Materials Physics and Mechanics. 2022;50(3): 373-387
Research article
http://dx.doi.org/10.18149/MPM.5032022_2

Submitted: June 12, 2022
Approved: October 17, 2022
Accepted: November 11, 2022

Synthesis and wear behavior of varying particle sized B_4C reinforced Al2618 alloy composites

G. Veeresha[1], B. Manjunatha[1], M. Nagaral[2]✉, V. Auradi[3], V. Bharath[4]

[1]New Horizon College of Engineering, Bangalore 560103, India

[2]Aircraft Research and Design Centre, Hindustan Aeronautics Limited, Marathahalli, Bangalore, India

[3]Siddaganga Institute of Technology Tumkur, Tumkur 572103, India

[4]Sri Venkateswara College of Engineering, Bangalore 562157, India

✉ madev.nagaral@gmail.com

Abstract. In this work, the influence of reinforcement particle size and weight percentage on the wear behavior of Al2618 alloy composites was investigated. 63, 44 and 20 microns varying sized B_4C reinforced Al2618 composites were synthesized with 4 and 8 wt. % of B_4C using novel two stages stir cast method. Al2618 alloy with 63, 44, and 20 micron sized B_4C composites were studied for microstructural characterization by SEM and EDS. Further, to know the particle size effect on the behavior of Al2618 alloy, hardness, wear, and worn morphology studies were carried out. Wear tests were conducted at varying loads 10 N to 40 N at a constant sliding velocity of 2.08 m/sec, similarly, one more set of was studies were done by varying speeds of 0.52 m/sec to 2.08 m/sec at a constant 40 N load. Microstructural characterization revealed the uniform distribution of particles in the Al2618 alloy and elements were confirmed by EDS spectrums. The hardness of Al2618 alloy was enhanced with 63, 44, and 20 micron sized B_4C particles. With the addition of varying particle sized B4C all the wear properties were improved. Load and speed affected the wear behavior of all the prepared samples. Worn morphology studies confirmed the various wear mechanisms involved in the tested samples.
Keywords: Al2618 Alloy, B_4C, Microstructure, Hardness, Wear Properties, Worn Morphology

***Acknowledgements**. No external funding was received for this study.*

Citation: Veeresha G, Manjunatha B, Nagaral M, Auradi V, Bharath V. Synthesis and wear behavior of varying particle sized B4C reinforced Al2618 alloy composites. *Materials Physics and Mechanics*. 2022;50(2): 373-xxx. DOI: 10.18149/MPM.5032022_2.

1. Introduction

Metal matrix1composites (MMCs) offer1very high temperature1limits, increased toughness, and1strength against1ductility [1,2]. These are used on the skin of a hypersonic aircraft. Some of the metal matrix composites are Al_2O_3 or SiC fibers in Al alloys, glass fibers in lead, SiC coated boron fibers in aluminium matrix, and tungsten carbide particulates in cobalt matrix [3,4]. These have a wide range of application areas like piston rings, connecting rods, battery plates, compressor blades, etc.

Aluminium and its alloys are used in industries and structural activities. Many components of aerospace and space vehicles are made out of aluminium alloys. Parts of aluminium used in industry and structural utility are largely produced by both hot and cold extrusion processes. The components of aluminium used in engineering applications are subjected to variable speeds and required to transfer a large intensity of stress. The most demanding and not easy to intervene in is the situation in space where the environment is free from the atmosphere and lacks the facility of direct corrective measures. The above said peculiar situations demand more directed research exploration of tribo-behavior of aluminium in an adverse environment where temperature and lack of atmosphere exist [5].

Processing of MMC composites can be practiced by different strategies of liquid and solid-state processing including stir casting route, spray deposition, fluid penetration, powder metallurgy course, mechanical alloying, centrifugal casting, diffusion bonding, and in-situ process, and so on, most normal being customary melt stir casting and in-situ method as these are savvy when contrasted with other procedure's [6,7]. A few augmentations of the metal composites idea can be imagined. At present, the prime inspiration for creating MMCs lies in the improvement of mechanical properties. In any case, the upgrade of mechanical properties will be critical. Opportunities for further progression around these incorporate the reinforcement of quickly set matrix to give extra reinforcing, and the blend of broken and consistent reinforcements of the matrix to permit both extra reinforcing and to allow the enhancement of mechanical properties. Broad researcher about programs are required to exhibit these ideas on a research facility scale [8,9].

Tribology is the part of designing that manages the investigation of comparative or different materials which are in sliding contact with one another. There is contact produced when the material is scouring with one another subsequent in wear. There are 3 significant divisions in tribology managing corrosion, wear, and lubrication. Wear is the consequence of two materials' surface scouring against one another [10]. Wear brings about the evacuation of material as powder, consequently decreasing the first measurement. The examination of wear gets significant as it prompts a decline in generally speaking effectiveness of the material when exposed to its applications. The ASTM G99 standard portrays the harming of strong material including nonstop wear of materials, because of the scouring of two surfaces [11,12]. In numerous applications where segments slide each other MMCs are supplanting solid alloys. The sliding activity brings about wear of the parts. Testing the wear surface of the MMCs is thusly basic before changing over into an application. The specialists have broadly utilized pin-on-disc wear mechanical assemblies over the globe to test the wear surface of the MMCs [13].

Harun et al [14] examined the wear of B_4C particulates reinforced Al composites with weight percentages of 5 and 10 wt. %. A close look at the microstructure revealed that the boron carbide was widely dispersed throughout the base matrix. As the weight of the particles increased, so did their wear resistance.

Ruth et al. [15] used the gravity casting method to create a composite Al-Cu-Mg material reinforced with hard AlB_2 particles. Wear volume decreases as boron concentrations increase. The improved antifriction behavior of reinforced elements acting as load-bearing components may be to blame for the decreased wear coefficient in Al-Cu-Mg-B composites containing more AlB_2 particles.

Al7075-SiC-Al_2O_3 hybrid composite tensile and hardness were examined by Suresh et al. [16]. When making the composite, they used a constant weight percentage of SiC reinforcement and a variable weight percentage of Al_2O_3. An increase in hardness of up to 120 VHN and tensile strength of 399 MPa can be achieved by adding reinforcement to Al7075. Because of the effective distribution of reinforcements SiC and Al_2O_3 in the Al7075 matrix, the composite exhibits improved properties.

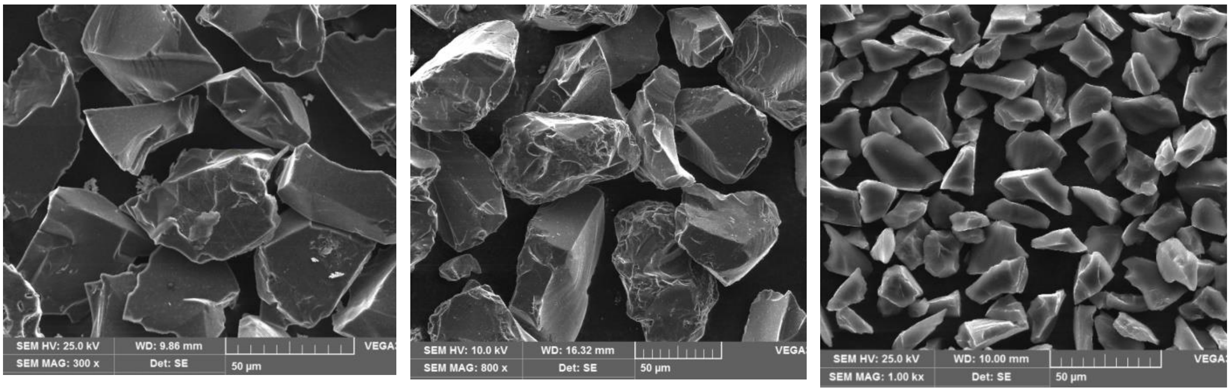
In this, an attempt has been made to develop Al2618 alloy with 4 and 8 wt. % of 63, 44, and 20 micron sized B_4C reinforced composites. Thus developed composites were exposed to microstructural characterization and wear behavior.

2. Experimental details

Materials used and composites preparation. By using the stir method of casting, metal composites with 4 and 8 weight % of 63, 44, and 20 micron sized B_4C composites were created. An Al2618 alloy was employed as the primary material, with B_4C particles having diameters of 63, 44, and 20 microns serving as reinforcements, as illustrated in Fig. 1. Table 1 shows the chemistry of the alloy employed in this experiment.

Table 1. Chemistry of Al2618 alloy by weight %

Zn	Mg	Si	Fe	Cu	Ni	Mn	Cr	Al
0.1	1.8	0.2	1.3	2.7	0.9	0.3	0.1	Balance



(a) (b) (c)

Fig. 1. SEM micro-photographs of (a) 63 micron (b) 44 micron (c) 20 micron sized B_4C particles

An Al2618 alloy composite with 4 and 8 weight percent of 63, 44, and 20 micron particulates was prepared using a stir casting fabrication method in the current study. When the graphite crucible is inserted into the electrical furnace, it is filled with the pre-weighed Al billet that has been cut into small chunks. The temperature of the electrical resistance furnace is 750°C. They were heated to 500°C in a graphite crucible for the preheating of the micro B_4C reinforcement particles. Temperature readings were taken from a digital controller that was placed in an electrical furnace to monitor the temperature of the aluminium molten melt. An agent known as solid hexachloro-ethane (C_2Cl_6) was used to remove the unwanted gases from the molten melt [17]. Using a zirconia-coated stirrer, molten metal was mechanically stirred at 400 rpm for about 5 minutes before reinforcing particles were added. The preheated B_4C particles were fed into the molten metal at a rate of one gram per second in a two-step addition process once the vortex had formed. After the molten melt is prepared, it is poured into a preheated cast iron die at a temperature of 730°C and indorsed to cool, as shown in Fig. 2 with a diameter of 15 mm, to obtain the necessary samples for further processing.

After casting, the specimen is prepared for SEM microstructural investigation to determine the uniform distribution of reinforcing particles in the Al2618 alloy. Microstructure images of Al2618 alloy and Al2618 reinforced composites with various amounts of B_4C are taken. The microstructure specimen has a diameter of 15 mm and a height of 5 mm. The specimen's surface is ground with 240, 600, and 800 grit paper. On the polishing machine, the surface is next polished with 4 micron polishing paper for a smoother finish. Following that, the samples are cleaned with distilled water to remove any foreign particles that may have accumulated on the polished surface, such as dirt or other contaminants. The samples are etched using Keller's reagent to create a contrasting surface.

Fig. 2. Al2618 alloy with B_4C composite

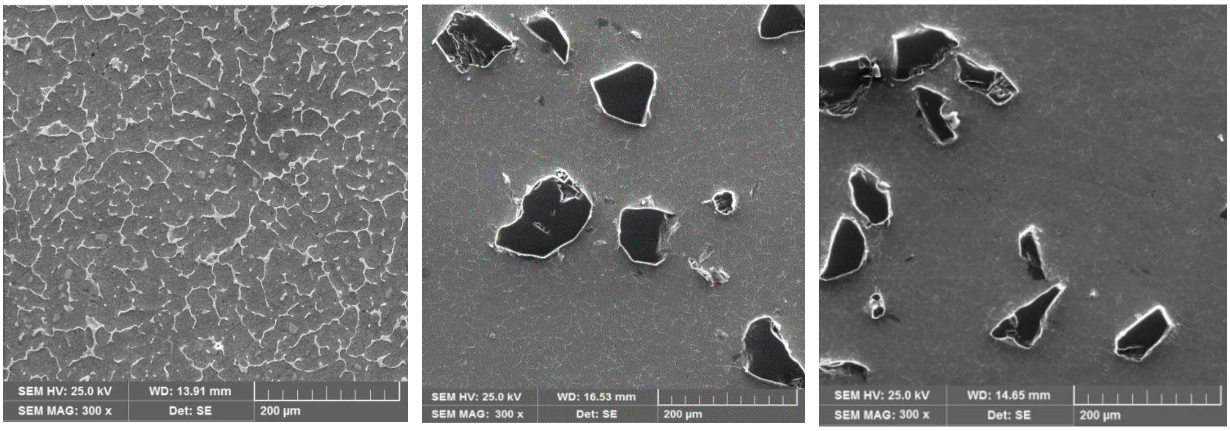
Pin-on-disc machine wear tests were used to study the wear behavior (DUCOM, TR-20LE). According to ASTM G99 standards [18], the dry sliding wear tests were conducted on both reinforced and unreinforced materials with an 8-mm diameter and 30-millimeter height. EN32 steel was used in the counter disc of the wear machine. The disc and test pin surface are cleaned with acetone liquid before testing begins. Sliding at 2.08 m/sec at 2000 m distance and 10 N, 20 N, 30 N, and 40 N loads were used for the various experiments. At 40 N constant loads, tests were conducted at 0.52, 1.04, 1.56, and 2.08 m/sec, respectively. During testing, the circular plate was pivoted while the test pin was kept opposite and stationary to the spherical steel disc. A digital electronic machine was used to accurately measure the weight of the test pins samples to the milligramme level of 0.0001 g. The worn surface was cleaned with acetone liquid after each test. Before and after the surface had been worn, a test pin was weighed to determine how much wear had occurred. The weight loss information was transformed and converted into volumetric wear loss using the measured data. In Figure 3 you can see the wear test specimen used in the study.

Fig. 3. Wear test specimen

3. Results and discussion

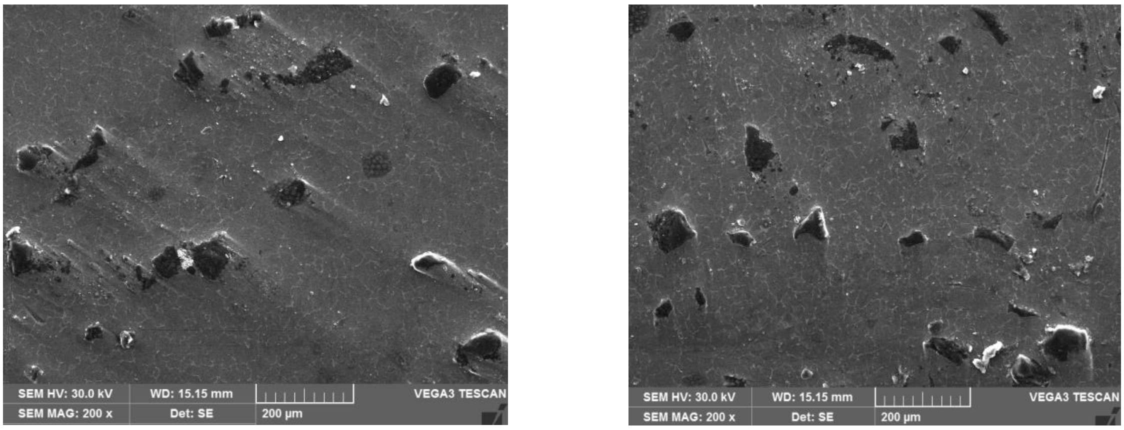
Microstructural characterization. The microstructure of the cast Al2618 alloy is depicted in Fig. 4 (a), and it is obvious that no B_4C particles are present. SEM microstructures of Al2618-4 wt. % of 63 micron B_4C, Al2618-8 wt. % of 63 micron B_4C composites are shown in Fig. 4 (b-c). Similarly, SEM micrographs of Al2618-4 wt. % of 44 micron B_4C and Al2618-8 wt. % of 44 micron B_4C composites are shown in Fig. 5. SEM micrographs of Al2618-4 wt. % of 20 micron B_4C and Al2618-8 wt. % of 20 micron B_4C composites are shown in Fig. 6.

Figure 4 (a) is demonstrating the SEM of as cast Al2618 alloy. In the Al2618 alloy grain boundaries are visible properly without any particles. The surface of the micrograph is free from pores and cavities which indicate the casting method is suitable for the preparation of composites. Further, Fig. 4(b-c) are representing the micrographs of Al2618 alloy with 4 and 8 wt.% of 63 micron B_4C particles composites. The particles distribution is clear and uniform in these images. Similar observations are made in Fig. 5 and Fig. 6 which are showing SEM micrographs of Al2618 alloy with 4 and 8 wt. % of 44 and 20 micron sized B_4C reinforced composites respectively. All the micrographs exhibit strong bonding between the B_4C particles and Al2618 alloy. This strong bonding helps in the enhancement of the properties of Al2618 alloy composites.



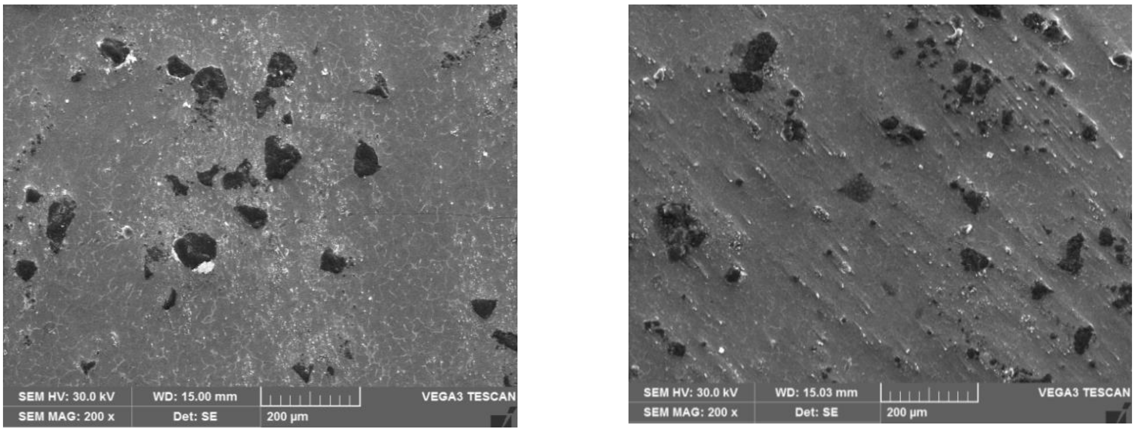
(a) (b) (c)

Fig. 4. SEM micrographs of (a) as cast Al2618 (b) Al2618-4 wt. % of 63 micron B_4C (c) Al2618-8 wt. % of 63 micron B_4C composites



(a) (b)

Fig. 5. SEM micrographs of (a) Al2618-4 wt.% of 44 micron B_4C (b) Al2618-8 wt.% of 44 micron B_4C composites



(a) (b)

Fig. 6. SEM micrographs of (a) Al2618-4 wt.% of 20 micron B_4C (b) Al2618-8 wt.% of 20 micron B_4C composites

Figure 7 are demonstrating the EDS of Al2618 alloy, Al2618 with 8 wt. % of 63 micron B_4C, Al2618 with 8 wt. % of 44 micron B_4C, and Al2618 with 8 wt. % of 20 micron B_4C composites respectively. Fig. 7 (a) is showing Al and Cu elements, this Cu element is the major alloying element in the aluminium 2XXX series alloys [19]. Further, Fig. 7 (b-d) is showing boron (B) and carbon (C) elements along with the Al peaks, which indicates the occurrence of B_4C in the prepared Al2618 alloy with B_4C composites.

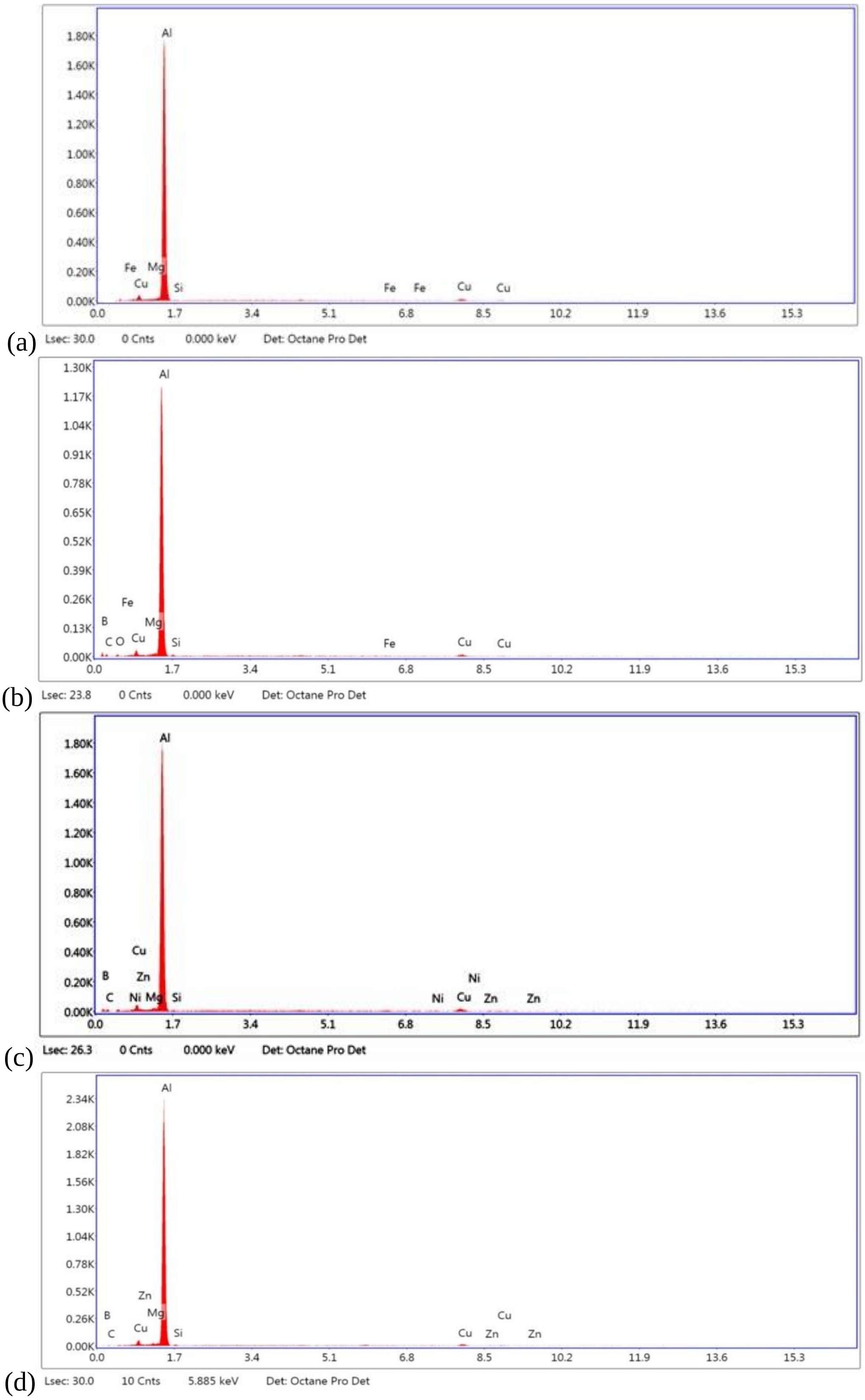


Fig. 7. EDS spectrums of (a) Al2618 alloy (b) Al2618-8 wt.% of 63 micron B_4C composites (c) Al2618-8 wt.% of 44 micron B_4C composites (d) Al2618-8 wt.% of 20 micron B_4C composites

Hardness measurements. Composites of Al2618 alloy with 4, 8, and 12 weight percent of boron carbide particles ranging in size from 63 to 44 to 20 microns are tested for hardness. As shown in Figs. 8, 9, and 10, the composites' hardness linearly increases with increasing percentages of B4C as the particle sizes are reduced. Hardness increases of around 35.8%, 62.6%, and 72.4% were seen in the case of 8 wt.% of 63, 44, and 20 micron sized B_4C reinforced composites, respectively. As a result of B_4C's incorporation into the Al2618 matrix, its hardness has increased significantly. All throughout the matrix, strengthening particles work to prevent the matrix from undergoing plastic deformation because they are stronger and more rigid than the matrix. However, the dispersal of the boron carbide particles throughout the Al2618 matrix is crucial for preventing the matrix from plastically deforming. There may be a significant difference in hardness value at different locations in composite samples if particle distribution is concentrated in one area and absent in others.

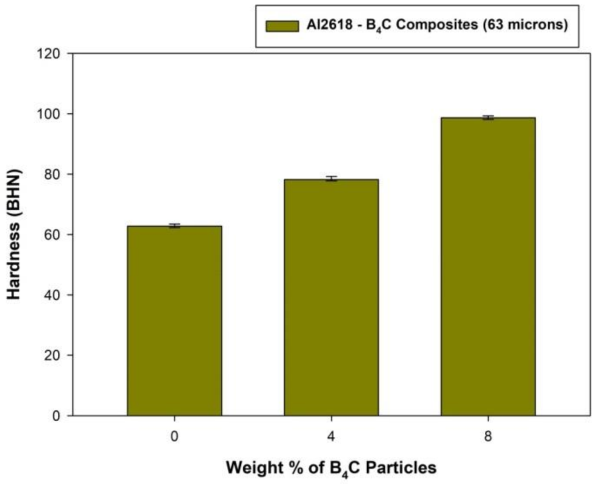


Fig. 8. Hardness of Al2618 alloy with 63 micron sized B_4C composites

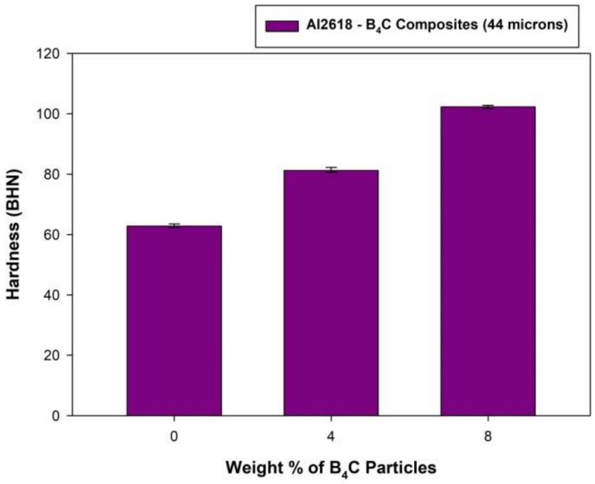


Fig. 9. Hardness of Al2618 alloy with 44 micron sized B_4C composites

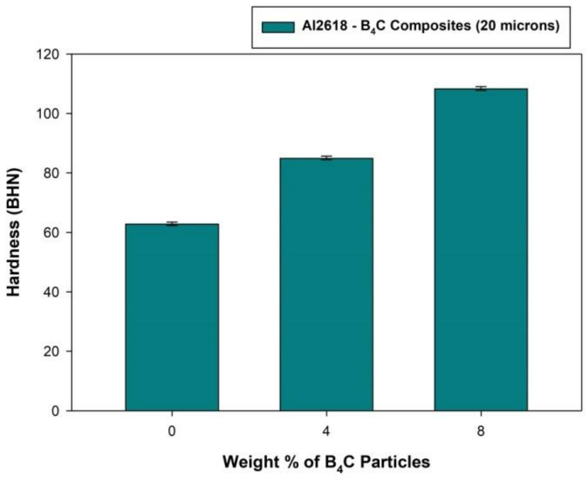


Fig. 10. Hardness of Al2618 alloy with 20 micron sized B_4C composites

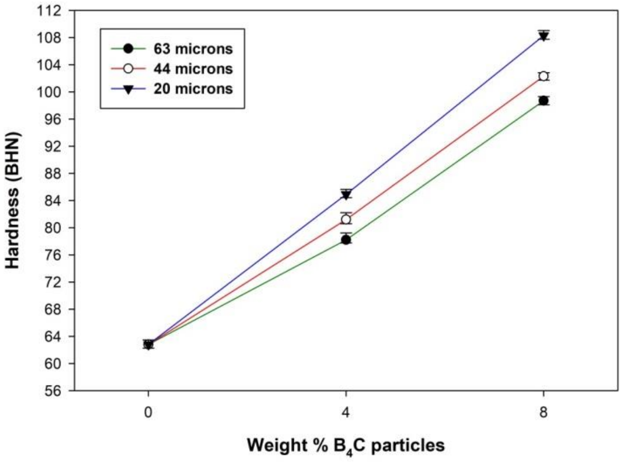


Fig. 11. Comparison of hardness of Al2618 alloy with 63, 44, and 20 micron sized B_4C composites

The hardness of Al2618-B_4C composites as a function of boron carbide weight percentage and particle size is shown in Fig. 11. Figure 11 demonstrates that the hardness of reinforced composites can be improved by decreasing particle size. It's possible to take into account a wide range of variables in situations of this kind. To begin, the smaller, 20 micron-sized particles will have a higher interface than the larger, 63, and 44 micron-sized particles, all of which will result in increased hardness. Compared to a composite reinforced with larger size particles, the surface area of a smaller size particle is greater. As for the second, it's because the distance between particles of different sizes is roughly the same in all cases, though it's shorter for particles between 44 and 63 microns.

Wear studies

Effect of load on volumetric wear loss. Al2618 alloy and 63, 44, and 20 micron sized B_4C composites volumetric wear loss at varying loads of 10 N to 40 N at a constant speed of 2.08 m/sec for 2000 m sliding distance is shown in Figs. 12, 13, and 14.

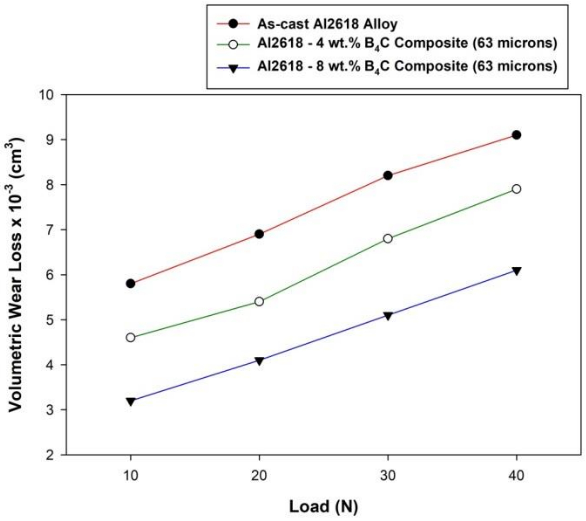


Fig. 12. Volumetric wear loss of Al2618 with 63 micron sized B_4C composites at varying loads

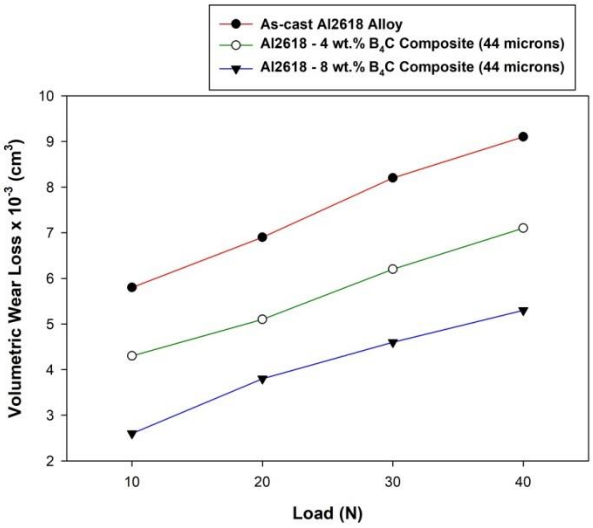


Fig. 13. Volumetric wear loss of Al2618 with 44 micron sized B_4C composites at varying loads

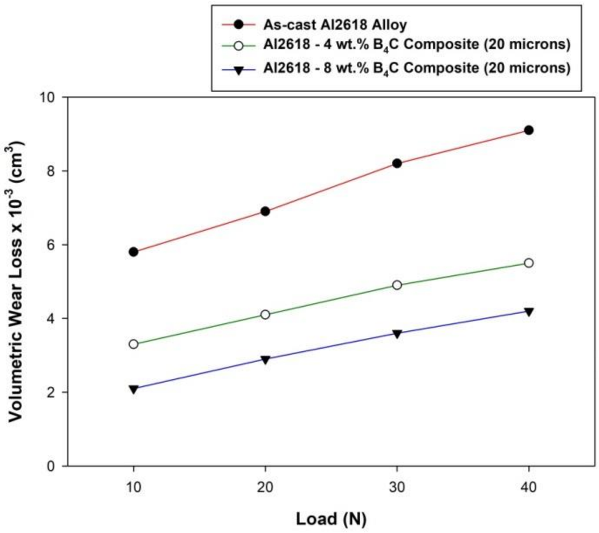


Fig. 14. Volumetric wear loss of Al2618 with 20 micron sized B_4C composites at varying loads

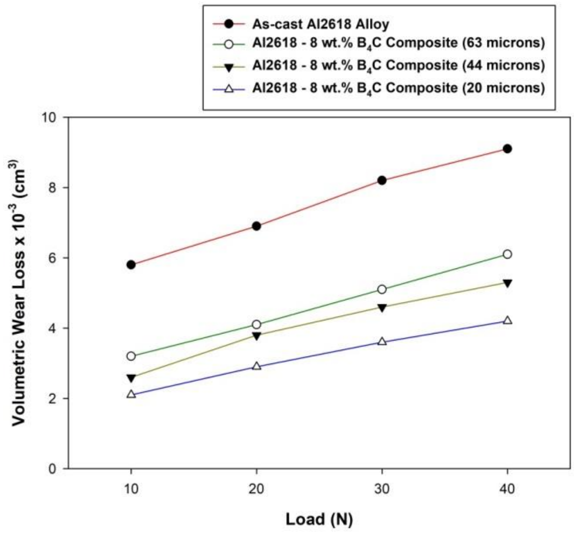


Fig. 15. Comparaison of volumetric wear loss of Al2618 with 63, 44, and 20 micron sized B_4C composites at varying loads

From Figures 12, 13, and 14 wear of Al2618 alloy increases as the load on the specimen increased from 10 N to 40 N. Highest wear of material is observed at an applied load of 40 N in all 63, 44, and 20 micron sized carbide reinforced composites. The temperature of the sliding surface and the pin exceeds the critical value when the load is at its highest point. The matrix alloy and B_4C composites' wear loss increases as the pin's load increases. However, it has been discovered that adding 4 or 8 weight percent of B_4C reinforcements to the matrix alloy reduces the composites' wear loss. When it comes to preventing material loss from occurring in composites, boron carbide particulates serve as an effective barrier because of their high hardness [20]. Thirumalai et al. [21] investigated the wear behavior of B_4C and graphite-reinforced hybrid composites. Hybrid composites exhibited wear resistance as compared to as-cast alloy. Further, Al2618 alloy with 20 micron sized B_4C composites exhibited more wear resistance as compared to the 63 and 44 micron sized particles composites as shown in Fig. 15.

Figures 12, 13, and 14 show that up to 40 N of load, volumetric wear loss increases steadily. Al2618 and Al2618 - B_4C composites at varying particle sizes exhibit an increase in wear loss with increasing load due to a maximum amount of plastic deformation. As can be seen in Fig. 15, the volumetric wear loss in Al2618 alloy and all composites with 4 and 8 wt.% of 63, 44, and 20 micron sized B_4C particles is initially low at 10 N and high at higher load 40 N. Increased material loss occurs at maximum loads during the wear test because metals normally protected by an oxide film experience greater stress. Solid metallic layers make contact when the oxide film between them cracks.

Effect of speed on volumetric wear loss. Al2618 alloy and 63, 44, and 20 micron sized B_4C composites wear behavior at varying speeds of 0.52 m/sec to 2.08 m/sec at a constant load of 40 N for 2000 m sliding distance is shown in Figs. 16, 17, and 18.

Al2618 alloy and B_4C composites volumetric wear loss is shown in Figs. 16, 17, and 18 as a function of the sliding speed. Wear on the Ai2618 and its constituent composites increases as the sliding speed rises from 0.52 m/sec to 2.08 m/sec.

There has been delamination in Al2618 alloy, which has resulted in the transfer of pin fragments onto the disc and larger fragments being thrown out [22]. Adding B_4C to the Al2618 reduces wear loss. Wear resistance on aluminium composites is improved by B_4C particles, which form mechanically mixed layers at their interface with the steel disc.

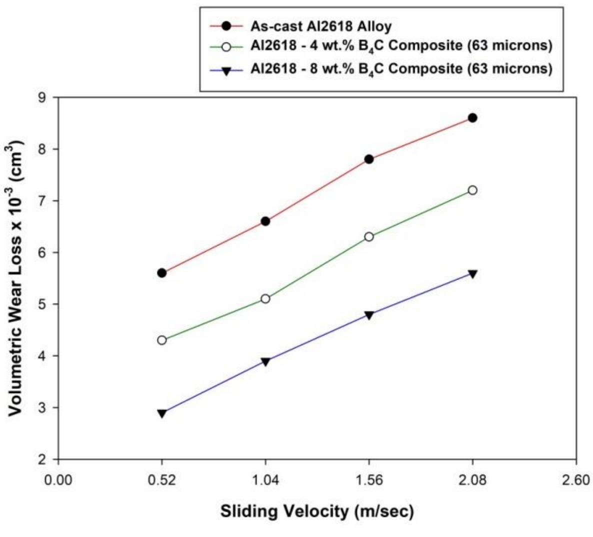


Fig. 16. Volumetric wear loss of Al2618 with 63 micron sized B_4C composites at varying speeds

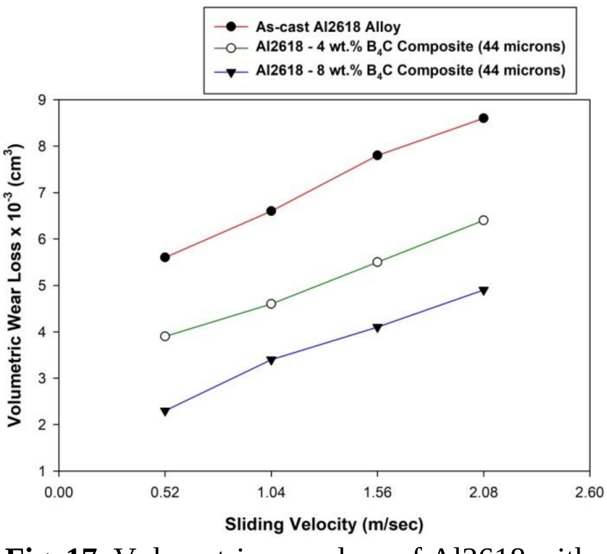


Fig. 17. Volumetric wear loss of Al2618 with 44 micron sized B_4C composites at varying speeds

Figures 16, 17, and 18 show that at lower sliding speeds of 0.52 m/sec, volumetric wear loss is mild, but at intermediate speeds of 1.04 and 1.56 m/sec, the transition from mild to severe begins, and at higher sliding speeds of 2.08 m/sec, severe wear is experienced in both the Al2618 alloy and all produced composites. An increase in wear loss is expected for both the matrix and the composites that result from this. High strain deformation of the subsurface is the primary cause of the rise in wear loss. Fracture and asperity fragmentation areas are increased when the rate of subsurface deformation is accelerated. This results in greater volumetric wear loss and enhanced delamination.

Additionally, as the sliding speed increases, the wear loss also increases due to the softening of the composite due to rubbing action at higher temperatures. Due to higher sliding speeds, the test piece deforms as a result of the increase in temperature [23]. As a result, there is more delamination, which leads to more wear [24,25]. Further, Al2618 alloy with 20 micron sized B_4C composites exhibited more wear resistance as compared to the 63 and 44 micron sized particles composites as shown in Fig. 19.

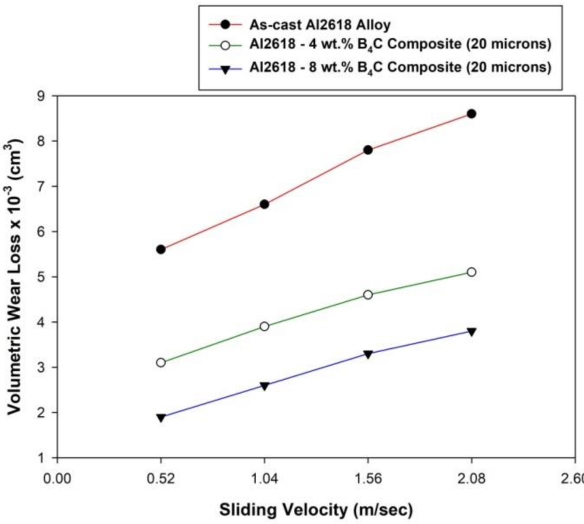


Fig. 18. Volumetric wear loss of Al2618 with 20 micron sized B_4C composites at varying speeds

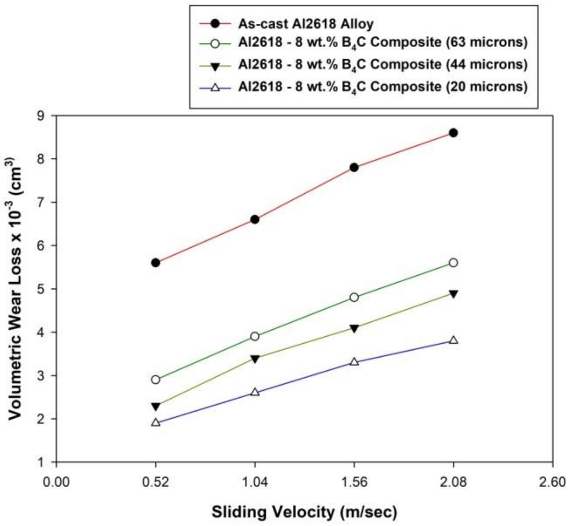


Fig. 19. Comparaison of volumetric wear loss of Al2618 with 63, 44, and 20 micron sized B_4C composites at varying speeds

Figure 19 shows the volumetric wear loss results for all composites with 63, 44, and 20 microns on different sliding speeds. The volumetric wear loss of the composite made with a fine particle is found to be lower than that of the composites made with 44 and 63 micron particles and the unreinforced alloy at all sliding speeds. Possible explanation: at a given mass fraction, a greater number of particles can fit into a given volume if the particle size is decreased. Hardening and low plastic deformation are enhanced by an increase in the number of particles or dislocation barriers [26,27].

Effect of coefficient of friction on volumetric wear loss. Figures 20 and 21 are demonstrating the effect of coefficient of friction on Al2618 alloy and 63, 44, 20 micron sized B_4C reinforced composites at varying loads and sliding speeds respectively. Figure 20 depicts the effect of coefficient friction of 4 and 8 wt. % of 63, 44, and 20 micron sized B_4C at varying loads of 10 N to 40 N, constant speed of 2.09 m/sec. The coefficient of friction is high in the case of as-cast Al2618 alloy compared to all other produced composites. Further, the coefficient of friction is increased as load increased from 10 N to 40 N for all composites with 63, 44 and 20 micron sized composites and unreinforced alloy. The increase in coefficient of friction is mainly due to the more plastic deformation of produced composites at higher loads. There is a decrease in the coefficient of friction as the particle size of the reinforcement decreases. The lowest coefficient of friction is observed in the case of Al2618 alloy with 8 wt. % of 20 micron sized B_4C reinforced composites. The smaller contributes have more particle distribution in the base and the distance between the particles is lesser which creates more resistance to friction.

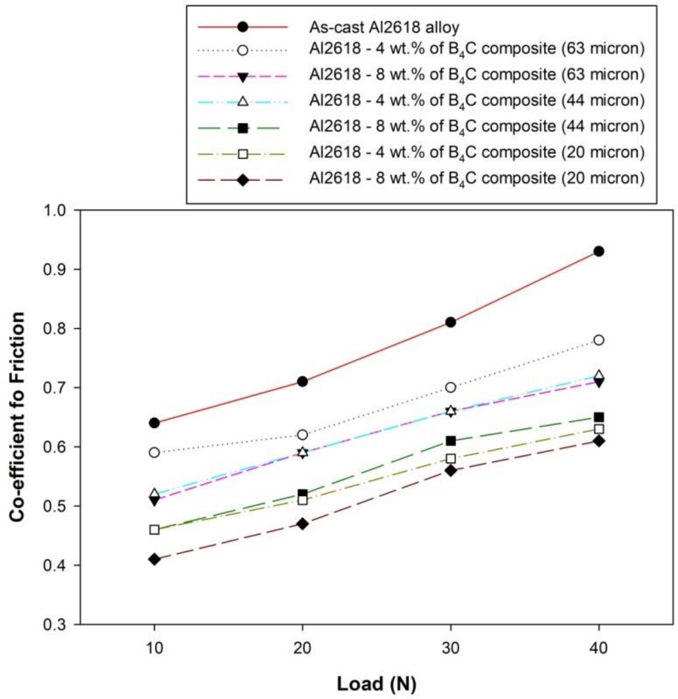


Fig. 20. Comparaison of co-efficient of friction of Al2618 with 63, 44, and 20 micron sized B_4C composites at varying loads

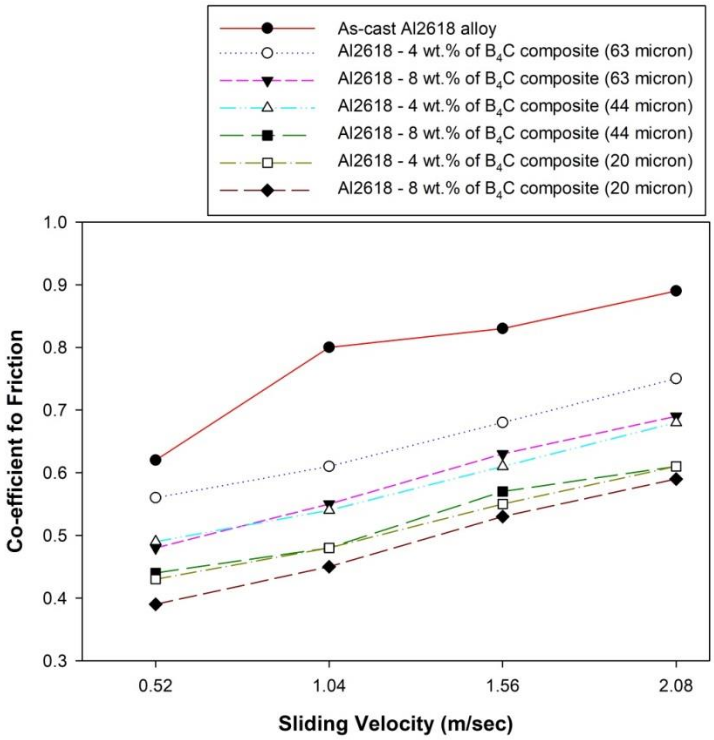
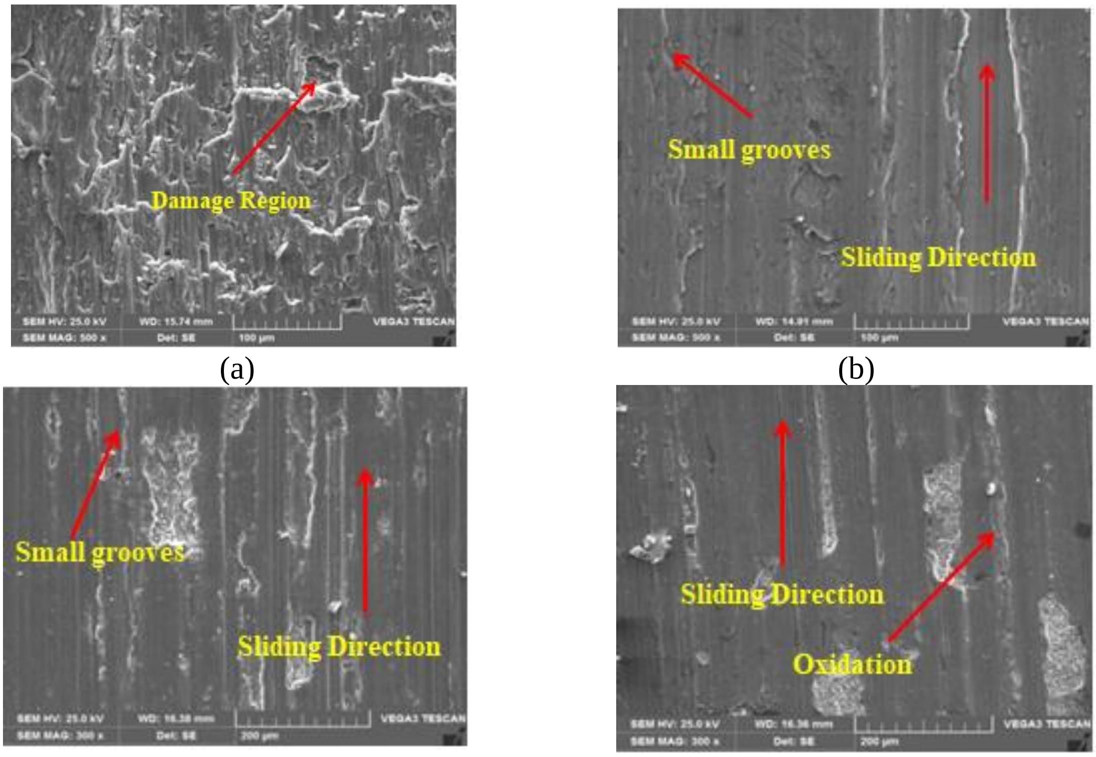


Fig. 21. Comparaison of coefficient of friction of Al2618 with 63, 44, and 20 micron sized B_4C composites at varying speeds

Figure 21 depicts the effect of coefficient friction of 4 and 8 wt. % of 63, 44, and 20 micron sized B_4C at varying sliding speeds of 0.52 m/sec to 2.08 m/sec, the constant load of 40 N. The coefficient of friction is high in the case of as-cast Al2618 alloy compared to all other produced composites. Further, the coefficient of friction is increased as sliding speed increased from 0.52 m/sec to 2.08 m/sec for all composites with 63, 44 and 20 micron sized composites and unreinforced alloy. Further, coefficient of friction is lesser in the case of 8 wt. % of 20 micron sized particle reinforced composites.

Worn morphology. SEM microphotographs are used to examine the worn surface of Al2618 alloy and B_4C reinforced composites. Matrix Al2618 alloy (Fig. 22(a)), Al2618 with 8 wt.% of 63 B_4C composite (Fig. 22(b)), Al2618 with 8 wt.% of 44 B_4C composite and Al2618 with 8 wt.% of 20 B_4C composite tested at 40 N load and 2.08 m/sec sliding speed.



(c) (d)

Fig. 22. Worn surfaces SEM micrographs of (a) Al2618 Alloy (b) Al2618-2 wt. % B_4C (c) Al2618-4 wt. % B_4C (d) Al2618-6 wt. % B_4C (e) Al2618-8 wt. % B_4C composites with 20 micron particles

Figure 22(a) shows the particular edges and depressions that run parallel to each other in the sliding direction. Under comparable conditions, the micrograph shows that the cracks in lattice combination Al2618 are deeper and more widespread than in micron composites. Figures 22(b), 22(c), and 22(d) show that the well-used outer surface of the Al2618-8 wt. % of B_4C composite has a break as a result of the sliding of oxide molecules in the reinforced composite. To prevent the basic matrix from coming into contact with the sliding partner, a thick layer of composites was created. This layer helps to reduce wear damage [28,29]. Since metal-metal contact is suppressed by the self-protective layer on the composites, these results in the metal-metal contact being prevented.

4. Conclusions

The stir cast route effectively produces the Al2618 alloy with 63, 44, and 20 micron sized B_4C particles MMCs with 4 and 8 wt. %. The SEM micrographs show that the B_4C particles are dispersed uniformly in the Al2618 alloy. The EDS study exposed the occurrence of B_4C particles in manufactured composites. The hardness of Al2618 alloy has increased with the addition of 63, 44, and 20 micron sized B_4C particles. Further, the highest hardness is found in the 8 wt. % of 20 micron sized boron carbide reinforced composites. B_4C reinforced composites wear resistance increased with the addition of B_4C particles. Al2618 alloy with 20 micron sized B_4C composites exhibited greater wear resistance as compared with 63 and 44 micron sized B_4C reinforced composites. The load and sliding speed impacted the volumetric wear loss and coefficient of friction of Al2618 alloy and its 63, 44, and 20 micron sized B_4C reinforced composites. Al2618 alloy with 8 wt. % of 20 micron sized boron carbide particles reinforced composites exhibited lesser wear loss and low coefficient of friction. The various wear surface mechanisms of the base alloy Al2618 alloy and produced composites were revealed by wear surface analysis using SEM.

References

1. Madeva N, Shivananda K, Virupaxi A, Shivaputrappa K. Mechanical characterization of ceramic nano B_4C-Al2618 alloy composites synthesized by semi solid processing. *Transactions of the Indian Ceramic Society*. 2018;77(3): 1-4.

2. Siddesh Kumar NG, Shivashankar GS, Basavarajappa S, Suresh R. Some studies on mechanical and machining characteristics of Al2219/n-B_4C/MoS2 nano hybrid metal matrix composites. *Measurement*. 2017;107: 1-11.

3. Pankaj RJ, Sridhar BR, Nagaral M, Jayasheel IH. Mechanical behavior and fractography of graphite and boron carbide particulates reinforced A356 alloy hybrid metal matrix composites. *Advanced Composites and Hybrid Materials*. 2020;3: 114-119.

4. Prasad HN, Srinivas HK, Nagaral M. Characterization of tensile fractography of nano ZrO_2 reinforced copper-zinc alloy composites. *Frattura ed Integrity Strutturale (Fracture and Structural Integrity)*. 2019;48: 370-376.

5. Bharath V, Nagaral M, Auradi V. Preparation, characterization and mechanical properties of Al2O3 reinforced 6061 Al particulate MMCs. *International Journal of Engineering Research and Technology*.2012;1(6): 1-6.

6. Bharath V, Auradi V, Nagaral M, Satish BP, Ramesh S, Palanikumar K. Microstructural and wear behavior of Al2014-alumina composites with varying alumina content. *Transactions of the Indian Institute of Metals*. 2022;75(1): 133-147.

7. Veereshkumar GB. Assessment of mechanical and tribological characteristics of Silicon Nitride reinforced aluminium metal matrix composites. *Composites Part B: Engineering*. 2019;175: 107138.

8. Raj K, Deshpande RG, Gopinath B, Jayasheel H, Nagaral M, Auradi V. Mechanical Fractography and Worn Surface Analysis of Nanographite and ZrO_2-Reinforced Al7075 Alloy Aerospace Metal Composites. *Journal of Failure Analysis and Prevention*. 2021;21: 525-536.

9. Matti S, Shivakumar BP, Shashidhar S, Nagaral M. Dry sliding wear behavior of mica, fly ash and red mud particles reinforced Al7075 alloy hybrid metal matrix composites. *Indian Journal of Science and Technology*. 2021;14(4): 310-318.

10. Rajmohan T, Palanikumar K, Ranganathan S. Evaluation of mechanical and wear properties of hybrid aluminium matrix composites. *Transactions of Nonferrous Metals Society of China*. 2013;23: 2509-2517.

11. Sallahauddin A, Nagaral M, Reddappa HN, Auradi V. Effect of B_4C particulates addition on wear properties of Al7025 alloy composites. *American Journal of Materials Science*. 2015;5(3C): 53-57.

12. Bharath V, Auradi V, Nagaral M, Satish BP. Experimental investigations on mechanical and wear behaviour of 2014Al–Al_2O_3 Composites. *Journal of Bio-and Tribo-Corrosion*. 2020;45: 6.

13. Nagaral M, Auradi V, Kori SA, Veena S. Mechanical characterization and wear behavior of nano TiO2 particulates reinforced Al7075 alloy composites. *Mechanics of Advanced Composite Structures*. 2020;7(1): 71-78.
14. Harun M. Reciprocal sliding wear behaviour of B_4C particulate reinforced aluminum alloy composites. *Materials Letters*. 2010;64: 405-407.
15. Ruth GH, Nayomi P, Oscar MS. A study on tribological characterization of Al-Cu-Mg-B composites subjected to mechanical wear. *Sci Eng Compos Mater*. 2014;21(3): 333-339.
16. Suresh S, Harinath G, Deva Kumar MLS. Mechanical and wear behavior of Al 7075/Al2O3/SiC/mg metal matrix nanocomposite by liquid state process. *Advanced Composites and Hybrid Materias*. 2019;2: 530-539.
17. Nagaral M, Deshapande RG, Auradi V, Satish BP, Samuel Dd, Anilkumar MR. Mechanical and wear characterization of ceramic boron carbide-reinforced Al2024 alloy metal composites. *Journal of Bio-and Tribo-Corrosion*. 2021;7(1): 1-12.
18. Nagaral M, Auradi V, Parashivamurthy KI, Shivananda BK, Kori SA. Dry sliding wear behaviour of aluminium 6061-SiC-graphite particulates reinforced hybrid composites. *IOP Conference Series: Materials Science and Engineering*. 2018;310(1): 012156.
19. Samuel D, Satish BB, Auradi V, Nagaral M, Udaya RM. Evaluation of wear properties of heat-treated Al-AlB_2 in-situ metal matrix composites. *Journal of Bio-and Tribo-Corrosion*. 2021;(2): 1-11
20. Vinod L, Nagaral M, Suthan R, Auradi V. Microstructure and dry sliding wear behavior of Al2219-8 wt% of B_4C particulate Reinforced composites. *International Journal of Applied Engineering Research*. 2015;10.
21. Thirumalai T, Subramanian R, Dharmalingam S, Nachiappan R. Wear behavior of B_4C reinforced hybrid aluminium matrix composites. *Materials and Technologies*. 2015;49(1): 9-13.
22. Prashant SN, Nagaral M, V Auradi V. Preparation and evaluation of mechanical and wear properties of 6061 Al reinforced with graphite particulate metal matrix composite. *International Journal of Metallurgical & Materials Science and Engineering*. 2012;2(3): 85-95.
23. Nagaral M, Auradi V, Kori SA. Dry sliding wear behavior of graphite particulate reinforced Al6061 alloy composite materials. *Applied Mechanics and Materials*. 2014;592: 170-174.
24. Nagaral M, Auradi V, Parashivamurthy KI, Kori SA. Wear behavior of Al_2O_3 and graphite particulates reinforced Al6061 alloy hybrid composites. *American Journal of Materials Science*. 2015;5(3C): 25-29.
25. Nagaral M, Auradi V, Kori SA, Vijaykumar H. Investigations on mechanical and wear behavior of nano Al2O3 particulates reinforced AA7475 alloy composites. *Journal of Mechanical Engineering and Sciences*. 2019;13(1): 4623-4635.
26. Krishna UB, Vasudeva B, Auradi V, Nagaral M. Effect of percentage variation on wear behaviour of tungsten carbide and cobalt reinforced Al7075 matrix composites synthesized by melt stirring method. *Journal of Bio-and Tribo-Corrosion*. 2021;7(3): 1-8.
27. Pankaj RJ, Nagaral M, Shivakumar R, Jayasheel IH. Impact of boron carbide and graphite dual particulates addition on wear behavior of A356 alloy metal matrix composites. *Journal of Metals, Materials and Minerals*. 2020;30(4): 106-112.
28. Zeeshan A, Muthuraman V, Rathnakumar P, Gurusamy P, Nagaral M. Investigation on the tribological properties of copper alloy reinforced with Gr/ZrO_2 particulates by stir casting route. *Materials Today: Proceedings*. 2020;33: 3449-3453.
29. Kumar G, Saravanan R, Nagaral M. Dry sliding wear behavior of nano boron carbide particulates reinforced Al2214 alloy composites. To be published in *Materials Today: Proceedings*. 2021. Available from: https://doi.org/10.1016/j.matpr.2021.03.065.

THE AUTHORS

Veeresha G.
e-mail: veermech87@gmail.com

Manjunatha B.
e-mail: manjunatha.princi@gmail.com

Nagaral M.
e-mail: madev.nagaral@gmail.com
ORCID: 0000-0002-8248-7603

Auradi V.
e-mail: vsauradi@gmail.com
ORCID: 0000-0001-6549-6340

Bharath V.
e-mail: bharathv88@gmail.com