Fabrication and Characterization of Aluminum 8011 Alloy and nano Zro₂ Metal Matrix Composite

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Abstract: Composites of nano metal matrix produced by stir casting technology have major attractive properties like high ductility, highly conductivity, light weight, and high strength to weight ratio compared to some other approaches. Nano Zro₂ particulates with varying weight percentages (2, 4 and 6%) are reinforced with aluminium 8011 using the process of stir casting. Mechanical properties such as tensile, compression and hardness behavior have been investigated. In the current analysis, scanning electron microscopy (SEM) is carried out to show Nano Zro₂ particulates are successfully incorporated into the matrix of aluminium 8011 with homogeneous distribution. The findings showed that improved mechanical properties such as tensile strength, compression strength and hardness, were enhanced by increasing weight percentage of Nano Zro₂ particulates in the matrix of aluminium 8011.

I. INTRODUCTION
The demand for materials with a high strength to weight ratio in the aerospace and automotive industries is contributing to the production of innovative new materials. The combination of two or more creates this new material with matrix and reinforcement [1]. Aluminum Metal-Matrix Composites (MMCs) are an important class of engineering materials of extreme promise because of their comparatively stronger physical and mechanical properties, aluminium MMCs are potential materials for various applications with the inclusion of sufficient reinforcements [2-3], properties such as wear, hardness, creep, specific strength and fatigue can be increased relative to conventional engineering materials. The alloy of aluminium 8011 has a rare mix of desirable features, such as its low weight, corrosion resistance and simple final product maintenance. The matrix content of aluminium 8011 has a low density, non-toxic content and high thermal conductivity [4-6]. For the past 30 years, nano material-reinforced composites have been widely favored in the automotive and aerospace industries in terms of wear resistance, damping properties and mechanical strength [7], Aluminium reinforced with Nano ZrO₂ Composite was developed effectively by means of the casting process. The nano particles dispersion in aluminium matrix will strengthen the base metal [8].
II. LITERATURE REVIEW

With the assistance of stir casting process, the proposed experimental research on titanium carbide (TiC) and red mud is reinforced with aluminium 7075 at 3, 6, 9 and 12 percent by weight. In which, the mechanical properties are tested and compared with considering yield strength, ultimate tensile strength and micro hardness. It is observed that 48% improvement in the ultimate tensile strength compared to base metal has been investigated in [1]. The authors in [2] reviewed on the stir casting process with considering how base metal is liquefied. The analysis is carried out at different temperature ranges with maintained state, particles condition, mixing time and mixing speed. The mixing speed of final composite material is significantly affected on the electrical resistance furnace than the fired coke furnaces. The electric stir casting process used to fabricate Aluminium/Nano Sic composite [3]. Mechanical properties such as tensile strength, micro-hardness and wear behavior have been studied. The findings revealed that nano-silicon carbide (SIC) powder incorporation increases the wear resistance of nano-aluminum composites and enhances mechanical properties such as stiffness and tensile strength. The Aluminum 7075 alloy reinforced with boron carbide with different weight percentage by stir casting technique reveals in [4] shows increased Yield strength and Ultimate tensile strength by increasing boron carbide weight percentage. It is explicitly observed that the percentage of boron carbide increases, the wear rate decreases.

A study conducted in [5] on latest developments and techniques used in preparing particulate metal matrix composites using friction stir process. This study reveals that friction stir processing has been shown to be an environmentally sustainable solid-state extreme plastic deformation process with reduced carbon footprint, reasonably energy-efficient for fine-grained structure surface and bulk composites processing. The method of stir-casting [6] is used to process the different particle sizes of SiC (63, 76, 89) μm is conjugated with aluminium 8011. The conjugation was made with 2 and 4 weight percentage. The findings show that with the rise in the weight fraction of SiC, the stiffness, yield strength and tensile strength increase, while the resilience and ductility decrease. A review on Metal Matrix Composites Strengthened by Nano-Particles in [7] shows the most important processing methods used for the synthesis of bulk metal matrix nano composites. Impressive results have been obtained in terms of hardness, mechanical efficiency, wear resistance, creep activity and damping properties. Experimental and FEM work on Aluminium 8011 alloy reinforced with Fly-Ash and E-Glass fiber composite prepared by stir casting was discussed in [8]. The results show that the ultimate tensile strength and compression strength of the hybrid composites are improved in comparison with base Aluminum 8011 alloy. The characterization of aluminum 6061 and nano zirconia as a reinforcement was conducted in [9] with different weight percentages. The present work focuses on mechanical characterization through different weight percentages of reinforcement by tensile test, hardness test and compression test. The results reveal that ultimate tensile strength, compression strength and hardness increased with increasing weight percentage of nano zirconia. The Review in [10] summarizes the effect of processing techniques, types of reinforcement on the mechanical properties of aluminum metal matrix composites. The more emphasis was given to tribological properties. Stir casting, high-pressure torsion, and powder metallurgical methods. The study in [11] on impact of temperature on the dry sliding wear behavior of 7075 aluminum with ZrB2 particulates at 0, 3, 6, 9 and 12 wt.%. The wear resistance of the produced composites is improved with the increased substance of ZrB2 particulates at all test temperatures. Mechanical Characterization of Ceramic Nano B4C and Aluminum 2618 Alloy Composites in [12] validate the homogenous distribution of nano B4C particles in the matrix of aluminum. It was noted that the tensile strength (ultimate strength and yield strength) and compression strength increased with the addition of 6 wt% nano B4C particles. In the research work [13] characterization and wear Behavior of Aluminum 2014-ZrO2 Nano- composites are studied. From the investigation, it was observed that the tensile behavior of composites was enhanced due to addition of nano-sized ZrO2 particles in the Aluminum 2014 alloy matrix. The Enhancement of mechanical and tribological properties of SiC and Carbon black reinforced aluminum 7075 hybrid composites [14]. The study demonstrates the novel feature that 2.5 times increment in the ultimate tensile strength and significant improvement in wearing resistance.
III. OBJECTIVES

1. Material Selection: Aluminium 8011 alloy was used as the base matrix material and Nano ZrO₂ particulates as reinforcement.
2. Fabrication of Aluminium 8011 and Nano ZrO₂ composite with different weight percentages (2, 4 and 6 %) by stir casting.
3. To prepare specimens for tensile test, compression test and micro hardness test according to ASTM standards.
4. To conduct scanning electron microscopy to study the distribution of Nano ZrO₂ particulates in the matrix of Aluminium 8011.

IV METHODOLOGY
The detailed methodology used for the manufacturing of composite materials as shown in figure below

- Selection of Matrix and reinforcement material
- Preparation of Composite by stir casting
- Specimen preparation according to ASTM standards
- Experimentation
- Results and discussion
- Conclusion

Fig.1: Detail experimental procedure for composite material preparation

V EXPERIMENTAL PROCEDURE
A. Selection of materials
Matrix: Aluminum 8011 was used as a strong machinability matrix material. In both ordinary ambient and marine environments, it exhibits excellent corrosion resistance. Aluminum for aerospace, spacecraft and maritime applications has a high strength-to-low weight ratio.

| Chemical Composition of Aluminum 8011 by weight percentage |
|-----------------|---|---|---|---|---|---|---|---|---|
|                | Si | Fe | Cu | Mn | Mg | Cr | Zn | Ti | Al |
| Aluminum 8011  | 0.50 | 0.60 | 4.35 | 0.6 | 1.5 | 0.1 | 0.25 | 0.15 | Remaining |

Reinforcement: Zirconium oxide nano particles (ZrO₂) are a technologically significant substance with strong natural color, high strength, resistance to transformation, high chemical stability, outstanding resistance to corrosion and chemical and microbial resistance. In the form of nano dots, nano fluids and nano particulates, zirconium oxide nano particles (ZrO₂) are available.

Zirconium Oxide Nano Powder Specifications
Molecular Formula: ZrO₂
Molecular Density: 5.89 g/cm³
Appearance: White
Particle Size: 30 NM

Table 2: Chemical composition of nano ZrO₂ by weight percentage

| PARAMETERS | SPECIFICATIONS |
|------------|----------------|
| ZrO₂       | 99.9%          |
| Al         | <0.06%         |
| Fe         | <0.02%         |
| Pb         | <0.02%         |

B. Manufacturing of composite materials

By stir casting technique, composites are prepared. In the electric resistance furnace, the base metal aluminum 8011 is then heated and melted in a crucible at a temperature of 750°C. In the molten metal bath, the stirrer was immersed and the stirrer rotates at a speed of 100 to 300 rpm to create vortexes in the liquid metal. Preheated nano particles of zirconium oxide (ZrO₂) are applied from the side of the vortex to the molten metal. The stirrer was continued for 5 minutes after completion of the addition of nano ZrO₂ and pour molten metal mixture into the necessary mould cavity. After casting, aluminium 8011 metal matrix with zirconium oxide nano particles (ZrO₂) composite materials have been obtained as seen in the figures below.

V. RESULTS AND DISCUSSION

A. Tensile test: The tensile strength of the various formulations is measured using a 5 tone size servo-hydraulic universal test unit. Test samples were held in parallel with the applied load. The experiments
carried out were carried out in compliance with the ASTM E8-82 guidelines and the findings obtained from this test are shown in Table 3.

![Specimens after the tensile test](image1)

![Specimens after the tensile test](image2)

**Fig. 7: Specimens after the tensile test**

**Fig. 8: Specimens after the tensile test**

| Specimen | Peak load in KN | % of elongation | Tensile strength in N/mm² |
|----------|-----------------|-----------------|--------------------------|
| Test 1   | 2%              | 13.230          | 14.62                    | 110.981                   |
| Test 2   | 4%              | 13.350          | 24.16                    | 115.714                   |
| Test 3   | 6%              | 12.100          | 19.82                    | 116.089                   |

**Table 3: Tensile test results**

![Graph showing variations of Tensile strength v/s weight percentage of Nano Zro2](image3)

**Fig. 9: variations of Tensile strength v/s weight percentage of nano zro₂**

**B. Compression test:** The compression test was carried out using a 5 tonne universal test machine capability and is carried out on 22 mm long machined and 13 mm diameter cast composites. Initially, the loads are added steadily and the resulting strains of the following composites, as seen in Table 4, are determined before the failure of the specimen. The related experiments are carried out at room temperature, according to ASTM E9.
Table 4: Compression test results

| SPECIMEN | Load at peak in KN | Elongation at peak in mm | Compression strength in N/mm² |
|----------|--------------------|--------------------------|-----------------------------|
| Test 1   | 2%                 | 187.446                  | 17.790                      | 586.945                     |
| Test 2   | 4%                 | 187.728                  | 20.870                      | 598.454                     |
| Test 3   | 6%                 | 210.306                  | 19.650                      | 657.536                     |

Fig. 10: specimen prepared for compression test
Fig. 11: Specimens after compression test

Fig. 12: variations of compression strength v/s weight percentage of nano ZrO₂

C. Vickers Hardness Test: In this work a hardness test is conducted to detect the tolerance of the plastic deformation of the composites under static or dynamic loads. Micro Vickers Hardness Test is selected to determine the hardness of the specimen. In this test, the indenter has a diameter of 5 mm shall be tested by adding a load of 0.5 kg on each specimen for 20 seconds. The related test parameters are shown in Table 5.
| Composition                  | Ball diameter in mm | Applied load in kg | Average diameter of indentation | VHN |
|-----------------------------|---------------------|--------------------|--------------------------------|-----|
| Aluminium 8011-2wt% Nano ZrO2 | 5                   | 0.5                | 2.620                           | 38.6|
| Aluminium 8011-4wt% Nano ZrO2 | 5                   | 0.5                | 2.750                           | 40.0|
| Aluminium 8011-6wt% Nano ZrO2 | 5                   | 0.5                | 2.745                           | 42.2|

Fig. 13: variations of Hardness number v/s weight percentage of nano zro₂

**D. Microscopy:** The dispersion of reinforcements in the MMC was measured using optical microscopy and reveals the microstructure of the MMC with 2, 4 and 6 percent percentages of particulate reinforcements. Reinforcement marks are indicated by the arrow marks on the diagram. The SEM images show that the distributions of zirconium oxide nano particles (ZrO₂) are even and competitive with Aluminum 8011. The study showed that a much lower porosity was observed in zirconium oxide nanoparticles (ZrO₂) with Aluminum 8011.

![Microstructure](image)

Microstructure consists of interdendritic precipitates in a matrix of Aluminium solid solution.

Fig 14: Microstructure of Aluminum 8011 - 2 wt % nano zro₂
VI. CONCLUSION

Based on the study conducted on aluminium 8011 and Nano ZrO$_2$ Composite the following conclusions are made:
1) Using stir casting method Nano ZrO$_2$ particulates can be successfully introduced in the aluminium 8011 alloy matrix to fabricate composite material.
2) The maximum tensile strength was observed with aluminium 8011 + 6 wt% Nano ZrO$_2$ is 116.089 N/mm$^2$.
3) Highest compression strength was observed with aluminium 8011 + 6 wt% Nano ZrO$_2$ is 657.536 N/mm$^2$.
4) By increasing the reinforcement percentage better hardness properties are obtained.
5) The microscopic images have been revealed that uniform distribution of Nano ZrO$_2$ in aluminium 8011 with inter dendritic precipitation.

Fig 15: Microstructure of Aluminum 8011 - 4 wt % nano zro$_2$

Fig 16: Microstructure of Aluminum 8011 – 6 wt % nano zro$_2$
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