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(Research Article)

Influence of boron nitride reinforcement particles on physical and tribological properties of Al7079 MMCs

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Abstract

Metal matrix composites (MMCs) are regarded as viable alternatives to conventional materials such as metals, plastics, and ceramics in structural applications due to their properties, including lightweight, high specific stiffness, elevated elastic modulus, enhanced specific strength, and excellent wear resistance. Among the many metal composites, aluminum metal matrix composites (MMCs) have emerged as sophisticated engineering materials for several prospective applications in engineering industries due to their superior qualities compared to typical aluminum alloys. Ceramic particles are the most extensively utilized reinforcements in MMCs due to their superior wear resistance, thermal stability, and exceptional bonding with the matrix. This research work has been conducted to develop ceramic particle-reinforced aluminum matrix composites and to evaluate their physical and mechanical properties. Al7079 alloy and Boron Nitride (BN) are selected as the matrix and reinforcement for the study respectively. The stir casting technique was utilized to fabricate the composites.Al7079-BN composites are prepared by varying the percentage of BN reinforcement particles from 0 to 8% by volume, with an increment of 2%. Test specimens were machined from the produced composites for the evaluation of microstructural, physical and tribological properties according to ASTM standards. The microstructural analysis of the produced samples was conducted using scanning electron microscopy (SEM). The density of the composite was assessed empirically using Archimedes' principle and theoretically through the rule of mixture. Microstructural analysis reveals a homogeneous distribution of BN particles throughout the matrix without any agglomeration, and it also demonstrates excellent bonding. The density of the composites decreased by approximately 4.6% with the incorporation of BN reinforcement up to 8%, attributed to the lower density of BN particles. Wear loss of the composite was found to decrease with increase in reinforcement content as a result wear resistance of the composites increased as compared to unreinforced alloy.

Keywords: Metal matrix composite; Aluminium alloy; Boron nitride; Microstructure; Tribological property

1. Introduction

The 7xxx aluminum alloy possesses high strength, low density and excellent processing capabilities, making it a crucial structural material in the aerospace sector, automobile and marine industry. As these sectors advances, high-strength aluminum alloys must possess exceptional overall qualities. In recent decades, some engineering materials including magnesium alloy, titanium alloy and composite materials, have exhibited significant advancement, presenting challenges to 7xxx aluminum alloy. Consequently, to maintain competitiveness in its primary sector and secure additional prospects in emerging industries, the 7xxx aluminum alloy necessitates continued enhancement of its performance. Micron and nano-scale ceramic particles such as alumina (Al_2O_3), silicon carbide (SiC), titanium oxide (TiO_2), titanium carbide (TiC), aluminium nitride (AlN) and boron carbide (B_4C) are extensively utilized as reinforcements in aluminum matrix composites (AMCs) for many industrial applications. BN particles are among the

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most commonly utilized reinforcement materials for Al matrix composites, owing to their availability and exceptional qualities, including high mechanical strength and excellent chemical stability at elevated temperatures. The process of liquid casting facilitates the production of composites featuring complex designs. It is preferable to produce lightweight bulk components composed of metal matrix composites that exhibit uniform reinforcing distribution and preserve structural integrity. The use of micro-sized ceramic particles poses difficulties owing to their elevated viscosity, poor wettability in metal matrices, and substantial surface area-to-volume ratio. Attaining a homogeneous distribution of these particles in liquid metals is challenging. To resolve this issue, pretreatment of the particles is essential to improve their bonding capacity with the metal matrix.

The primary drawback of aluminium alloys is their diminished resistance to elevated temperatures and wear characteristics. To address this issue, researchers commenced the fortification of aluminium alloys. using ceramic nanoparticles such as boron carbide, silicon carbide, and aluminum oxide. It is essential to develop advanced mechanical strength aluminum matrix composites for the aerospace and automotive sectors to ensure prolonged fatigue lifetimes in structural components [1]. Investigated the impact of Si_3N_4/Gr incorporation in an Al matrix produced through powder metallurgy techniques. The findings indicated an increase in compressive strength and wear resistance, while the hardness values decreased with the rise in Gr content [2].The density of the fabricated AMCs diminished by up to 9 wt% with additional reinforcement, whereas porosity escalated from 3.7% to 11% in the Al/10%SiC/15%RHA composite compared to pure Al alloy. The microstructural study of the composite demonstrated a homogeneous distribution of SiC and RHA particles, except for the 15% RHA composite, which displayed aggregation of RHA particles [3]. This study examines the synergistic enhancement of wear and tribological qualities conferred by B_4C and TiC, revealing that increased TiC concentration, particularly at 5 wt% TiC and 3 wt% B_4C, enhances performance. TiC and B_4C both enhance friction performance. At 4500 rpm, TiC exhibits a greater propensity to enhance friction performance compared to B_4C. Moreover, B_4C significantly influences tribological behavior at 6000 rpm, resulting in the development of the B_2O_3tribofilm [4]. Examined the influence of B_4C on the mechanical and wear characteristics of Al2618 composites using stir casting. The researchers fabricated Al2618-B_4C metal matrix composites with B_4C concentration varying from 2 to 8 weight percent in 2 percent increments. The resultant composites were evaluated for hardness, compressive strength, and tensile properties. The incorporation of B_4C particles improved the mechanical properties and wear resistance of the Al2618 alloy, while it resulted in a minor decrease in elongation [5]. Investigated the mechanical and wear resistant properties of Al 7075-Al_2O_3-Gr hybrid composites and found that the coefficient of friction of the composites decreases with the addition of 5% Gr, as well as for combinations containing Al_2O_3 at 2, 4, 6, and 8 Wt% [6]. Investigated the tribological performance of Al-7Si-Zr-SiO4 composites across various temperature conditions. The composites demonstrate significantly greater wear resistance in comparison to the base Al alloy [7]. Examined the mechanical and tribological performance of Al-Fe-SiC-Zr hybrid composites produced via the powder metallurgy process. The findings indicate that the density of the Al-10Fe-10SiC-10Zr hybrid composites reached a notable value of 3.44 g cm^{-3}. The rise in Zr content has affected the micro hardness of the hybrid composites. The compressive strength of the Al-10Fe-10SiC-10Zr hybrid composites has shown an increase with higher SiC and Zr content, reaching approximately 205 MPa. The wear-resistant properties exhibited an enhancement with the increase in Zr content [8]. Examined the wear, corrosion, and mechanical performance, including microhardness, tensile, and compressive strength of Al6061-BN-Al_2O_3-C hybrid composites. The findings indicate that the microhardness and compressive strength of Al6061–30BN-10 Al2O3–5 C hybrid composites are 63HV and 187 MPa, respectively, demonstrating an enhancement compared to the base Al6061 alloy. The electrochemical corrosion analysis indicates that the Al6061–30BN-10Al2O3–5 C hybrid composites exhibit enhanced corrosion resistance in comparison to the base Al6061 alloy [9]. Investigated the wear characteristics of AA7075 combined with B_4C and fly ash using the stir casting technique. The uniform distribution of reinforcement and strong interfacial bonding contributed to the improved mechanical and tribological characteristics of the prepared MMC. Smaller-sized particulates act as obstacles to dislocation, enhancing the mechanical properties of the material. Additionally, friction occurs between the steel disc and the composite sample, resulting in the fracture of the composite sample and the formation of white patches [10]. Investigated the tribological and mechanical performance of hybrid Al7075-SiC MMCs in conjunction with graphite, molybdenum disulphide, and hexagonal boron nitride. The liquid metallurgical stir casting procedure was employed to develop the hybrid MMCs. The composite's hardness, tensile strength, and compression were observed to be greater due to the presence of Gr, while other reinforcements exhibited lower values attributed to the porosity within the material. The hBN reinforcement demonstrated superior wear behavior compared to alternative reinforcements, attributed to the formation of a homogeneous transfer film by SiC particulates, which function similarly to a load-bearing component. Another purpose is the improved thermal conductance of hBN, which dissipates the heat generated due to friction [11].

The motivation and interest behind the research work is to produce a lightweight and higher strength-to-weight ratio which should have good physical, mechanical and tribological properties for sustainable aerospace, automotive and marine applications. The addition of BN improves the mechanical and wear strength of the composites. This investigation aims to study the effect of adding Boron Nitride (BN) to the Aluminium 7079 alloy (AA7079) matrix as a reinforcement processed through the stir casting route. Density, Brinel hardness and wear tests are utilized to get the results and for further evaluation of the prepared composites.

2. Material Selection

2.1. Matrix

The aluminum alloy 7079 has been selected as the matrix material. The Al7079 alloy in its ingot state is depicted in Fig. 1. Zinc is the primary alloying element, added in quantities of 3.8 to 4.8%, and is combined with a lesser percentage of magnesium, 2.9 to 3.7%, resulting in a heat-treatable alloy. The chemical composition of the Al7079 alloy is presented in Table 1. These alloys are advantageous for medium to high-strength applications when copper and chromium are incorporated in minimal proportions. High-strength Al7079 alloy has reduced susceptibility to stress corrosion cracking and is frequently utilized in a slightly lower temper to provide an improved mix of strength, fracture toughness, and corrosion resistance.

Table 1 Composition of Al 7079

Element	Content (%)
Zn	3.8-4.8
Mg	2.9 – 3.7
Cu	0.40-0.8
Fe	0.40 max
Si	0.30 max
Mn	0.10 – 0.30
Cr	0.10 – 0.25
Ti	0.10 max
Al	Remainder

Figure 1 Al7079 in ingot form

2.2. Reinforcement

2.2.1. Boron Nitride

Boron nitride (BN) particles of size less than 10 µm shown in fig. 2 (a) are used as reinforcement material. Its SEM image is shown in fig. 2 (b). BN is stable at high temperatures in inert atmospheres and melts at 1300 ˚C, density of BN is 2.1 g/cc. BN is a ceramic compound that consists of boron and nitrogen atoms. It possesses unique characteristics that make it suitable for reinforcement in various composite systems. With addition of BN it improves the mechanical properties, thermal conductivity and electrical resistivity.

Figure 2 (a) BN powder sample

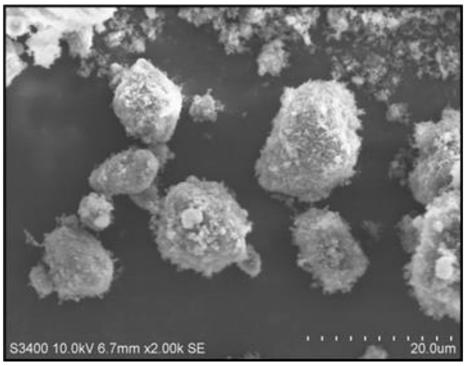
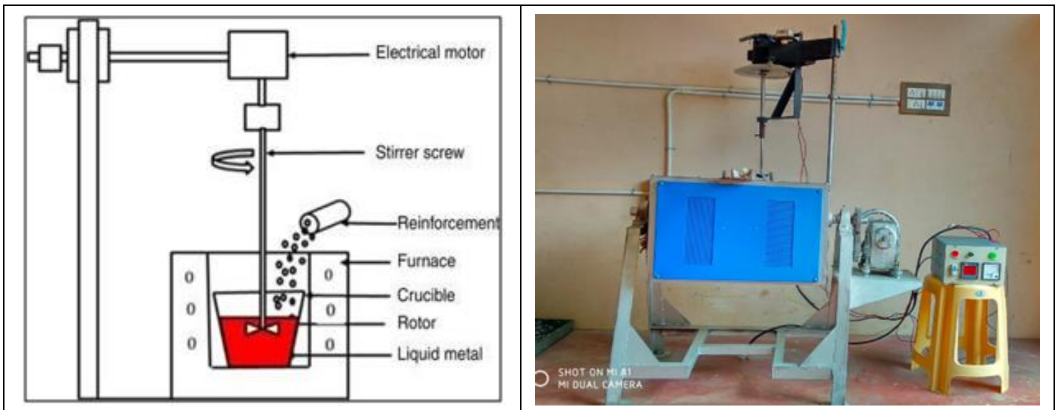


Figure 2(b) SEM image of BN particles

2.3. Fabrication process

The fabrication of specimens with varying percentages of aluminium nitride was conducted via the stir casting technique at ambient temperature, utilizing optimal process conditions. The schematic diagram of stir casting and the actual setup utilized for the current study are illustrated in Fig. 3(a) and (b). This method entails the incorporation of particles into molten aluminium via stirring, followed by the solidification of the material in the mould under standard environmental conditions. The requisite quantity of Al7079 alloy in ingot form was initially melted at 700 – 750 ºC utilizing an electric resistance furnace. The aluminum nitride particles and permanent mold were warmed to 400 ºC to mitigate the chilling impact during solidification. Degassing of the molten metal was accomplished by using commercially available tablets of Hexachloroethane (C_2Cl_6). The primary limitation of the particle reinforced metal matrix composite is wettability, which can be enhanced by using a tiny proportion (<2%) of magnesium chips. Coverall (1%), a drossing flux with a melting temperature of 607 ºC, is incorporated to diminish the surface tension between metals and to create a continuous layer over the molten metal, so safeguarding it against oxidation and the absorption of air hydrogen. The stainless steel stirrer, coated with zirconia and featuring a blade angle of 30º, is employed to create a vortex in the melt. The stirrer height is adjusted to ensure that two-thirds of its length is submerged in the melt. The preheated reinforcement was gradually introduced into the melt, with stirring maintained at 400 rpm for an additional 15 minutes following the complete incorporation of the reinforcement. The temperature was consistently maintained with an accuracy of ±5 ºC via a digital temperature controller.



(a) schematic diagram **(b) Actual setup**

Figure 3 Stir casting process

2.4. Specimen preparation

Specimens were prepared from Al7079-BN composites for microstructure observation, density measurement, hardness test and wear test. Wear test specimens are prepared as per the ASTM G99 standard for pin on disc test. Typical cylindrical or spherical pin specimen diameter of 8 mm and the length is 30mm.

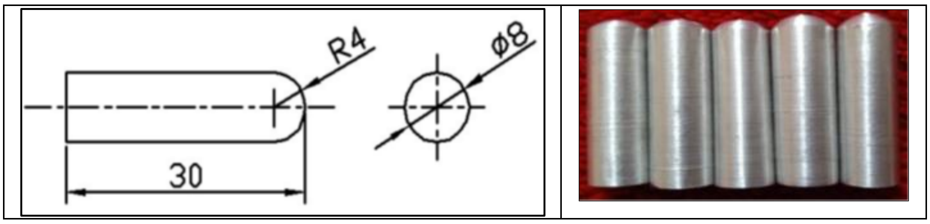


Figure 4 Wear test specimen and geometry

3. Experimental work

3.1. Microstructural study

A metallographic study was done for the casted aluminium matrix composites using Scanning Electron Microscopy to ensure the homogeneity of distribution and interfacial bonding between matrix and particle.

3.2. Density measurement

The effect of BN reinforcement on the density of the developed composites are studied both experimentally by using Archimedes principle and theoretically by using the mass by volume ratio.

The experimental density is determined by using mathematical equation is given below.

$$\rho_{ex} = \frac{m}{m - m_1} \times \rho_w$$

Where
m is the mass of the composite sample in air,
m_1 is the mass off the same composite sample in distilled water.
ρ_w is the density of the distilled water.

3.3. Hardness test

Hardness of the composites was measured using Brinell hardness tester. This is the simple indentation test for determining the hardness of a wide variety of materials. The test surface was prepared to obtain a metallographic finish, a steel ball of diameter 5mm is forced by a load of 750 kg into the test piece and the diameter d of the indentation left on the test surface is measured after the removal of load.

3.4. Wear test

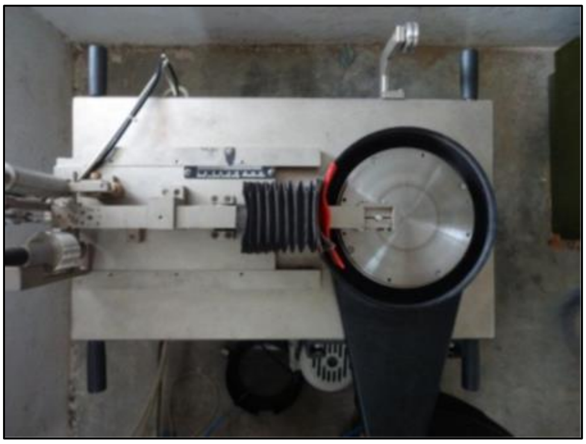


Figure 5 Wear Test setup

The wear test was conducted by pin-on-disc apparatus manufactured by Ducom instruments as per ASTM G99-951standards, the cylindrical, specimens of 8mm diameter rand 30 mm l length were iused as a test samples. Prior to test thelend surfaces of the specimen were polished with SiC-1200 grit emery paper and cleaned with acetone. The initial surface finish of the l steel disc was 1μm. A track I radius of 80mmf has been used f for all the experiments. The specimen was fixed on a holder with two jaws clutch and load was applied to the specimen and the arm of the machine was balanced by means of counter weight. The parameters considered for evaluating the sliding wear behaviour of the composite were normal, load, sliding velocity and constant sliding distance. The I normal load of 20, 40 andi60 N, sliding velocity of 0.5 m/s, 1.0 m/s and 1.5 m/s and constant sliding distance of 600 mm were used.

4. Results and Discussions

4.1. Microstructural analysis

The microstructure and distribution of BN reinforcement particles in the developed composites were analysed using SEM. Fig. 6 (a) to (e) shows the SEM images of fabricated composites. It reveals the presence of BN particles in aluminium metal matrix and it is observed that the reinforcement particles are adequately dispersed in the matrix. The composites exhibits rich interface between the matrix and alloy, during solidification of composites the dendrites of aluminium solidify initially BN particles are precluded by solid-liquid interface resulting in segregation of BN particles at the inter dendrite region. The developed composites are also observed to be free from any kind of casting defects such as porosity, inclusion of slag and shrinkage, which may result from the poor bonding between the matrix and reinforcement at the time of casting and solidification [12]. The average spacing between the reinforcement particles is reduced with the increase in reinforcement content. The homogeneous distribution of the particles in the developed composites may be attributed to the parameters selected for the fabrication of these composites. The microstructure of the composites indicates that the stirring process was adequate to achieve a homogeneous structure. The distribution of reinforcement particles is actually depends on the density gradient between the molten alloy and particles[13].

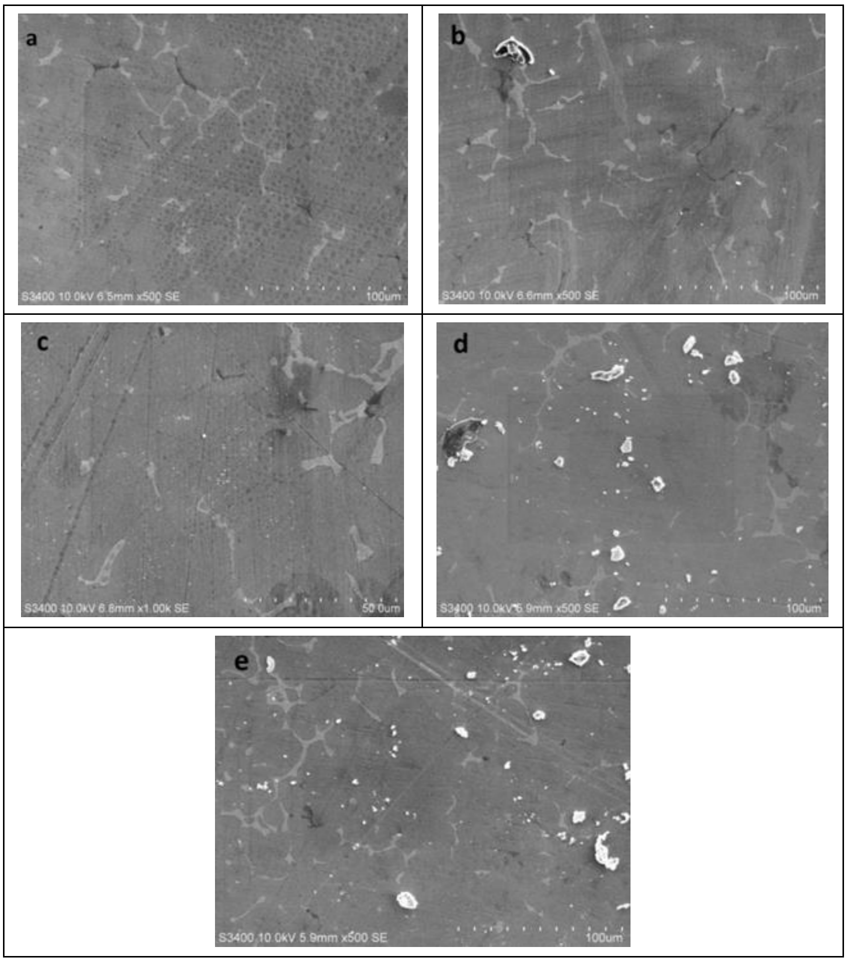


Figure 6 SEM images of (a) Al7079 (b) Al7079+2%BN (c) Al7079+4%BN (d) Al7079+6%BN(e) Al7079+8%BN

4.2. Density

The variation of density values with respect to increasing reinforcement percentage is illustrated in fig. 7. From the results it is observed that experimental density of Al7079 alloy was 2.56×10^{-3} g/mm^3 and density of Al7079 -8% BN composite is found to be 2.68×10^{-3}g/mm^3 and theoretical density of Al7079 alloy is 2.61×10^{-3} g/mm^3 and density of Al7079 -8% BN composite is found to be 2.71×10^{-3} g/mm^3. It is witnessed that both theoretical and experimental density of the samples decreases by 4.6 % and 3.8 % the addition of BN particles about 8 %. This decrease in density is attributed to lower density of reinforcement particles [15,16]. This decrease in density is attributed to the addition of slightly lower density BN particles (2.11 g/cm^3) to higher density Al7079 alloy (2.72 g/cm^3).

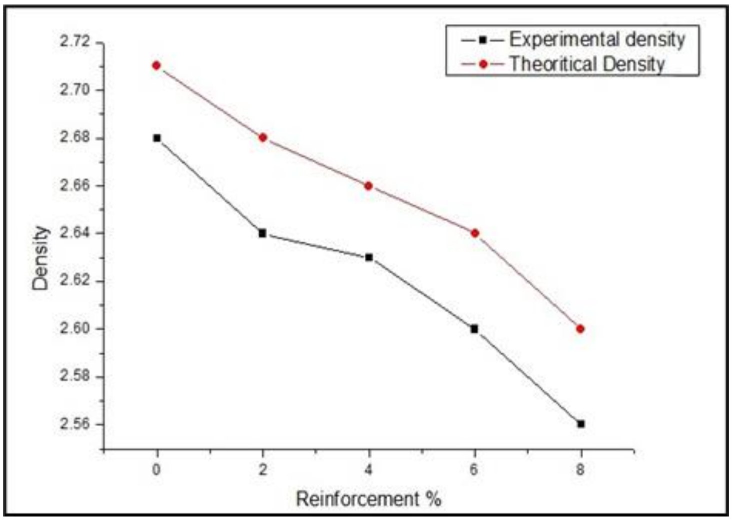


Figure 7 Variation of density with various % of reinforcement

4.3. Hardness

It is observed that hardness for unreinforced Al7079 alloy is 76.9 BHN and for Al7079 -8% BN composite is 95.72 BHN. From the results it is observed hardness of the composite increased by 24.4% for the addition of BN reinforcement about8%. The variation of Brinell hardness with percent of reinforcement is shown in Fig. 8.

This increase in hardness of the samples can be ascribed to the particle strengthening and capacity to bear the load due to increased content of the comparatively harder reinforcement in the matrix [17]. The addition of BN particles in the continuous matrix increases its surface area and it also reduces the grain size of aluminium matrix, the presence of BN particles offers large confrontation to plastic deformation which fall outs into rise of the hardness of the developed composites [18,19].

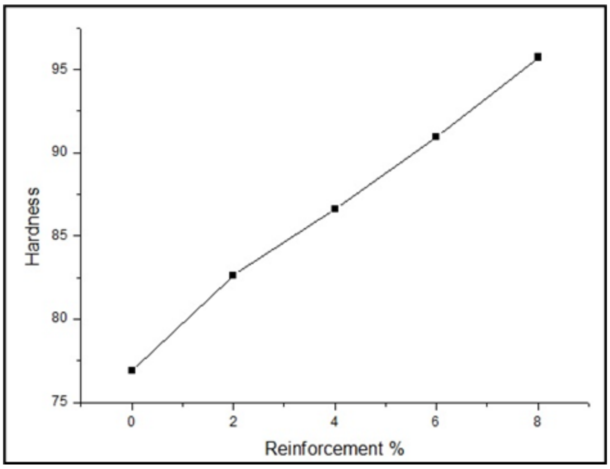


Figure 8 Variation of hardness value with various % of reinforcement

4.4. Wear behavior of MMCs

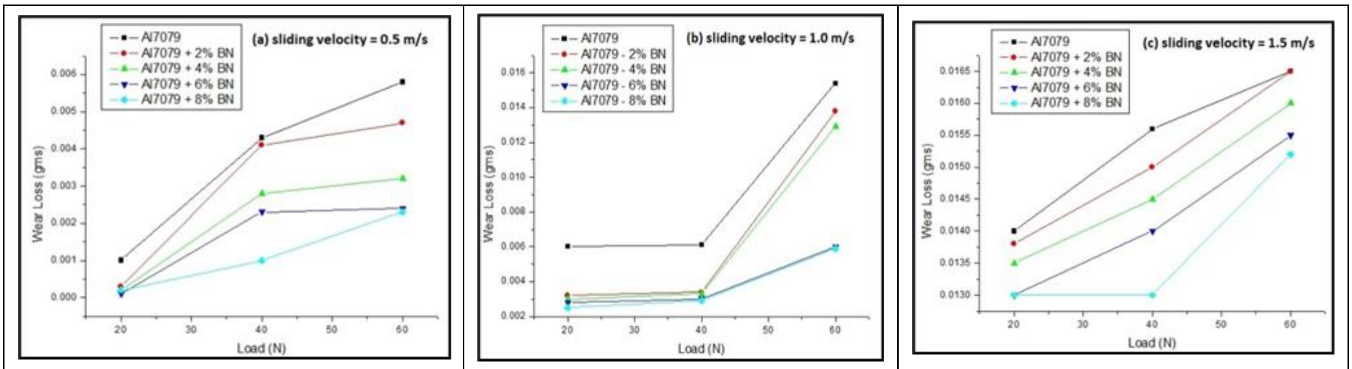
The wear test is performed in accordance with the G99 standard. The dry sliding wear behaviour of Al7079-BN composites is investigated experimentally utilizing a pin-on-disc wear testing apparatus. The metrics such as sliding velocity, applied normal load, and sliding distance are utilized to assess the wear characteristics of the composites. The values of these parameters are given in the table 2.

Table 2 Parameters selected to study the wear behaviour

Parameters	**values**
Applied load (L) N	20,40,60
Sliding distance (D) m	600
Sliding velocity (v) m/s	0.5,1.0,1.5

Figure 9 illustrates the impact of applied load on the wear loss of the composite at various sliding velocities for all compositions. The graph indicates that wear loss escalates with an increase in load for all compositions. However, the increase in wear loss diminishes with an increase in reinforcing percentage. The wear loss for unreinforced Al7079 rose by 60.3% whereas with Al7079-8%BN the wear loss was 12% under identical loading circumstances. The incorporation of reinforcing particles improves the wear resistance of the fabricated composites.

The introduction of BN particles disrupts metal-to-metal contact due to the presence of hard ceramic particles, resulting in a two-body abrasion process. A tribolayer composed of oxides, which extracts particles from the counter surface material and generates wear debris, forms at the interface, resulting in strain hardening [20,21]. The incorporation of BN particles improves the tribolayer's resistance, hence diminishing direct metal-to-metal contact and resulting in reduced wear loss compared to the unreinforced alloy under standard loads, as illustrated by the graph. Under increased load the creation of the tribolayer diminishes exponentially due to intense contact pressure and a moderate wear rate, attributed to the strain hardening of the wear surface [22,23]. The wear loss at all applied loads for the BN-reinforced composite sample are inferior to those of the unreinforced alloy.



(a) sliding velocity = 0.5m/s

(b) sliding velocity = 1 m/s

(C) sliding velocity = 1.5m/s

Figure 9 Effect of load on wear loss of the composite for different wt% of reinforcement

5. Conclusion

Al7079-BN composites were successfully fabricated using stir casting process. Microstructural study of composites shows the even distribution of reinforcement particles throughout the matrix without agglomeration and tough bonding were perceived which is due to the addition of K_2TiF_6 and preheating of reinforcement particles before adding which increases the wettability of the particles. Density of the composites increased nearly by 4.6% as the content of BN particle reinforcement increased upto 8%.Hardness of the composite enhanced by 24.4% for the addition of BN particles of 8%. As the sliding velocity increases from 0.5 m/s to 1.5 m/s, the wear loss of the composite increases for all compositions. As the load increases from 20N, 40N, 60N, the wear loss and wear rate of the composite increases for all the compositions, But it is observed that this increase in wear loss is decreased with increase in reinforcement percentage. The wear loss of unreinforced alloy Al7079 is increased by 60.3% when the load is increased from 20 to 60

N for the sliding velocity of 1.0 m/s, but wear loss of Al7079- 8% BN-3% Aloevera composites for the same loading condition the wear loss is increased by 12% .

Compliance with ethical standards

Disclosure of conflict of interest

The author declares no conflict of interest in the conduct of this research or the preparation of this manuscript. This study was not funded by any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The author has no financial or personal relationships with individuals or organizations that could inappropriately influence or bias the content of this work. The views and opinions expressed in this article are those of the author and do not necessarily reflect the official policy or position of any affiliated institution or organization.

References

[1] Vasanthakumar P, Sekar K. Koduru Venkatesh Recent developments in powder metallurgy-based aluminium alloy composite for aerospace applications. Mater Today Proc 2019;18:5400–9. https://doi.org/10.1016/j.matpr.2019.07.568

[2] ŞenelMC, GürbüzMandKoç E 2019 Fabrication and characterization of aluminum hybrid composites reinforced with silicon nitride/graphene nanoplatelet binary particles J. Compos. Mater. 53 4043–54.

[3] Naim Shaikh Mohd Bilal, Arif Sajjad, Aziz Tariq. Microstructural, mechanical and tribological behaviour of powder metallurgy processed SiC and RHA reinforced Al-based composites. Surface Interfac 2019;–15:166–79. https://doi.org/10.1016/j.surfin.2019.03.002.

[4] Wu J, Li Z, Luo Y, Gao Z, Li Y, Zhao Y, Liao Y, Wu C, Jin M. Influence of synergistic strengthening effect of B4C and TiC on tribological behaviour of copper-based powder metallurgy. Ceram Int 2022. https://doi.org/10.1016/j.ceramint.2022.09.282.

[5] Veeresha G, Manjunatha B, Bharath V, et al. Synthesis, microstructural characterization, mechanical, fractographic and wear behavior of micro B4C particles reinforced Al2618 alloy aerospace composites. Fratturaed IntegritàStrutturale. 2022;16(62):385–407. https://doi: 10.3221/IGF- ESIS.62.27

[6] Baradeswaran A and Elaya Perumal A 2014 Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites Composites B 56 464–71

[7] Thandalam S, Shalini S and Priyadharshini S 2021 Effect of T6 treatment on wear behavior of Al-7Si/ ZrSiO4 composites Silicon 13 1051–8

[8] RaghavGR, Janardhanan S, Sajith E, Chandran Vand SruthiV2021 Mechanical and tribological performance of Al-Fe-SiC-Zr hybrid composites produced through powder metallurgy process Mater. Res. Express 8 016533

[9] Gopinath S, PrinceMandRaghavGR 2020 Enhancing the mechanical, wear and corrosion behaviour of stir casted aluminium 6061 hybrid composites through the incorporation of boron nitride and aluminium oxide particles Mater. Res. Express 7 016582

[10] Reddy TP, Kishore SJ, Theja PC, et al. Development and wear behavior investigation on aluminum-7075/B4C/fly ash metal matrix composites. Adv Compos Hybrid Compos. 2020;3:255–265.

[11] Devaganesh S, Dinesh Kumar PK, Venkatesh N, et al. Study on the mechanical and tribological performances of hybrid SiC-Al7075 metal matrix composites. J Mater Res Technol. 2020;9:3759–3766.

[12] Kesharwani R, Jha KK, Imam M, Sarkar C, Barsoum I. Comparison of microstructural, texture and mechanical properties of SiC and Zn particle reinforced FSW 6061-T6 aluminium alloy. Journal of Materials Research and Technology. 2023 Sep 1;26:3301-21. https://doi.org/10.1016/j.jmrt.2023.08.161

[13] Yao H, Xu X, Luo Y, Han T, Zhou Q. Microstructure and properties of a HIP manufactured SiCp reinforced high alloyed Al–Zn–Mg–Cu–Zr–Ti aluminum matrix composite. Journal of Materials Research and Technology. 2024 May 1;30:4856-67. https://doi.org/10.1016/j.jmrt.2024.04.190

[14] Wang Y, Monetta T. Systematic study of preparation technology, microstructure characteristics and mechanical behaviors for SiC particle-reinforced metal matrix composites. Journal of Materials Research and Technology. 2023 Jul 19. https://doi.org/10.1016/j.jmrt.2023.07.145

[15] Bharathiraja P, Xavior A. Effect of B4C and graphene on the microstructural and mechanical properties of Al6061 matrix composites. Journal of Materials Research and Technology. 2024 Jul 1;31:496-505. https://doi.org/10.1016/j.jmrt.2024.06.098

[16] Liu J, Khan U, Coleman J, Fernandez B, Rodriguez P, Naher S, Brabazon B. Graphene oxide and grapheneNanosheet reinforced aluminium matrix composites: powder synthesis and prepared composite characteristics. Mater Des 2016;94: 87–94. https://doi.org/10.1016/j.matdes.2016.01.031

[17] Barakat WS, Habba MI, Ibrahim A, Fathy A, Elkady OA. The effect of Cu coated Al2O3 particle content and densification methods on the microstructure and mechanical properties of Al matrix composites. Journal of Materials Research and Technology. 2023 May 1;24:6908-22.https://doi.org/10.1016/j.jmrt.2023.05.010

[18] Mohamed A, Mohammed MM, Ibrahim AF, El-Kady OA. Effect of nano Al2O3 coated Ag reinforced Cu matrix nanocomposites on mechanical and tribological behavior synthesis by P/M technique. Journal of Composite Materials. 2020 Dec;54(30):4921-8. https://doi.org/10.1177/0021998320934860

[19] Sadoun AM, Mohammed MM, Elsayed EM, Meselhy AF, El-Kady OA. Effect of nano Al2O3 coated Ag addition on the corrosion resistance and electrochemical behavior of Cu-Al2O3 nanocomposites. Journal of Materials Research and Technology. 2020 May 1;9(3):4485-93. https://doi.org/10.1016/j.jmrt.2020.02.076

[20] S. Sathishkumar, P. Jawahar & Prasun Chakraborti (2022) Influence of carbonaceous reinforcements on mechanical and tribological properties of PEEK composites – a review, Polymer-Plastics Technology and Materials, 61:12, 1367-1384,https://doi.org/10.1080/25740881.2022.2061995

[21] J. Pradeep Kumar, D. S. Robinson Smart, Stephen Manova, Abayomi A. Akinwande & M. Saravana Kumar (22 May 2023): Mechanical and tribological assessment of AA7075 reinforced Si3N4/TaC/Ti hybrid metal matrix composites processed through stir casting process, Advances in Materials and Processing Technologies. https://doi.org/10.1080/2374068X.2023.2215603

[22] R. MalkiyaRasalin Prince, D. Arulkirubakaran, Tapas Debnath, S. P. Arunkumar, N. Bagath Singh, R. B. Jeen Robert & I. Living Prephet (2022) Mechanical and wear behaviour of TiB2-B4C reinforced Al7075 alloy hybrid composites for aerospace applications, Advances in Materials and Processing Technologies, 8:4, 4209-4228. https://doi.org/10.1080/2374068X.2022.2050043

[23] VarunJurwall, Ashok Kumar Sharma, Anand Pandey, Ashish Goyal, S.K. Joshi, Lovi Raj Gupta & Kuldeep Kumar Saxena (2024) Physio-mechanical and tribological characterisation of aluminium alloy matrix composite: an effect of nano/micro fillers, Advances in Materials and Processing Technologies, 10:2, 464-472. https://doi.org/10.1080/2374068X.2023.2168237