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Research paper

Development and Mechanical Characterization of Al6061-Zircon Composites

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Abstract

Composite materials are widely used in variety of applications such as aerospace, automotive and structural components resulting in savings of material and energy. Particulate reinforced Aluminium metal matrix composite materials which are having desirable properties such as high specific stiffness, high specific strength, high coefficient of thermal expansion, increased fatigue resistance and superior dimensional stability compared to unreinforced alloys. In the present work an attempt has been made to develop composites using Al 6061 as a matrix material reinforced with Zircon particulates using stir casting technique. The Zircon particulates were varied in steps of 0 %, 3%, 6%, 9% and 12%. The Specimens were prepared as per the ASTM standards. The prepared composites were characterized by microstructural studies using optical microscope and tensile strength and hardness properties were evaluated. Zircon particles were observed to refine the grains and were distributed homogeneously in the aluminium matrix at 9% of Zircon. The tensile and hardness properties were higher in case of composites when compared to unreinforced Al 6061 matrix. Also increasing addition level of Zircon has resulted in further increase in both tensile strength and hardness values and optimum value was obtained at 9% of Zircon.

Keywords*: Al 6061, Zircon, ASTM, Stir Casting, BHN.*

1. Introduction

These Conventional monolithic materials have limitations in achieving good combination of strength, stiffness, toughness & density. To overcome this draw backs and to meet the ever increasing demand of modern day technology, composites are most promising interest. Composite materials are used in variety of applications such as aerospace, automotive and structural components resulting in savings of material and energy [1].

Particulate reinforced Aluminium metal matrix composite materials which are having desirable properties such as high specific stiffness, high specific strength, high coefficient of thermal expansion, increased fatigue resistance, superior dimensional stability compared to unreinforced alloys at the elevated temperatures .These properties of MMC's enhance their research in automotive and tribological applications. In the field of automobile MMC's are used for Piston's, brakedrum and cylindrical block because of better corrosion resistance & wear resistance. The most commonly employed composite system consists of Aluminium alloy reinforced with hard ceramic particles usually silicon carbide, alumina and soft particles usually graphite, flash etc.

The particulate composite can be prepared by injecting the reinforcing particles into liquid matrix's through liquid metallurgical route by casting. Casting route is prepared as it is less expensive and amenable to mass production .The simplest and the most cost effective method of liquid state fabrication is Stir Casting.

Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of Mechanical stirring. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies. Among the entire liquid state production routes, Stir casting route is chosen because of low cost and widely used metal casting technique [2].

Al6061 is an aluminium alloy, with copper and magnesium as the alloying elements. It is used in applications requiring high strength to weight ratio, as well as good fatigue resistance. It is not weldable, and has average machinability. Al6061 aluminium alloy 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 use. Al6061 is commonly used for the construction of aircraft structures, such as wings and fuselages, more commonly in homebuilt aircraft than commercial or military aircraft.2024 alloy is somewhat stronger, but Al6061 is more easily worked and remains resistant to corrosion even when the surface is abraded, which is not in the case for 2024, which is usually used with a thin Aluminium clad coating for corrosion resistance, construction, including small utility boats. Automotive parts, such as wheel spacers, the manufacture of aluminium cans for the packaging of foodstuffs and beverages [3].

Zirconium silicate ($ZrSiO_4$) occurs in nature as mineral Zircon. Ore is mined from natural deposits and concentrated by various techniques.

It is separated from sand by electrostatic and electromagnetic methods. Also, the compound can be made by fusion of SiO_2 and

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ZrO_2 in an arc furnace, or by reacting a Zirconium salt with sodium silicate in an aqueous solution. Zirconium silicate is used for manufacturing refractory materials for applications where resistance to corrosion by alkali materials is required. It is also used in production of some ceramics, enamels, and ceramic glazes. Another use of Zirconium silicate is as beads for milling and grinding [4].

The development of Al6061-Zircon particulate composite is still in the nascent stage. Hence the present research is aimed at developing Aluminium alloy (Al6061)-Zircon ($ZrSiO_4$) composites by stir casting method and studying the microstructure, tensile strength and compression strength properties.

A. Matrix and Reinforcement

Al6061 was taken as the matrix as it is easily machinable and heat treatable. Zircon ($ZrSiO_4$) is selected as the reinforcement particle due to its easiest availability and its high temperature applications.

B. Matrix: Al 6061 Alloy

Al6061 is an aluminium alloy, with copper and magnesium as the alloying elements. It is used in applications requiring high strength to weight ratio, as well as good fatigue resistance. It is not weldable, and has average machinability.

2. Experimental Procedure

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

C. Reinforcement :Zirconium Silicate ($ZrSiO_4$)

Zirconium Silicate occurs in nature as mineral Zircon. The ore is mined from natural deposits and concentrated by various techniques. It is separated from sand by electrostatic and electromagnetic methods. Also the compound can be made by fusion of SiO_2 and ZrO_2 in an arc furnace, or by reacting a zirconium salt with sodium silicate in an aqueous solution.

Zirconium Silicate is used for manufacturing refractory materials for applications where resistance to corrosion by alkali materials is required. It is also used in production of some ceramics, enamels, and ceramic glazes. Another use of Zirconium Silicate is as beads for milling and grinding.

Table 2: Physical Properties of Zirconium Silicate ($ZRSIO_4$)

Molecular formula	$ZrSiO_4$
Molecular mass	183.31 g mol^{-1}
Appearance	Colourless crystals
Density	4.56 g cm^{-3}
Melting point	2550 °C

A. Development of Al6061-Zircon ($ZrSiO_4$) Composites Stir Casting Process

A stir casting setup consists of Electrical resistance Furnace and a stirrer assembly was used to synthesize the composite. The stirrer assembly consisted of a graphite stirrer, which was connected to a variable speed motor with range of 50 to 800 rpm by means of a steel shaft. The stirrer head was made by cutting and shaping a graphite block to desired shape and size manually.

The stirrer consisted of three blades at an angle of 120° apart. Cast iron crucible of 4 Kg capacity was placed inside the furnace. The Stir Casting set up is shown in the below figure.

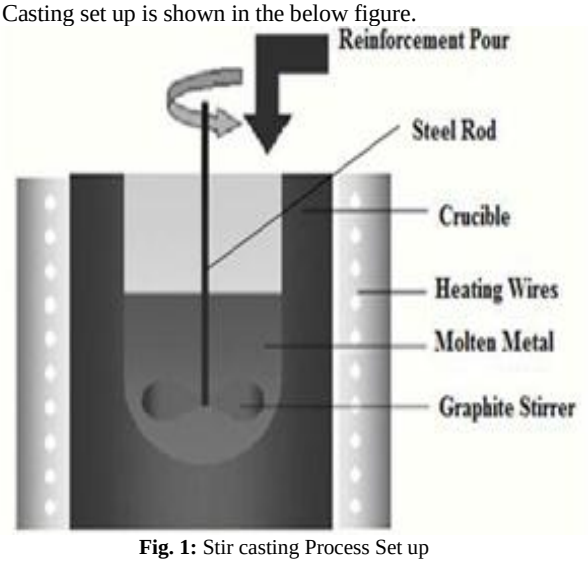

Fig. 1: Stir casting Process Set up

The Synthesis of the metal matrix composite used in the present work was carried out by stir casting route. The Al6061 is used in the form of ingots. The cleaned metal ingots were melted to the desired temperature of 700 ^{0}C in graphite crucibles. The Zirconium Silicate Particles of Size 65µicrons were introduced into the vortex of the molten alloy after degassing using Solid Hexachloroethane (C_2Cl_6). Before introducing reinforcement particles into the melt they were preheated to a temperature of 300^{0}C.

The extent of incorporation of $ZrSiO_4$ Particles into the matrix alloy was achieved in steps of 0%, 3 %, 6%, 9% and 12% i.e., the amount of reinforcement required was calculated into melt 5 times rather than introducing all at once. At every stage of before and after introduction of reinforcement particles, mechanical stirring of the molten alloy was carried out for a period of 10 minutes. The stirrer was preheated before immersing into the melt and run at a speed of 200 rpm. A Pouring temperature of 700 ^{0}C was adopted and the molten composite was poured into permanent cast moulds. Thus composites containing Zircon particles 0, 3, 6, 9 and 12 % were obtained in the form of Cylinders of diameter 20 mm and length 125 mm.



Fig. 2: Casted Al6061-Zircon Composite

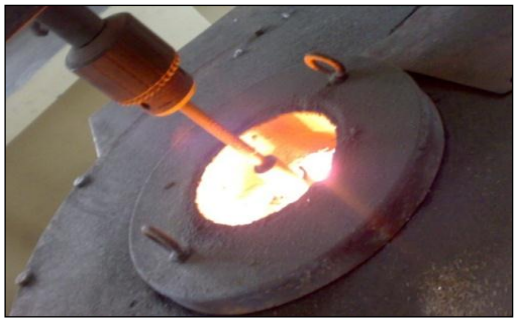

Fig. 3: Melting Furnace

3. Specimen Preparation and Testing

The cast composites were machined and the Specimens for the measurement of tensile strength, Brinell Hardness Number and Microstructure were prepared as per ASTM standards.

Metallographic samples were sectioned from the cast bars and were prepared using a technique specially developed for such composites. A 0.5% HF solution was used to etch the samples wherever required. Microstructures were examined under the optical microscope. Tensile and compression were prepared as per ASTM E8 standard. The tensile & Compression tests were carried out on Instron testing machine. 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-$ZrSiO_4$ Composites.

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

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.

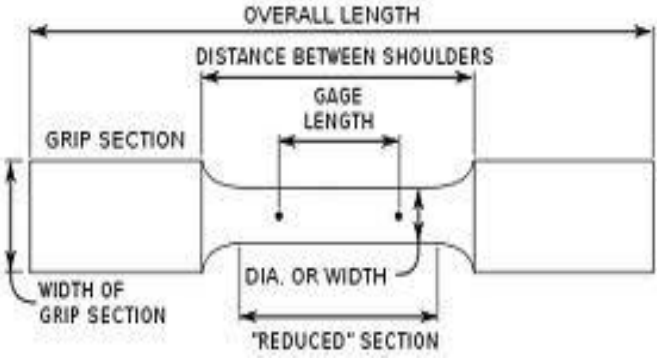

Fig. 4: Tensile Specimen Sketch

Gauge length =30mm Diameter=6mm Radius of fillet=6mm Reduced section=36mm

Thread type= M09 Thread



Fig. 5: Tesile Strength Specimens after Testing



Fig. 6: Tesile Strength Specimens after Testing

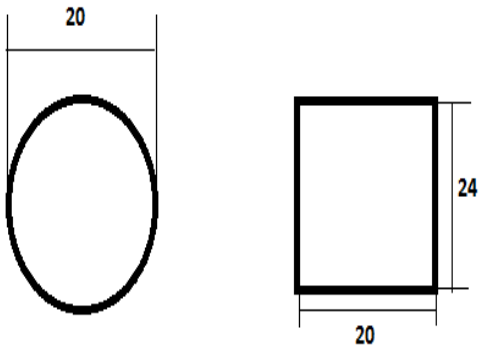

Fig. 7: Hardness Specimen Sketch



Fig. 8: Hardness Specimens before Hardness Testing



Fig. 9: Hardness Specimens after Testing

4. Results and Discussions

A. Microstructure Analysis

The microstructure shown in Fig.13 at 500X magnification in the optical microscope reveals better dispersion of Zircon reinforcement in the Aluminium matrix. The Microstructure consists of fine precipitates of alloying elements dispersed along the grain boundary in the matrix of aluminium solid solution. Zircon Particles are dispersed in the matrix. As the wt% of Zircon increases in the matrix, the reinforcement particles increases and the inter particle space decreases. There is no indication of agglomeration of reinforcement in the matrix. From optical microscope images we can observe the uniform distribution of Zircon particulates in the aluminium alloy matrix at 9% of Zircon.

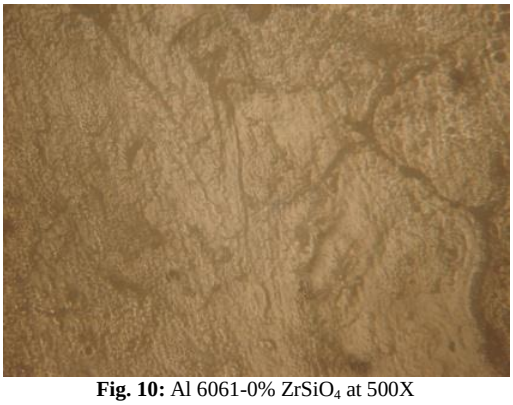

Fig. 10: Al 6061-0% $ZrSiO_4$ at 500X

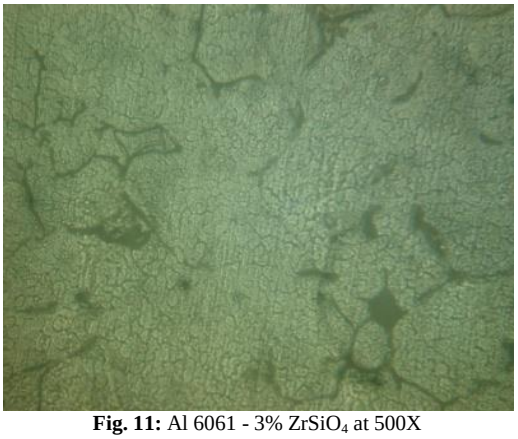

Fig. 11: Al 6061 - 3% $ZrSiO_4$ at 500X

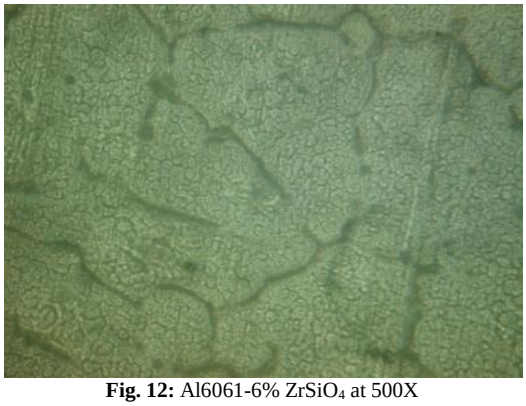

Fig. 12: Al6061-6% $ZrSiO_4$ at 500X

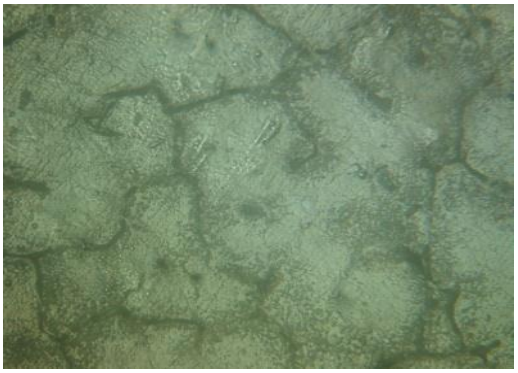

Fig. 13: Al 6061 - 9% $ZrSiO_4$ at 500X

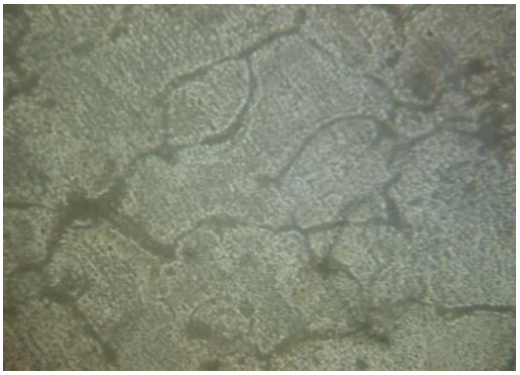

Fig. 14: Al 6061 -12% $ZrSiO_4$ at 500X

B. Tensile Strength

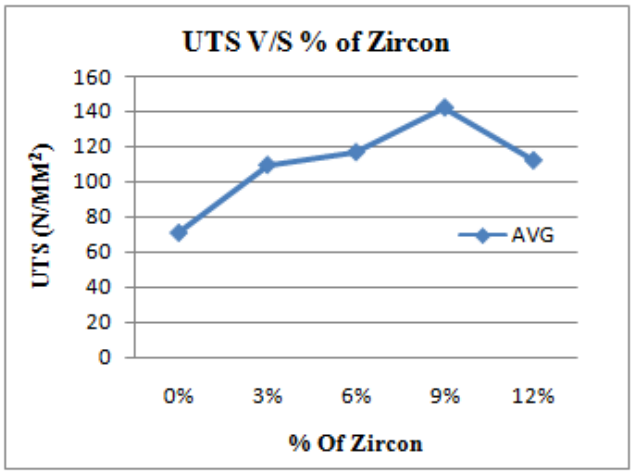

Fig. 15: Tensile Strength Variation verses % of Zircon

The variation in ultimate tensile strength with varying percentages of Zirconium silicate is shown in the graph above. Study on the UTS reveals that there is an increase in the UTS from 0% to 9% reinforcement and decreases there afterwards. The decrease in the UTS after 9 % is due to poor wetability and poor bonding between the Al6061 alloy matrix and Zircon particulate. The optimum value of UTS is obtained at 9% of Zircon.

C. Hardness Test

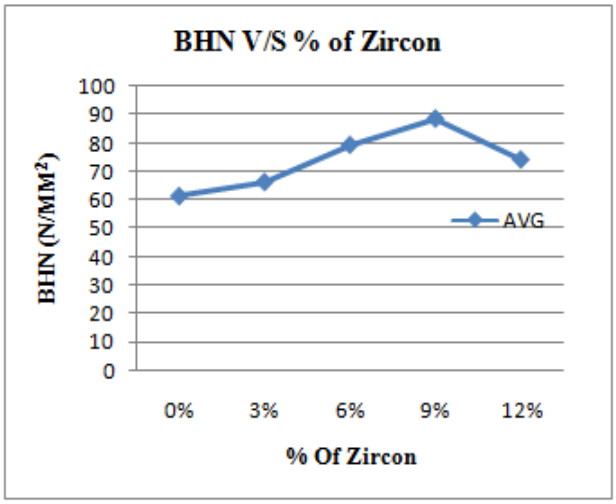

Fig. 16: BHN Variation verses % of Zircon

The variation in BHN with varying percentages of Zirconium Silicate is shown in the graph above. Study on the BHN reveals that there is an increase in the BHN from 0% to 9% reinforcement, and there is a slight decrease from there onwards. The decrease in the BHN after 9 % is due to poor wetability and poor bonding

between the Al6061 alloy matrix and Zircon particulate. The optimum value of BHN is obtained at 9% of Zircon.

5. Conclusions

The present work on preparation of Al6061-Zircon metal matrix composite by stir casting and evaluation of tensile and compression properties has led to following conclusions

- The Al6061 reinforced with $ZrSiO_4$ particulates that is Al6061-$ZrSiO_4$ metal matrix composite were successfully fabricated through liquid metallurgy route for 0%, 3%, 6%, 9% and 12% reinforcement.
- The optical micrographs of composites produced by stir casting method shows fairly uniform distribution of Zircon particulates in the Al6061 metal matrix at 9% of Zircon.
- The tensile strength of the composite is found to be is more than base metal Aluminium alloy and increases with the increase in reinforcement up to 9% and decreases there afterwards. The optimum value of UTS was obtained at 9% of Zircon.
- The BHN of the composite is found to be is more than base metal Aluminium alloy and increases with the increase in reinforcement up to 9% and decreases there afterwards. The optimum value of BHN was obtained at 9% of Zircon.

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