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Experimental Investigation on Zirconia Reinforced Aluminium 6061 Metal Matrix Composite

Chandan Gowda B E[1], Girish K B[2], Manjunath S H[3], B K Narendra[4]
[1]Student, [2]Professor & PG Coordinator, [3]Professor & Head Department of Mechanical Engineering, [4]Dean & Principal, BGSIT Adichunchanagiri University, B G Nagara.

***Abstract:** Composites prepared of aluminium that are reinforced with particles are frequently used in applications related to aerospace, defence, marine and space due to their exceptional characteristics, such as their high corrosion resistance, high fatigue resistance, high strength, high stiffness, high wear resistance, etc. In the current work, Zirconium dioxide was added in various percentages from 0.5% to 1.5% to Aluminium Alloy Al6061 composites using stir casting technique. The samples were made in accordance with ASTM standards for hardness, tensile strength, and microstructure analysis. Zirconium dioxide particles were found in the aluminium matrix according to microstructure investigations done with an optical microscope. The current study says that Zirconium dioxide was evenly distributed throughout the aluminium matrix and that there were no holes or porosities in the matrix. More than the base metal aluminium alloy, it had higher tensile strength and hardness qualities. Tensile strength and hardness qualities increased with an increase in zirconium dioxide content up to 1.5%.*
***Keywords:** MMC, Reinforcement, Zirconium dioxide, Interfacial bond strength, Hardness*

I. INTRODUCTION

In modern engineering, composite materials are extensively used in a wide range of structures, including spacecraft, vehicles, boats, sports equipment, bridges, aeronautical systems etc. Composite materials are well-established engineering materials and in comparison to monolithic materials, they often have greater specific moduli, specific weights, thermal stabilities, stiffness qualities and wear resistance[1-4].

A class of sophisticated materials known as Metal Matrix Composites (MMCs) are thought to possess the following properties: low density, high elastic modulus, high tensile strength, low coefficient of thermal expansion and good wear resistance [5-6]. These properties could not be combined in the monolithic materials. The increased specific strength and higher specific stiffness of particle reinforced MMCs at both room and high temperatures have recently attracted particular interest. And their applications include aerospace, automotive and tribological fields. Particle-reinforced MMCs are used in the automotive sector to create pistons, brake drums and cylinder blocks because they provide improved corrosion and wear resistance[7-8]. Aluminium oxide, graphite, fly ash, silicon carbide and other materials are the most often used particles. The fabrication processes used for MMCs include squeeze casting, stir casting, and powder metallurgy. Stir casting is a popular and environmentally friendly method for creating metal matrix composites. It is used to produce materials with an aluminium alloy as their base[9-11]. Hence the easiest way to create composites made of aluminium and metal is through stir casting and is frequently employed for MMC's bulk production[12-13].

The most popular material for making metal matrix materials, among the several types of matrix materials for composites, is aluminium and its alloys. Due to their processing versatility, low density, wide range and abundant availability of aluminium alloy-based composites, as well as their high thermal conductivity, high wear resistance, high heat treatment capability, high strength, improved elastic modulus, high stiffness and high dimensional stability, make them very alluring[14-16]. In recent years, the use of aluminium based MMCs as engineering materials has increased. A composite material is created by mixing a ceramic substance with a metal matrix and it has desirable physical and mechanical qualities that can't be achieved with monolithic alloys. Discontinuously reinforced aluminium matrix composites were created in response to the demand for lightweight, highly rigid materials that are ideal for a variety of applications, particularly in aerospace and automotive items like engine pistons, cylinder liners, braking discs/drums, etc. The potential of aluminium alloys for structural applications and wear resistance has been significantly boosted by reinforcing them with small reinforcement ceramic particles[17-18]. The creation of metal matrix composites (MMCs) with low-cost reinforcements, high stiffness, high strength and improved wear resistance are becoming more and more popular.The alloys in which aluminium predominates are known as aluminium alloys. Usually, copper, magnesium, manganese, silicon, and zinc are used as alloying components.

Casting alloys and wrought alloys are the two main divisions and both are further classified into groups like heat treatable and non-heat treatable. Since the invention of metal-skinned aircraft, alloys mostly made of aluminium have played a significant role in the aerospace manufacturing industry. Aluminium-magnesium alloys are both lighter than conventional aluminium alloys and far less combustible than alloys with a very high concentration of magnesium[19].

Magnesium and silicon make up most of the alloying components in the precipitation-hardening aluminium alloy known as Al6061. It offers good weldability and excellent mechanical characteristics. For general use, Al6061 is the most affordable heat-treatable aluminium alloy, and is used frequently due to its many beneficial features, including good formability, good weldability, and strong corrosion resistance.

Zirconia (ZrO_2) is one of the most accessible and reasonably priced particle reinforcements, and it also has exceptional mechanical and wear properties. It can sustain high strength at high temperatures. Due to its strength, toughness, and wear resistance, it is a good material. The mechanical and wear properties of zirconia (ZrO_2)-containing aluminium alloys significantly increase at high temperatures. Al6061 is a heat-treatable alloy with medium to high strength. Zirconia is a good material with strong, hard, and wear-resistant qualities that can be mixed with Al6061. It is evident that no attempt has been made to create stir-cast Al6061-Zirconia (ZrO_2) Particulate Reinforced Composites and examine their mechanical properties. As a result, the current effort aims to create Al6061-Zirconia (ZrO_2) composites using the stir casting method and to analyse the mechanical properties[20].

II. METHODOLOGY

The Al6061 base material, which contains 95 percent aluminium metal and has 5 percent of magnesium and silicon as key alloying ingredients, is the subject of the investigation. The literature review is used to determine the reinforcement's percentage composition. The stir casting technique is used to create MMC. The hybrid composite material plate was created at 779.3°C and 574.2 rpm. The tensile and hardness of aged Al6061 reinforced with Zirconium-dioxide particles are the main subjects of the investigation. Aluminium 6061 + ZnO_2 is the component in composite aluminium.

STEPS INVOLVED:

A. *Selection Of Matrix And Reinforcement*

Reinforcements are used to offer the composites improved mechanical properties, such as high strength, stiffness, and other qualities. It is also important to notice their impact on additional properties like conductivity and the coefficient of thermal expansion. Al6061 was selected as the matrix of the composite in the current study due to its density, which makes it useful for light weight components, low melting point, which makes it easier for casting purposes, higher thermal conductivity, which increases its commercial usage, easy availability, which makes it immediately available for experimentation, and low cost, which makes it appealing for experimental as well as industry purposes.

The nominal composition of type 6061 aluminium is 97.9% aluminium, 0.6% silicon, 1% magnesium, 0.2 percent iron, and 0.28 percent copper. The density of 6061 aluminium alloy is 2.7 g/cm3 (0.0975 lb/in3). The alloy of aluminium is readily producible, weldable, and corrosion resistant. Zirconium oxide, also referred to as zirconia or ZrO_2, is a white, crystalline zirconium oxide which is used as a reinforcement material. The mineral baddeleyite has a monoclinic crystalline structure and is the most prevalent naturally occurring variety of it.

Zirconia does not exist in nature as a pure oxide, but it can be found in zircon ($ZrSiO_4$) and baddeleyite, which are the main sources of the substance. The most common of these two, zircon, is also the least pure and requires the most processing to turn into Zirconia. This material has the following properties such as, Density-4.9 gm/cm3, Melting point-2715 °C Thermal, Conductivity-60.7 W/m, K (Specific heat capacity)- 0.46 J/g °C, Poisson's Ratio-0.31 and Young's Modulus-207 GPa. Zirconia is processed by separating and removing unwanted components and impurities. Zirconia can be extracted from zircon using a number of processes, including chlorination, alkali oxide breakdown, lime fusion, and plasma dissociation. At room temperature, pure zirconia exists in the monoclinic form. At higher temperatures, the cubic and tetragonal phases are also stable. At 800-1000°C, monoclinic Zirconia changes into cubic Zirconia, and this is followed by a significant change in the lattice size.

B. *Stir Casting*

A mechanical stirrer is used in the stir casting process to produce vortices that mix the reinforcement with the matrix material. It is a suitable technology for producing metal matrix composites because it is affordable, suitable for mass production, simple, virtually net-shaped, and easy to manage the composite structure.

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Stir casting is an excellent processing technique for producing hybrid aluminium matrix composites and aluminium matrix composites since it is a cost-effective process and is chosen for mass production. The first stage of stir casting involves melting aluminium. When the atmosphere and moisture interact with the melting aluminium, they produce an oxide covering of aluminium. During the stir casting process, the melt is continuously stirred, exposing its surface to the air, which tends to continuously oxidise the melt's aluminium content. When producing aluminium utilising stir casting techniques, several process variables, including as stirring speed, impeller blade angle, stirring time, impeller placement, impeller size, and feed rate, must be taken into account due to continuous oxidation. The reinforcement particles remain unmixed, which reduces the wettability of the aluminium.

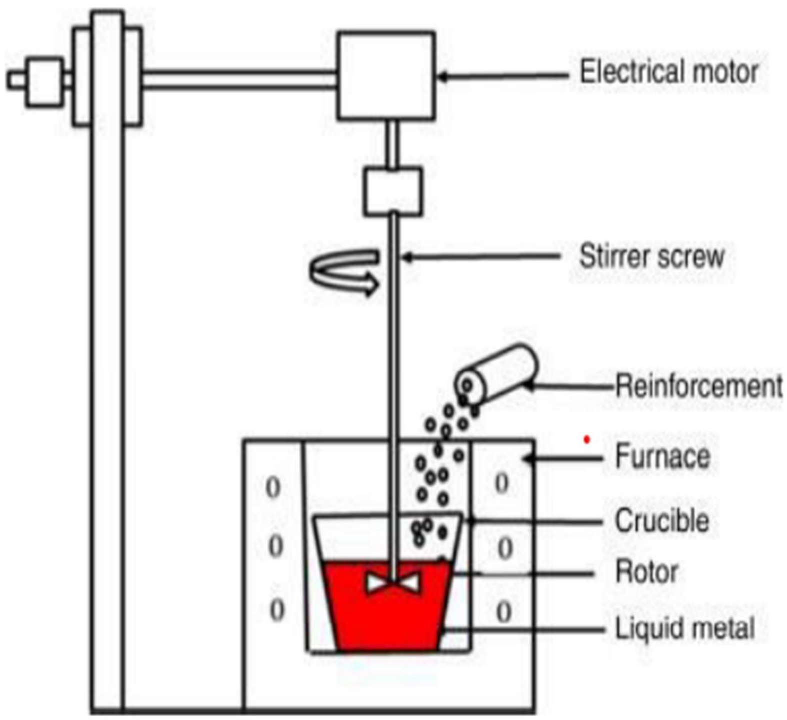

Figure 1: Stir Casting Process

C. Preparation Of Composite Material

(ZrO_2) were added to the melt after being warmed for an hour at 400°C. Degassing tablets (Hexachloroethane) were applied to the molten metal after it had completely melted to lessen the porosity. To stir the molten metal at a speed of 574 rpm, a stainless-steel stirrer was progressively dropped into the melt. Throughout the stirring period, warmed ZrO_2 particles of size 60 microns were continuously introduced to the molten metal. Even after the particle feeding was finished, the churning kept going for an additional five minutes. To achieve homogeneous solidification, the slurry was put into a mould that had similarly been warmed for 30 minutes at 500°C. ZrO_2 particle reinforced composites of 0.5, 1 and 1.5 percent by weight were produced using stir casting method.

D. Tensile Test For Composite Material

The tensile test is crucial in the selection of materials for engineering applications. The material's tensile strength provides information about its composition and behaviour under various loading circumstances.

The atoms in the substance lose their cohesive strength and separate when it is subjected to external loading. They return to their initial position once the load is released. This is referred to as Elastic deformation. And also, it is referred to as plastic deformation if the atoms are unable to separate and regain their original positions. The material goes through plastic deformation before it fractures. More plastic deformation of the ductile material will occur before the final fracture. The purpose of the tensile test is to evaluate how a material will behave mechanically under an axial pull at room temperature. These tests specifically aim to measure ultimate strength, percentage elongation, and reduction in area, yield strength, and tensile strength. According to ASTM E8M-09 standard, the zirconium dioxide with aluminium 6061 composite material used in this study, which is cut to dimensions of 350 mm in length, 115 mm in gauge length, and 20 mm in diameter. The specimen is then provided for tensile strength testing. Using a universal testing device, the composite's tensile strength reading was calculated.

Figure 2: Universal Testing Machine (UTM).

Figure 3: Vickers Hardness Testing Machine.

E. Hardness Test For Composite Material

Hardness is an attribute of a material, not its essential quality. Its definition is "resistance to indentation," and its measurement is the indentation's permanent depth. A form of optical testing called the Vickers hardness test is used to evaluate samples with coarse or irregularly shaped grains. The bulk or macro hardness of a material can best be determined using this test method, especially for materials with heterogeneous structures. The Vickers scale employs testing with a pyramid-shaped diamond with a square base. While "Macro" Vickers loads can be as heavy as 30 kg or more, most loads are quite low, weighing between 10gm and 1 kg-f is applied on the composite material for the precisely specified dwell time.

III. RESULT AND DISCUSSION

A. Tensile Test

Test specimen preparation:

1) The specimen is set up in accordance with ASTM Standard.
2) Cut the specimen with a power hacksaw, 20 mm diameter and 115 mm gauge length.
3) After cutting the knurling, the procedure is carried out using a lathe machine. Knurling has a gripping function.

Figure 4: Specimen for Tensile test.

Figure 5: Tensile tested Al6061 specimen

Figure 6: Tensile tested Al6061 + 0.5% ZrO_2 specimen

Figure 7: Tensile tested Al6061 + 1.0% ZrO2 specimen

Figure 8: Tensile tested Al6061 + 1.5% ZrO2 specimen

B. Result Graphs Of Tensile Test

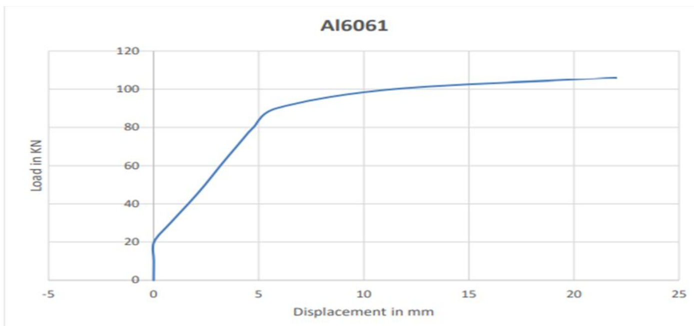

Figure 9: Result graph of Al6061 specimen

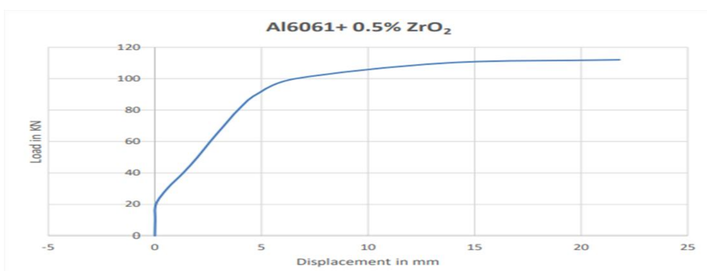

Figure 10: Result graph of Al6061+ 0.5% ZrO2 specimen

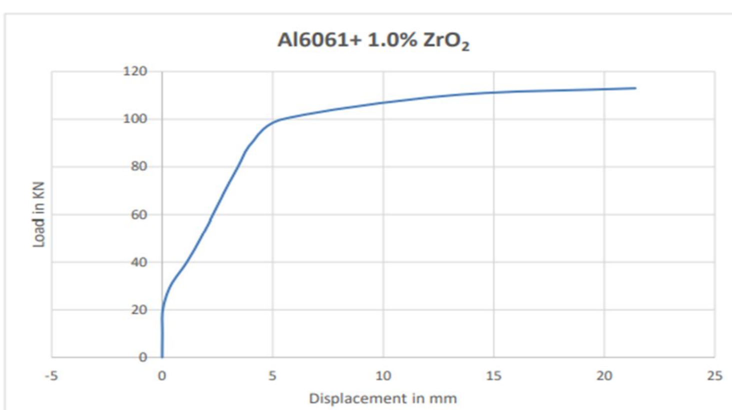

Figure 11: Result graph of Al6061+ 1.0% ZrO2 specimen

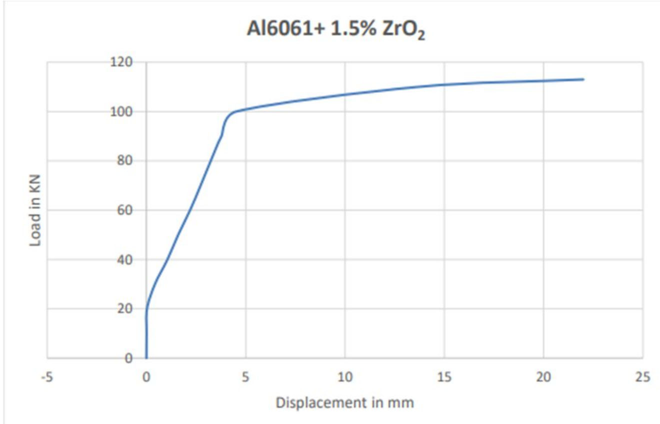

Figure 12: Result graph of Al6061+ 1.5% ZrO2 specimen

C. Result Table of Tensile Test

Table 1: Result table of Tensile Test

Sl No	Test Information	Al6061	Al6061+ 0.5% ZrO_2	Al6061+ 1.0% ZrO_2	Al6061+ 1.5% ZrO_2
01	Preload				
	Initial Parameter				
02	Gauge Length in mm	115	115	115	115
03	Diameter in mm	20	20	20	20
04	Area of c/s in mm^2	314.16	314.16	314.16	314.16
	Final parameters				
05	Gauge length in mm	134	135	137	140
06	Diameter in mm	15.7	15.42	15.30	15
07	Area of c/s in mm^2	193.59	186.75	183.85	176.71
08	Ultimate Load in KN	106	113	116	118
09	Ultimate Tensile Strength in KN/mm^2	0.3374	0.3597	0.3692	0.3756
10	Breaking Load in KN	100	100	100	100
11	Breaking Stress in KN/mm^2	0.3183	0.3183	0.3183	0.3183
12	Gauge Elongation in mm	19	20	22	25
13	Percentage Elongation	16.52	17.39	19.13	21.73
14	Percentage Area Reduction	38.38	40.55	41.48	43.75

D. Hardness test

1) The Vickers Hardness Tester consists of Diamond cone indenter.
2) Specimen size with Diameter of 20 mm and height of 10 mm.
3) The machine is provided with a Diamond cone indenter with pyramidal square base of 1360 apex angle to transmit test load on to the specimen.

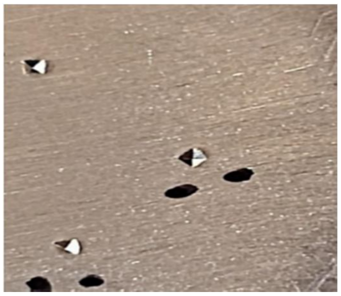

Figure 13: Diamond cone indentation

Figure 14: Hardness Tested Specimen

E. Result Table Of Hardness Test

Table 2: Result table of Hardness Test

Sl. No	Composite Sample	Load Applied (Kg)	Vickers Hardness Number (VHN) in Kg/mm^2			
			1	2	3	Average
1	Al6061	30	88.49	89.91	90.60	89.67
2	Al6061+ 0.5% ZrO_2	30	102.26	92.72	95.91	96.96
3	Al6061+ 1.0% ZrO_2	30	105.67	103.51	105.38	104.75
4	Al6061+ 1.5% ZrO_2	30	129.05	103.09	96.67	109.60

F. Result Graph of Hardness Test

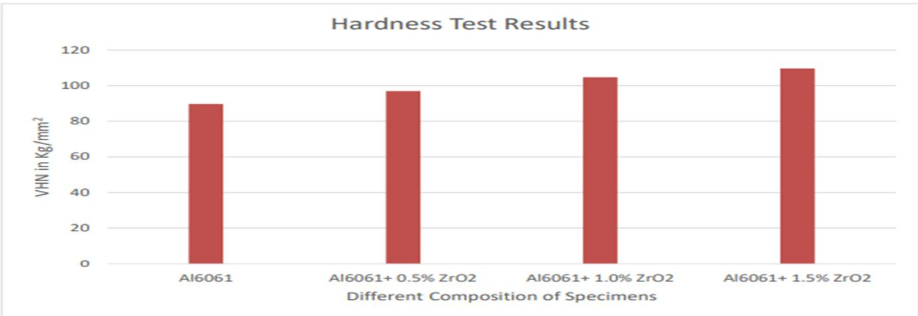

Figure 15: Result graph of Hardness Test

IV. CONCLUSION

The Al6061-ZrO_2 composites were fabricated using the stir casting technique by reinforcing ZrO_2 in varying 0.5 %, 1 % and 1.5 % zirconium dioxide. According to the microstructure analyses, 1% percent of the zirconia particles were distributed uniformly throughout the aluminium matrix. The Al6061-ZrO_2 composite's tensile strength values were found to be higher than those of the base metal Aluminium alloy, increased with the addition of ZrO_2 reinforcement up to 1.5 %, and then reduced. At 1.5 % zirconia content, UTS was at its highest value. The ZrO_2 reinforcement in the A16061 exhibits enhanced hardness.

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