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Evaluation and Experimental Investigation on A356.1 Aluminum Composite Reinforced with Zirconium Oxide Nano Metal Matrix Composites through Stir Casting technique

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ABSTRACT
Because of their durability, aluminum composites are employed in self-propelled industries. Despite their superior malleability and formability, high electrical and thermal conductivity, and low densities, aluminum alloys have several drawbacks when used in engineering appliances due to their strength and mechanical behavior. The preparation of nanoparticles by means of the combustion mixture method is presented in this paper. ZrO_2 nanoparticles are added to A356.1 aluminum alloy by stir casting at weight percentage ratios of 1.0, 2.0, 3.0, and 4.0% while the mixture is continuously stirred at 100 rpm. PXRD was used to characterize the produced nanoparticles, revealing their elemental compositions. Results from hardness testing with a Brinell hardness apparatus and tensile testing with a tensometer showed that the mechanical characterization of Nano Metal Matrix Composites (NMMCs) with 4.0 weight percentage is superior.
Keywords— NMMCs, Stir casting, PXRD, Hardness, UTS

1. Introduction

Metal is a necessary component of contemporary life these days. The most substantial metal known to man, aluminum is silver-white, soft, and non-magnetic. It makes up a significant portion of the earth's crust. Its use in composite materials, which have excellent mechanical properties like hardness and strength, is also very important. An interface separates two or more Nano, micro, or macro elements that differ in structure and chemical composition and are essentially insoluble in one another to form a composite material. There are two parts to it, matrix and reinforcement. The matrix is a continuous phase or component, while reinforcement is a discrete or discontinuous component. Based on the matrix constituents, composites are divided into three main groups: metal matrix composites (MMCs), ceramic matrix composites (CMCs), and polymer matrix composites (PMCs). MMCs with low weight, such as Al, Ti, and Mg, are widely utilized in MMCs. Composites are frequently utilized in businesses, the aerospace industry, and automobiles due to their mechanical and tribological properties. Aluminum's low density, high strength, stiffness, ductility, and affordability make it a crucial component of these composites. Recently, materials known as nanocomposite have been used as practical substitutes for micro- and monolithic-composites, but they also present preparation challenges related to the control of basic composition and stoichiometry in the nanocluster phase. Additionally, anon composites offer superior properties over

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monolithic materials. It is necessary for the reinforcement particles to be stiffer and stronger than the matrix material in order to achieve the desired strengthening effect. However, consideration must be given to the type, material, size, and volume amount of the reinforcements as well as their interactions with the matrix in order to achieve the desired results. Of all the ceramic reinforcements, carbides, borides, nitrides, and alumina (SiC, Al2O3, ZnO, Gr, and ZrO2) are the most appealing because of their high thermal stability. Composites made of aluminum exhibit the appropriate mechanical and physical properties, including high strength, hardness, and melting point. ZrO_2 is the most effective, affordable, and widely accessible low-density reinforcement when combined with various matrix dispersions.

2. Experimental Method or Methodology

The density of aluminum 356.1, which is 2.67 g/cm^3, was selected to be the matrix material. ZrO_2 Nano, which has a particle size of 30-50 nm and a density of 5.68 g/cm^3, was selected as the reinforcement material because of its wettability, reactivity, and density when combined with the matrix material. It displays extreme toughness, hardness, and strength.

2.1 Fabrication process

Tables 1 and 2 shows the chemical composition of A356.1 and ZrO_2

Table 1: A356.1 Chemical Composition

Element	**Al**	**Si**	**Mg**	**Fe**	**Cu**	**Zn**	**Ni**	**Mn**
Wt%	91.7	7.2	0.38	0.32	0.18	0.05	0.05	0.02

Table 2: ZrO_2 Chemical Composition

Element	**ZrO_2**	**SiO_2**	**TiO_2**	**FeO_3**	**Other**
Wt%	99.5	0.10	0.007	0.002	0.39

To fabricate the aluminum Nano metal matrix composite, stir casting was employed. Al 356.1 is measured to the required amount, placed in a graphite crucible, and heated in a melting furnace with electric resistance until the metal melts at 650°C.At that point, nano-sized ZrO_2 is added to the molten metal in weight percentage ratios of 1.0, 2.0, 3.0, and 4.0%. The mixture of matrix and reinforcement is continuously stirred for 20 minutes at a constant speed of 100 rpm using a ceramic-coated stirrer. Room temperature solidification was made possible by molten metal. Once the material has solidified, the materials were removed from die.

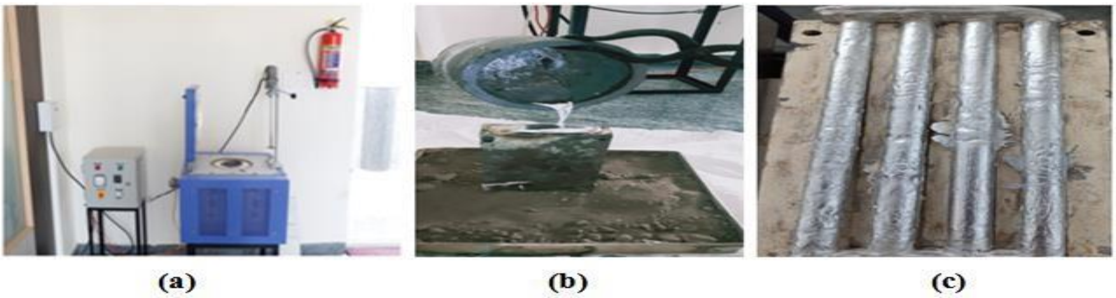
(a) (b) (c)

Fig 1: (a) Melting furnace with Stirrer (b) Pouring of molten metal in to die (c) Fabricated NMMCs

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3. Results and Discussions

3.1 Characterization PXRD

The X-ray diffraction was performed using the Powder X-ray diffraction system, which is equipped with a Rigaku Miniflex 600 model. The X-ray diffraction pattern, which also provides information on the crystal size, verifies that the Nano-ZrO_2 powder is in the crystalline phase. The measured and peak view are determined. With heights of peaks 8389, 3592, and 2282 of peaks 1, 2, and 3, respectively, and corresponding angles of 28.6°, 38.66°, and 44.91°, some notable peaks were established in this observation. Increased intensity of the recognizable peaks suggests a better crystalline life for the products. The fact that there are no peaks associated with impurities indicates that the final product is solely ZrO_2 Nano powder.

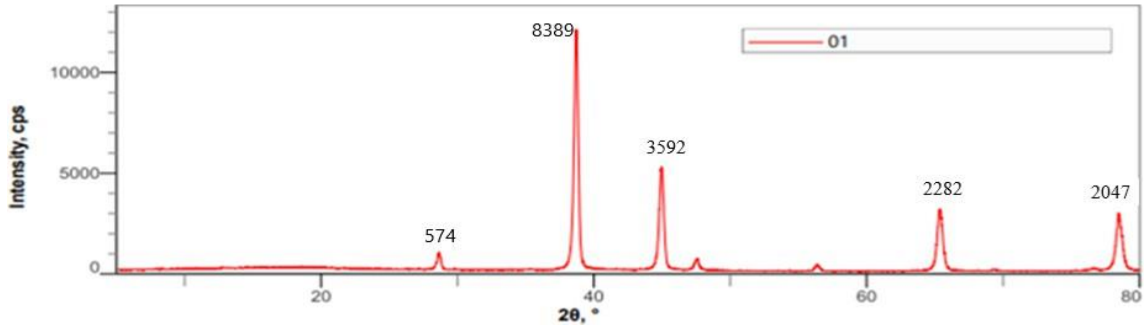

Fig 2: PXRD of ZrO_2

3.2 Hardness

The results of the Brinell hardness test, which was conducted on samples of NMMCs, showed that 4.0% matrix hardness rose as reinforcement increased. The results show that as the volume of reinforcement increases, the hardness increases significantly. 50.23BHN is the hardness as cast, and 71.23BHN is the hardness at 4.0% as shown in figure 3. This is mostly because of stronger ZrO2 nanoparticles, which provide a better constraint on localized deformation during indentation due to their smaller grain size and presence.

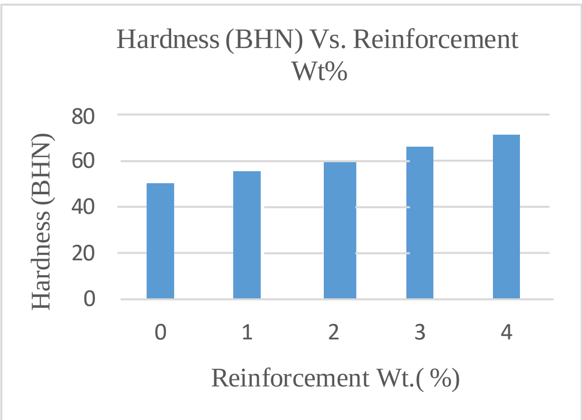

Fig 3: Hardness vs. Reinforcement wt. %

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3.3 Tensile Test

To conduct tensile tests on materials, a Tensometer with bench model MMT 2000, accuracy of ±0.05, and capacity of 20KN is utilized. It is sometimes referred to as a tensile testing machine or a universal testing machine (UTM). A mechanical test called tensile testing is used to gauge a material's strength, elasticity, ductility, and other characteristics. It is widely used in engineering, manufacturing, and material science to determine the behavior of materials under stress. Testing specimens mounted on a tensometer in compliance with ASTM E8 are shown in Figure 5. The specimen's ultimate tensile strength of roughly 337.54 MPa was recorded.

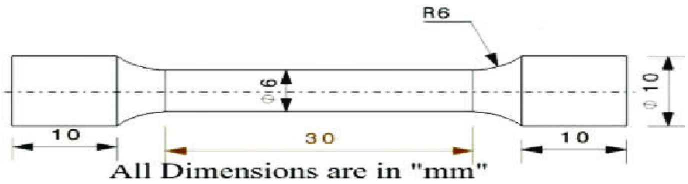

Fig 4: Specimen Dimensions

Fig 5: Specimens after test

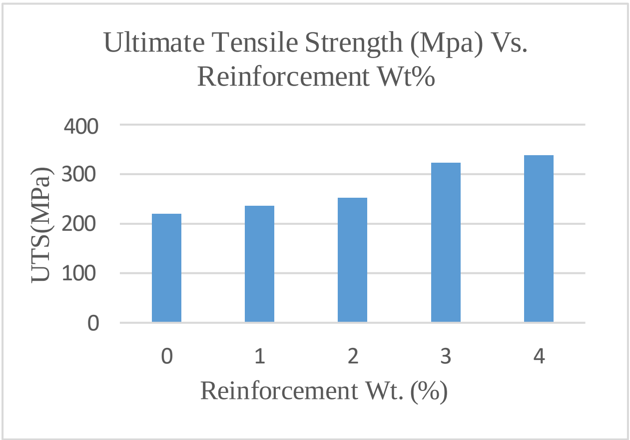

Fig 6: UTS vs. Reinforcement Wt. %

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Figure 6 illustrates the change in tensile strength with weight percentage of ZrO_2 nanoparticle reinforcement. The lowest tensile strength for cast specimens, 215MPa, increases as the percentage of reinforcement weight increases. The ultimate tensile strength at a 4.0% weight ratio is approximately 337.54MPa

Conclusion

Stir casting at a constant 100 rpm stirring speed was used to successfully fabricate A 356.1 reinforced with ZrO_2 nanoparticles. Random distribution of the reinforcement was done across the matrix. Conversely, composites with a high ZrO_2 content displayed indications of particle agglomeration. Stir casting is the most effective technique for producing these types of composites. PXRD provided information on the composition of ZrO_2-reinforced A356.1. The results showed that the mechanical properties of Aluminum 356.1 reinforced with ZrO_2 (1.0%, 2.0%, 3.0%, and 4.0%) were improved by the presence of reinforcement in the matrix. This is due to the fact that reinforcement fortifies the composites, raising their hardness and tensile strength. The hardness and tensile strength increased at a weight percentage of 4.0 when compared to the cast alloy.

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