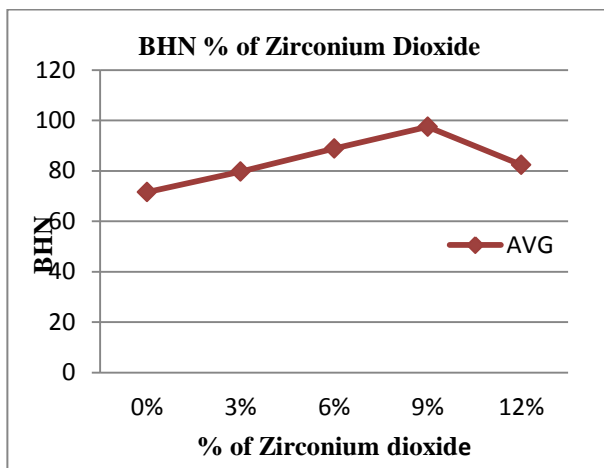


Fig. 16: BHN Variation versus % of Zirconium dioxide

The variation in BHN with varying percentages of Zirconia is shown in the above graph Fig. 16. From the above graph we can observe that there is an increase in the BHN up to 9% and decreases their afterwards due to poor wettability and poor bonding between the Al6061 alloy and Zirconia particulate. The optimum value of BHN for the composite is obtained at 9% of Zirconia.

5. Conclusions

The following conclusions were observed in this present study

- The Al6061-ZrO₂ composites were developed through stir casting technique for 0%, 3%, 6%, 9% and 12% of Zirconium dioxide reinforcement.
- From the microstructure studies, it revealed that the uniform distribution of ZrO₂ particulates in the Aluminium matrix was obtained at 9% of Zirconia.
- The tensile strength values of the Al6061-ZrO₂ composite was found to be more than base metal Aluminium alloy and increased with the increase in ZrO₂ reinforcement up to 9% and decreased their afterwards. The optimum value of UTS was obtained at 9% of Zirconia.
- The BHN of the Al6061-ZrO₂ composite was found to be more than base metal Aluminium alloy Al6061 and increased with the increase in ZrO₂ up to 9% and decreased their afterwards. The optimum value of BHN was obtained at 9% of Zirconia.

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