Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 12, Special Issue 2, 2024
DOI (Journal): 10.37591/JoPC

http://engineeringjournals.stmjournals.in/index.php/JoPC/index

Research JoPC

Fabrication And Evaluation of Aluminum Hybrid Metal Matrix Composite Via Powder Metallurgy Approach

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Abstract

The increasing demand for lightweight materials in the automotive industry has driven the advancement of Aluminum-based metal matrix composites (AMMCs). The powder metallurgy method, a cost-effective fabrication technique, has been employed to produce these composites. Specifically, composites of Al6061 were created with varying amounts of Si C (6–18 wt%, powder size-8 microns) and B4C (6–18 wt%, powder size-10 microns) to evaluate their physical and mechanical properties. Scanning Electron Microscope (SEM) analysis confirmed the uniform dispersion of Si C and B4C particles within the aluminum matrix. This study focused on the improvements in hardness and tensile properties of the AMMC. The study examined the impact of different weight percentages of Si C and B4C on AMMC, revealing significant variations in density, hardness, tensile rupture strength, and tensile strength. As the SiC and B4C content in the composite changed, so did its overall performance characteristics. This indicates that the composition of reinforcing particles is crucial in determining the mechanical properties of the composite. The findings highlight that by adjusting the proportions of Si C and B4C, the material properties of AMMCs can be tailored to meet specific requirements, emphasizing the importance of these composites as effective lightweight materials in the automotive industry. The research demonstrated that adjusting the proportions of Si C and B4C in the aluminum matrix can tailor the material properties of AMMCs to meet specific requirements. The findings underscore the potential of these composites as effective lightweight materials in the automotive industry, balancing cost and performance. This highlights the importance of optimizing the composition of reinforcing particles to enhance the mechanical properties of AMMCs, making them suitable for various automotive applications.

Keywords: Al6061 alloy; Si C; B_4C; powder metallurgy; scanning electron microscope

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Received Date: February 27, 2024
Accepted Date: May 01, 2024
Published Date: May 17, 2024

Citation: A.K. Sethi, A Nirala, Om Vikash, Prateek Kumar, Nitesh Pandey. Fabrication and Evaluation of Aluminum Hybrid Metal Matrix Composite via Powder Metallurgy Approach. Journal of Polymer & Composites. 2024; 12(Special Issue 2): S205–S211p.

INTRODUCTION

Aluminum based metal matrix composites are most commonly used composite material and are being used in modern automotive industries due to the demand for properties like elastic strength, hardness, wear resistance, chemical inertness [1–2], impact toughness and good strength to weight ratio over unreinforced alloys [3–5]. In recent year development of new composite materials with minimum waste and cost advantages are find application in aerospace, automobile and marine industries [6]. Solid state procedures, such as powder metallurgy consolidation process [7–9], vaporization coating technique, diffusion bonding [10], and liquid state processes have been used to fabricate AMMC. Many authors have suggested different material like SiC, B_4C, TiC, TiO_2, Al_2O_3, MoS_2, BN, WC, TiB_2, MgO, AlN, ZrO_2, graphite, reinforced with aluminum metal for the improvement in mechanical and tribological properties [11–13]. Aluminum metal with Si C and fly-ash reinforced composites developed through by powder metallurgy method had better mechanical and wear properties than base metal [4,11]. The stir cast eggshell reinforced AA2014 composite material had improved the tensile strength and hardness [14]. The mechanical properties and dispersion of B_4C in the composite of AA6061-B_4C composite prepared by P/M process investigated and the results showed that evenly dispersion of B_4C in the composite [15]. The addition of Al_2O_3 in Al6061 refined grain size in the composite. Groundnut shell ashes as reinforcement in metal matrix composite reduces the density and cost of the composite and improve the mechanical properties [16]. The tribological properties of AMMC reinforced with MoS_2 and B_4C investigated, and result indicate that wear rate of AMMC slightly decreases [17]. The XRD analysis confirmed the uniform distribution of reinforcements and no contamination in the aluminum matrix of B_4C, BN and Al6061 metal matrix composites developed through powder metallurgy technique [18]. The Al6061 metal matrix composite reinforced with MoS_2, Si C and B_4C was fabricated and characterize to determine the mechanical strength, wear, density and microstructural behavior. As compared to base metal density increased with the addition of SiC and MoS_2 and hardness improved with the boron carbide dispersion. Preheated SiC particles as reinforcement in aluminum alloy improved the mechanical strength and further improved after adding the MgO particle whereas corrosion loss and thermal expansion decreased [19]. The evenly distribution of B_4C particle in Al6061 based MMCs improved the wire cutting performance and roughness quality of machined part [20–21].

In this research work the composites of Al6061 containing 6–18 wt% Si C (8 microns) and 6–18 wt% B_4C (10 microns)) were fabricated through powder metallurgy method. The geometry of the reinforcement, the volume percentage of reinforcement added to the matrix, and the desired attributes of composites, such as mechanical and wear resistance, all influence the selection of this fabrication technique. The powder metallurgy fabrication method is one of the best economical/easiest processes to produce AMMC in liquid-state process. The equally distributed reinforcing particle is accomplished by changing the process parameter of metal matrix composites.

EXPERIMENTAL PROCEDURE

Materials Composition and Properties

The Al6061 is used as matrix materials and formed AMMC and 6–18 wt% Si C (8 microns) and 6–18 wt% B_4C (10 microns) were used as the reinforcements. The Al6061materials chemical composition in weight percentage is shown in Table 1. Table 2 shows the varied weight and weight % compositions of the metal matrix composites. Sample 1 is made up of 100% Al6061, and the other samples are made up of different % of B_4C and Si C. Table 3 shows the fundamental characteristics of Al6061, B_4C, and Si C.

Table 1. Chemical composition of 6061 aluminum alloy

Elements	Si	Fe	Cu	Mg	Mn	Zn	Ti	Cr	Others	Al
Weight %	0.4-0.8	0.7	0.15-0.40	0.8-1.2	0.15	0.25	0.15	0.04-0.35	0.15-0.20	Balance

Composite preparation and process methodology

The Al6061 composite specimens reinforced with B_4C, and Si C were prepared via the powder metallurgy method to investigate the effect of the mechanical and microstructural properties. The reinforcement particles in varying proportions are prepared by mixing properly to ensure uniform distribution of reinforcements in the matrix material. The Al6061 in powder formiscompacted and sintering in atubular furnacein inert atmosphere and heating have done by electrical resistance heating. The resultant matrix and reinforcement combination is then sent into the compressing machine, which applies 100 kN of force for 10 minutes. In order to eliminate volatile chemicals and surface contaminants, the reinforcing particles of boron carbide and silicon carbide are warmed in a separate electric muffle furnace. The sintered specimen is allowed to cool as furnace cooling. The insertion of reinforcements comes before the compaction. The reinforcement tends to aggregate or cluster if the mixing is not done properly to achieve a homogeneous distribution of reinforcement in the matrix and to produce a composite with higher mechanical characteristics. The samples were cut and polished by standard metallographic procedure for SEM analysis.

Table 2. Composition of composites

Sample	Al6061 (%)	SiC (%)	B_4C (%)
S1	100	0	0
S2	82	12	6
S3	82	9	9
S4	82	6	12
S5	82	0	18
S6	82	18	0

Table 3. Properties of Al6061, Si C and B4C

Property	Al6061	Si C	B_4C
Melting point	580^0 C	2200-2700^0 C	2445^0 C
Modulus of Elasticity	70-80 GPa	410 GPa	450 GPa
Poisson's Ratio	0.33	0.14	0.18
Density	2.7 g/cm^3	3.2 g/cm^3	2.52 g/cm^3
Co-Efficient of Thermal Expansion (20-100 C)	24.3 μm/m ^{0}C	4 μm/m ^{0}C	5 μm/m ^{0}C
Thermal Conductivity	173 W/mK		
Grain Size	<100 microns	<8 microns	<10 microns

RESULTS AND DISCUSSION

Rock well hardness test was performed to find the influence of Si C and B_4C particles in AMMC to for the hardness value. Rockwell hardness B scale with 100 kgf load and l/16" diameter WC ball is selected to get the hardness results as shown in Table 4.

Table 4. The hardness value of the composite

Sr. No	Composite Specimen	Hardness Value (HB)
1.	S1	50
2.	S2	57
3.	S3	60
4.	S4	73
5.	S5	72
6.	S6	51

The mechanical characteristics of composites are decreased by density decreases. The compact powder is sintered to increase the sintering density of the composite. Density of the composite is measured by dimensional and Archimedes method of theoretical and experimental density respectively as shown in Figure. 1 of the different specimen. The powders were compact at room temperature and measured their density and found that average densities are higher than 87 %. Al6061 had the maximum density (90.8%) of the cold-pressed samples, whereas S5 composites had the lowest density (87.12 %). Although Al6061 and S6 have densities that are almost identical, the densities decrease as the B_4C ratio rises. All of the samples that were sintered were found to have average densities of 93%. While the maximum density (94.74%) observed for Al6061 alloy and minimum density (92.23%) for 18% reinforced B_4C composite.

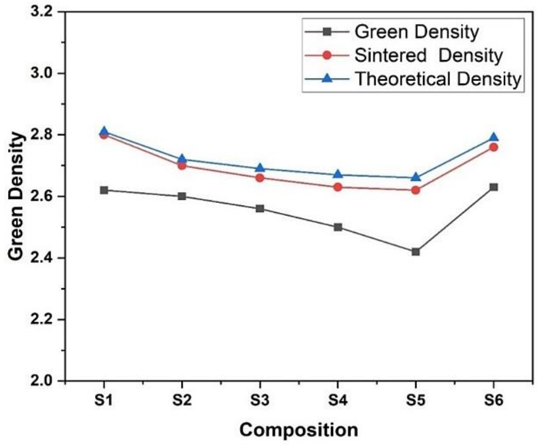


Figure1. Density variation of green compact and sintered composite

When compared to the reinforced Al6061 alloy, the hardness value increases with increasing the reinforcement as shown in Figure. 2. The bulk hardness of pure alloy and S4 composite is 50 HB and 73 HB respectively. According to calculations, S6 composites show hardness of 51 HB. The hardness values showed an increase by increasing boron carbide in the composite, but silicon carbide doesn't show such effect. It was discovered that the presence of reinforcement materials in the composite caused a strain to occur in the matrix structure, which contributed to the increase in hardness. The inclusion of ceramic particles can enhance the mechanical characteristics of aluminum alloys.

The S6 composite shows the transverse rupture strength of 394 MPa as shown in Figure. 3. The highest hardness observed fS5, S5 but this composite shows lowest TRS value of 359 MPa. The TRS value of the composite rises initially as the B_4C reinforcement is increased, but it falls from S2 to S4 and is found to be at its lowest point at S4 while reaching its highest point at S6, where 18% Si C is reinforced. S1, S2, S3, and S5 composites' transverse rupture strengths were obtained as 364, 379, 367, and 360 MPa, respectively.

Figure. 4 shows the tensile strength of the composite. The 18% Si C composite exhibited a tensile strength of 187 MPa, whereas the Al6061 material had the lowest value at 171 MPa. Thus, our investigation showed that the tensile strength values in B_4C/Si C composites tend to decrease when the B_4C reinforcement ratio rises. Agglomerations of the reinforcement materials in the matrix had an impact on the tensile strength, just as they did on the transverse rupture values.

Figure.5 shows the SEM microstructure of pure Al6061 and composites of Al6061 with varying percentages of Si C and B_4C. The macrostructure revealed that the reinforcement particles were distributed uniformly throughout the base material.

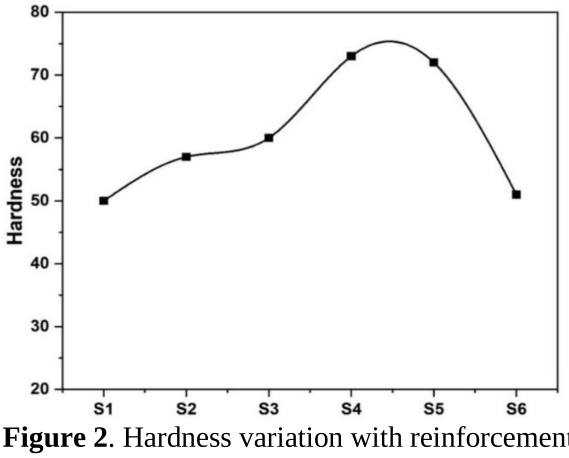


Figure 2. Hardness variation with reinforcement of the composite

Journal of Polymer & Composites
Volume 12, Special Issue 2
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

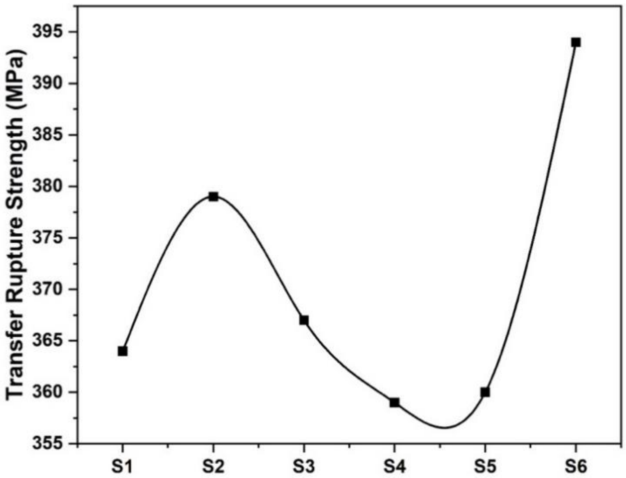


Figure 3. Variation of transfer rupture strength with reinforcement

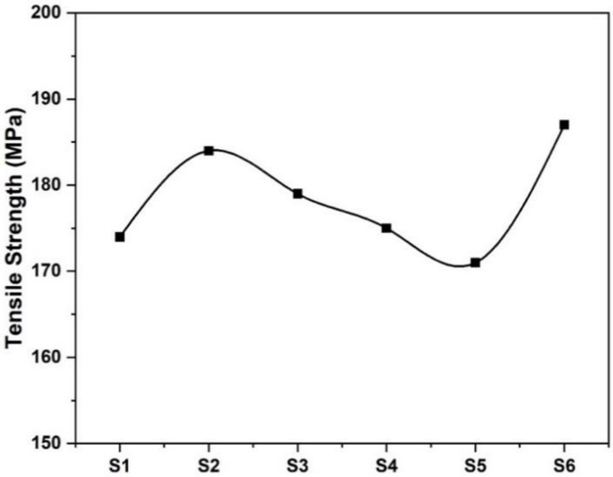
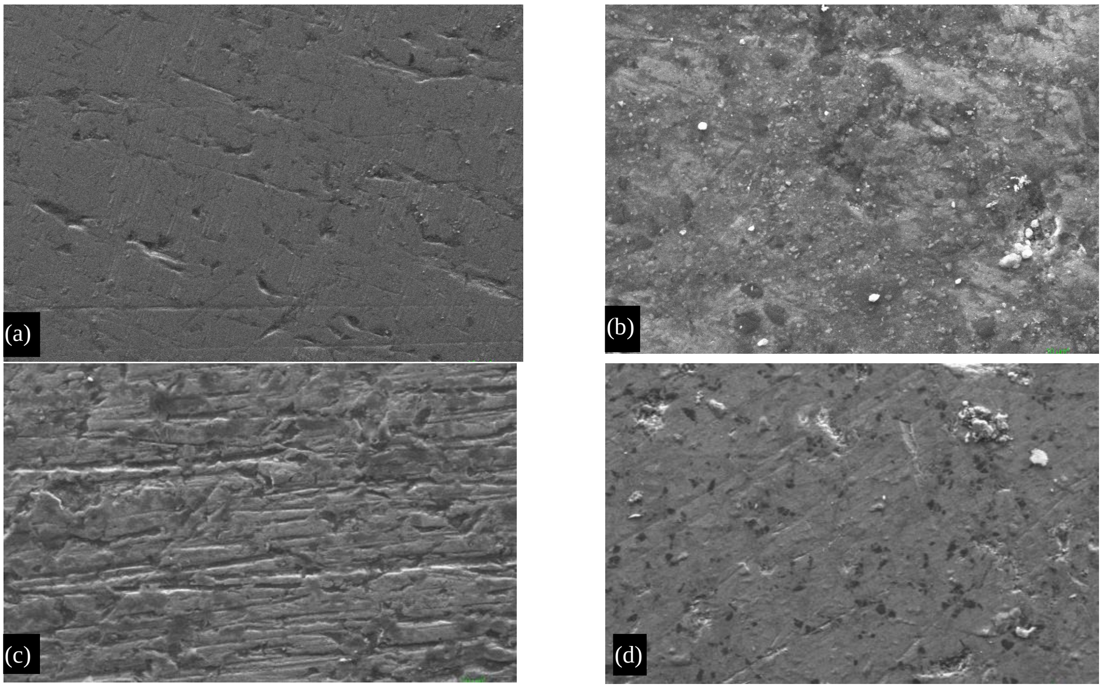
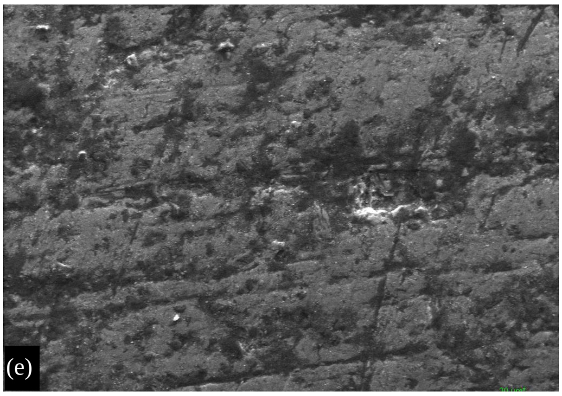


Figure 4. Tensile strength of the composite varies with reinforcement





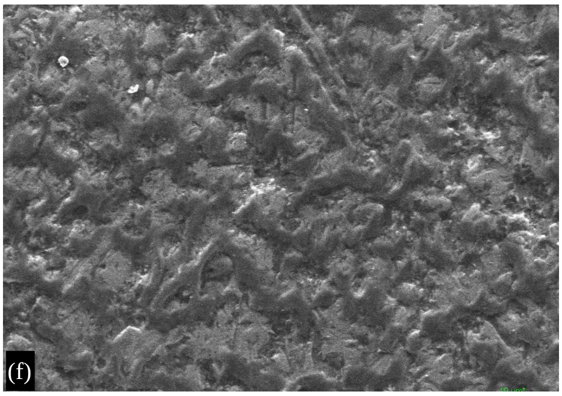


Figure 5. SEM microstructure of (a) Pure Al, (b) Al+ 18% B_4C, (c) Al+ 18% Si C, (d) Al+ 9% Si C+ 9% B_4C (e) Al+12% B_4C + 6% Si C and (f) Al+12% B_4C + 6% Si C

CONCLUSIONS

The composite used in the current research was fabricated using the powder metallurgy method and a scanning electron microscope confirmed that Si C and B_4C were distributed uniformly throughout the Al6061 matrix. The powder metallurgy process parameters, compaction pressure, sintering temperature, reinforcement of the particle size and shape are to be maintained to get the desired properties of the composite. The density of the composite is essential to achieve the mechanical and physical properties. The maximum density (94.74%) observed for Al6061 alloy and minimum density (92.23%) for 18% reinforced B_4C composite. The hardness values showed an increase by increasing boron carbide in the composite, but silicon carbide doesn't show such effect. The highest hardness observed for S 5 but this composite shows lowest TRS value of 359 MPa. The 18% Si C composite exhibited a tensile strength of 187 MPa, whereas the Al6061 material had the lowest value at 171 MPa. The tensile resistance of the 18% Si C composite was 187 MPa, whereas the Al6061 material obtained the lowest value at 171 MPa.

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