

Investigation of Mechanical Properties of Heat Treated Al6061-Zirconium Dioxide Composites Produced Through Stir Casting

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ABSTRACT: Aluminium alloy materials found to be the best alternative with its unique capacity of designing the material to give required properties. Aluminium alloy metal matrix composites (MMCs) are gaining wide spread acceptance for automobile, industrial and aerospace application because of their low density, high strength and good structural rigidity. This work focuses on the fabrication of aluminium alloy (Al6061) matrix composites (AMCs) reinforced with 3 to 12 wt% Zirconium dioxide particulates using stir casting route. The cast samples were subjected to T6 heat treatment, which includes solutionizing and ageing. In T6 Heat Treatment the cast composites were introduced in the furnace and solutionizing was carried out at a temperature of 530 °C for a period of 2 hours. After solutionizing the specimens were quenched in water and then artificially ageing was carried out at 175 °C. The ASTM standard test specimens were prepared from heat treated samples. The Optical microscope and mechanical properties of the fabricated AMCs were analyzed. The mechanical properties like hardness and compression strength of the unreinforced alloy and composites have been measured. The mechanical properties like hardness and compression strength have improved with the increase in weight percentage of zirconium dioxide in the aluminium matrix.

KEYWORDS: Al6061, Metal Matrix Composite, Heat Treatment, Stir Casting Process, Zirconium Dioxide.

I. INTRODUCTION

Metal matrix composites are gaining wide popularity in several sectors due to its improved mechanical properties and lighter density when compared with metal/alloy, especially in application where weight and strength are of prime importance. Al/Al alloy based MMC's are being used in several applications such as pushrods, cylinder, connecting rod, piston and brake disc etc. MMC's reinforced with particles tend to offer enhancement of properties processed by conventional routes [1].

Zirconium dioxide is the most common particles used as reinforcement in aluminium alloy composites. By adding ceramic particles as reinforcement to aluminium matrix, the properties are enhanced and lead to the development of materials for many industrial light weight applications.

Al6061 alloy is heat treatable and as a result further increase in strength can be expected. The main objective of heat treatment is to make the material system structurally and physically fit for engineering application. Al6061 alloy have numerous benefits like formability, weldability, corrosion resistance and low cost [2]. For production of Aluminium particulate reinforced composite stir casting method appears to be promising method among various conventional processing methods. Heat Treatment process is carried out to modify the microstructure of aluminium alloy composites with aluminium alloy matrix is the final production stages of composite [3]. Most of the researchers have investigated aluminium composites using SiC, Al₂O₃, MgO, Zircon etc. and these composites are commercially available in different structural forms.

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In the present research work the study is made on the investigation of mechanical properties of heat treated Al6061-Zirconium dioxide composites produced through stir casting.

II. RELATED WORK

A scan of literature survey has been carried out on the Al6061 alloy based particulate reinforced metal matrix composites, Zirconium dioxide particulate reinforced metal matrix composites and are discussed below.

B. Ravi et.al., studied the Characterization of Aluminium Matrix Composites (AA6061/B₄C) Fabricated by Stir Casting Technique and concluded that the production of homogeneous AA6061/B₄C composite could be achieved by using Stir Casting Technique. The optical metallographic study revealed the presence of B₄C particles in the composite with homogeneous dispersion. Addition of B₄C reinforcement particles decreased the grain size of the matrix. The microhardness of the composites increased from 62 HV to 68 HV with incremental weight percentage of B₄C particles. The B₄C reinforcement has enhanced the tensile strength of Aluminium Matrix Composites (AMCs) from 117 MPa to 145 MPa. **J.Jebeen Moses et.al.**, worked on the The Characterization Of Silicon Carbide Particulate Reinforced AA6061 Aluminium Alloy Composites Produced Via Stir Casting and showed that the AA6061/SiC AMCs were successfully fabricated using stir casting technique. The distribution of SiC in the aluminium matrix was fairly homogeneous. SiC particles enhanced the microhardness and UTS of the composite. AA6061/15 wt. % SiC AMC exhibited 133.3 % higher microhardness and 65.2 % higher UTS compared to unreinforced AA6061 alloy. **M.Kamaraj [9] et.al.**, worked on the Experimental Investigation On Mechanical Behaviour Of Sand Cast Al 6061-SiC Metal Matrix Composites and concluded that the Microstructure characterization revealed the uniform distribution of SiC particles and particle clustering in some places. The values of density in composites are increased by increasing the volume fraction of reinforcements, but experimental density was lower than theoretical density. The hardness and impact energy of composites increased linearly with the volume fraction of reinforcements in the Al alloy.

S. Madhav Reddy et.al., studied the Effects of Porosity on Mechanical Properties of Zirconium Oxide/AA1100 Alloy Metal Matrix Composites and found that the porosity has been increased with increase of ZrO₂ particles in AA1100 alloy matrix. In the presence of porosity, the stresses developed in the composites have exceeded the allowable stress for the same load applied on all the composite specimens. The stress concentrations were observed in the regions of porosity in the composites. The elastic modulus decreased with porosity in the composites. **Adil Ahmed.S, et.al.**, worked on the Mechanical Properties of Aluminium Alloy Al356.2 Matrix Reinforced with Zirconium Particles and concluded that Vortex method is used for successful incorporation of Zirconium particles into the aluminium alloy. Using this method 10, 15 and 20 wt% composites were fabricated. It is found that hardness and tensile strength of the composites increases with increase in reinforcement (%) upto 15% and decreases.

From the above literature survey it is evident that there has been no attempt to develop Al6061-Zirconium dioxide Particulate Reinforced Composites using stir casting method and to study the effect of heat treatment on its mechanical properties.

III.MATERIALS

Al6061 Alloy

The aluminium alloy Al6061 was used as matrix phase in this composite material which is used in various aerospace and automotive applications. It is a heat treatable aluminum alloy. The Chemical composition of aluminium alloy Al6061 is shown in the below Table 1.

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Table 1: Composition of Al6061 Alloy

| Element | Al | Mg | Si | Fe | Cu | Zn | Ti | Mn | Cr |
|-----------------|---------|------|------|------|------|------|------|------|------|
| Quantity (wt.%) | Balance | 0.90 | 0.50 | 0.50 | 0.30 | 0.20 | 0.10 | 0.10 | 0.25 |

Zirconium Dioxide

As reinforcement a hard Zirconium dioxide (ZrO_2) powder is used. ZrO_2 is very high in hardness and low co-efficient of expansion which made to choose as reinforcement. ZrO_2 also has major unique properties includes good mechanical properties, high refractory and good oxygen ion conductor thermal shock resistance. The Physical Properties of Zirconium Dioxide (ZrO_2) is shown in the below Table 2.

Table 2: Physical Properties of Zirconium Dioxide (ZrO_2)

| | |
|-------------------|----------------|
| Molecular formula | ZrO_2 |
| Molecular mass | 123.218 g/ mol |
| Appearance | White |
| Melting point | 2715°C |

IV. EXPERIMENTAL PROCEDURE

Fabrication of Composites

The metal matrix composites Al6061-Zirconium dioxide have been produced by simplest and most economical used technique known as vortex technique or stir casting technique. The addition of reinforcement particulate Zirconium dioxide varied from 3 to 12 wt. % insteps of three by mechanical stirring. Degassing agent solid hexachloroethane (C_2Cl_6) was added to expel all absorbed gases from the molten metal once the temperature have been reached. Before the addition of Zirconium dioxide particulates, mechanical stirring process was carried out with the help of a stirrer to form a fine vortex. The speed of the stirrer is rotated for 5 mins at a spindle speed of 500 rpm. The Zirconium dioxide particulates were preheated to a temperature of 400°C in a preheater to increase the wettability. Before pouring the molten metal into the mould die, the molten metal was heated for about 5 mins. After stirring, the stirrer was removed and the molten composite was poured into the mould and allowed to cool. Figure 1 shows the electric arc furnace used for the development of composites.

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Figure 1: Electric Arc Furnace

Heat Treatment Procedure

The Al6061 matrix alloy and cast Al6061-Zirconium dioxide composites were subjected to T6 heat treatment in a muffle furnace. During T6 heat treatment the composites were introduced in the furnace and solutionizing was carried out at a temperature of 530 °C for a period of 2 hours. After solutionizing the specimens were quenched in water and then artificially ageing was carried out at 175 °C. Figure 2 shows the muffle furnace used for the heat treatment process.



Figure 2: Muffle Furnace

V. SPECIMEN PREPARATION AND TESTING OF COMPOSITES

Microstructure and mechanical behavior of the Al6061 alloy and its composites were carried out. A metallographic examination was carried out by using optical microscope. The sample preparation for microstructural study was carried out first by polishing the sliced samples with emery paper. The polished surface was etched with Keller's reagent and examined with a optical microscope. The compression strength of the ASTM standard Al6061 alloy and Al6061-Zirconium dioxide specimen were measured using universal testing machine. Hardness tests were performed on ASTM standard Al6061 alloy and Al6061-Zirconium dioxide composites using Brinell hardness testing machine to know the

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effect of zirconium dioxide particles in the matrix material. Three sets of readings were taken at different places of the specimen and an average value was used for calculation.

The following equation (1) is utilized to ascertain the Brinell Hardness of Al6061-ZrO₂ composites.

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})} \text{ ----- (1)}$$

Where,

P = applied load (kgf)

D = indenter diameter (mm)

d = indentation diameter (mm).

VI. RESULTS AND DISCUSSIONS

Microstructure Study

It is evident from the below Figures 3, 4, 5, 6 and 7 that the distribution of Zirconium dioxide particles is observed in the Al6061 matrix. The heat treatment of Al6061-Zirconium dioxide composites with water as quenching media results in the grain refinement. This leads to improvement in compression strength and hardness properties than as-cast composites. The grain refinement increases the interfacial bonding between the Al6061 alloy and Zirconium dioxide particles which in turn increases the strength of the composites. From the above microstructures images we can observe that as the percentage of Zirconium dioxide particles from 0 % to 12 % increases the distribution of Zirconium dioxide particles in Al6061 alloy also increases. Also from the above microstructure images we can observe the uniform distribution of Zirconium dioxide Particulates in the matrix Al6061 is observed at 9% of Zirconium dioxide.

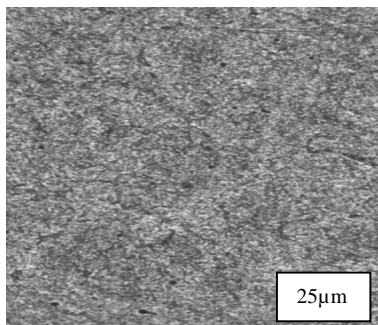


Figure 3: Al 6061-0% ZrO₂

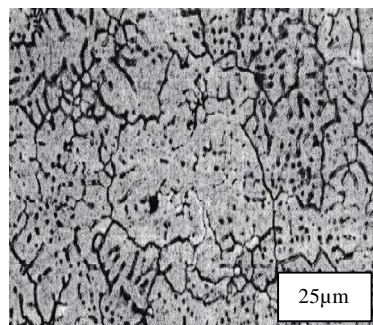


Figure 4: Al 6061-3% ZrO₂

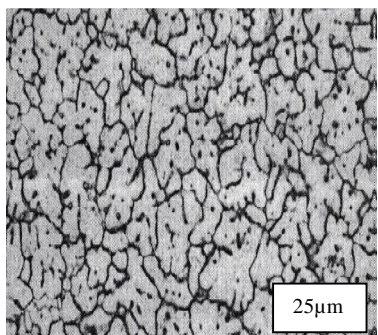


Figure 5: Al 6061-6% ZrO₂

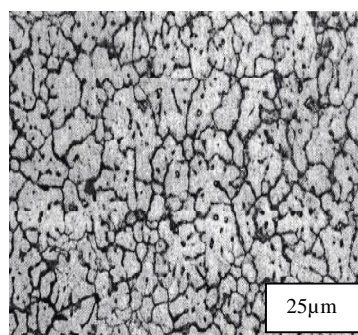


Figure 6: Al 6061-9% ZrO₂

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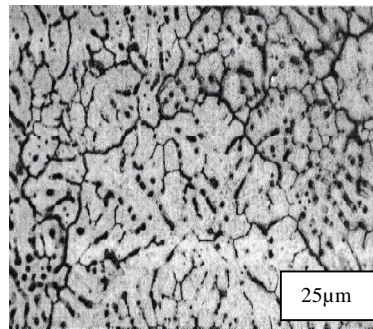


Figure 7: Al 6061-12% ZrO₂

Hardness Test

The below Figure 8 shows the variation of Brinell Hardness Number v/s % of Zirconium dioxide of heat treated Al6061-Zirconium dioxide composites with water as quenching media.

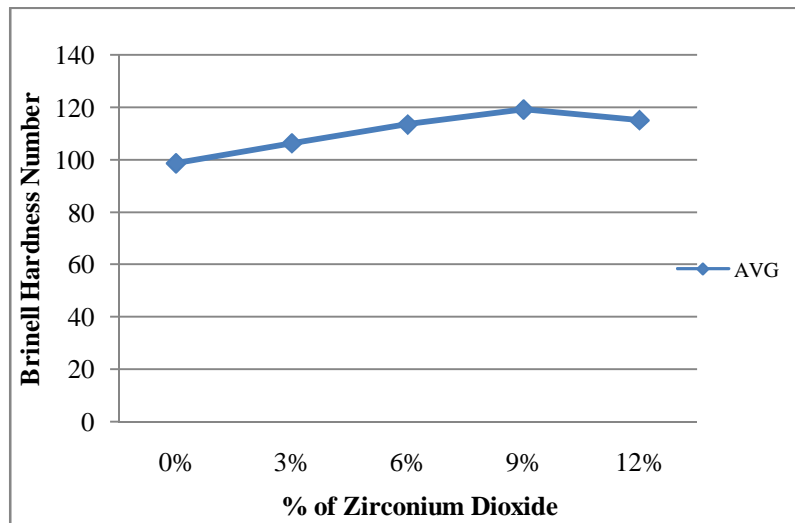


Figure 8: BHN variation v/s % of Zirconium dioxide

From the above figures we can see that as the percentage of zirconium dioxide increases the Brinell Hardness Number increases up to 9 % of zirconium dioxide and decreases there afterwards due to poor wettability and bonding between Al6061 alloy and zirconium dioxide. The heat treatment of Al6061-Zirconium dioxide composites with water as quenching media results in the grain refinement which increases the Brinell Hardness Number of the composites than as-cast composites. The grain refinement increases the interfacial bonding between the Al6061 alloy and Zirconium dioxide particles which in turn increases the Brinell Hardness Number of the composites. The optimum value of Brinell Hardness Number is obtained at 9 % of zirconium dioxide.

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Compression Strength Test

The variation in compression strength with varying percentages of Zirconium dioxide of heat treated Al6061-Zirconium dioxide composites with water as quenching media is shown in the below Figure 9.

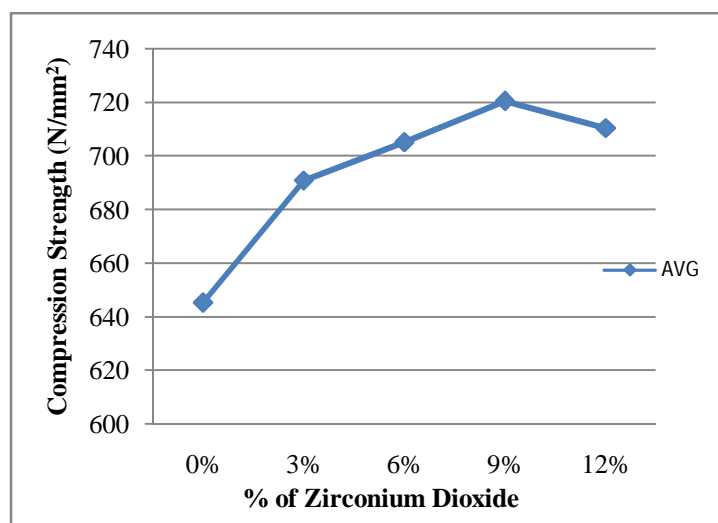


Figure 9: Compression Strength variation v/s % of Zirconium dioxide

It is revealed from the above Figure 9 that there is an increase in the compression strength from 0% to 9% reinforcement, and there is a slight decrease from there onwards. The decrease in the compression strength after 9 % is due to poor wettability and poor bonding between the Al6061 alloy matrix and Zirconium dioxide particulate. The optimum value of compression strength is obtained at 9% of Zirconium dioxide. The heat treatment of Al6061-Zirconium dioxide composites with water as quenching media results in the grain refinement which increases the compression strength of the composites than as-cast composites. The grain refinement increases the interfacial bonding between the Al6061 alloy and Zirconium dioxide particles which in turn increases the compression strength of the composites.

VII. CONCLUSION

Al6061-Zirconium dioxide composites have been successfully developed with fairly uniform dispersion of Zirconium dioxide particulates using liquid metallurgy route. The microstructural study clearly reveals that nearly uniform distribution of reinforcement particulates in the Al6061 matrix alloy. The Brinell hardness of the composites increased significantly with increased content of zirconium dioxide particulates. Heat treatment has a significant effect on Brinell hardness of Al6061 matrix alloy and its composites. Water quenching followed by artificial ageing resulted in maximum improvement in hardness of matrix alloy and its composites. Al6061-Zirconium dioxide particulate composites exhibit superior compression strength than Al6061 matrix alloy under heat treated condition.

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