Vol. 02, Iss. 4 (2024) 267-272, DOI: 10.61552/JME.2024.04.004

JME

Journal of Materials and Engineering

www.jme.aspur.rs

Research article

# Microstructural Evaluation of Al-$Al_2O_3$ Composites Processed by Stir Casting Technique

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Keywords:

*MMC*
*A356*
*$Al_2O_3$*
*Stir casting*
*Microstructural studies*

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*Received: 26 March 2024*
*Revised: 28 April 2024*
*Accepted: 20 May 2024*



A B S T R A C T

*The exceptional qualities of aluminum alloys, including their superior thermal properties, high specific strength and low density make them widely employed as industrial materials. By adding a tougher ceramic reinforcement phase to the aluminum matrix phase, aluminum alloy components can perform even better with improved mechanical properties. It has been discovered that the liquid state processing method is the most affordable and straightforward for processing MMCs out of all the existing ways. Primary processing, such as casting composite materials has its own restrictions on agglomerate formation and porosity. A metal matrix composite made of aluminum and aluminum oxide ($Al_2O_3$) has been chosen for the current investigation based on the literature review. A composite material including aluminum A356 and different percentages of $Al_2O_3$ (3%, 6%, 9%, and 12%) particles of 23µm size is chosen for the study. Using the SEM and EDAX test, the impact of these materials on the microstructural investigations is being investigated and the results indicates that uniform distribution of the reinforcement is difficult to achieve at higher percentages.*



## 1. INTRODUCTION

Various steel alloys have been used in industries for a long time because of their superior strength, durability, and thermal characteristics. Nonetheless, many technical applications require materials with appropriate strength and thermal qualities that have a lower density. One such material is aluminum alloy, which has better corrosion resistance and a lower density than structural steels [1].

Ceramic materials such as SiC, $Al_2O_3$ can be added to aluminum for further improvement in its properties such as hardness, tensile strength, and coefficient of thermal expansion. Composite materials are such combinations of materials that are specifically designed to accomplish the required mechanical, structural, and physical properties. A composite system is made up of materials from two distinct groups that are isolated from one another by interfaces and have diverse physical and chemical properties. A continuous phase (called the matrix phase) is embedded in one or more discontinuous phases (called the reinforcing phases) to form composite materials [2].

Matrix materials like titanium, magnesium or aluminum are light weight and gives the reinforcement a compliant support. The reinforcement can be discontinuous or continuous, providing the necessary variations in enhancing the ability to perform better. MMC are materials of this type in which the reinforcing phase improves the characteristics of the metallic matrix phase [3].

MMC can be processed in a variety of ways, both in liquid and solid states. The liquid state processing method, also known as stir casting, is thought to be the most cost-effective way to prepare metal matrix composite material. When making MMCs using liquid state processing, reinforcement is mixed with the molten metal matrix and allowed to solidify to form an appropriate shape. Normal flaws in MMC materials are porosity, blow holes and uneven grain structure [4].

## 2. LITERATURE REVIEW

Composite materials are replacing traditional engineering materials because of their advantages over homogeneous materials, which can include metal, polymer, or ceramic matrices that are reinforced with fibers, whiskers, or particles. Figure 1 shows several types of reinforcing based on their geometry. In contrast to traditional materials, a matrix is a monolithic material into which reinforcements are placed to improve properties such as specific strength, wear, stiffness, creep, and fatigue properties [5].

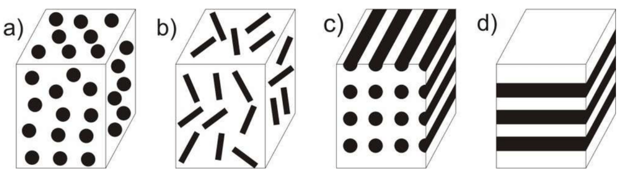

**Fig. 1.** Types of reinforcements [6]

MMCs are becoming more and more common in many contemporary industrial applications due to their advantageous qualities which may be customized to meet specific needs. Numerous studies have been conducted to assess the performance characteristics of MMCs under various processing and operating settings as their properties are reliant on numerous parameters.

By carefully choosing the matrix and reinforcing elements as well as the right manufacturing and processing techniques, aluminum metal matrix composites properties can be adjusted to suit the needs of a variety of applications.

The following are the advantage of using aluminium MMCs:

- Better damping capabilities
- Enhanced tribological properties
- Better coefficient of thermal expansion
- Higher strength and stiffness [7].

In the recent past, MMC processing has become increasingly important and the majority of MMC applications centres are around aluminum as the matrix metal. Aluminum alloys are highly machinable and are most commonly used in automotive and aircraft components because of their superior qualities which include outstanding low-temperature performance, chemical inertness, greater strength to weight ratios, and corrosion resistance. Due to its simplicity of manufacturing and financial concerns, the liquid metallurgy or vortex process is the most widely utilized fabrication technique available for creating MMCs [8, 9].

Enhancing the mechanical characteristics of these materials is largely dependent on the microstructural factors. The improvement of the characteristic is also caused by parameters such as the volume fraction, matrix composition, size, shape and orientation of the reinforcing particles [10].

In addition to their benefits, these materials' low ductility and hardness as compared to unreinforced aluminum and alloys is a drawback. Because ceramic reinforcements are brittle and have poor wettability, they have low toughness and ductility which leads to low interface strength. However, by carefully choosing processing methods, coating particles with wetting agents, heating reinforcing particles beforehand, and reinforcing using hybrid particles, these drawbacks can be reduced [11].

The kind of reinforcement material used has a significant impact on the characteristics of the composite materials. Due to their qualities such as high stiffness, high specific strength, high wear resistance, high specific modulus, low density, low thermal coefficient of expansion, and superior corrosion resistance, particulate reinforcements such as $Al_2O_3$ (alumina), silicon carbide (SiC), graphite, rice husk, fly ash, red mud, etc. are frequently used. [12]. Due to its low cost, strong interfacial bonding, high melting point, high electrical resistance and high hardness all of which contribute to the desirable properties of the composite material so aluminum oxide is employed as reinforcing material. The material is strengthened by the addition of reinforcement and the quantity of reinforcement particles that is, their size, shape, volume fraction and processing method specifies the degree of strengthening [13, 14].

## 3. OBJECTIVES

The specific objectives of the present work are as follows:

- Selection of the matrix and the reinforcement materials based on the literature study.
- Stir casting of the composites with varying percentage of reinforcements.
- To study the influence of percentage composition of $Al_2O_3$ particulates by microstructural examinations.

## 4. EXPERIMENTAL DETAILS

The parts that follow provide more information about the experimental study that is intended to achieve the goals established for this work.

### 4.1 Details of work materials

Particulate aluminum oxide ($Al_2O_3$) has been used as reinforcement in this work with aluminum A356 serving as the matrix material. Aluminum A356 consists of Silicon, magnesium with good strength, ductility and casting qualities in addition to being naturally anti-corrosive. The increased silicon content in A356 enhances the material's castability and fluidity. In an alloy, silicon and magnesium can also produce a second phase component that strengthens the material through precipitation. These characteristics of A356 alloy materials make them more suitable for usage in maritime and automotive applications. Table 1 lists the alloy material's chemical composition, Table 2 lists its key characteristics and Table 3 shows the salient properties of $Al_2O_3$.

**Table 1.** Chemical composition of A356.

| Elements | Al | Cu | Fe | Mg | Si | Ti | Zi | Other |
|---|---|---|---|---|---|---|---|---|
| Percentage Composition | 91.1-93.3 | <0.2 | <0.2 | 0.25-0.45 | 6.5-7.5 | <0.2 | <0.1 | <0.05 |

**Table 2.** Salient properties of A356.

| Properties | Values |
|---|---|
| Elastic Moduls (GPa) | 70-80 |
| Density (g/cc) | 2.75 |
| Poisson's Ratio | 0.33 |
| Tensile Strength in Mpa | 220 |
| Hardness (Vickers) | 99 |
| Melting Temperature | $660^0C$ |
| Thermal Conductivity | 151 W/m-$^0K$ |

**Table 3.** Salient properties of $Al_2O_3$.

| Properties | Values |
|---|---|
| Density (g/cc) | 3.69 |
| Melting Temperature | $2072^0C$ |
| Thermal Conductivity | 30 W/m-$^0K$ |

### 4.2 Primary processing details (Stir Casting):

The stir casting method is used to process particle reinforced MMCs. The current project includes a bottom-pouring furnace that is controlled by a valve that is operated from below. A motor-driven stirrer positioned at the top of the surface aids in combining the molten metal with the reinforcing particles. To ensure that the molten metal flows precisely into the mold cavity, molds are positioned at the bottom of the furnace, as indicated in Fig. 2.

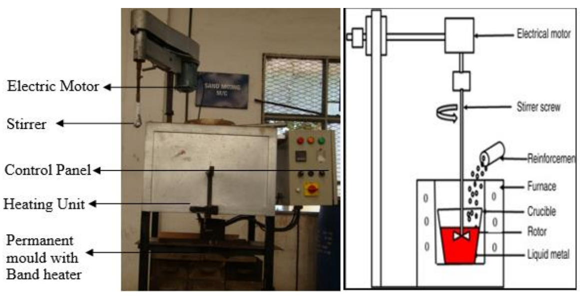


**Fig. 2.** Casting equipment.

## 5. RESULTS OBTAINED

### 5.1 SEM Analysis

The SEM pictures of the alumina particles used in MMC processing are displayed in Fig. 3. The SEM image shows that the particles are multi-cornered and irregularly shaped, which aids in better interlocking with the matrix material following the casting process and enhances the mechanical properties of the composite structure. The presence of equally dispersed reinforcement particles with a few agglomerates which are observed at a greater percentage of reinforcement (12%) is indicated by SEM images (Fig 8).

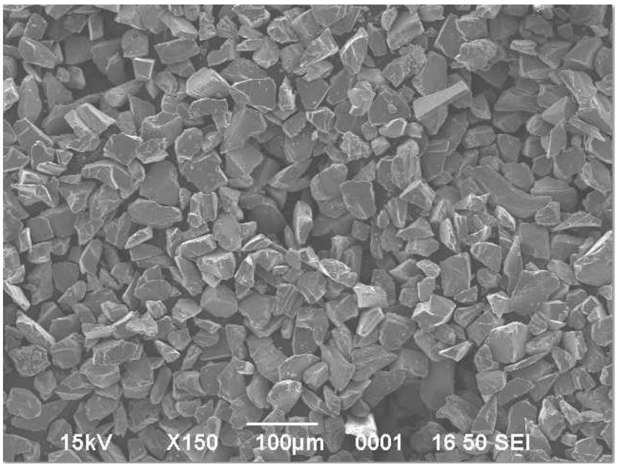


**Fig. 3.** SEM image of $Al_2O_3$ particulates of 23µm size.

A homogeneous distribution (Fig 4-7) can be visualized in the SEM analysis. This uniform distribution of the particles will aid in structure's mechanical strengthening. Additionally, the SEM picture reveals the microscopic pores that are a natural feature of the cast composite structure.

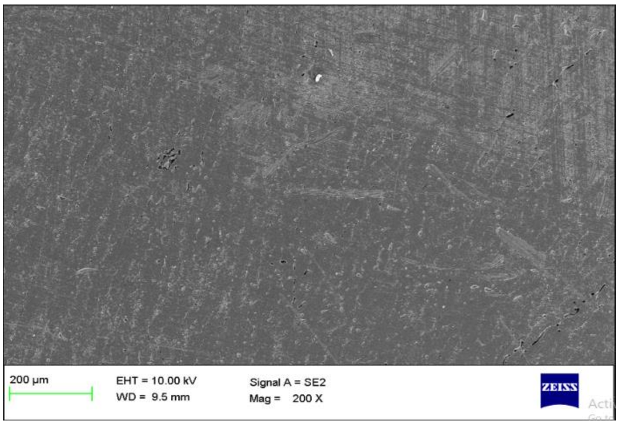


**Fig. 4.** SEM image of Base Material A356.

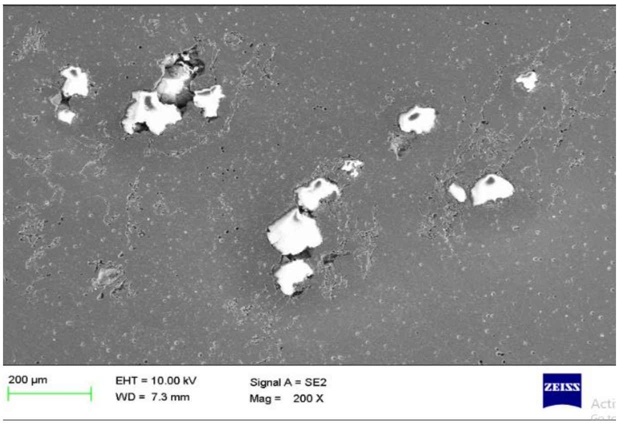


**Fig. 5.** SEM image of 3% $Al_2O_3$.

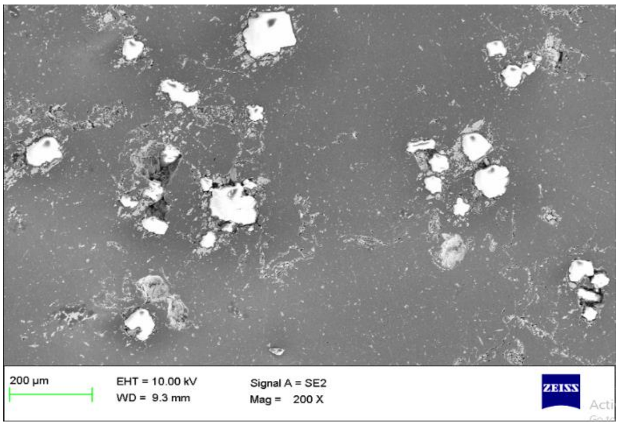


**Fig. 6.** SEM image of 6% $Al_2O_3$.

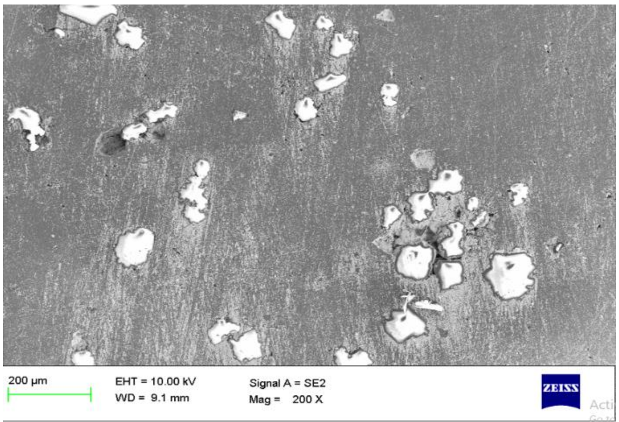


**Fig. 7.** SEM image of 9% $Al_2O_3$.

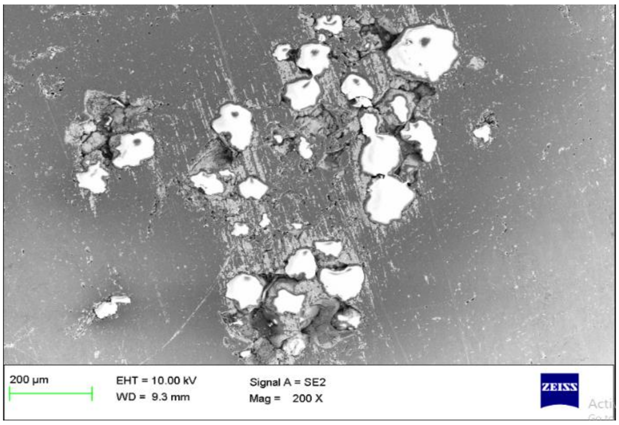


**Fig. 8.** SEM image of 12% $Al_2O_3$.

### 5.2 EDAX Analysis

EDAX is utilized in conjunction with scanning electron microscopes (SEM) to examine a material's elemental analysis.

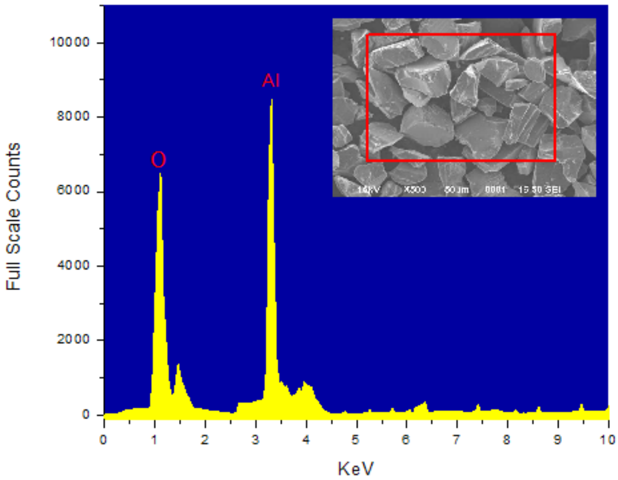


**Fig. 9.** EDAX image of $Al_2O_3$ particulates.

**Table 4.** Elemental analysis of $Al_2O_3$.

| Element | Weight % |
|---|---|
| O | 45.12 |
| Al | 54.88 |
| Total | 100.00 |

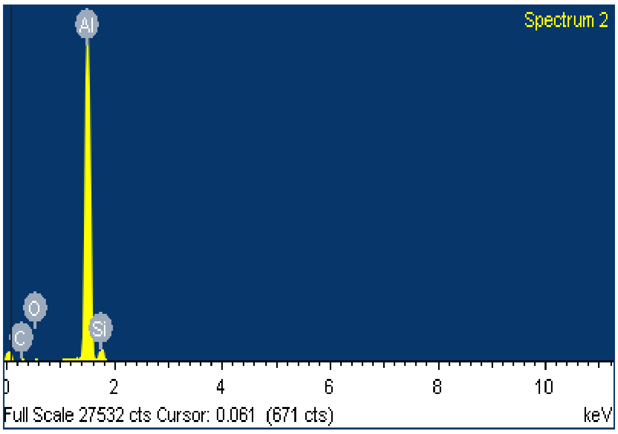


**Fig. 10.** EDAX analysis of Al–$Al_2O_3$ composite (9% reinforcement).

**Table 5.** Elemental data of Al-$Al_2O_3$ composites.

| Element | Weight% |
|---|---|
| **C** | 2.24 |
| **O** | 10.72 |
| **Al** | 80.56 |
| **Si** | 6.48 |
| **Total** | 100.00 |

Fig 9 shows the elemental analysis (EDAX) of Alumina powders and the Table 4 shows the elemental composition of the material. Fig 10 shows the EDAX analysis of Al–$Al_2O_3$ composite material and percentage composition of individual constituent elements present in the extruded composite material is listed in Table 5. Any additives or contaminants in the sample will also show up as extra peaks in the spectrum. Qualitative and quantitative examination of contaminants or additives can be identified with the narrow peaks and the broad peaks. Narrow and the sharp peaks represent the purity of the materials and broader peaks indicates the presence of the impurities which are very less in the content.

## 6. CONCLUSIONS

Drawing on the outcomes of the conducted experimental investigations, the subsequent conclusions are made:

- Stir casting is successfully employed to process the composite material.
- The microscopic analysis reveals that the $Al_2O_3$ particle distribution is quite homogeneous upto 9% of the reinforcement.
- Little agglomerates are noted at the higher percentage of the reinforcement (12%).
- Existence of pores can be visualized is some cases.
- EDAX analysis showcase the purity of the material used and its identical elements in the matrix material.

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