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Microstructure and Wear Behaviour Assessment of Different Micron-Sized B_4C Reinforced Al2021 Alloy Composites

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Abstract

This study examines the impact of the size and wt.% of reinforcement particles on the wear characteristics of Al2021 alloy composites. Composites of Al2021 reinforced with B4C particles of varied sizes (45 and 90 microns) were synthesised utilising a unique two-stage stir cast technique. The composites were primed with B4Cc content of 5 and 10 wt.%. The microstructural characterisation of Al2021 alloy with B4C composites of 45 and 90-micron sizes was conducted using Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS). In addition, wear and worn morphology tests were conducted to examine the impact of particle size on the behaviour of Al2021 alloy. Furthermore, another set of wear studies was conducted with the load maintained at 40N and the sliding speeds changed from 100 to 400 rpm. The microstructural analysis disclosed that the particles in the Al2021 alloy were evenly distributed, and the presence of elements was verified using EDS spectra. Using B4C particles of different sizes enhanced wear characteristics with resistance to wear. The load and the speed affected the wear behaviour of every prepared sample. The morphological analysis of the worn samples recognised multiple wear mechanisms.

Keywords: *Al2021 Alloy, Boron Carbide (B4C), Microstructure, Wear Properties, Worn Morphology*

1.0 Introduction

Metal Matrix Composites (MMCs) have exceptional resistance to high temperatures, enhanced toughness and improved strength associated with ductility[1,2]. These are applied on the surface of hypersonic aircraft. Several examples of composites include Al_2O_3, TiC or SiC fibres embedded in aluminium alloys, glass fibres embedded in

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lead, SiC-coated boron fibres embedded in an Al matrix and Tungsten Carbide (WC) particles embedded in a cobalt matrix[3,4]. These materials have a diverse range of applications, including rings of pistons, connecting rods, battery plates and compressor blades[5,6].

Aluminium alloys find application in various industries and structural ventures. A significant number of aircraft and space vehicle components are constructed using aluminium alloys[7,8]. The production of aluminium components for industrial and structural purposes primarily involves the utilisation of hot and cold extrusion techniques. The aluminium components utilised in engineering applications experience varying speeds and are expected to withstand high levels of stress. The most challenging circumstance is the environment in space, which is devoid of atmosphere and lacks the ability to implement immediate corrective measures. The aforementioned unique circumstance necessitates further focused investigation into the tribological behaviour of aluminium in a hostile environment characterised by extreme temperatures and the absence of atmosphere[9,10].

MMC composites can undergo processing in many ways, including liquid and solid-state processing. The methods mentioned are stir casting, spray deposition, fluid penetration, powder metallurgy, mechanical alloying, centrifugal casting, diffusion bonding and *in-situ* processing[11].

The most commonly used methods are melt stir casting and *in-situ* processing, as they are cost-effective compared to other methods[12,13]. Several enhancements to the concept of metal composites can be envisioned. The primary reason for creating MMCs is to improve their mechanical properties further. Future directions in this field could include the use of a quickly positioned matrix to provide reinforcement and the mix of continuous and fragmented matrix reinforcements to allow for both more reinforcement and an improvement in mechanical characteristics. It will take an in-depth programme to illustrate these ideas in a large-scale research facility[14,15].

Tribology is a branch of engineering that focuses on the study of ingredients that come into interaction and slide against each other. Contact occurs when the material rubs against one another, resulting in abrasion and wear. Tribology encompasses three major disciplines that focus on corrosion, wear and lubrication. Wear is the result of the surfaces of two constituents rubbing against each other[16]. The original size is decreased by wear because the material is removed as powder. When a material is used, its total efficiency decreases and thus the evaluation of wear becomes essential. The degradation of solid materials brought about by the continuous abrasion between two surfaces is described in the ASTM G99 standard[17,18].

MMCs are replacing solid alloys in many applications where segments slide against one another. The act of sliding causes the parts to experience wear. Evaluating the wear resistance of the MMC is essential prior to their implementation in practical applications. Experts worldwide have extensively employed the pin on disc wear apparatus to evaluate the wear of the MMCs[19].

Umanath and colleagues[20] studied the wear of Al6061 with dual-phase composites of SiC and Al_2O_3. This work used the matrix Al6061 in the T6 state, with reinforcements SiC and Al_2O_3 to create the composites and examine their wear characteristics. Testing for each experiment was done with a pin-on-disc wear tester.

Santanu and colleagues[21] investigated the wear behaviour of both Al7075 and Al7075 with 20 wt.% alumina composites. The samples underwent testing to evaluate their resistance to abrasive wear. This assessment took into account features such as load and speed. The Al7075 alloy exhibited improved tribological properties, which were effectively elucidated using SEM analysis of debris and worn surfaces, providing a comprehensive understanding of the wear mechanisms.

Basavarajappa *et al.*[22] examined the wear characteristics of Al2219 composites supplemented with SiC and graphite. The findings indicated that as the sliding speed increases, the wear rate also increases in both the Al2219 and SiC-Graphite composites. The accelerated wear at higher speeds can be attributed to a greater level of sub-surface deformation in both the aluminium and composites. In addition, the wear rate is reduced in composites due to the creation of a tribo-layer by the graphite particles.

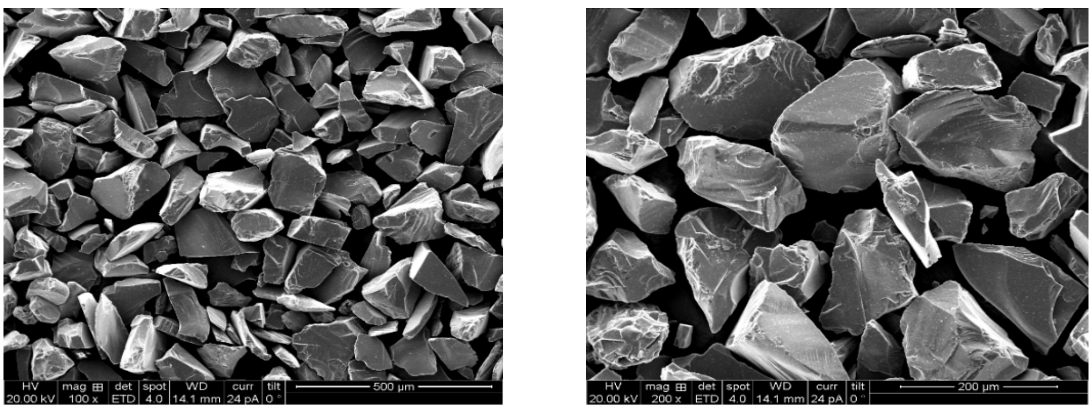
This study aims to create Al2021 alloy composites strengthened with 5 and 10wt. % of B_4C particles sized at 45 and 90 microns. The composites were subjected to microstructural characterisation and analysis of their wear behaviour under varying loads and sliding speeds. In the present research, an attempt has been made to develop varying particle-sized reinforced Al alloy composites. Here, the particle size of the reinforcement has been selected based on the wettability effect. If the particle size is too small, there will be clustering among the particles which reduces the interfacial strength. On the other side, if the particle size is too large like above 125 microns causes deboning. Hence, in the current research novelty was made by choosing 45 and 90-micron-sized reinforcement particles to synthesize Al2021 alloy metal composites.

2.0 Experimental Details

2.1 Materials and Fabrication of Composites

Metal composites comprising 5 and 10 weight % of B_4C composites with particle sizes of 45 and 90 microns were produced using the stir casting method. The basic material used was an Al2021 alloy, which was with B_4C particles of 45 and 90 microns in diameter, as shown in Figure 1 (a-c). Table 1 displays the chemistry of the Al2021 used in this experiment.

In this study, a composite of Al2021 alloy was created utilising a stir-casting fabrication process. The composite consisted of 5 and 10 weight per cent of 45 and 90-micron particles. The electrical furnace loads the pre-weighed, small-bit aluminium billet into the graphite crucible. The operation temperature of the electrical resistance boiler is 750°C. The micro B_4C reinforcement particles were preheated by heating them to a temperature of 500°C in a graphite crucible. A digital controller placed within an electrical furnace was used to measure the temperature of the molten aluminium. Solid hexachloro-ethane (C_2Cl_6) was used to remove undesired gases from the molten melt[23,24]. Molten metal was mechanically agitated using a stirrer covered with zirconia, rotating at a speed of 400rpm, for approximately 5 minutes, prior to the introduction of reinforcing particles. The warmed B_4C was added to the molten metal in two stages, one gramme per second, following the creation of a vortex. The



(a) (b)

Figure 1. SEM of **(a)** 45 micron **(b)** 90 micron sized B_4C particles.

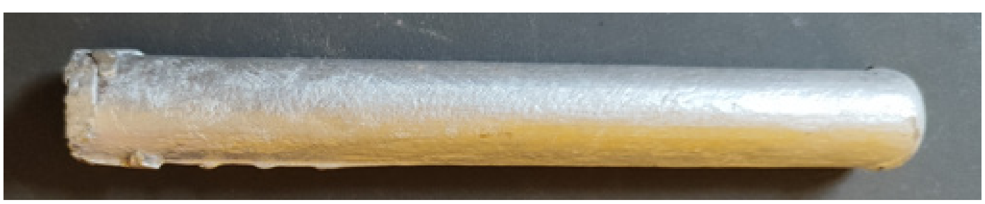


Figure 2. Al2021 alloy with B_4C composite.

Table 1. Chemistry of Al2021 alloy by weight %

Si	Fe	Cu	Fe	Mn	Mg	Zn	T1	Al
0.25	0.23	6.5	1.3	0.4	0.02	0.1	0.1	Balance

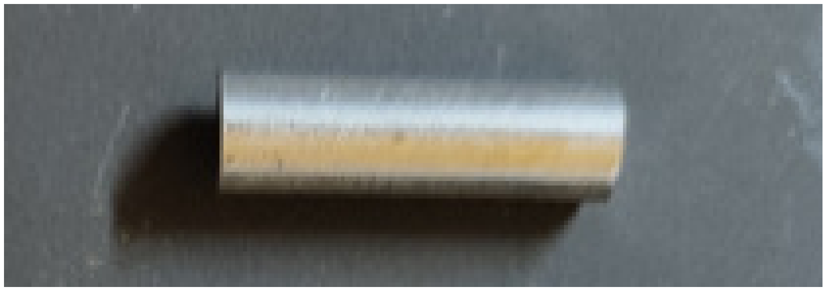


Figure 3. Wear test specimens.

melted mixture is then put onto a cast iron die that has been heated to 730°C. The die is then allowed to cool, as depicted in Figure 2, resulting in samples with a diameter of 15mm. These samples are then used for further processing.

Following the casting process, the specimen undergoes preparation for SEM microstructural analysis to measure the even circulation of particles within the Al202 alloy. Microscopic pictures of Al2021 alloy and Al2021 composites strengthened with different quantities of B_4C are captured. 5mm in height and 15mm in diameter make up the microstructure specimen. 240, 600 and 800 grit paper is used to abrade the sample's surface. To give a more sophisticated finish, the polishing machine's surface is then polished with polishing paper that is micron-sized. The specimens are then cleaned with distilled water to remove any debris, such as soil, that might have collected on the polished surface. The samples are etched using Keller's reagent to produce a surface having different characteristics[25,25].

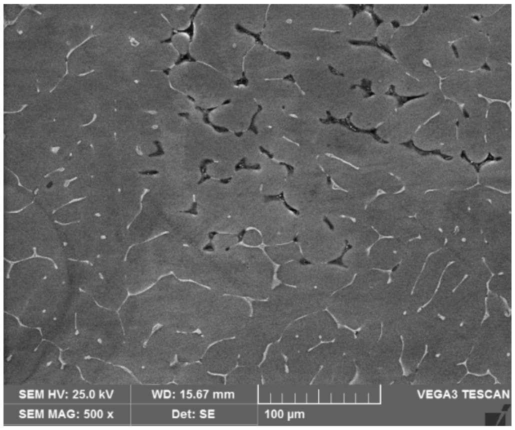
The wear behaviour of the pin-on-disc machine was investigated using DUCOM TR-20LE wear tests. The wear tests were accomplished following the ASTM G99 criteria[27,28]. The specimens used had a diameter of 8mm and a height of 25mm. The counter disc of the wear machine was constructed using EN32 steel. Before commencing the testing process, the disc and test pin surface are thoroughly cleansed using acetone liquid. The studies involved sliding at a speed of 400 revolutions per minute across a distance of 3000 metres. Different loads of 10N, 20N, 30N and 40N were used for these experiments. Tests were conducted at a constant load of 40N, at rotational speeds of 100, 200, 300 and 400 rpm, respectively. During the testing phase, the circular plate was rotated around a fixed point, while the test pin remained motionless and directly facing the steel disc. A digital device was employed to precisely measure the weight of the test pin samples to the level of 0.0001g, which is equivalent to one milligramme. The worn surface was prepared using acetone solvent following each test. Before and subsequent to the surface's erosion, a test pin was measured to ascertain the extent of the wear that had taken place. The material loss data was transformed into wear loss using the measured information. Figure 3 displays the worn specimens utilised in the investigation.

3.0 Results and Discussions

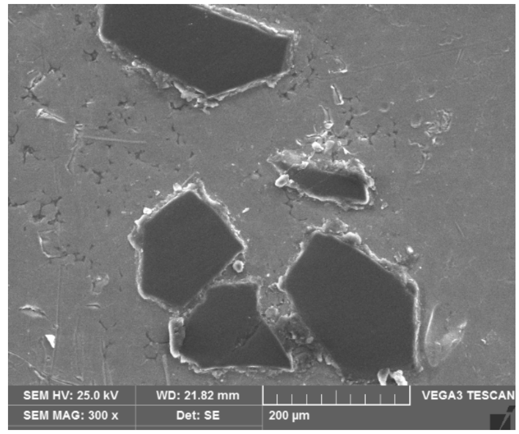
3.1 Microstructural Characterisation

Figure 4(a) illustrates the microstructure of the cast Al2021, clearly showing the absence of B_4C particles. The Scanning Electron Microscope (SEM) images of composites containing 10wt.% of 90 micron B_4C in Al2021 and 10wt.% of 45 micron B_4C in Al2021 are displayed in Figure 4 (b-c).

Figure 4 (a) shows the SEM micrographs of the Al2021 alloy in its as-cast state. The Al2021 alloy has visible grain boundaries devoid of any particulate matter. The micrograph's surface exhibits a lack of pores and cavities, suggesting that the casting procedure is appropriate for manufacturing composites. Additionally, Figure 4(b-c) depicts the micrographs of composites consisting of Al2021 alloy with 10 wt.% of 90 microns size and 10wt.% of 45 micron B_4C particles. The dispersion of particles in these photographs is evident and consistent. The micrographs demonstrate a robust connection between



(a)



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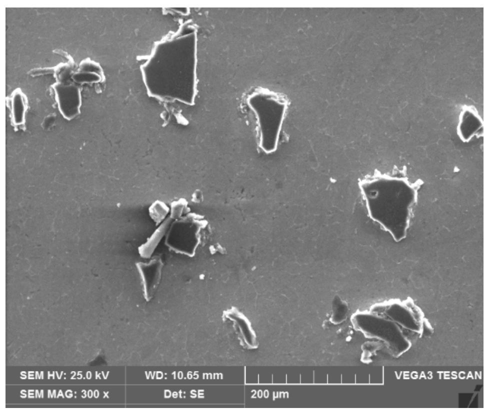
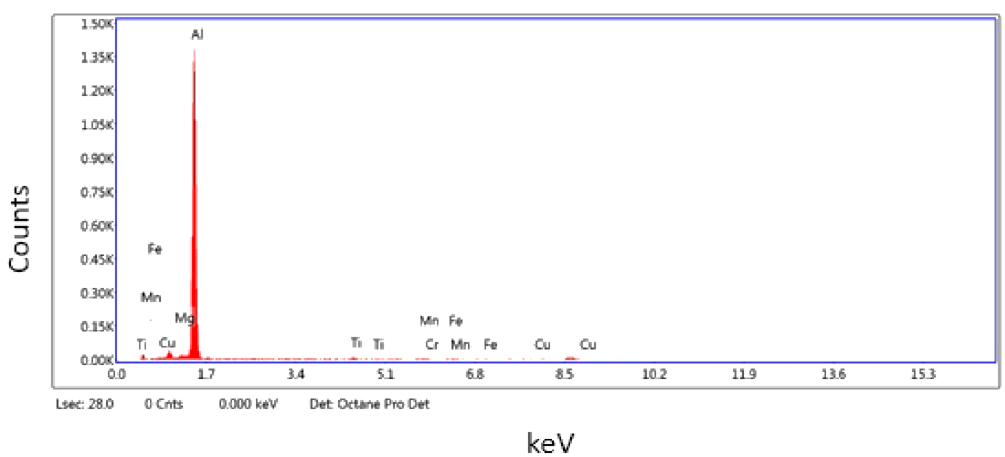


(c)

Figure 4. **(a-c).** SEM micrographs of **(a)** as cast Al2021 **(b)** Al2021 - 10wt.% of 90 micron B_4C **(c)** Al2021-10wt.% of 45-micron B_4C composites.



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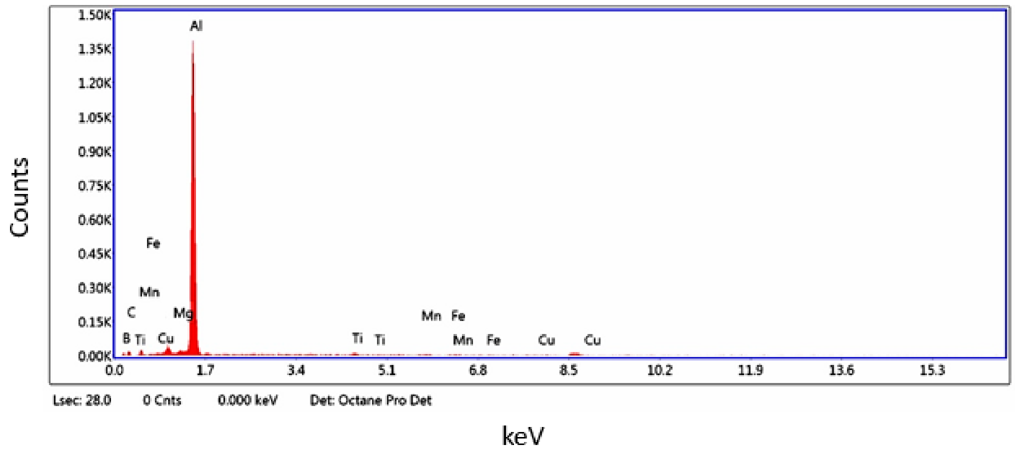

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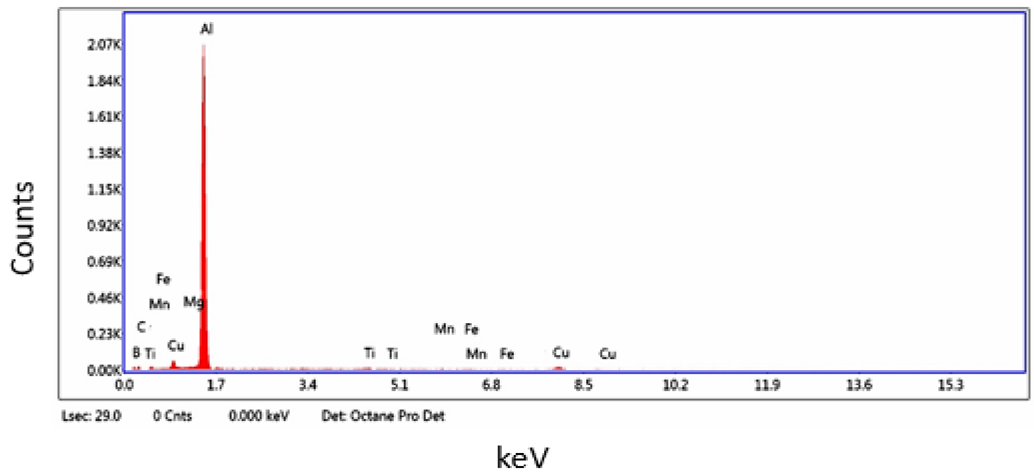


(c)

Figure 5. **(a-c).** EDS spectrums of **(a)** Al2021 alloy **(b)** Al2021 - 10wt.% of 90 micron B_4C composites **(c)** Al2021 -10 wt.% of 45 micron B_4C composites.

the B_4C and the Al20211 alloy. The strong bonding amongst the components contributes to the improvement of the characteristics of Al2021 alloy composites.

Figures 5 (a-c) illustrate the EDS results of three different composites: Al2021 alloy, Al2021 with 10wt.% of 90 micron B_4C and Al2021 with 10wt.% of 45 micron B_4C. Figure 5 (a) displays the components Al and Cu. Cu is the primary element in the 2XXX kind of aluminium[29,30]. In addition, Figure 5 (b-c) displays the presence of boron (B) and carbon (C) components, alongside the Al peaks, indicating the presence of B_4C in the generated Al2021 with B_4C composites.

3.2 Wear Studies

3.2.1 Effect of Load

The wear behaviour of Al2021 and B_4C composites with particle sizes of 90 and 45 microns, respectively was studied under varied loads fluctuating from 10N to 40N. The sliding distance was kept persistent at 3000m, while

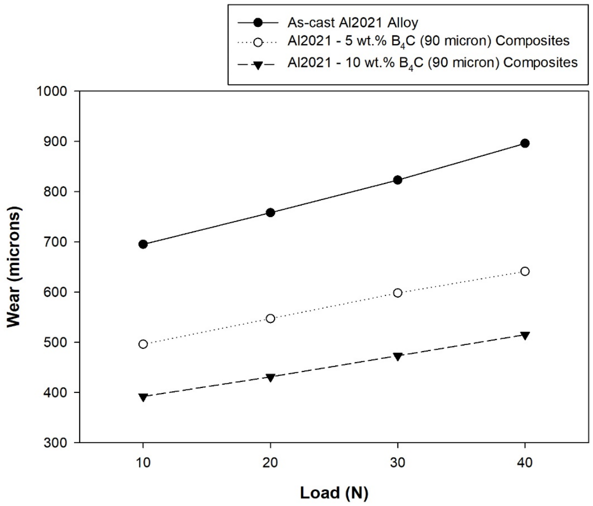


Figure 6. Wear of Al2021 with 90-micron-sized B_4C composites at varying loads.

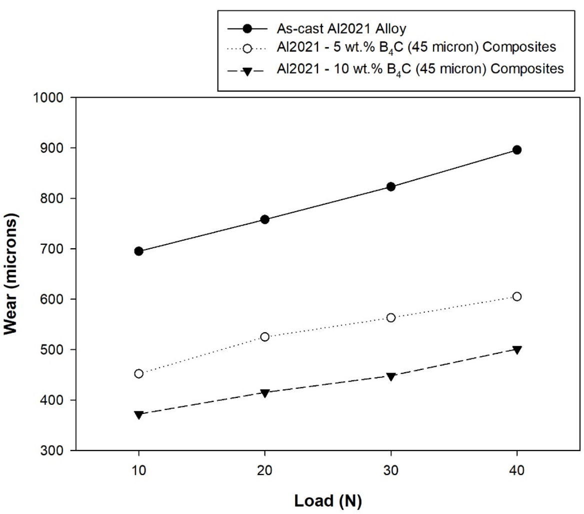


Figure 7. Wear of Al2021 with 45-micron-sized B_4C composites under different loads.

the rotational speed was preserved at 400 rpm. The results are presented in Figures 6 and 7.

Based on Figures 6 and 7, the wear of Al2021 upsurges according to the growth in load on the specimen, ranging from 10 N to 40 N. The greatest level of material erosion is observed when a load of 40 N is applied to both 90 and 45-micron-sized carbide-reinforced composites. When the load reaches its maximum point, both the slithering

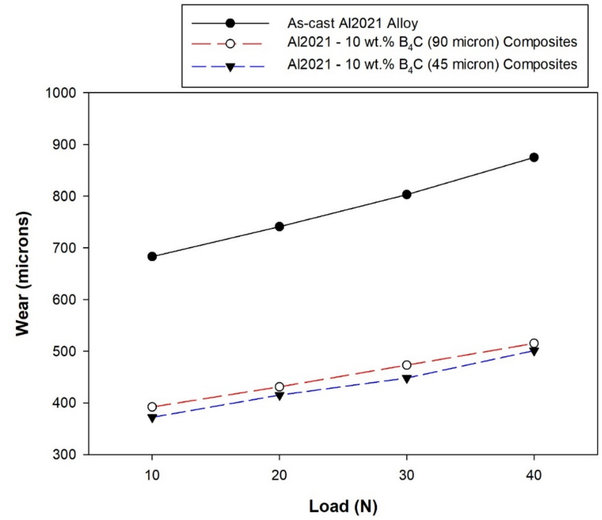


Figure 8. Comparison of wear of Al2021 with 90 and 45-micron-sized B_4C at different loads.

surface and the pin surpass the critical temperature. The material loss of the matrix and B_4C composites exhibits a positive correlation with the upsurge in the load applied to the pin. Recent findings indicate that the inclusion of 5 or 10wt.% of B_4C in the Al alloy effectively decreases the wear loss of the composites. Boron carbide particles are highly effective in reducing the loss in composites due to their high hardness. Ravindranathan *et al.*[31] and their colleagues conducted the wear characteristics of Al composites containing B_4C and graphite. The research utilised Al2219, a material primarily composed of copper, which was strengthened by including two distinct ceramic particulates, 8% boron carbide and 3% graphite by weight. Ultimately, the composites were contrasted with mono-composite materials, revealing that the wear confrontation of the former is significantly higher.

The Al2021 composites revealed greater wear confrontation in contrast to the alloy. The Al2021 reinforced with 45-micron B_4C composites had greater resistance matched to the composites containing 90-micron-sized particles, as illustrated in Figure 8.

3.2.2 Effect of Speed

The wear behaviour of Al2021 and B_4C composites with particle sizes of 90 and 45 microns, respectively, was

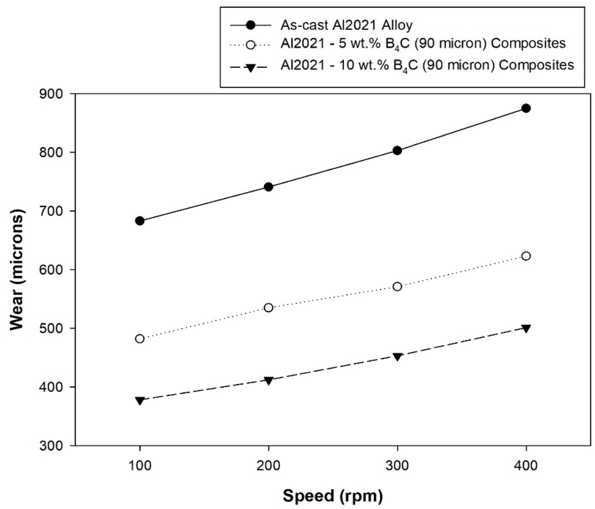


Figure 9. Wear of Al2021 with 90-micron B_4C composites at different speeds.

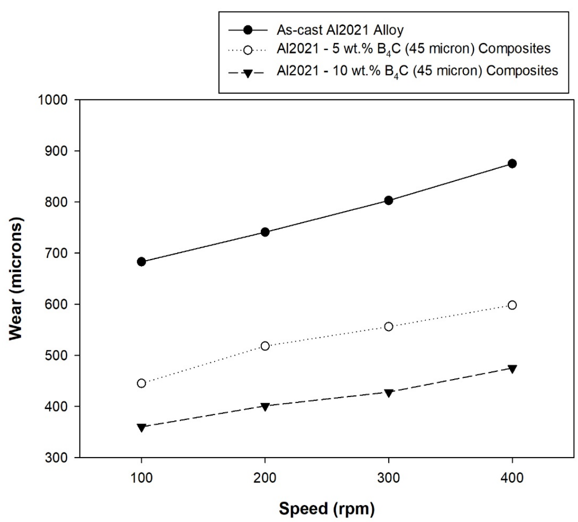


Figure 10. Wear of Al2021 with 45-micron-sized B_4C composites at different speeds.

studied under different speeds of 100rpm and 400rpm. The tests were conducted at a constant load of 40N and a sliding distance of 3000m. The results are presented in Figures 9 and 10.

Figures 9 and 10 separately show, the wear loss of B_4C composites and Al2021 as a function of sliding speed.

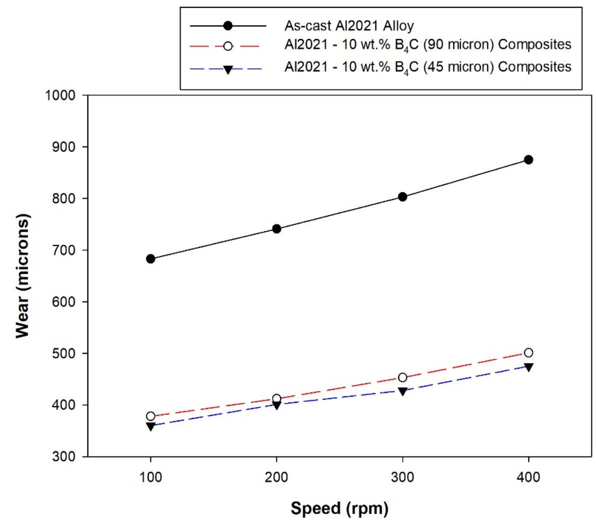


Figure 11. Comparison of wear of Al2021 with 90 and 45-micron B_4C composites at different speeds.

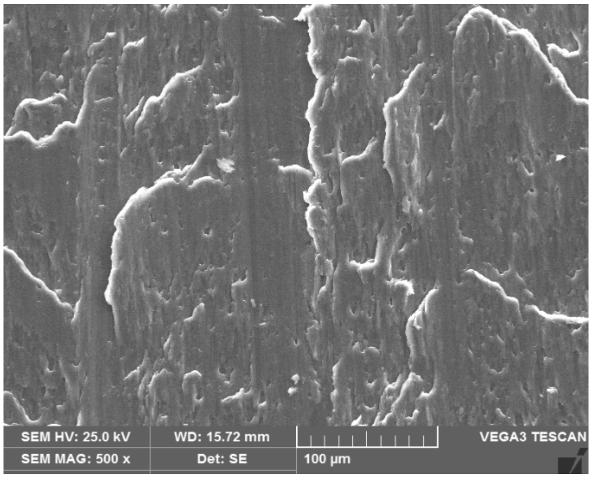
The wear on the Al2021 and its component composites increases between 100 and 400 rpm

Delamination occurs in the Al021 alloy, causing pin fragments to be transferred onto the disc and bigger fragments to be ejected[32,33]. The addition of B_4C to the Al2021 alloy decreases the amount of wear experienced. The addition of B_4C particles to the aluminium composites improves their wear confrontation by creating mechanically mixed layers in contact with the steel disc.

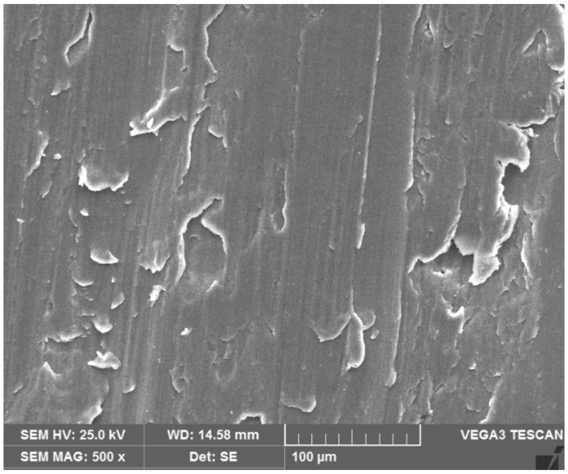
Moreover, when the velocity of sliding escalates, the degradation of the composite material intensifies as a result of the frictional contact at elevated temperatures, leading to increased wear. The test item undergoes deformation due to elevated temperatures caused by increased sliding speeds[34]. Consequently, an increase in delamination occurs, resulting in a higher level of wear[35,36]. In addition, the Al2021 alloy reinforced with 45-micron-sized B_4C materials revealed good wear resistance associated with the composites having 90-micron-sized particles, as illustrated in Figure 11.

3.2.3 Worn Morphology

SEM microphotographs are utilised for the analysis of the worn surface of Al2021 and B_4C composites. The Matrix Al2021 alloy (Figure 12(a)), Al2021 with a 10wt.% of 90 B_4C composite (Figure 12(b)) and Al2021 alloy with a 10wt.% of 45 B_4C composite were



(a)



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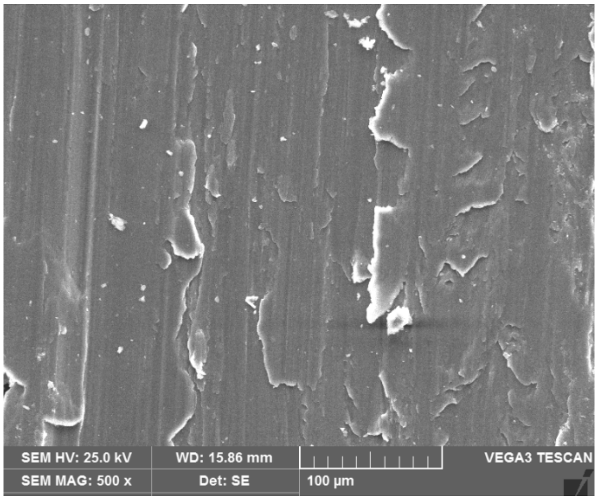

(c)

Figure 12. **(a-d).** Worn surfaces of **(a)** Al2021 alloy **(b)** Al2021 -10 wt.% of 90 micron B_4C composite **(c)** Al2021-10 wt.% of 45-micron B_4C composite.

subjected to testing under a 40N load and 400rpm sliding speed.

Figure 12(a) illustrates the specific parallel edges and depressions that occur in the direction of sliding. Under similar circumstances, the micrograph reveals that the fractures in the Al2021 lattice amalgamation are more profound and extensive compared to the micron composites. Figures 12(b) and 12(c) illustrate that the outer surface of the Al2021 10wt% of 90 and 45 microns B_4C composites, which have been comprehensively employed, exhibit fractures due to the movement of molecules within the composite[37,38]. A substantial layer of composites was established to prevent the primary matrix from making contact with the sliding counterpart. This layer serves to mitigate wear-induced damage. Due to the occurrence of a self-protective layer on the composites, metal-metal contact is effectively prevented[39,40].

4.0 Conclusions

The current study involved the fabrication of Al2021 alloy and Al2021 with 5 and 10 wt.% of B_4C MMCs using the stir casting method, with different particle sizes of B_4C. An assessment was conducted on the microstructure and wear behaviour of the MMCs. The present analysis leads to the following significant conclusions.

- The stir casting method is efficient in producing the Al2021 alloy with 90 and 45-micron-sized B_4C composites containing 5 and 10 weight percent.
- The scanning electron microscope images demonstrate the homogeneous distribution of B_4C particles within the Al2021 alloy. The EDS examination revealed the existence of B_4C particles in fabricated composites.
- The wear resistance of B_4C composites is enhanced by the inclusion of B_4C particles. The Al2021 alloy reinforced with 45 micro-sized B_4C composites demonstrated greater wear resistance associated with composites reinforced 90 micron-sized B_4C.
- The wear performance of Al2021 and carbide-reinforced composites was influenced by both the applied load and speed. The Al2021 composites containing 10wt.% of B_4C particles with a size of 45 microns exhibited enhanced wear resistance.
- The wear surface investigation using SEM revealed the different wear surface mechanisms of the Al2021 and the composites it formed.

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