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Research article

Comparative Study on the Mechanical Properties of Boron Carbide and E-Glass Fiber Reinforced Aluminum 7075 Composites

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A B S T R A C T

Aluminum matrix composites (AMCs) have gained significant attention for their superior mechanical properties compared to traditional alloys, particularly in demanding applications such as aerospace and automotive industries. This study focuses on the mechanical characterization of Aluminum 7075 reinforced with boron carbide (B4C) and chopped E-glass fibers. The primary aim is to enhance the material's strength and toughness while mitigating its inherent brittleness. The reinforcement process involves the integration of ceramic particles and chopped glass fibers into the Aluminum 7075 matrix using the stir casting method. This method ensures a uniform dispersion of reinforcements, leading to a homogeneous composite structure. The experimental setup includes varying the weight percentages of B4C and E-glass fibers to assess their impact on the composite's mechanical properties. The composites were evaluated for density, porosity, hardness, and tensile strength following ASTM standards. Results indicate that the addition of boron carbide and E-glass fibers significantly improves the composite's hardness and tensile strength, while reducing porosity. Scanning Electron Microscopy (SEM) analyses of the worn surfaces provided insights into the wear mechanisms and the effectiveness of the reinforcements in enhancing tribological performance.

1. INTRODUCTION

Aluminium matrix composites (AMCs) have emerged as promising materials for various engineering applications due to their enhanced mechanical properties compared to conventional alloys. Among these, Aluminium 7075 stands out for its excellent strength-to-weight ratio and fatigue resistance, making it a preferred choice for structural components in aerospace and automotive industries [1]. However, its inherent brittleness limits its applicability in certain high-stress environments. To overcome this limitation, researchers have focused on reinforcing Aluminium 7075 with ceramic particles and chopped glass fibers, aiming to improve its mechanical performance while maintaining its desirable characteristics.

Ceramic particles, such as silicon carbide (SiC) or alumina (Al_2O_3), offer high hardness and wear resistance, making them effective reinforcements in aluminium matrices [2]. Similarly, chopped glass fibers provide additional toughness and impact resistance, enhancing the composite's fracture toughness and fatigue life [3]. The combination of these reinforcements with Aluminium 7075 via stir casting process offers a promising route for fabricating high-performance composite materials.

Stir casting, a cost-effective and scalable manufacturing technique, involves the addition of ceramic particles and chopped glass fibers into the molten Aluminium 7075 matrix, followed by stirring to achieve uniform dispersion of reinforcements [4]. Subsequent solidification results in a homogeneous composite structure with improved mechanical properties.

Metal matrix composites (MMCs) represent an exciting edge in materials science, where their mechanical and tribological attributes are influenced by a assembly of factors covering material composition, processing methodologies, and operational conditions. These intricate interplays offer a versatile palette for tailoring MMC properties to suit diverse applications. In the quest for high-performance materials crucial for cutting-edge technological demands, a steadfast commitment to ongoing exploration is imperative. It's essential to delve into the nuanced influence of various parameters on MMC behavior to unlock their full potential.

The tribological performance of materials centers on their underlying structural intricacies, intricately linked to the processing techniques and parameters applied. Consequently, deciphering the tribological characteristics of MMCs crafted through both primary and secondary processing routes presents a formidable challenge for design engineers. Navigating this intricate landscape demands a fusion of expertise, innovation, and relentless inquiry to harness the full capabilities of these advanced materials for a numerous of applications [2].

The utilization of Metal Matrix Composites (MMCs) extends to applications where components undergo sliding or rolling motions relative to matching surfaces. Understanding the tribological behavior of these components is paramount to enhancing system performance. This study represents a modest effort to investigate the impact of select parameters on the wear behavior of Al7075-E-Glass-B_4C hybrid MMCs.

2. SURVEY OF LITARATURE

Extensive research has been conducted on composite materials, with a selection of related literature provided in this section.

To produce cost-effective particulate-reinforced metal matrix composites (MMCs), the stir casting technique was employed for fabricating aluminum matrix composites (AMMCs). A stirrer was used to ensure even distribution of the reinforcement material within the aluminum base. The melting process was conducted at temperatures ranging from 600°C to 800°C. To achieve a uniform dispersion of the reinforcement particles within the matrix, they were introduced into the vortex created by stirring [5].

Author summarized the effects of various reinforcement materials, such as silicon carbide (SiC) and aluminum oxide (Al_2O_3), on the microstructure and mechanical properties of 7075 aluminum alloy composites. The addition of reinforcements generally improves hardness, tensile strength, and wear resistance while maintaining a relatively low density [6].

As per ASTM G99 standard using Pin on Disc Wear Test, composite specimens of Aluminium 7075, reinforced with SIC for various reinforcements such as zero, one, two, three and four percentage by weight were conducted wear test to obtain required tribological properties. The results shown that increase in reinforcement increased the hardness, It was also observed that weight percentage of silicon carbide increment reduced the wear rate [7-12].

3. OBJECTIVES

Objectives of this comprehensive study is aimed at understanding the tribological properties of Al7075 composites reinforced with E-Glass and B4C particles, with a focus on the processing techniques and material characteristics.

- Matrix and Reinforcement Materials selection
- Composite Material Preparation- Al7075 with E-Glass (1%) and B4C (1, 3, 5%) by Stir Casting.
- Sample Preparation for Mechanical properties Evaluation.
- Evaluation of theoretical and actual density, porosity, Hardness and Tensile strength of the Processed Materials.

4. EXPERIMENTAL WORK

The dominant material within the series primarily comprises Boron carbide, particularly in the higher range. B4C stands out for its array of advantageous properties, spanning from exceptional strength to excellent thermal conductivity. These materials are well-suited even for secondary processes. The inclusion of B4C renders the material notably harder compared to other series within the materials spectrum.

When the current grade of material is fortified with an increased quantity of B4C, its strength undergoes further enhancement. However, it is imperative to exercise caution to prevent the introduction of brittleness resulting from a higher percentage of B4C.

In this study, E-Glass fibres(chopped) and B4C particles (with a size of 45μm) are incorporated as reinforcement materials alongside the Al7075 matrix material. The weight percentages of these reinforcements range from 1% to 5%, with increments of 2%, and are processed using the casting methodology. The overall fraction of reinforcements is capped at 6%, ensuring an appropriate balance with the matrix material. Table 1 provides a comprehensive overview of the reinforcement percentages utilized in the current investigation. Figure 1 to figure 5 represents fabrication, testing equipments and test specimen as per astm standards.

Table 1. Reinforcements Percentage**.**

Test Samples	E-Glass%	B4C%	Al7075 %
S 1	0	0	100
S 2	1	0	99
S 3	1	1	98
S 4	1	3	96
S 5	1	5	94

Fig. 1. Stir Casting Process with Reinforcement particles.

Fig. 2. Hardness Testing setup.

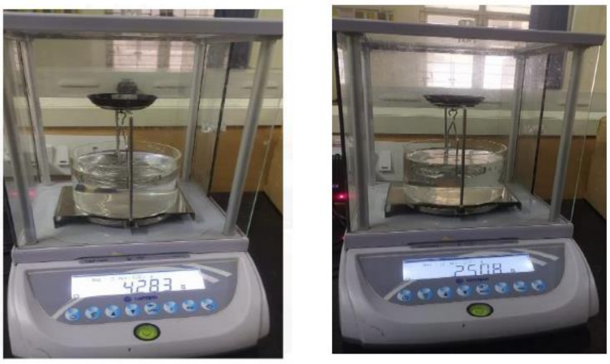

Fig. 3. Density Measurement In Air And Water.

Fig. 4. Tensile Test Specimen.

Fig. 5. Hardness test specimen.

The materials undergo processing via the stir casting technique, a method involving the addition of preheated reinforcement particles to the molten aluminum material. Following this procedure, the evaluation of properties is conducted in accordance with ASTM standards, ensuring consistency and reliability in the assessment process. The tribological test samples are meticulously prepared in accordance with the ASTM standard, ensuring adherence to established protocols and methodologies for consistent and standardized testing procedures.

5. RESULTS & DISCUSSIONS

5.1 Porosity of Composite Materials

Figure 6 shows graph of porosity v/s composite samples. The findings reveal a consistent trend, Decrease in porosity is noticed with addition of reinforcement particles to the aluminium alloy during the manufacturing process, particularly in liquid state processing methods like casting, lesser density particles are less likely to settle at the bottom of the mold due to gravity. This reduced settling helps maintain a uniform distribution of particles throughout the composite, preventing areas with high porosity that could occur if denser particles segregate.

Lighter reinforcement particles may have better compatibility with the aluminum matrix, promoting stronger interfacial bonding. Stronger bonds between the particles and the matrix can reduce the formation of micro-voids at the interface. Good interfacial bonding helps in minimizing the porosity that might arise from weak spots or gaps where particles do not adhere well to the matrix.

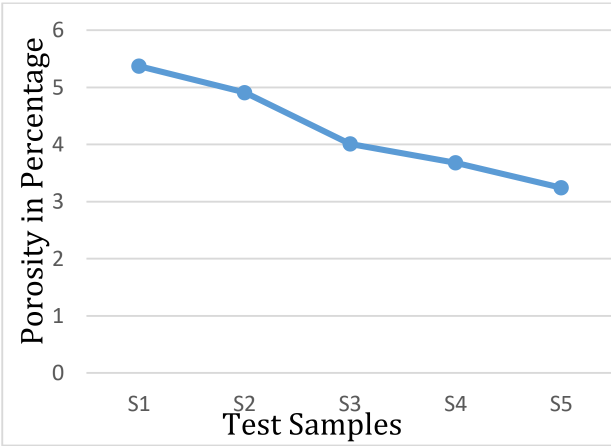

Fig. 6. Porosity v/s Test samples.

5.2 Hardness of Composite Materials

The reduction in porosity often implies better particle-matrix interaction and distribution. Well-distributed reinforcement particles can effectively hinder dislocation motion within the matrix, which is a primary mechanism for plastic deformation. Also This uniform load distribution minimizes localized stress, preventing early failure and allowing the material to exhibit higher hardness values as shown in figure 7.

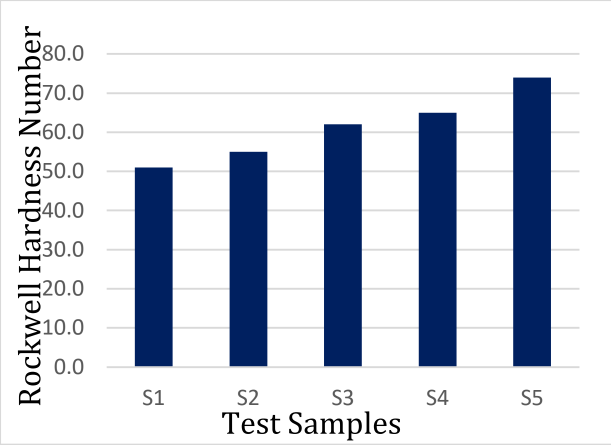

Fig. 7. Hardness v/s Test samples.

5.3 Tensile Strength of Composite Materials

Figure 8 shows graph of ultimate tensile strength v/s composite samples. It can be observed in the figure that tensile strength of composites with reinforcement particles has shown improvement compared to base material. Tensile strength increases with increase in boron carbide percentage and E-glass fibre. This could be due to Well-distributed and bonded reinforcement particles in a less porous matrix provide effective load transfer paths, improving the composite's tensile strength.

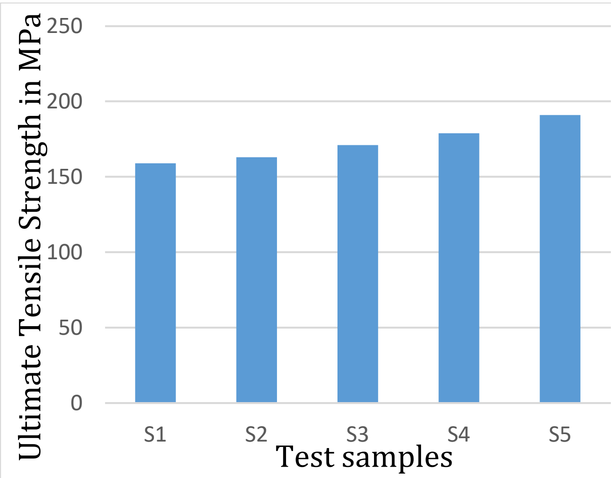

Fig. 8. Tensile Strength v/s Test samples.

5.2 SEM Results

The SEM images in Fig. 9 depict the worn out surface of the MMC Al7075 with E-Glass fiber 1% and 5% boron carbide specimen under sliding wear conditions. The image reveal how the material undergoes plastic deformation, leading to the formation of grooves aligned with the direction of sliding.

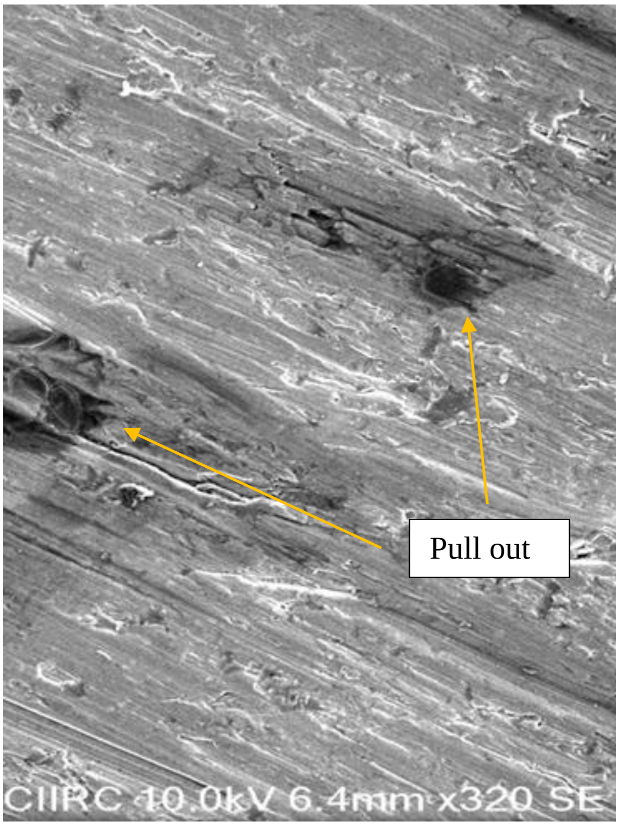

Fig. 9. SEM of worn out surface of Sample 5.

It can be noted that as the sliding distances increases, wear is also found to be increased, higher normal load result in deeper grooves than lower load. From this, it can be inferred that the wear contact surface temperature rises as the normal load increased. Additionally, there are visible craters where material has been pulled out. During dry sliding wear, the asperities on mating surfaces experience a critical situation where they either remain in contact or separate. This process involves elastic and plastic deformation before eventual separation. Subsurface fissures, either pre-existing or formed due to stress, have the potential to propagate and reach the surface. This propagation results in the formation of craters as material is removed from the surface. More fractures will emerge at the grain boundaries as sliding continues, and the coalescence of these cracks will form a continuous intergranular crack parallel to the surface.

6. CONCLUSSIONS

The initial findings from the preliminary investigations suggest the following conclusions:

- Reinforcement particles, such as E-glass fibers and boron carbide particles, into an aluminium matrix can be incorporated by using stir casting process as it is economical and easy material processing technique.
- Uniform distribution of reinforcement particles can effectively improved by proper stirring which significantly enhances the composite's mechanical properties.
- Reduction in porosity of composite materials can be achieved by Uniform distribution of reinforcement particles.
- Increase in hardness of composite materials can be achieved by addition Boron carbide particles with proper distribution as it minimizes localized stress, preventing early failure and allowing the material to exhibit higher hardness values
- Reduced porosity typically leads to fewer internal voids and defects, resulting in a more uniform and continuous matrix that can better bear applied loads. With fewer voids, the composite material can distribute applied loads more evenly, reducing stress concentrations that can lead to premature failure. This results in higher tensile strength

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