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An Experimental Investigation on Effect of B_4C/CeO_2 Reinforcements on Mechanical, Fracture Surface and Wear Characteristics in Al7075 Hybrid Metal Matrix Composites

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Abstract

Stircasting method is commonly used to efficiently produce high-grade Metal Matrix Composites (MMCs). In the current study, we produced hybrid materials by altering the weight percentages of B_4C, which were 2%, 4%, 6%, and 8%, while maintaining a constant weight percentage of 5% for Cenosphere. Following that, we performed examinations of microstructure, hardness, and tensile properties on both the as-cast materials and the hybrid composites. The microstructural analysis unveiled a consistent dispersion of reinforced particles throughout the base matrix, which was observed in both the as-cast and hybrid composite samples. Highest hardness of 86.55 VHN is achieved for the 8% B_4C + 5% cenosphere reinforced MMCs. The maximum tensile strength of 180.58 MPa is obtained for 6% B_4C + 5% cenosphere reinforced MMCs. Minimum wear loss is observed in the 6% B_4C + 5% cenosphere reinforced MMCs. The ductility of the hybrid composite is decreased as the amount of reinforcement was increased. The tensile fractured sample shows the voids, micro-cracks and particles pullouts. It indicates the strong adhesion between the reinforcements and the matrix material, with bonding influenced by the reinforcement geometry and grain size. The wornout surfaces of the as-cast show the deep grooves, delamination and ploughs on the wear directions. However, hybrid MMCs micro-graphs indicate the deep grooves, particles pullouts and voids in the wear directions. It is due to the high hard reinforcement's presence in the matrix and resists wear of MMCs.

1. Introduction

The term "composite" pertains to a material formed by blending two distinct or closely related materials [1]. Aluminium Matrix Composites (AMC) are renowned for their exceptional characteristics, including enhanced hardness, low density, outstanding wear resistance, and stability at elevated temperatures. These qualities make them highly valuable in applications within the fields of wear and mechanical industries worldwide [2-4]. The utilization of aluminum alloys is increasingly prevalent in commercial sectors owing to their non-toxic properties and ease of recyclability, spanning a range of industries, such as structural, aerospace, and automotive sectors [5-8]. Ceramic particles called cenosphere particulates are formed from fly ash. Increasing the presence of fly ash particles enhances hardness and reduces composite density. Using Cenosphere as a filler in aluminium casting reduces costs, lowers density, and increases hardness, stiffness, wear resistance, and abrasion resistance. Cenosphere also enhances damping capacity and the coefficient of friction, making it suitable for industries such as aerospace and automobile sectors [3]. Extensive research has been focused on developing aluminium composites with various reinforcing combinations. For instance, R. Balachandar et al. [1] investigated the mechanical properties of Al- 6xxx + magnesium composites that were fabricated through the stircasting method, and these composites featured varying weight percentages. Their findings demonstrated that the introduction of AZ31 led to an augmentation in tensile strength, whereas density of the composite decreased as a result of the inclusion of rock dust. Sridhar Raja et al. [9] examined the impact of ceramic particles on the microstructure and mechanical characteristics of Al composites and found that increasing the reinforcing content increased tensile and hardness strength. S. Gopalakrishnan [10] noted that a higher rate of wear was seen when the applied load was increased, while augmenting the concentration of carbide particles decreased the wear rate. Abrar Ahamed and Prashanth T [11] conducted an evaluation of how Cenosphere particles influenced aluminum composites mechanical characteristics and microstructure. Their investigation revealed that an optimal weight percentage of Cenosphere had a positive impact on the tensile strength. Ashoka et al. [12] found that Cenosphere improved the mechanical attributes of aluminium alloys, reaching its peak as the weight percentage of Cenosphere increased in all composite samples. Hamidreza Ghandvar et al. [13] studied the role B_4C addition on microstructure, mechanical, and wear characteristics of Al-20%Mg2Si hybrid metal matrix composite. The results revealed that the addition of B_4C particles up to 10 wt% reduced the nucleation temperature (TN) and growth temperature (TG) of the primary Mg2Si phase. Moreover, the proper amount of B_4C added to Al-20%Mg2Si composite has a significant effect on the microstructural alteration, mechanical, and tribological properties of the composite. Chetan S Patil et al. [14] studied the influence of micro B_4C ceramic particles addition on mechanical and wear behavior of aerospace grade Al alloy composites. The outcome of the experimental investigation revealed that 2% B_4C particulate reinforced composite exhibits better mechanical, physical and tribological properties. 10% B_4C particulate reinforced composite shows clustering and agglomeration at some local regions causing a drop in the properties. However, there is limited information on the wear and mechanical attributes of B_4C and Cenosphere-reinforced Al7075 hybrid MMCs in the literature. This research aims to address this gap by investigating how the addition of B_4C-Cenosphere particles influences the mechanical and wear attributes of Al7075 hybrid composites. Various weight percentages of B_4C (2%, 4%, 6%, and 8%) were used in combination with a constant weight percentage of Cenosphere (5%) to create the hybrid MMCs. Cenosphere is used as a one of the lubricating agents in the MMCs. The cenosphere helps secondary processes like machinability and other processes. So, it has been kept constant at 5% in all the developed MMCs samples. Additionally, this study explores the microstructure, hardness, tensile strength, and wears behavior of Al7075/B_4C-Cenosphere hybrid MMCs. To examine the fracture surfaces of the test specimens used for tensile and wear testing, Scanning Electron Microscopy (SEM) analysis was performed. The novelty of the present work was to examine the study on microstructure, mechanical, wear and fracture behavior of Al7075 Alloy reinforced by B_4C - CeO_2. In this present research work, hybrid composites were developed by stircasting method. Mechanical and wear behavior were studied. Finally, fractured surfaces were examined using SEM analysis.

2. Materials and Methodology

2.1 Reinforcements and Matrix

The primary alloying elements in the precipitation-hardened alloy Al7075 are zinc and magnesium. Alloy 7075 stands out among other alloys due to its lightweight nature, medium to high strength, and exceptional anti-corrosion properties in the presence of air and sea water [16–19]. Boron Carbide (B_4C), an extremely hard particle, is produced through the crystalline complexes of carbon and silicon sand. Since the late 18th century, B_4C has played a crucial role in cutting tools, grinding wheels, and sandpapers. It's also considered as suitable material for the blanket components of fusion reactors and is used in nuclear fuel particulate coatings for high-temperature gas-cooled reactors [6]. Cenosphere is a mineral with silica and alumina content. It behaves like a tiny ball bearing, enhancing workability. Cenosphere possesses qualities of being rigid, hard, lightweight, non-toxic, waterproof, and insulative. It combines the advantages of a spherical shape with lower density, all at an economical cost [20].

2.2 Fabrication of Composites

The stir casting process led to enhance the properties of aluminum composites because of homogenous distribution [21]. So, in the present investigation, stircasting technology was selected for manufacturing of hybrid MMCs. The schematic diagram of stircasting process is showed in Fig. 1. To create these composites, bright extruded rods of Al7075 and B_4C and Cenosphere powders were used. The chemical composition of Al7075 in wt. % is as in Table 1. Properties of the B_4C & CeO_2 are tabulated in Table 2. The process began by melting Al7075 alloy at 700°C in a graphite crucible [22, 23]. The molten metal was then combined with pre-heated (400°C) reinforcements, including B_4C (2%, 4%, 6%, and 8%) with a size of 5-10 micrometers and 5% of Cenosphere with a size of 15 micrometers. 5% of CeO_2 was maintained constant in the hybrid MMCs for weight reduction purposes (waterproof and insulative). Also, CeO_2 acts as a solid lubricant in the matrix. Due to the above unique properties, CeO_2 is widely used for fillers in hybrid MMCs. The reinforcement particles, which had been preheated, were blended with the base alloy during the stirring process. A degassing tablet was used to remove inert gases from the molten aluminum metal matrix. Stirring was carried out at 100 rpm for 2 minutes, after which the molten slurry was poured into a preheated mold [24]. Once solidified, the as-cast samples were removed from the mold. The samples were pre-machined using CNC turning, ensuring a homogeneous dispersion of reinforcement throughout the base material by continuous stirring. The metallic die was then filled with molten metal, and castings were removed from it. CNC machining was employed to manufacture both as-cast and hybrid composites. Test specimens for hardness, tensile, and wear tests were prepared as per the appropriate ASTM standards. For microstructural examination, hybrid MMC samples underwent a polishing process using diamond paste and grit sheets of varying sizes to achieve a smooth surface finish. These samples were then etched using Keller's reagent and allowed to dry in the air. Microstructure studies of the formed hybrid MMCs were conducted using optical microscopy (Nikon E-200). Vickers Micro Hardness testing instrument was used to conduct microhardness testing on the formed hybrid MMCs in accordance with E92-ASTM standards. Specimens measuring 25 mm in diameter and 20 mm in thickness were utilized for hardness assessment. A diamond-shaped indenter was applied with a consistent 5 kg load for duration of 30 seconds. Tensile testing, in accordance with ASTM E8 specifications (gauge length: 50 mm & gauge dia: 10 mm), was performed using a 450 KN weight on Universal Testing Machine (UTM). The results considered were the average values of three tensile test samples with similar compositions, showing fluctuations in tensile strength values of less than 5%. To assess wear loss, the pin-on-disc test equipment was employed following ASTM G99 standards (35 mm length and 6 mm dia). Three wear test specimens with similar compositions were examined, and the mean values were considered, with deviations of less than 5%.

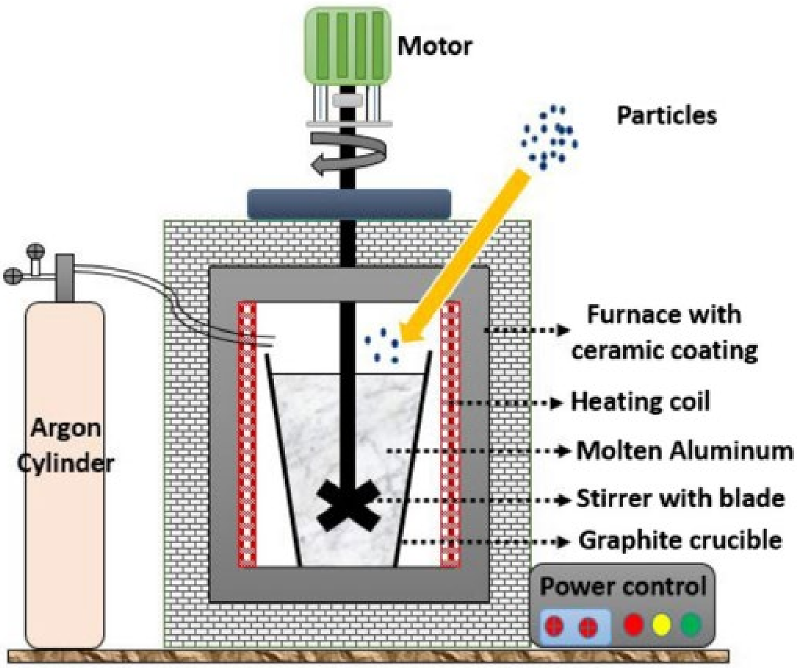


Fig. 1 *Schematic diagram of stircasting process [21]*

Table 1 *Chemical composition of Al7075 alloy (wt. %)*

Content	Al	Cu	Mg	Si	Fe	Mn	Ni	Pb	Sn	Ti	Zn	Cr
Wt. %	Rem	1.480	2.306	0.059	0.256	0.052	0.052	0.023	0.012	0.052	5.424	0.280

Table 2 *Properties of the B_4C & CeO_2*

Elements	Density (g.cm-3)	Melting Point (°C)	Young's Modulus (GPa)	Thermal Expansion Co-eff. x10-6 (°C)	Molar mass (g/mol)
B_4C	2.52	2445	450 - 470	5	55.255
CeO_2	7.6	2340	180	11	172.115

3. Experimental Results and Discussion

3.1 Micro-Structural Inspection

Microstructural inspection was carried out to examine the homogeneous scattering of B_4C and Cenosphere particles were incorporated, yielding enhanced outcomes regarding the mechanical and wear attributes of Metal Matrix Composites (MMCs) [25–27]. The sample used for the microstructural inspection is as shown in Fig. 2. In Fig. 3 (a & b), an optical microscopic perspective of Al7075 and B_4C-Cenosphere reinforced hybrid MMCs is presented. These images distinctly display the existence of reinforcing particles and grain boundaries [28]. Moreover, it is apparent that the reinforced particles within the alloy matrix are evenly dispersed. The outcome shows that continuous stirring led to a consistent and even distribution of hard reinforcements throughout the structure of matrix [29]. Fabricated hybrid MMCs display smaller grains compared to the as-cast alloy, primarily due to the occurrence of strong reinforcements, which contribute to improved grain refinement [30]. In the development of hybrid MMCs, the presence of both B_4C and Cenosphere underscores the significance of a grain refining process. In Fig. 2(a), the microstructure of the matrix alloy (Al7075) is depicted, while Fig. 2(b) illustrates the hybrid composites microstructure (8% B_4C and 5% Cenosphere). It is widely recognized that the incorporation of hard particles into the Al matrix results in improved grain refinement. Due to improved particle wettability, improved reinforcement structure, and uniform dispersion of reinforcements within the base matrix alloy, hybrid composites also show a more durable bond between the base matrix and reinforcements. The strength of the hybrid MMCs is ultimately influenced by these parameters [31, 32].

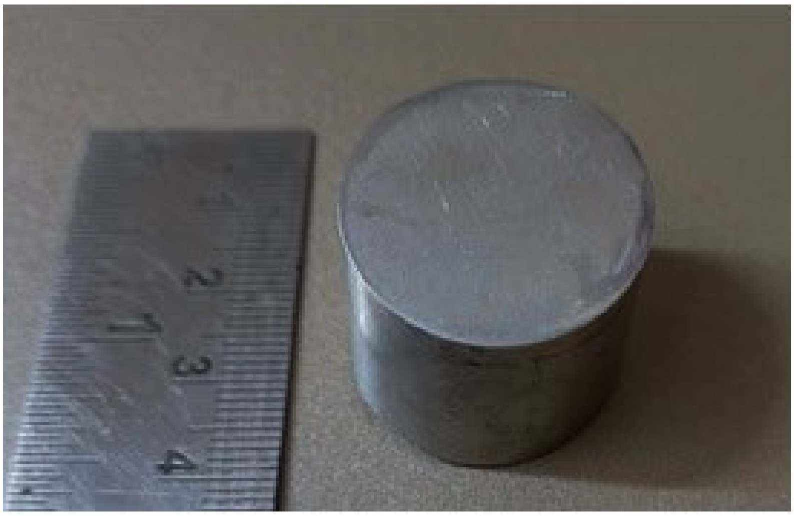


Fig. 2 *Sample used for optical micrograph*

3.2 Hardness

The hardness of the manufactured MMCs was assessed using “Vickers Hardness" testing equipment, as per E92-ASTM standards [33, 34]. A diamond-shaped indenter measuring 10 mm, under 5 kg steady load, was used for 30-second test duration. To obtain average hardness values, hardness examinations were conducted at ambient temperature at three different locations on the surface of the test samples. Fig. 4 shows the sample used for hardness test. Fig. 5 illustrates both the as-cast and B_4C-Cenosphere reinforced composites hardness. When comparing the outcomes to those of the base matrix, it became clear that the inclusion of B_4C and Cenosphere particles improved the hardness of the developed hybrid Metal Matrix Composites. Ceramic particles are instrumental in displacing density during the solidification process in cast composites [35, 36].

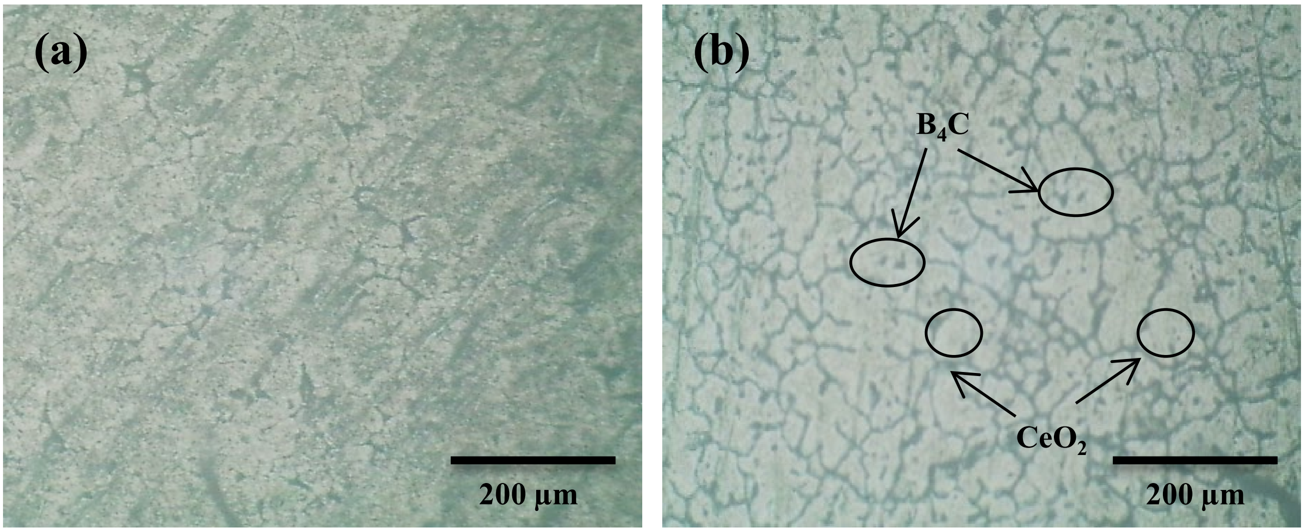


Fig. 3 *Optical micrograph of (a) Ascast; (b) Al7075 reinforced with 8% B_4C and 5% Cenosphere*

Fig. 4 *Sample used for hardness test*

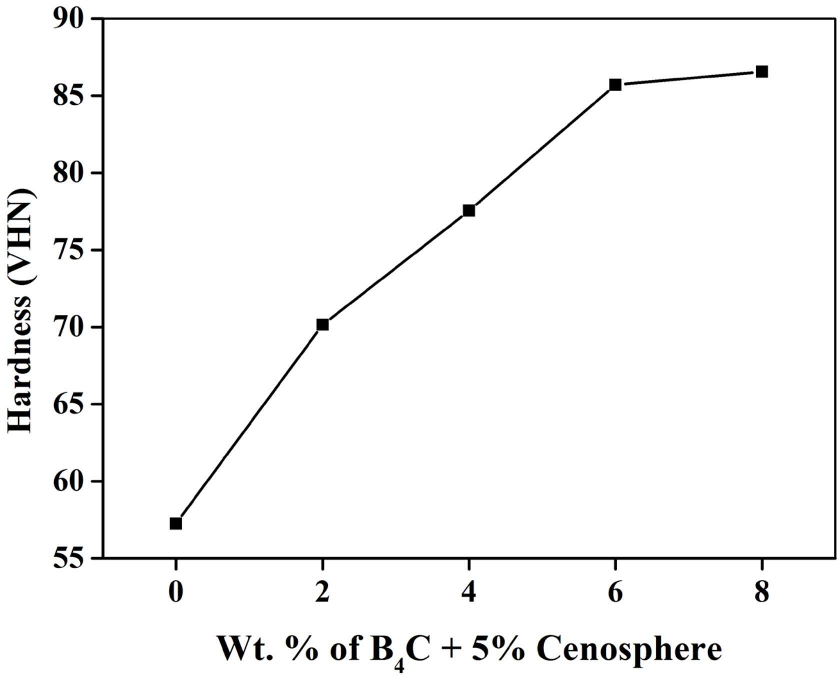


Fig. 5 *Hardness results of as-cast and hybrid MMCs*

The stircasting technique employed in composite fabrication fostered a robust connection between the reinforcement and matrix, which in turn bolstered the material attributes of the hybrid composites. The even spreading of B_4C and Cenosphere particulates within the base alloy heightened overall stress levels, consequently leading to a growth in hardness. According to Xuedan Dong [37], increasing the Cenosphere content improved material strength of the MMCs. In this study, the load was typically borne by the reinforcing ceramic particulates within the soft matrix, providing higher resistance [38, 39]. Hard ceramic particles acted as load-bearing elements in the current study, withstanding the highest applied force before plastic deformation occurred, thereby enhancing the hardness in the created hybrid MMCs [35]. Furthermore, the hardness of hybrid composites, which was added with silica and Cenosphere, had the potential for improvement through grain refinement. Ultimately, the composition of B_4C, Cenosphere, and the existence of hard particulates exerted a substantial influence on the mechanical strength of the produced hybrid MMCs [40]. The hard particulates in B_4C enabled material flow without deformation, and they fractured without additional deformation once critical values were surpassed. In accordance with the Hall-Petch equation, a reduction in grain size resulted in increased hardness [39]. Beyond 6% B_4C, the stircast hybrid MMCs exhibited only a slight elevation in hardness, mainly because of the accumulation of increased weight percentages of reinforcements. This observation aligns with findings from other researchers [37]. Additionally, the restraint of B_4C and Cenosphere particle movement contributed to increased hardness. These robust particles within the matrix, including B_4C and Cenosphere, acted as barriers to dislocation motions and increased the stress required for dislocation movement [11, 12, 15].

3.3 Tensile Strength

Experiments were done employing a Universal Testing Machine (UTM) with a maximum load of 450 kN. The test samples had been prepared in accordance with the ASTM-E8 guidelines [41–43]. Fig. 6 represents the tensile test sample used for the investigation. Fig. 7 presents the tensile behavior of the developed MMCs. The overall mechanical strength of the composites increased by the addition of B_4C and Cenosphere particles.

Int. Journal of Integrated Engineering Vol. 16 No. 5 (2024) p. 100-113

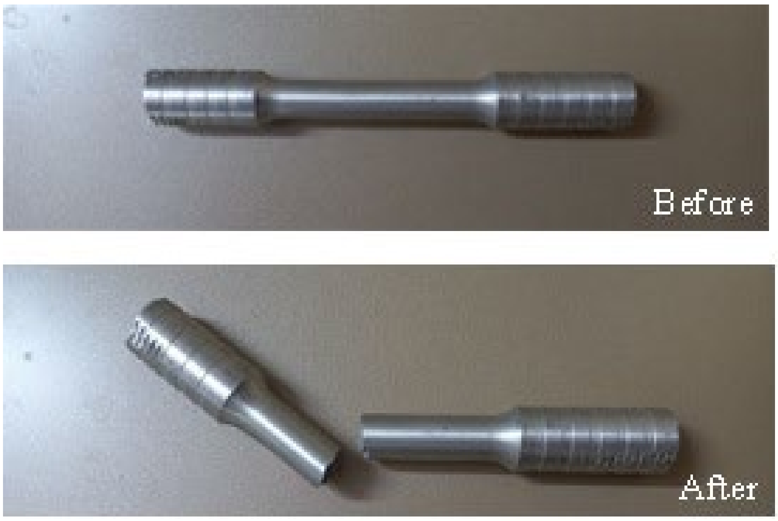


Fig. 6 *Sample used for tensile test*

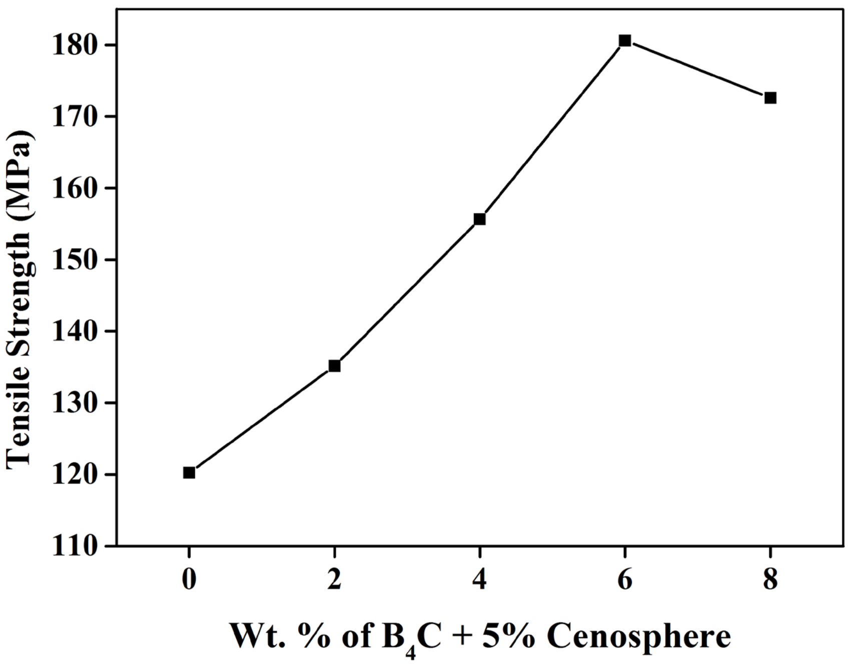


Fig. 7 *Tensile strength of as-cast and hybrid MMCs*

Various factors played a role in enhancing the mechanical performance of the fabricated hybrid Metal Matrix Composites, encompassing the even distribution of particulates, grain size, and the interface bonding between the matrix and reinforcements. Stirring played a crucial role in achieving a more even distribution of reinforcement throughout the base matrix. This resulted in improved bonding between B_4C and Cenosphere particles and the matrix alloy, particularly during solidification. Additionally, mechanisms such as grain refinement, dislocation strengthening, and load transfer were linked to the increased tensile strength. It was found that establishing a robust interface between the material matrix and the hard reinforcement particulates is vital for the efficient transfer of loads within the bulk material. Enhanced bonding among the matrix and reinforcement particles resulted in a more effective transfer of loads from the matrix alloy to the hard reinforcements [28]. The mechanism for strengthening involved recrystallization that could occur during thermo-mechanical processing. The occurrence of hard particulates led to the formation of a deformation zone due to mismatches between the hard particulates and the surrounding material. From the Hall-Petch principles, grain refinement induced by particulate-stimulated nucleation increased the material strength of hybrid MMCs. The higher dislocation density in hybrid MMCs significantly enhanced their strength. Furthermore, the "Orowan-

Strengthening" mechanism contributed to an improvement in tensile strength by impeding dislocation movement through finely dispersed hard particles like B_4C and Cenosphere [39]. These hard particles acted as barriers against dislocations by being uniformly distributed throughout the base matrix, owing to their extreme hardness and non-deformable nature, making dislocation movement, and cutting challenging. In this study, the hybrid MMCs displayed enhanced tensile strength up to a 6% B_4C content. Beyond this point, a decline in tensile strength became evident. This reduction was attributed to the clustering or agglomeration of higher weight percentages of reinforcements [37]. Additionally, restraint to B_4C and Cenosphere particle movement contributed to increased hardness. The hard particles within the matrix, including B_4C and Cenosphere, acted as barriers to dislocation motions and increased the stress required for dislocation movement. The maximum tensile strength of 180.58 MPa is obtained for 6% B_4C + 5% cenosphere reinforced MMCs. The obtained result indicates that, the as-cast shows the lower tensile strength when compared to the 6% of hybrid composites. Further increase of hybrid reinforcement (8%) tensile strength is decreased. In 8% of hybrid composite, it is observed that, the lower tensile strength was found when compared to 6% of hybrid composite. It is due to the brittleness formation at 8% hybrid composites. Fig. 8 depicts the elongation percentage for developed hybrid composites, indicating a slight decrease in ductility as the B_4C and Cenosphere particle content in Al7075 increased [44, 45]. However, the hybrid MMCs still exhibited greater ductility compared to the as-cast alloy. This reduction in ductility was primarily due to casting flaws such as solidification shrinkages and porosities, which served as crack nucleation sites, promoting fracture propagation. Moreover, the inclusion of hard particles in hybrid composites refined the grain, which in turn enhanced ductility. Higher weight percentages of B_4C and Cenosphere particulates caused a further decline in ductility. This reduction was primarily due to the existence of numerous sites where cracks initiated, especially at the contact point between the reinforced material and the base alloy, along with the presence of micro porosities [46].

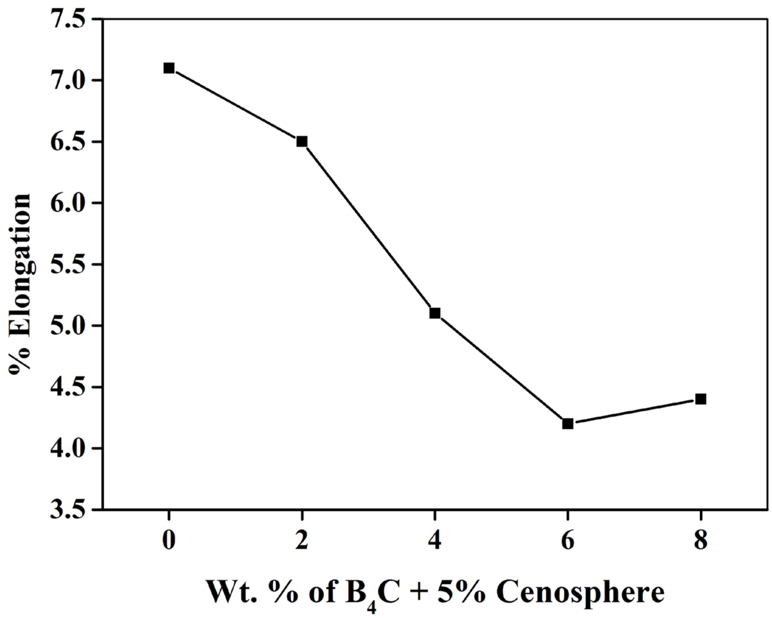


Fig. 8 *Elongation of as-cast and hybrid MMCs*

Elevated weight percentages of reinforcements resulted in substantial debonding at the contact point between the matrix and reinforcement material when subjected to tensile loading, consequently diminishing ductility [41]. Fig. 9 displays tensile fractography images of as-cast and hybrid MMC samples. Extreme ductility in MMC manufacturing was caused from the growth of microscopic pores on fractured material surfaces. as-cast element with a fractured surface exhibited more dimple forms, indicating better ductile strength compared to hybrid MMCs. Fractographic studies revealed that the failure type shifted from ductile to brittle as B_4C and Cenosphere content increased. The dimples on the broken surface and the deformed area are indicators of this shift. More microcracks appeared when there were more hard ceramic reinforcements, which suggests that the material was less ductile. Fractured surfaces often had a higher density of voids and cracks in their topology. A triaxial stress state developed around the robust ceramic particles due to their presence in the soft matrix, which eventually resulted in void formation. This suggests a strong adhesion between the reinforcements and the matrix material, with bonding influenced by the reinforcement geometry and grain size. Dimple sizes indicated a linear relationship between composite strength and dimple size. The broken surfaces of tensile samples provided insights into the mix of hard particles at the interface. Fracture mechanisms included hard particle pullout and fracture, both of which reduced ductility. Voids at the particle-matrix interfaces accelerated the outward spread of cracks from their centers [47-49]. Fig. 10 exhibits the stress-strain curve for both the as-cast material and the hybrid MMCs that were created. The findings suggest that the composite comprised of 6% B_4C + 5% Cenosphere can endure the greatest stress while also showcasing enhanced toughness. Nevertheless, it's worth emphasizing that several methods aimed at enhancing strength resulted in a reduction in ductility. From the Fig. 10, it can be reveal that, the percentage of elongation decreases with increase in % of B_4C reinforcement. Compared the % of deformation of hybrid composites with as-cast are shown in the stress-strain curve (Fig. 10). The obtained result indicates that, the as-cast shows the lower tensile strength when compared to the 6% of hybrid composites. Further increase of reinforcements it is observed that, reduction tensile strength. It is due to the brittleness formation at 8% hybrid composites.

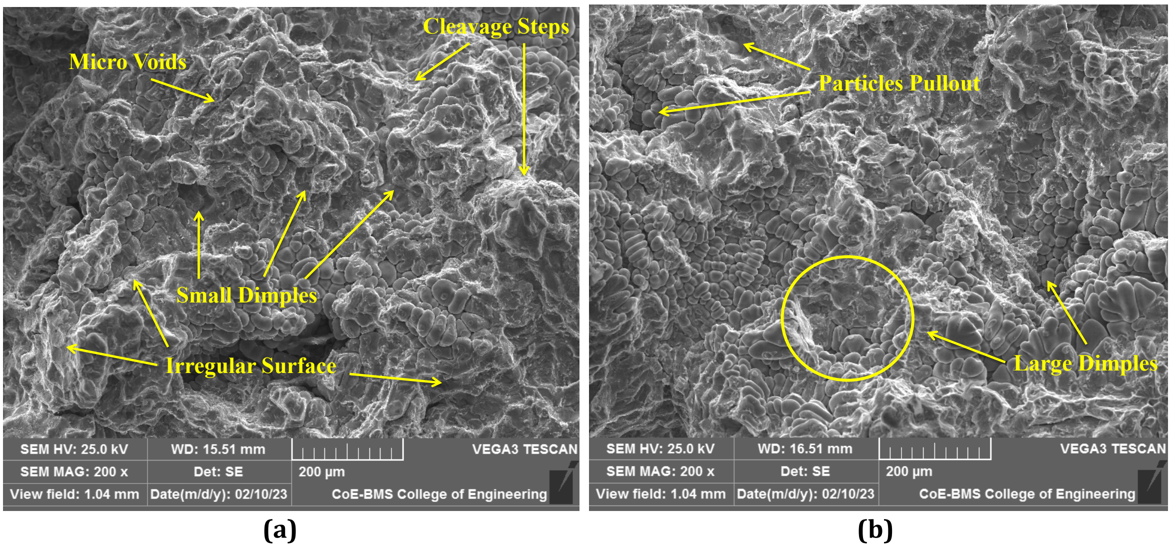


Fig. 9 *SEM of fracture surface of the tensile test samples (a) as-cast; (b) hybrid composites*

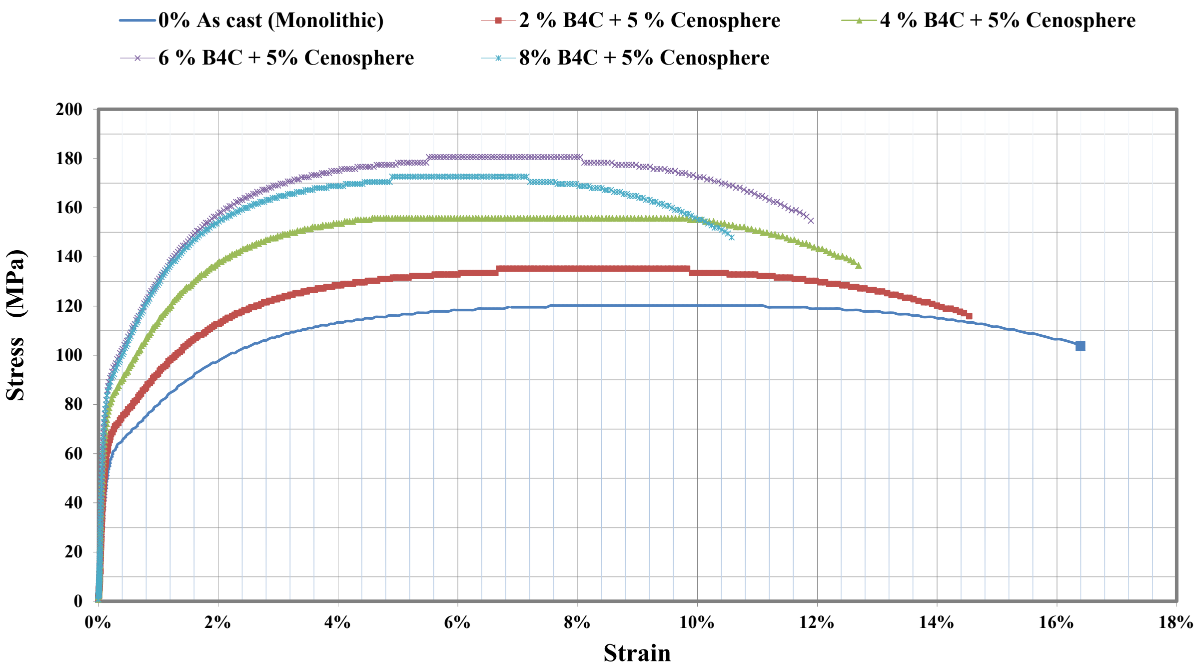


Fig. 10 *Stress strain curve of as-cast and hybrid composites*

3.4 Wear Loss

In accordance with ASTM guidelines, a wear test was conducted by PIN-ON-DISC method by using a steel disc of grade EN32 at a sliding speed of 2 m/s and a continuous load of 30 N. Test samples, measuring 30 mm in length and 8 mm in diameter, were prepared through CNC machining. The wear loss was determined in both as-cast and hybrid composites by measuring weight loss. Fig. 11 represents the sample used for the wear test. The wear pattern of the B_4C and Cenosphere reinforced Al hybrid composite is visually presented in Fig. 12.

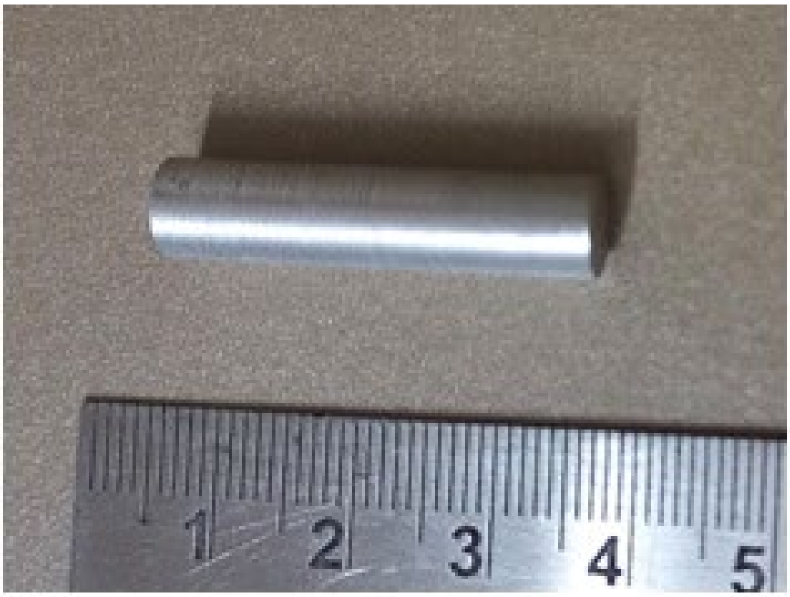


Fig. 11 *Sample used for wear test*

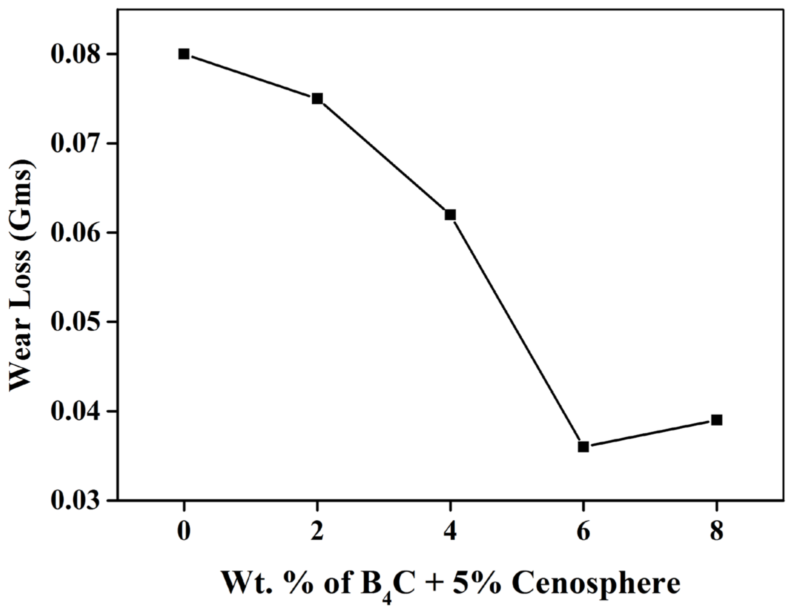
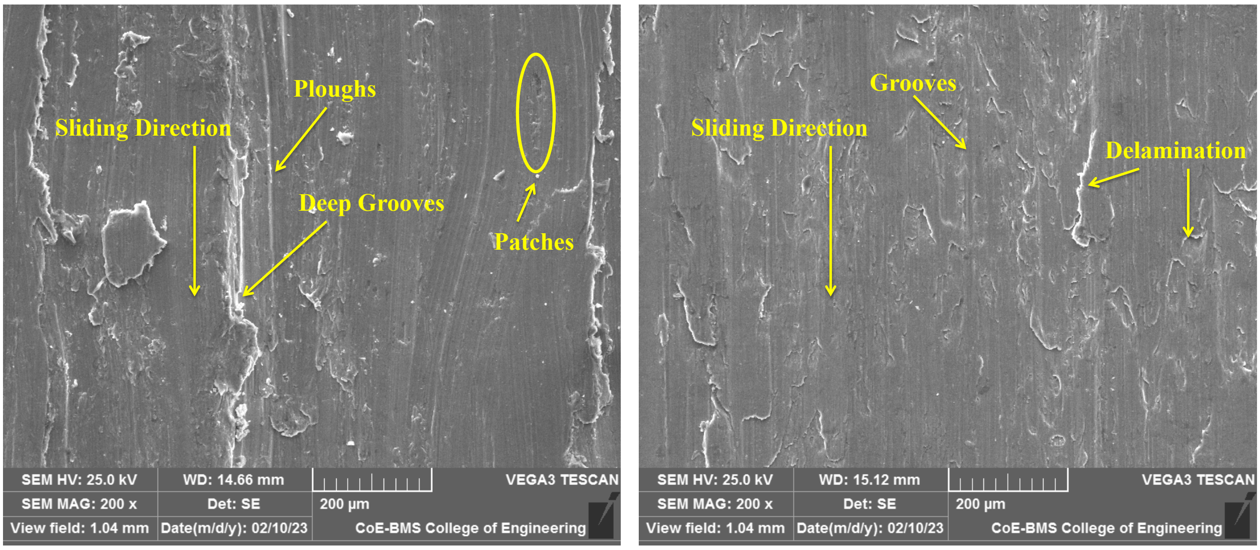


Fig. 12 *Wear loss of as-cast and hybrid composites*

The inclusion of hard particles, such as B_4C and Cenosphere, within the matrix material increased the van der Waals forces, leading to fewer dislocations and enhanced wear resistance [36]. This effect resulted in a higher load-bearing capacity for hard particles, reducing wear loss. It's evident that the combination of B_4C and Cenosphere particles contributed to the hybrid composites losing less weight over time compared to the as-cast alloy. The abrasive nature of B_4C and Cenosphere particles contributed to the increased hardness of the generated MMCs. Furthermore, the finer dispersion of harder shattered particles strengthened the hybrid composite [50]. However, an increase in the percentage weight of reinforcements further intensified wear loss, typically due to particle aggregation. Similar findings have been reported by other researchers [24, 27].

Scanning Electron Microscopy (SEM) analysis was utilized to inspect the sliding wear tracks of the test samples. SEM investigations of the worn surfaces offered insights into the effect of hard particles on the wear attributes of the MMCs. Fig. 13 presents test specimens from both as-cast and hybrid composites, showcasing worn surfaces captured in SEM images. These images unveil grooves of varying diameters on the worn surfaces, likely as a result of worn debris particles behaving as secondary abrasive bodies. The creation of these grooves and tiny patches on the worn surfaces was caused by the inclusion of hard particles in the base matrix, which hindered plastic deformation. The creation of a protective effect on the surface under the applied stress was facilitated by B_4C and Cenosphere particles, greatly improving wear resistance. This study has demonstrated the positive impact of B_4C-Cenosphere particles on the wear attributes of the MMCs. Both the test samples and the counterface were loaded with B_4C and Cenosphere particles, which led to micro-ploughing on the contact surfaces of the hybrid MMCs produced. Notably, there was material transfer between the sliding surfaces, which was evident in the wear surfaces. The matrix's increased wear resistance was largely attributed to the homogeneous distribution of B_4C and Cenosphere materials. SEM images of the fabricated hybrid MMCs in Fig. 13(b) show more uniform sliding wear tracks with significantly less debris, in contrast to Fig. 13 (a), which shows tracks with larger debris content in the produced hybrid MMCs. In contrast to as-cast alloys, hybrid composites have a higher density and better interfacial adhesion between the particles and the base matrix, which contributes to their improved wear resistance. Reduced wear loss was the result of the steel discs inability to penetrate the composite materials due to the presence of ceramic particles [48, 51, 52].



(a) **(b)**

Fig. 13 *SEM fractography of worn-out surface of (a) as-cast; (b) hybrid composites*

4. Conclusions

The primary emphasis of this investigation was on the production and study of hybrid Metal Matrix Composites (MMCs) consisting of Al7075, Boron Carbide (B_4C), and Cenosphere. Stircasting technique was employed for fabrication. The significant outcomes and conclusions drawn from this study can be summarized as follows: Stircasting was used effectively to produce hybrid Metal Matrix Composites. Microstructure analysis showed that the matrix and reinforcement had better bonds and that the boron carbide + cenosphere particles were dispersed uniformly. It was found that hybrid MMCs have higher tensile and hardness strengths than as-cast alloy. Ductility was reduced as cenosphere and boron carbide weight percentages increased. The highest hardness of 86.55 VHN was achieved for the 8% B_4C + 5% cenosphere reinforced MMCs. Maximum tensile strength of 180.58 MPa was obtained for 6% B_4C + 5% cenosphere reinforced MMCs. The fractography study illustrates how the inclusion of harder particles like boron carbide and cenosphere caused a change in failure types from ductile to brittle. The lowest wear loss was observed for the 6% B_4C + 5% cenosphere hybrid composites. Further increase of reinforcement leds to gradual wear taking place. Fractography was used to display the tensile specimen's interior fractured structure. It was observed from scanning electron microscopy research that hybrid Metal Matrix Composites showed fewer fracture initiation. Additionally, there was better enhanced adhesion between the reinforcements and the matrix interface.

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Data Availability Statement (DAS)

The data that support the findings of this study are available within the manuscript.

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Declarations

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design****: Ravikumar M;* ***data collection****: Ravikumar M, Hanumanthe Gowda;* ***analysis and interpretation of results****: Ravikumar M, Umesh G L, Raghavendra S;* ***draft manuscript preparation****: Ravikumar M, Darshan S M, Shivakumar M M, Santhosh Somashekar. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Yusuf, Medi, Lajis, Chan & Shamsudin (2021) Mechanical Properties of Direct RecyclingMetalMatrix Composite (MMC-AlR) AA7075 Aircraft Aluminium Alloy, *The International Journal of Integrated Engineering*. 89-94.

[2] Narayan Nayak, Reddappa, Vijendra Bhat & Ravikumar (2020) Comparative study of effect of sisal fibres in powder and short form on the mechanical properties of polypropylene. *AIP Conf. Proc.* 030014-1-030014-7, https://doi.org/10.1063/5.0022594.

[3] Sreenivasa Iyengar, Sethuramu & Ravikumar (2023) Mechanical, Wear, and Fracture Behavior of Titanium Diboride (TiB_2) - Cerium Oxide (CeO_2) Reinforced Al-6061 Hot-rolled Hybrid Composites, *Frattura ed Integrità Strutturale*, *63,* 289-300.

[4] Anil, Hemavathi & Adeebpasha (2023) Mechanical and fractured surface characterization of epoxy/red mud/fly ash/aluminium powder filled hybrid composites for automotive applications, *Frattura ed Integrità Strutturale*, *64*, 93-103.

[5] Vishal Kumar, Surjit Angra & Satnam Singh (2023) Influence of rare earth elements on aluminium metal matrix composites: A review, *Materials Physics and Mechanics*, *51(2),* 1-20.

[6] Soorya Prakash, Kanagaraj & Gopal (2015) Dry sliding wear characterization of al6061/rock dust composite, *Transactions of Nonferrous Metals Society of China, 25(12)*, 3893-3903.

[7] Arunprasath, Amuthakkannan, Vijayakumar, Sundarakannan, Selwin, Kavitha & Lavish Kumar Singh (2023) Effect of mechanical properties of Al7075/mica powder hybrid metal matrix composite, *Materials Physics and Mechanics*, *51(1)*, 142-150.

[8] Saravanan, Vinod & Tamilarasan (2015) Investigation of wear behavior of Al6061 alloy reinforced with SiC, Al_2O_3 and E-glass fiber, *International Journal of Scientific Engineering and Applied Science, 1(5)* 2015 430-434.

[9] Sridhar Raja, Hemanandh, Mohan Krishna & Muni Sai Preetham (2021) Effect of TiB2 on mechanical properties and microstructural of aluminium composite, *Advances in Industrial Automation and Smart Manufacturing - Lecture Notes in Mechanical Engineering*. 697-703, https://doi.org/10.1007/978-981-15-4739-3_60.

[10] Gopalakrishnan S, Murugan N, Production and wear characterization of Al 6061 matrix TiC particulate reinforced composites by enhanced stir casting method, Composites Part B: Engineering. 43(2) (2011) 302-308.

[11] Abrar Ahamed & Prashanth (2016) Mechanical properties of aluminium 6061 cenosphere composites *Journal of Manufacturing Engineering, 11(4)*, 229-233.

[12] Ashoka, Sharanaprabhu, Kodancha Krishnaraja & Kudari (2018) Experimental processing and the effects of cenosphere on some mechanical properties of Al6061-SiC composites, *AIP Conference Proceedings*, https://doi.org/10.1063/1.5029679.

[13] Hamidreza Ghandvar, Mostafa Abbas Jabbar, Seyed Saeid Rahimian Koloor, Michal Petru, Abdollah Bahador, Tuty Asma Abu Bakar & Katsuyoshi Kondoh (2021) Role B_4C Addition on Microstructure, Mechanical, and Wear Characteristics of Al-20%Mg2Si Hybrid Metal Matrix Composite, *Applied Sciences. 11*, 1-22.

[14] Chetan S Patil, Mohd Imran Ansari, Ras Selvan & Dineshsingh G Thakur (2021) Influence of micro B_4C ceramic particles addition on mechanical and wear behavior of aerospace grade Al-Li alloy composites, *Sadhana, 46(11)*, 1-9.

[15] SunilKumar & Girish (2021) Corrosion behavior of AA7075/E-Glass/Cenosphere hybrid MMC's *International Journal of Mechanical Engineering, 6,* 898-905.

[16] Vasanth Kumar, Keshavamurthy, Chandra S Perugu, Alipour & Siddaraju (2021) Influence of hot rolling on friction and wear behaviour of Al6061-ZrB2 in-situ metal matrix composites, *Journal of Manufacturing Processes*, *69*, 473-490.

[17] Senapati Ajit Kumar, Panda Sasank Shekhar & Mohanty Gopal Krushna (2021) Effect of hot rolling on physical and mechanical properties of Al 6061 alloy-based metal matrix composite. Advances in Mechanical Processing and Design, *Lecture Notes in Mechanical Engineering*, https://doi.org/10.1007/978-981-15-7779-6_27.

[18] Rajasekaran & Sampath (2011) Effect of In-Situ TiB2 particle addition on the mechanical properties of AA 2219 Al alloy composite, *Journal of Minerals & Materials Characterization & Engineering, 10(6)* (2011) 527-534.

[19] Suresh & Shengaga (2012) Aluminium-titanium diboride (Al-TiB2) metal matrix composites: challenges and opportunities, *Procedia Engineering, 38,* 89-97.

[20] Kousik Kumaar, Kannan, Boopathy & Surendar (2017) Fabrication and computational analysis of cenosphere reinforced aluminum metal matrix composite disc brakes, *International Journal of Mechanical Engineering and Technology, 8(6)*, 553-563.

[21] Priyaranjan Samal, Surekha & Pandu R Vundavilli (2021) Experimental Investigations on Microstructure, Mechanical Behavior and Tribological analysis of AA5154/SiC Composites by Stir Casting, *Silicon*, https://doi.org/10.1007/s12633-021-01115-2.

[22] Ononiwu, Ozoegwu, Jacobs, Nwachukwu & Akinlabi (2022) The influence of sustainable reinforcing particulates on the density, hardness and corrosion resistance of AA 6063, *Frattura ed Integrità Strutturale, 61*, 510-518.

[23] Vasanth Kumar, Keshavamurthy, Chandra S Perugu & Siddaraju (2020) Influence of heat treatment on microstructure and mechanical behaviour of hot-rolled Al-Mg-Si alloy, *Advances in Materials and Processing Technologies,* https://doi.org/10.1080/2374068X.2020.1796463.

[24] Gangadharappa, Reddappa, Ravi Kumar & Suresh (2018) Mechanical and wear characterization of Al6061 red mud composites, *Materials Today: Proceedings, 5,* 22384-22389.

[25] Byra Reddy, Bharathesh & Shiva Prasad (2021) Effect of hot rolling on microstructure and mechanical behaviour of B_4C nano particulates reinforced Al6063 alloy Composites, *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 18(2),* 53-62.

[26] Behnamfard, Taherzadeh Mousavian, Azari Khosroshahi & Brabazon (2019) Hot rolling effects on as-cast aluminum matrix nanocomposites reinforced by nano-sized ceramic powders, *AIP Conference Proceedings*, https://doi.org/10.1063/1.5112523.

[27] Murali Mohan, Kempaiah, Manjunatha, Madeva Nagaral & Auradi (2022) Processing and wear behavior optimization of B_4C and rice husk ash dual particles reinforced ADC12 alloy composites using Taguchi method, *Materials Physics and Mechanics, 50(2),* 304-318.

[28] Simpson, Withers, Lowe, Roy, Wanner & Anil (2023) Damage evolution in freeze cast metal/ceramic composites exhibiting lamellar microstructures, *Frattura ed Integrità Strutturale, 64,* 93-103.

[29] Madan Kumar, Mazen Muzammil Shariff, Mohammad Vasi Uz Zaman Shaik, Mohammed Afrid & Shanawaz Patil (2019) Effect of Hot Rolling on Mechanical Properties of Aluminum Metal Matrix, *JETIR*, *6(5)*, 489-493.

[30] Ravikumar, Reddappa & Suresh (2018) Study on mechanical and tribological characterization of Al_2O_3/SiCp reinforced aluminum metal matrix composite, *Silicon*, https://doi.org/10.1007/s12633-018-9788-1.

[31] Chate, Kulkarni, Manjunath, Lakshmikanthan, Harsha, Tophakhane, Shaikh, Kongi & Iranavar (2022) Synthesis and characterization of Fe_2O_3 nanoparticles reinforced to recycled industrial aluminium scrap and waste aluminium beverage cans for preparing metal matrix nanocomposites, *Frattura ed Integrità Strutturale, 60*, 229-242.

[32] Veereshkumar, Gouda, Pramod, Prasanna, Balasubramanya & Aradhya (2022) Fabrication, mechanical

and wear properties of aluminum (Al6061)-silicon carbide-graphite hybrid metal matrix composites, *Frattura ed Integrità Strutturale, 62,* 134-149.

[33] Dhuruva Maharishi, Arul Marcel Moshi, Hariharasakthisudhan & Surya Rajan (2022) Investigation on the mechanical behaviour of aluminium alloy 356 - zirconium silicate metal matrix composites (AA356-ZrSiO4 MMCs), *Silicon*, https://doi.org/10.1007/s12633-022-01896-0.

[34] Bharath, Auradi & Nagaral (2021) Characterization and tensile fractography of 88 micron sized Al_2O_3p particulates reinforced Al2014 alloy composites, *Frattura ed Integrità Strutturale, 57,* 14-23.

[35] Dinaharan, Murugan & Siva Parameswaran (2011) Influence of in situ formed ZrB2 particles on microstructure and mechanical properties of AA6061 metal matrix composites, *Materials Science and Engineering: A. 528*, 5733-5740.

[36] Ravikumar, Reddappa & Suresh (2018) Mechanical and Wear behavior of Al7075/Al_2O_3/SiC hybrid composite, *Materials Today: Proceedings. 5*, 5573-5579.

[37] Dong X, Wang A, Xie J & Zhu P (2021) Effect of CeO_2 content on microstructure and properties of SiCp/Al-Si composites prepared by powder metallurgy, *Materials, https://doi.org/10.3390/ma14164685.*

[38] Ramesh, Pramod & Keshavamurthy (2011) A study on microstructure and mechanical properties of Al6061-TiB2 in-situ composites, *Materials Science and Engineering: A. 528,* 4125-4132.

[39] Vasanth Kumar, Keshavamurthy & Chandra S Perugu (2016) Microstructure and mechanical behaviour of Al6061-ZrB2 In-situ metal matrix composites*. IOP Conf. Series: Materials Science and Engineering, 149,* https://doi.org/10.1088/1757-899X/149/1/012062.

[40] Veeresha, Manjunatha, Nagaral, Auradi & Bharath (2022) Synthesis and wear behavior of varying particle sized B_4C reinforced Al2618 alloy composites, *Materials Physics and Mechanics, 50(23),* 373-387.

[41] Vasanth Kumar, Keshavamurthy, Chandra S Perugu, Praveennath G Koppad & Mohammad Alipour (2018) Influence of hot rolling on microstructure and mechanical behaviour of Al6061-ZrB2 in-situ metal matrix composites, *Materials Science & Engineering A. 738*, 344-352.

[42] Ravi kumar, Reddappa, Suresh & Gangadharappa (2018) Effect of Heat Treatment on Tensile Strength of Al7075/Al_2O_3/SiCp hybrid composite by stir casting technique, *Materials Today: Proceedings, 5,* 22460-22465.

[43] Narayan Nayak, Reddappa, Suresh & RaviKumar (2019) The effect of reinforcing sisal fibers on the mechanical and thermal properties of polypropylene composites, *J. Mater. Environ. Sci., 10(12),* 1238-1249.

[44] Chandrashekar, Annaiah & Chandrashekar (2021) Microstructure and mechanical properties of aluminum cast alloy A356 reinforced with dual-size B_4C particles, *Frattura ed Integrità Strutturale, 57,* 127-137.

[45] Ferro P, Fabrizi, Bonollo & Berto (2021) Microstructural and mechanical characterization of a stainless steel wire mesh reinforced Al-matrix composite, *Frattura ed Integrità Strutturale, 55,* 289-301.

[46] Veeresh Kumar, Shivakumar Gouda, Pramod & Rao (2017) Synthesis and characterization of TiO2 reinforced Al6061 composites, *Advanced Composites Letters, 26(1),* 18-23.

[47] Ravikumar, Reddappa, Suresh & Sreenivasa reddy (2021) Experimental studies of different quenching media on mechanical and wear behavior of Al7075/SiC/Al_2O_3 hybrid composites, *Frattura ed Integrità Strutturale 55*, 20-31.

[48] Ravikumar & Suresh (2023) Study on mechanical and machinability characteristics of n-Al_2O_3/SiC-reinforced Al7075 composite by design of experiment technique, *Multiscale and Multidisciplinary Modeling, Experiments and Design,* 1-14, https://doi.org/10.1007/s41939-023-00179-4.

[49] Saritha, Saikumar, Venkatreddy & Ravikanth Raju (2018) Mechanical characterization and wear behaviour of Al7075 alloy reinforced with alumina and molybdenum disulphide, *International Journal of Mechanical and Production Engineering Research and Development, 8(6),* 395-404.

[50] Sachin & Shanmugasundaram (2019) Influence of Gr, MoS_2 and BN on the hardness and wear resistance of AA2014 hybrid composite after artificial aging, *IJITEE, 8(10),* 3608-3613.

[51] Ganesh, Hemachandra Reddy, Sudhakar Babu & RaviKumar (2023) Study on microstructure, tensile, wear, and fracture behavior of A357 by modifying strontium (Sr) and calcium (Ca) content, *Materials Physics and Mechanics, 51(2)*, 128-139.

[52] Suchendra, Sreenivasa Reddy & Ravikumar (2023) Influence of quenching agents on mechanical, wear, and fracture characteristics of Al_2O_3 / MoS_2 reinforced Al6061 hybrid metal matrix composite (MMCs), *Frattura ed Integrità Strutturale, 63*, 122-133.