THE EFFECT OF VARIOUS CERAMIC REINFORCEMENTS ON AA 7075 IN ITS MICROSTRUCTURE AND MECHANICAL PROPERTIES

Abstract

Metal matrix composites (MMCs) made of aluminium have drawn a lot of attention because of its advantageous combination of lightweight, high strength, and improved mechanical qualities. The objective of this study is to examine the microstructure and mechanical characteristics of an alloy of aluminium 7075 reinforced with titanium dioxide (TiO_2), zirconium dioxide (ZrO_2), and alumina (Al_2O_3). The composite specimens were created using the stir casting technique, and they were then thoroughly characterized using SEM, X-ray diffraction, and mechanical testing. The findings help in the development of cutting-edge lightweight materials for a variety of technical applications by revealing how different reinforcements affect the microstructural evolution and mechanical performance of Al 7075 alloy.

Keywords: Stir casting; XRD; Micro hardness; Microstructure

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I. INTRODUCTION

The mechanical characteristics of metal matrix composites based on aluminium have been successfully improved by including reinforcing ceramic particles. Due to its distinctive combination of lightweight characteristics and improved mechanical performance, Aluminium Matrix Composites (AMCs) are a class of innovative materials that have attracted a lot of attention recently. AMCs are made of an aluminium alloy matrix that has been strengthened by high-strength ceramic, metallic, or carbon-based elements. These reinforcements' inclusion gives the composites remarkable mechanical, thermal, and physical qualities, making them highly sought-after for a range of industrial applications. AMC research and development has been sparked by the rising need for lightweight, high-performance materials in sectors like aerospace, automotive, defence, and sporting goods. In comparison to traditional materials, these composites have better specific strength, stiffness; wear resistance, thermal conductivity, and damping characteristics. Additionally, AMCs have features that can be tuned to fit certain application needs. AMCs have a wide range of applications in the fields of aerospace, automotive, marine, electronics, sports equipment, and many more. Due of their lightweight and high specific strength, AMCs are used in the aerospace industry for satellite structures, engine parts, and structural elements of aircraft. AMCs are used in the automobile industry for lightweight cylinder liners, braking discs, engine pistons, and structural components, which improves fuel economy and lowers emissions. AMCs are used in electronic packaging as well because of their improved device dependability and heat dissipation capabilities. Overall, AMCs represent a promising class of materials with exceptional mechanical, thermal, and physical properties. The continuous research and development in the field of AMCs aim to further enhance their performance, expand their range of applications, and meet the evolving demands of various industries. Al 7075, known for its high strength-to-weight ratio, is an ideal choice for composite fabrication. This preliminary study focuses on investigating the effects of three different ceramic reinforcements, TiO_2, ZrO_2, and Al_2O_3, on the microstructure and mechanical properties of Al 7075 MMCs using the stir casting technique.

II. EXPERIMENTAL WORK

Its excellent combination of high strength, lightweight, and corrosion resistance drive the selection of Al 7075 as the base metal for a research paper. Al 7075 is a popular choice in various industries, including aerospace and automotive, due to its remarkable strength-to-weight ratio, making it suitable for applications where weight reduction is critical without compromising mechanical integrity. Its exceptional corrosion resistance ensures long-term durability in challenging environments. Furthermore, Al 7075 is readily available and cost-effective, making it a practical choice for studying the effects of different reinforcements or manufacturing techniques on the microstructure and mechanical properties of composite materials. In aerospace applications, Al7075 is extensively used for manufacturing aircraft structural components, such as fuselage frames, wing spars, and landing gear parts, due to its high strength and lightweight characteristics. Its resistance to fatigue and stress corrosion cracking also contribute to its suitability for demanding aerospace environments. In the automotive industry, Al7075 finds application in engine components, suspension systems, and wheels, where its strength and lightness play a vital role in improving fuel efficiency and overall vehicle performance. Additionally, its corrosion resistance ensures longevity in various weather and road conditions. Overall, the selection of Al7075 as the matrix material

for the paperwork provides a practical and relevant basis for studying the performance and potential advancements in metal matrix composites, contributing to the development of lightweight, high-strength materials for a wide range of engineering applications. Al7075 is also utilized in marine applications, such as boat structures and marine equipment, owing to its resistance to seawater corrosion. Its lightweight nature contributes to fuel savings and ease of handling making it a practical choice for studying the effects of different reinforcements or manufacturing techniques on the microstructure and mechanical properties of composite materials. The chemical composition of Al 7075 alloy in weight % is shown in Table.1.

Table.1 The chemical composition of Al 7075 in weight percentage

Al 7075	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Wt.%	0.039	0.18	1.37	0.036	2.54	0.2	5.71	0.054	Bal.

The selection of ceramic materials, such as Al_2O_3, ZrO_2, and TiO_2, for a research paper, is driven by their unique properties and suitability for specific applications. Al_2O_3, known for its high hardness and excellent wear resistance, is commonly chosen for applications requiring abrasive wear resistance. ZrO_2, with its exceptional fracture toughness and resistance to thermal shock, is suitable for applications demanding high mechanical strength and thermal stability. TiO_2, on the other hand, offers advantageous properties like high refractoriness, chemical stability, and photocatalytic activity, making it suitable for applications involving high temperatures and light-induced reactions. The selection of these materials allows for the investigation of their individual effects on the microstructure and mechanical properties of the composite, contributing to the understanding and advancement of ceramic-reinforced composites. As received reinforcement materials is shown in Fig.1.

Figure 1: As received reinforced materials

Stir casting equipment was used for preparing samples is shown in Figure 2. Table 2 shows the various weight percentages of Al 7075 and reinforcements.

Figure 2: Stir Casting Equipment**.**

Table 2: Composite Preparation with various weight percentages

Samples	Al 7075	Al_2O_3	TiO_2	ZrO_2
Sample 1	100%	-	-	-
Sample 2	95%	5%	-	-
Sample 3	90%	5%	5%	-
Sample 4	90%	5%	-	5%
Sample 5	85%	5%	5%	5%

In this table a rod and reinforcement material are separated by weight percentage 5% are separated with weight percentage. The Al7075 MMCs were fabricated through the stir casting process, involving the melting of Al7075 alloy followed by the addition of preheated ceramic particles. The composite samples were then cast into preheated molds and subjected to control cooling. The resulting specimens were subsequently analyzed using SEM and XRD techniques to examine the microstructural characteristics and phase composition. Fig.3 shows the rods before casting is separated by the weight percentages.

Stir casting is a manufacturing process in which reinforcement materials, such as ceramic particles or fibers, are mixed into a molten metal matrix. The mixture is stirred to ensure a uniform distribution of the reinforcement materials within the matrix. The resulting composite material exhibits improved mechanical properties compared to pure metal, making it suitable for applications requiring enhanced strength, stiffness, or other specific characteristics.

In the stir-casting process, the Al7075 matrix material is melted at temperatures between 650°C and 750°C for approximately one hour. Meanwhile, the reinforcement materials, such as Al_2O_3, TiO_2, and ZrO_2, are prepared in the form of particles and preheated at 200°C for 25 minutes. The preheated reinforcements are gradually added to the molten matrix material at 750°C while stirring at 300 RPM for 15 minutes. The resulting mixture is then poured into preheated molds and allowed to cool and solidify. The molds are preheated at 200°C for 30 minutes to remove moisture particles. This process leads to the formation of a solid composite with a uniform distribution of reinforcement particles within the matrix material. The resulting composite can exhibit enhanced mechanical properties compared to the pure matrix material, making it suitable for various applications. The total cost of this project is Rs 60,000.
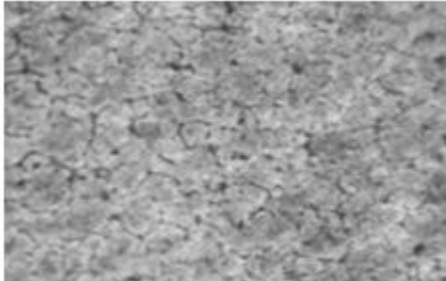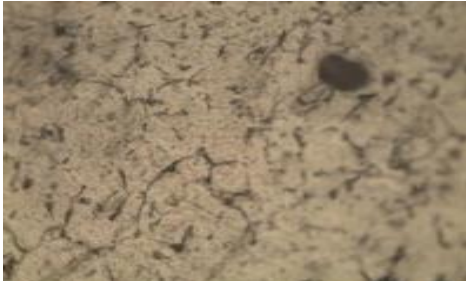

Figure 3: Before the casting process the rod is separated by weight percentages

III. RESULT AND ANALYSIS

1. **Characterization Analysis:** The process of preparing and analyzing the samples involves several steps. The samples were cut to a length of 4 cm using a wire-cutting machine (EDM). This ensures that the samples have the desired dimensions for further analysis. The cut samples undergo polishing using a grinding machine. The purpose is to achieve a mirror-like polish on the surface of the samples. The samples are polished at an RPM of 504 to ensure consistency. To capture the microstructure of the samples, an HN solution (Distilled water 95 ml, Nitric acid 2.5 ml, Hydrochloric acid 1.5 ml and Hydrofluoric acid 1.0 ml) is prepared The samples are then immersed in the HN solution for 45 seconds. This process allows for the selective removal of material, revealing the microstructural features of interest. After the microstructure analysis, the samples are cut again using the wire-cutting machine (EDM) to a size of 4 cm. This is done in preparation for the micro hardness testing. The polished samples undergo micro hardness testing. A load of 0.981 N is applied to study the micro hardness of the samples.

This test provides information about the material's resistance to indentation or deformation. Finally, the samples are cut into square-shaped dimensions of $10\times10\times10$ mm using the wire-cutting machine (EDM). This step is performed in preparation for XRD (X-Ray Diffraction) analysis. X-rays are passed through the specimen and diffracted by the atoms, providing information about the samples' crystallographic structure and phase composition. These sequential steps ensure the proper preparation and analysis of the samples, allowing for the examination of their microstructural characteristics, micro hardness, and crystallographic properties.

2. **Microstructural Analysis:** SEM analysis provides valuable insights into the dispersion, interfacial bonding, and distribution of the ceramic reinforcements within the Al7075 matrix. It enables the observation of particle-matrix interactions, such as particle agglomeration, interfacial bonding quality, and the presence of any voids or defects. The microstructural analysis aims to assess the uniformity and integrity of the composite microstructure. Scanning Electron images of prepared composite samples with various magnifications is shown in Fig. 4. From this figures, ceramic reinforcements were uniformly distributed in metal matrix composites. In high magnification, pores sizes increased and mechanical properties increased due to strengthening mechanisms.

| Samples	20 X Magnification	50 X Magnification
Al 7075		
Al7075+ Al$_2$O$_3$		
Al7075+ Al$_2$O$_3$+TiO$_2$		
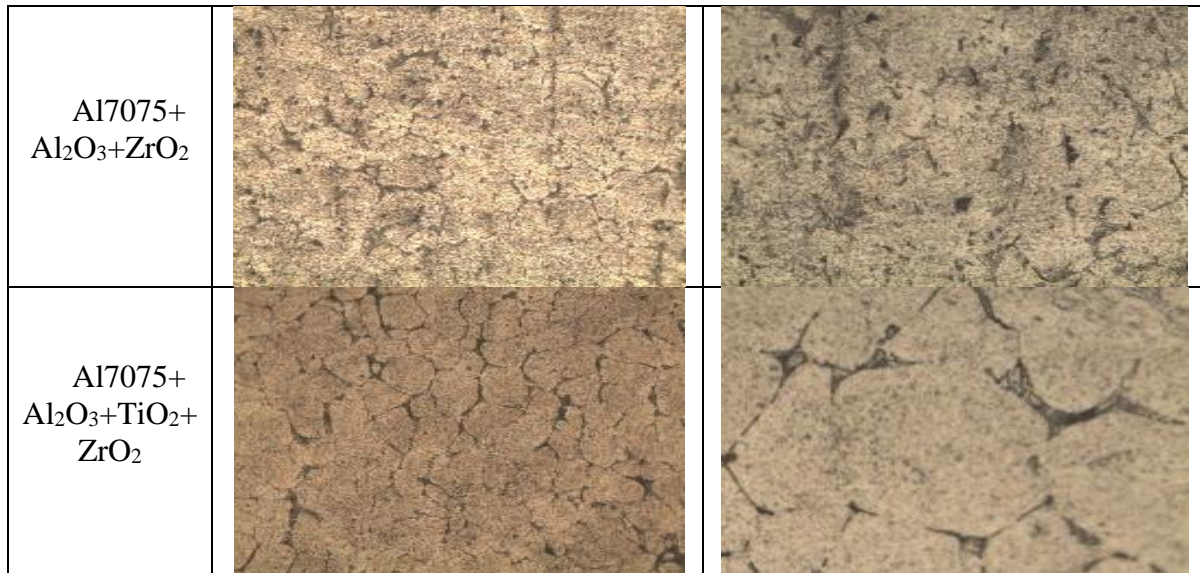
Figure 4: Scanning Electron Microscope Images of prepared samples

3. **X-Ray Diffraction Analysis:** The X-ray diffraction analysis of stir-cast Al 7075 composites has yielded significant findings. The XRD images of five prepared samples are shown in Fig.5. The presence of first five peaks corresponds to aluminium base metals. Other additional peaks in the diffraction pattern corresponds to the reinforcing particles that have been successfully incorporated into the aluminum matrix. These ceramic particles are dissolved in the base metal due to their low content. This observation confirms the effective integration of the reinforcement material within the composite. This X-ray diffraction analysis provides essential evidence for the successful incorporation of the reinforcement material and contributes to a better understanding of the overall crystallographic properties of the Al 7075 composite.
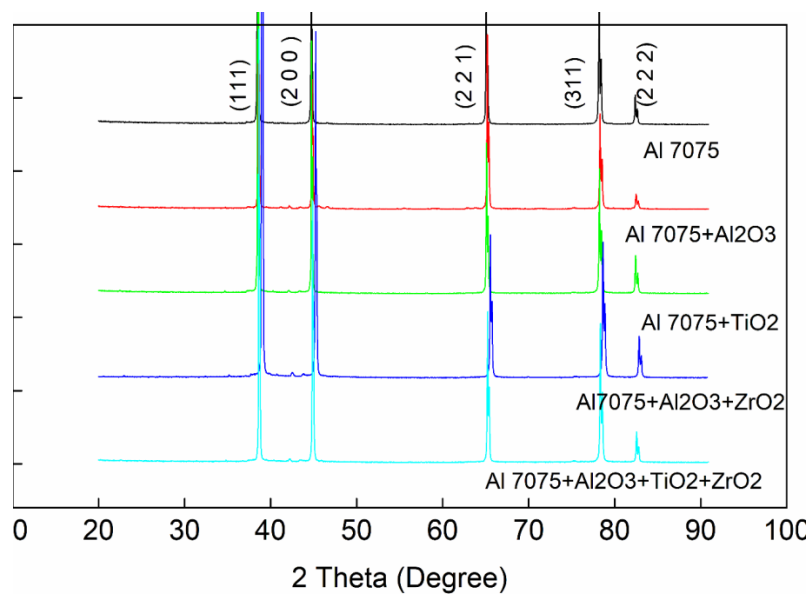
Figure 5: XRD Images for prepared composites

4. **Micro Hardness Analysis:** To compare the micro hardness of five different samples, it was observed that the sample 5 exhibited an increasing trend in micro hardness compared to the other samples. Micro hardness values are shown in Fig.6. The addition of ceramic reinforcements gave improvement in hardness. Al $7075+Al_2O_3+TiO_2+ZrO_2$ composite has reached 56 $HV_{0.5}$ due to more ceramic addition to parent metal.
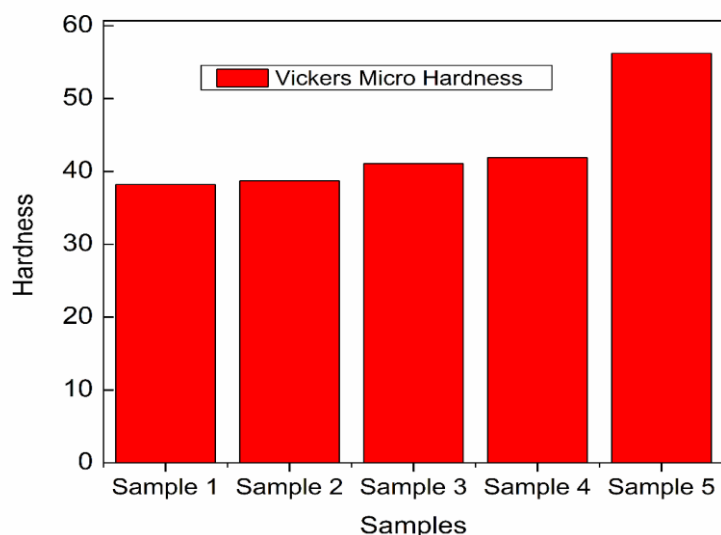
Figure 6: Vickers Micro hardness Values for prepared composites

IV. CONCLUSION

The application of the stir casting technique to produce Al 7075 alloy composites has yielded positive results in terms of micro hardness, X-ray diffraction (XRD) analysis, and microstructure evaluation. The successful incorporation of reinforcing particles into the aluminum matrix was confirmed through the presence of small additional peaks in the XRD patterns, indicating a promising integration of the reinforcement material. However, it is important to highlight that further research and optimization of the stir-casting process parameters are necessary to fully maximize the potential benefits and tailor the properties of Al7075 stir-cast composites to specific application requirements. This optimization process may involve variations in stirring parameters, such as stirring speed and time, as well as the selection and incorporation of different types and percentages of reinforcement materials. By addressing these aspects, further advancements can be made in enhancing the properties and performance of Al7075 stir-cast composites, opening up new possibilities for their utilization in various applications.

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