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Influence of Stir Casting Parameters on the Microstructure and Mechanical Properties of SiC–B_4C Reinforced Al6061 Composites

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Abstract –
In the present study, Al6061-based hybrid composites reinforced with silicon carbide (SiC) and boron carbide (B_4C) were fabricated using the stir casting technique to examine the effect of key processing parameters on microstructural features and mechanical behaviour. Stir casting process minimizes agglomeration and porosity while promoting uniform dispersion of SiC and B_4C particles, according to microstructural analysis using scanning electron microscopy. In comparison to the unreinforced Al6061 alloy, mechanical characterisation showed significant increases in hardness up to 72.6 VHN and tensile strength 159.37 MPa. Strong matrix–reinforcement interfacial integrity, efficient load transfer by adding SiC and B_4C reinforcements, and grain refinement are responsible for the improvement in mechanical properties. The results emphasise how important stir casting parameters in Al6061–SiC–B_4C hybrid composites structure–property relationship for possible structural and automotive uses.

Key Words: Al6061, Silicon Carbide, Boron Carbide, Scanning Electron Microscopy, Stir Casting

1. INTRODUCTION

The development of aluminium matrix composites (AMCs) for advanced engineering applications has accelerated due to the growing demand for lightweight materials with superior mechanical performance. Al6061 is a common aluminium alloy used in structural, automotive, and aerospace components because of its superior machinability, corrosion resistance, and strength-to-weight ratio [1]. Ceramic reinforcements have been added to improve its performance because its mechanical qualities are frequently insufficient for applications requiring high wear resistance and elevated strength. Ceramic particle-reinforced aluminium matrix composites have garnered a lot of interest because of their improved mechanical performance and low weight [2].

Because of their superior thermal stability, low density, and high hardness, silicon carbide (SiC) and boron carbide (B_4C) are two of the best reinforcement materials for aluminum-based composites. The combination of SiC and B_4C is beneficial for creating hybrid composites with balanced mechanical properties because SiC enhances strength and wear resistance and B_4C provides remarkable hardness and stiffness [3]. When evenly distributed throughout the aluminium matrix, the synergistic effect of these reinforcements can greatly increase load-bearing capacity and resistance to deformation [5].

One of the most affordable and scalable methods of manufacturing particulate-reinforced aluminium composites is still stir casting. Reinforcements are mechanically stirred into molten aluminium before being cast into a mould. Stir casting has benefits, but it also has drawbacks like particle agglomeration, poor wettability, and porosity, which can negatively impact mechanical properties and microstructural integrity [6]. Processing parameters such as stirring speed, stirring time, melt temperature, and reinforcement content have a significant impact on these problems.

Numerous studies have shown that achieving homogeneous particle distribution and strong interfacial bonding between the matrix and reinforcements requires careful optimisation of stir casting parameters. Increased mechanical qualities, such as hardness, tensile strength, and wear resistance, are directly correlated with improved microstructural features like grain refinement and decreased porosity. However, especially for Al6061-based hybrid composites, the combined effect of SiC and B_4C reinforcements under different stir casting conditions has not been thoroughly investigated [7].

The goal of this study is to examine how important stir casting parameters affect the microstructural development and mechanical characteristics of SiC–B_4C reinforced Al6061 composites. In order to optimise fabrication strategies and increase the potential applications of Al6061 hybrid metal matrix composites, this work aims to establish correlations between microstructure, mechanical performance, and processing conditions [9].

2. EXPERIMENTAL PROCEDURE

2.1 Stir Casting Process

Stir casting was used to create the SiC–B_4C reinforced Al6061 hybrid composites because it was easy to use, affordable, and suitable for large-scale production. The matrix material was commercially available Al6061 alloy, and the reinforcing phases were silicon carbide (SiC) and boron carbide (B_4C) particulates [10]. Al6061 alloy ingots were first melted in an electric resistance furnace after being charged into a graphite crucible. To achieve a fully molten state, the alloy was heated to a temperature higher than its liquidus. A tiny quantity of magnesium was added to the aluminium melt to increase its wettability with the ceramic reinforcements [11]. In order to reduce thermal gradients and improve particle–matrix bonding during incorporation, the SiC and B_4C particles were simultaneously preheated to a temperature of 300°C in order to remove moisture and surface impurities [12]. Mechanical stirring at 300 rpm was started using a stainless-steel impeller coated in alumina once the melt reached the required temperature. To create a stable vortex in the molten aluminium, stirring was done for 5 min time. In order to promote uniform distribution and avoid particle clustering, the preheated SiC and B_4C particulates were then progressively added to the vortex. To encourage uniform dispersion and efficient interfacial bonding, stirring was maintained for a further amount of time after the reinforcements had been fully added [13]. To lessen porosity, the composite melt was then degassed using the appropriate degassing agents. After that, the molten composite was transferred into metallic moulds that had been heated and left to solidify in the open. After being taken out of the moulds, the cast composite specimens underwent routine machining procedures to produce samples for mechanical testing and microstructural analysis [14]. Only samples free of casting flaws were chosen for additional characterization after the manufactured composites were visually examined for flaws. Reliable assessment of the impact of stir casting parameters on microstructure and mechanical properties was made possible by this fabrication method's consistent processing conditions and repeatable composite quality [15]. The Chemical composition of Al6061 and percentage of Al6061/ SiC/B_4C used in the proposed study is shown in Table 1 & 2.

Table 1: Chemical composition of Al6061

Elements	Cu	Si	Fe	Mg	Mn	Zn	Ti	Cr	Al
% by weight	0.261	0.64	0.293	0.88	0.095	0.33	0.032	0.089	Balance

Table 2: Composition of A6061/SiC/B_4C in Percentage

Sample No	Percentage of Al6061	Percentage of SiC	Percentage of B_4C
Sample 1	100	0	0
Sample 2	92	3	5
Sample 3	89	6	5
Sample 4	86	9	5
Sample 5	83	12	5

3. MECHANICAL PROPERTIES

To determine the impact of processing parameters and reinforcement addition on material performance, the mechanical properties of the stir-cast SiC–B_4C reinforced Al6061 composites were assessed [19]. To guarantee consistency and dependability of the measured results, standard test specimens were prepared in compliance with ASTM standards. Hardness, tensile strength which are essential for structural applications are examined.

3.1 Hardness Test

The Vickers hardness test is a widely used method to determine the hardness of materials by measuring their resistance to plastic deformation. In order to measure the diagonal lengths of the resulting indentation, a diamond pyramid indenter with a square base is pressed into the material surface under a predetermined load [21]. For aluminium alloys, the Vickers hardness number (VHN) offers a trustworthy indicator of hardness. Specimen is having diameter of 16 mm and height 16mm are prepared as shown in figure 1.

Figure 1: Hardness Test Specimens

3.2 Tensile Strength

The maximum stress a material can bear before failing under a uniaxial tensile load is known as tensile strength, a fundamental mechanical property [23]. It is typically ascertained by a tensile test and shows the material's capacity to withstand breaking under tension. Specimen is having diameter of 6 mm, gauge length 24 mm, radius of fillet 6 mm and total length of 65 mm is prepared. Figure 2 and 3 shows the dimensions for tensile test specimens.

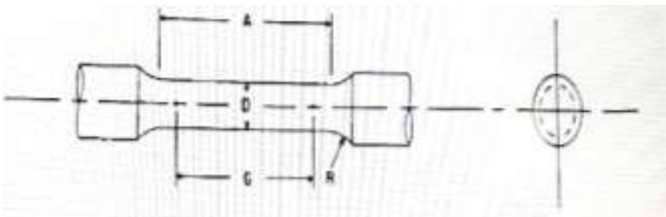

Figure 2: Dimensions for Tensile Test

Figure 3: Tensile Test Specimens

3.3 SEM Analysis

A potent characterization method for examining the surface morphology and microstructural characteristics of materials at high magnifications is scanning electron microscopy, or SEM. It offers comprehensive details on phase contrast, particle distribution, and flaws like cracks and porosity. SEM is frequently used in materials research to examine how processing conditions, microstructure, and final mechanical properties are related.

4. RESULTS AND DISCUSSION

4.1 Tensile Strength

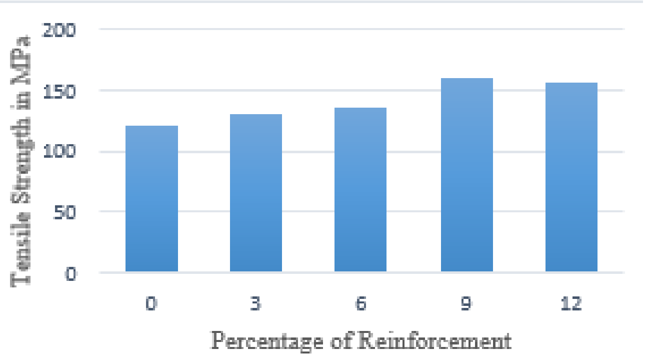

Figure 4: Tensile strength in MPa v/s Percentage of Reinforcement

According to the tensile test results, Al6061's tensile strength clearly increases as the SiC–B_4C reinforcement content increases. It rises from the unreinforced alloy to a maximum at about 9 weight percent reinforcement. Grain refinement brought about by ideal stir casting parameters and efficient load transfer from the ductile aluminium matrix to the hard ceramic reinforcements are responsible for this improvement. Particle agglomeration and increased porosity, which serve as stress concentrators, may be the cause of the slight decrease or saturation in tensile strength at 12 weight percent. Overall, the findings show that the mechanical performance of the composite is greatly improved by an ideal reinforcement percentage and appropriate stirring conditions.

4.2 Hardness

The hardness results show a consistent increase in Vickers hardness with increasing SiC–B_4C reinforcement content in the Al6061 matrix. The hard ceramic particles that prevent dislocation movement and improve resistance to plastic deformation are responsible for this improvement. The consistent increase in hardness suggests that the stir casting parameters were optimised to produce good interfacial bonding and efficient particle dispersion. Overall, the increased hardness validates the beneficial effects of processing conditions and reinforcement addition on the mechanical performance of the composite.

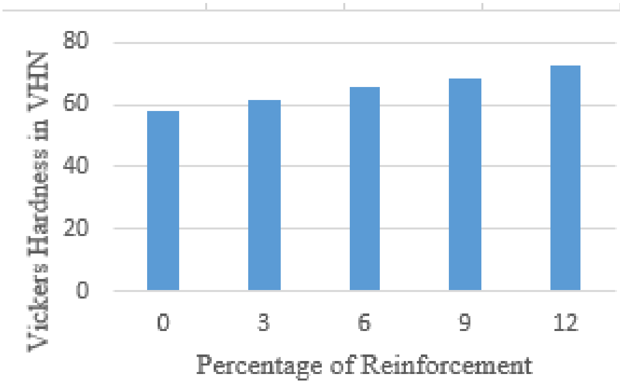

Figure 5: Vickers Hardness in VHN v/s Percentage of Reinforcement

4.3 Microstructural Characteristics using SEM

Effective stirring during the stir casting process is indicated by the SEM image, which displays a relatively uniform distribution of SiC and B_4C reinforcement particles within the Al6061 matrix. Strong interfacial bonding and good wettability are suggested by the clean and well-bonded particle–matrix interfaces. Stir-cast composites frequently exhibit isolated porosity and minor particle agglomeration, which may be caused by localised turbulence during stirring. Because of the hard ceramic reinforcements, the microstructure generally supports increased strength and hardness with a minor decrease in ductility.

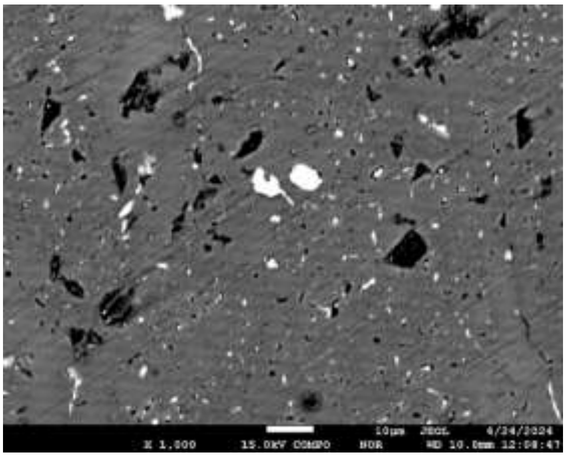

Figure 6: SEM images of Al6061 reinforced with 3%SiC and 5% B_4C

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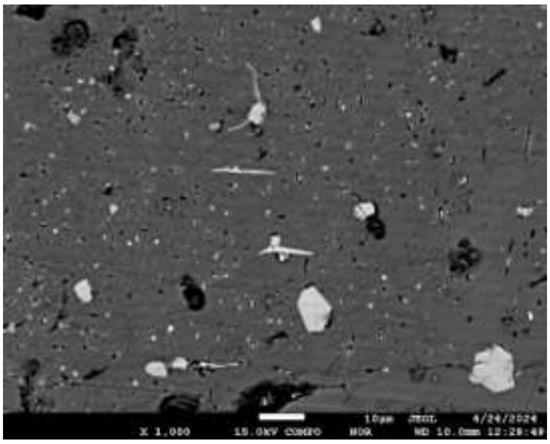

Figure 7: SEM images of Al6061 reinforced with 6%SiC and 5% B_4C

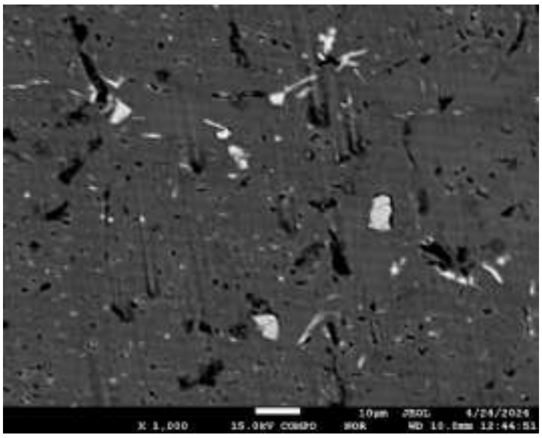

Figure 8: SEM images of Al6061 reinforced with 9%SiC and 5% B_4C

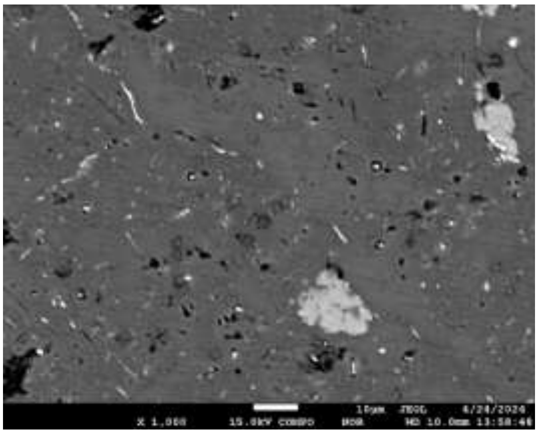

Figure 9: SEM images of Al6061 reinforced with 12%SiC and 5% B_4C

5. CONCLUSIONS

This study successfully compared the mechanical and microstructural characterization of Al6061 hybrid AMC using the Stir Casting technique. The composites are strengthened with reinforcement consisting of 5 weight percentage of B_4C and 3, 6, 9 and 12 weight percentage of SiC. Hardness and tensile strength are two examples of mechanical characteristics that are evaluated and compared. The investigation's notable conclusions are as follows:

• As the percentage of SiC increases the hybrid AMC exhibits improved hardness up to 72.6 VHN and tensile strength of 159.37 MPa for sample 4 (Al6061/9%SiC/5% B_4C).
• The ultimate tensile strength rises by 8% and the hardness improves by about 14% when compared to the base Al6061 alloy.
•The developed composite has a uniform distribution of reinforcement particles, according to SEM results.

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