Journal of
Materials Sciences and Applications

Research Article Open Access

The Influence of Hot Extrusion on the Mechanical and Wear Properties of an Al6063 Metal Matrix Composite Reinforced with Silicon Carbide Particulates

Abdul Nazeer[1*], Mir Safiulla[2], Adeel H Suhail[3] and Fiseha m Guangul[4]

[1]Senior Lecturer, Mechanical Engineering, Middle East College, Muscat, Oman
[2]Professor, Ghousia college of Engineering, Ramnagaram Karnataka, India
[3]Assistant Professor, Mechanical Engineering, Middle East College, Muscat, Oman
[4]Assistant Professor, Mechanical Engineering, Middle East College, Muscat, Oman

[*]**Corresponding Author:** Abdul Nazeer, Senior Lecturer, Mechanical Engineering, Middle East College, Muscat, Oman, E--mail: nazeer0301@gmail.com

Received Date: October 17, 2024 **Accepted Date:** November 17, 2024 **Published Date:** November 20, 2024

Citation: Abdul Nazeer, Mir Safiulla, Adeel H Suhail, Fiseha m Guangul (2024) The Influence of Hot Extrusion on the Mechanical and Wear Properties of an Al6063 Metal Matrix Composite Reinforced with Silicon Carbide Particulates. J Mater sci Appl 8: 1-12

Abstract

The study investigates the mechanical and wear properties of Al6063 metal matrix composites reinforced with silicon carbide (SiC) particulates. These composites were fabricated using the stir casting technique, with SiC weight percentages varying from 0 to 8 wt%. Post-casting, the composites were subjected to hot extrusion to analyze the effects of this process on their properties. Mechanical testing, including tensile and hardness tests, alongside wear evaluations, revealed significant improvements in the composite's performance. The results showed that increasing SiC content enhances the hardness and wear resistance of the composites. Additionally, hot extrusion was found to further improve these properties by achieving better density and uniform distribution of the reinforcement. This study confirms the beneficial impact of hot extrusion on the mechanical and wear behavior of Al6063-SiC composites.

Keywords: Al6063; Silicon Carbide; Stir Casting; Hot Extrusion; Pin on Disc

Introduction

The alloys are the main constituents for the development of metal matrix composites. Aluminium is the most efficient and commonly used alloy. Due to its high strength to weight ratio, high corrosion resistance, and ease of availability. Aluminium alloy have become popular in automobile, aerospace, recreational, and construction industries. Base aluminium alloys provide good mechanical, physical and chemical properties, but reinforcing aluminium alloy with ceramic particles will improve its mechanical as well as tribological properties [1]. Composites can be fabricated by liquid state processing or solid state processing; many researchers prefer liquid state processing over solid state processing because it is inexpensive and more cost-effective for mass production. Stir casting is the simplest and least expensive method of processing [2]. Non-uniform dispersion of particulates due to poor wettability and gravity-regulated segregation is a common problem with the stir casting technique. It is critical to avoid the reinforced material forming an intermetallic compound with the matrix element [3,4]. To improve its physical and mechanical properties, aluminium alloy is reinforced with ceramic particles such as SiC CeO_2, TiO_2, and others. Several aluminium alloy series have been used in industries; the most popular are Al 6xxx and Al 7xxx series due to their good mechanical properties, high corrosion resistant, can strengthened by heat treatment and better machinability. A.M. Xavior et. al [5] developed composites considering aluminium alloys 2xxx series as matrix and SiC and Al_2O_3, reinforcement by powder metallurgy route. The composite had 1.5 times the compressive strength of peak-aged aluminum alloy 6061. The molten metal and ceramic foam only slightly reacted. Other study investigates the integration of hard ceramic particles, such as SiC, into a softer aluminum matrix using powder metallurgy techniques. It examines the mechanical properties and microstructural characteristics of Al/SiC composite materials sintered in a microwave furnace. The study reveals improvements in density, porosity, hardness, ultimate tensile strength (UTS), and yield strength (YS) with varying SiC content and particle size [6]. Many researchers have attempted to develop metal matrix composites with widely available reinforcements such as graphite, silicon carbide, titanium carbide, tungsten, boron Al_2O_3, Al-Mg, ZA27, and TiB_2[7-10].

The wear coefficient is a more precise measure of material wear behavior. Kalyan et al. [11] investigated the friction and wear behavior of SiC-based aluminum metal matrix composites (MMCs) under various normal loads and sliding speeds. Their results showed a lower coefficient of friction and reduced wear rates compared to aluminum matrix alloys in both dry and lubricated environments. The influence of titanium diboride (TiB_2) loading on the dry sliding wear characteristics of Al 6063-TiB_2 composites, results increasing TiB_2 content improved wear performance, reduced the coefficient of friction, and increased hardness, with the 10 wt% TiB_2 composites exhibiting the good wear resistance [12]. The challenge with primary processed metal matrix composites is the non-uniform reinforcement distribution despite optimized parameters, some localized clustering of SiC particles may occur due to gravitational settling and poor wettability, which leads to porosity, temperature inconsistencies during transfer process from furnace to mold are some of the existing issues to be addressed and optimized. To address this issue, researchers are exploring secondary processing techniques such as forging, rolling, and extrusion. In the light of the forgoing. This research focuses on evaluating the effect of secondary processing on the properties of aluminum 6063 matrix composites reinforced with varying percent of silicon carbide (SiC) particulates. While existing studies primarily concentrate on the characterization of primary processed cast aluminum 6063 systems, there is a noticeable gap in exploring how secondary processing influences the material's performance. The composites were developed using the liquid metallurgy route through the stir casting technique, with SiC weight percentages ranging from 0 to 8 wt% in 2 wt% increments, followed by mechanical testing and adhesive wear test conducted on Pin on disk set up. After casting, the composites underwent hot extrusion to investigate the effects of extrusion and to comprehensively understand the impact of varying SiC content on their mechanical and wear properties.

Experimental Work

Fabrication of Composite

Al6063-SiC composites were fabricated using a liquid metallurgy route (stir-casting). Locally procured aluminium ingots were melted in an electric resistance furnace till they reaches to molten state. Silicon carbide is preheated to 400°C to remove moisture and trapped gases. The preheated silicon carbide were then introduced into molten aluminium at a predefined weight percentage. To ensure thorough mixing and uniform distribution of reinforcement within the aluminum matrix, continuous stirring was performed using a mechanical stirrer of impeller blade type connected to one end of rod and a motor on another end. The molten melt temperature was maintained at 720°C, and the stirring process was continued for 10 minutes at a speed range of 300-400rpm. The stirring time of 10 minutes and a stirring speed of 300–400 rpm, were selected based on a combination of insights from prior research and trial-based efficiency improvements. Mohit et al suggests that sufficient stirring time and optimal speed are critical for ensuring uniform dispersion of reinforcements in the matrix. Stirring times shorter than 10 minutes may result in incomplete mixing. The developed molten melt is then poured into permanent molds made of cast iron with overall dimensions of 300mmx450mm that are pre-heated to 200°C to drive out moisture. The stirring speed, duration, and temperature, which are crucial parameters, were meticulously considered [13]. Subsequent hot extrusion processing was performed on the cast composite to enhance its mechanical properties. The hot extrusion operation was conducted by direct mode using a 500-ton extrusion press at a temperature of 550°C. An extrusion ratio of 9.0 was maintained to ensure significant deformation and consolidation of the composite material. The ram speed during the extrusion process was set to 2 millimeters per second, providing a controlled and consistent flow of the material through the die. For mechanical and wear testing, all developed composite specimens were machined following ASTM and IS standards. Each test consisted of a set of three samples, and the average readings were calculated. This approach ensured consistency and reliability in the test results, providing a representative understanding of the material's properties. Tensile tests were conducted according to ASTM B557M standards, while compression tests followed ASTM E9-09 standards. This ensured that the specimens met the required specifications for accurate and reliable testing results. Al6063 and its developed composites systems were subjected to tensile test on FIE (Fluid Instruments and Engines) machine of 400kN capacity. Vickers microhardness tests were performed on all samples as per ISO 6507-1:2018. The polished samples were subjected to microhardness tests on a Shimadzu Micro hardness tester. The microhardness was determined by applying 10 N load for 20 seconds. The specimen of 10 mm × 10 mm cross section area and a length of 55 mm were prepared as per IS: 1757 part 1: 2020 metallic standard, fourth revision for charpy impact test. The notch of V-shape 2mm at center placed opposite to the hammer. Adhesive wear test was performed on a standard pin on disc wear test rig as per ASTM G99-17 standard, wear test samples for various loads ranging from 10 N to 60 N in step of 10N at a constant speed of 100 rpm and constant track radius of 0.2 m were used to study the wear rate of both the matrix alloy and its composite system.

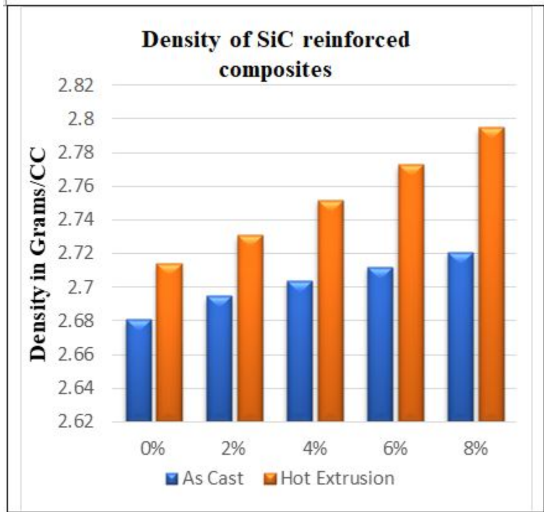
Results and Discussion

Density and Porosity

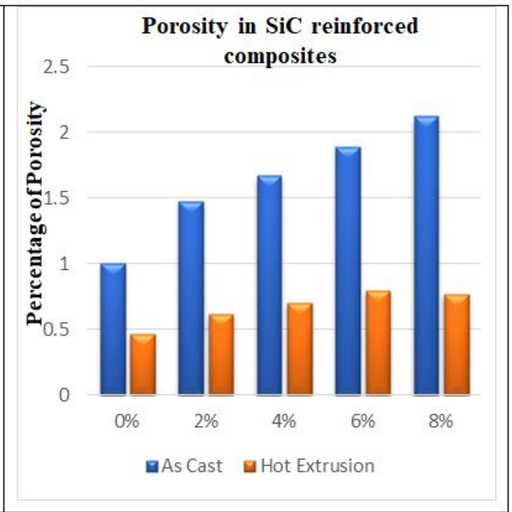
The density test was conducted by standard water displacement method on all prepared composite systems, for both as-cast and hot extruded condition.

The results reveal that the density continued to increase with increasing weight percentages of reinforcement in composites. Due to differences in density and mechanical structure of crystals and atomic arrangement in ceramic reinforcements, density exhibits relative enhancement with increasing weight percentage of reinforcement. This is consistent with the findings of other researchers such as Hima et al. [14].

Density improved further by 1.2% in post-casting process. This is due to reduction in porosity, improving particle distribution, enhancing metal flow, refining grains, and eliminating defects (generally in higher state of temperature), similar observation found with other researchers [15,16]. It was noticed that the porosity of the composite, is mainly influenced by the particle size of ceramic reinforcements; thus, as the volume fraction of reinforcement is increased, porosity is also increased due to the inhomogeneity of alloy and reinforcing element at the atomic level and the particulate nature of reinforcements. Mohanakumar et al. [17] reported that the porosity percentage was significantly reduced in secondary processing extrusion when compared with the cast composite.



Graph 1: Density of composites with different reinforcement percentages in as-cast, and hot extruded conditions.



Graph 2: Porosity of composites with different reinforcement percentages in as-cast, and hot extruded conditions.

Graphs: Graphs 1 and 2 show the density and porosity of the developed composite systems with varying weight percentage in as-cast and hot extruded conditions.

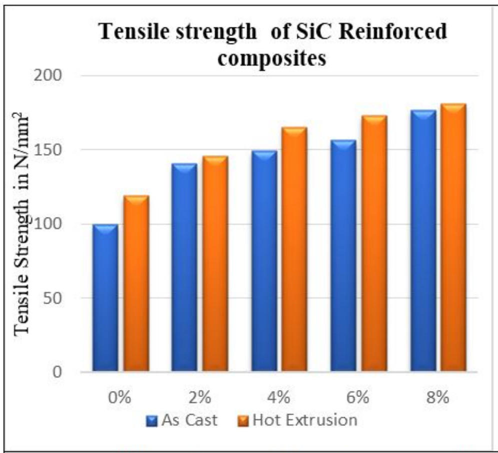
Tensile Test Results

Tensile tests were performed under controlled conditions on composites containing varying weight percentages of SiC, reinforcements of 2%, 4%, 6%, and 8%, as shown in Figure1.

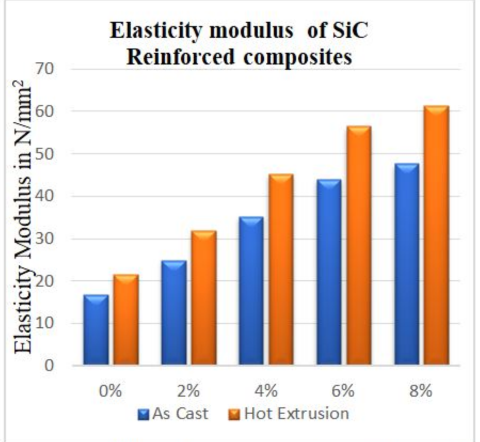
Figure 1: Tensile tested specimen

The test results were compared to those of the unreinforced Al6063 alloy. The ASTM E-8 standard was followed in the test, and testing standards were carefully studied. Three specimens were tested for each sample to statistically optimize the test data. The mechanical testing data were used to calculate the tensile properties and the strength of the composites, resulting in tensile strength, and elasticity modulus. The elongation of the material is observed to decrease with the incorporation of ceramic reinforcements. A similar observation was made by another researcher [18].

The elasticity modulus of composites with SiC reinforcement had a significant effect on tensile strength. Tensile strength was improved by 78% with increased reinforcement quantity in composites. Furthermore, with post-casting conditions of hot extrusion, tensile strength was improved as observed in graph 3. The young's modulus of the composites was improved at a maximum reinforcement of 8%, as seen in graph 4.



Graph 3: Effect of progressive integration of SiC reinforcement from 0wt% to 8wt% on tensile strength in as-cast and hot extruded conditions.

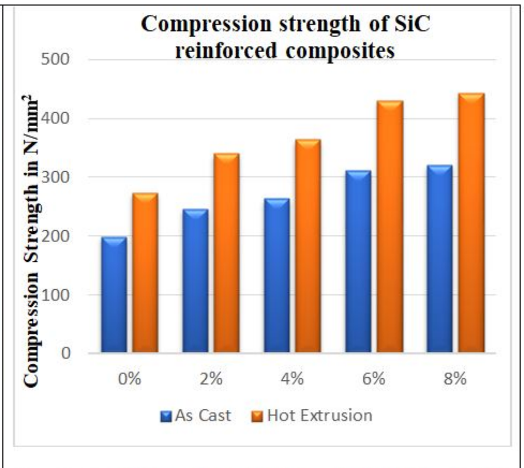


Graph 4: Effect of progressive integration of SiC reinforcement from 0wt% to 8wt% on elastic modulus in as-cast and hot extruded conditions.

Graphs 3 and 4

Compression Test

Figure 2: Samples of compression test specimen



Graph 5: Effect of progressive integration of SiC reinforcement from 0wt% to 8wt% on compression strength in as-cast, and hot extruded conditions.

Figure 2 and Graph 5

The crushing of SiC-reinforced composites was observed to be linearly varying with changing the weight percentage of SiC reinforcement into aluminium alloy. Compression strength was increased by 62% for maximum SiC reinforcement of 8%, as seen observed in graph 5. The fracture behaviour of silicon carbide reinforced composites was found to be identical to that of the as cast condition, with progressive integration of SiC reinforcement resulting in harder and stronger material under compression.

Vickers Hardness Test

The graph below clearly illustrate the influence of reinforcement on hardness properties. It is evident that higher levels of reinforcement in the matrix alloy lead to increased hardness of the composites. This enhancement is attributed to the inherent hardness of SiC ceramics. The addition of a hard particulates to a soft, ductile matrix results in improved composite hardness which correlates directly with the weight percentage of reinforcement. In hot extruded composites, variations in microhardness can be explained by the healing of minor flaws during the extrusion process, contributing to further hardness improvement compared to cast samples. The investigation shows the significant impact of reinforcement on hardness, with silicon carbide at an 8wt% shows the highest hardness among the tested compositions. This is coherent with the observations of other researchers [19,20].

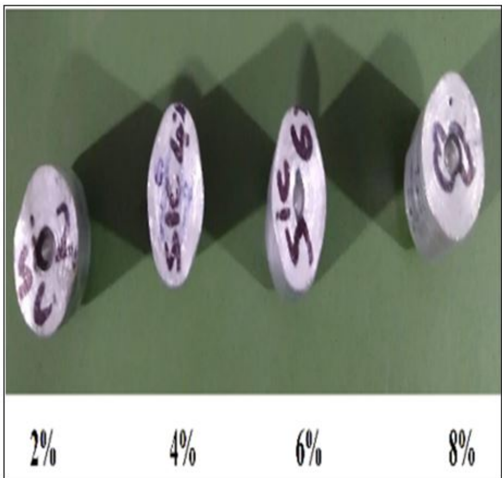
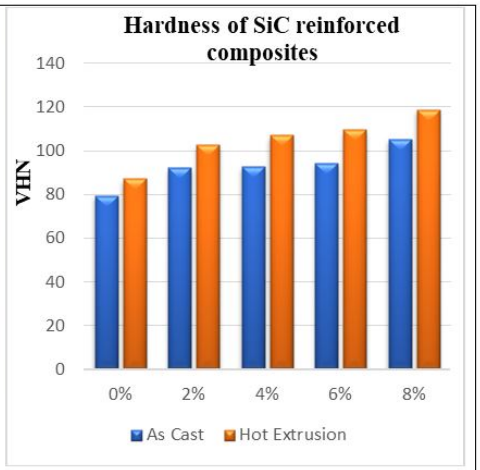


Figure 3: Specimens tested for hardness using Vickers hardness tester



Graph 6: Hardness of composites by varying the percentage of reinforcement in as cast and hot extruded condition

Figure 3 and Graph 6

Impact Test

Graph 7 shows significant reduction in the impact strength with increased content of reinforcement. This is due to the fact that densification of the material, increased hardness, and brittleness thus resulted in crack propagation by intergranular augmentation, and thus the material failed due to embrittlement. Also due to intense doping of ceramic reinforcements causing over interstitialcy and reduction in ductile nature of the material, as observed with other research findings [21,22]. Due to high temperature working, the hot extrusion process has significantly reduced the distortion of impact strength. Also mechanical working of hot extrusion enhances the bonding between the matrix and reinforcement particles. So from the above discussion it is clear that hot extrusion significantly the improves the impact strength compare to cast composite by improving and eliminating the casting flaws, which is in agreement with similar findings with other researchers [23].

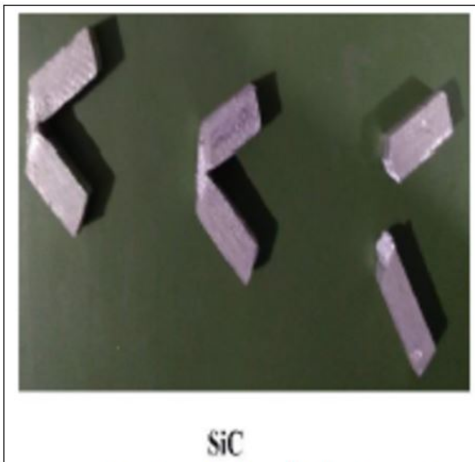
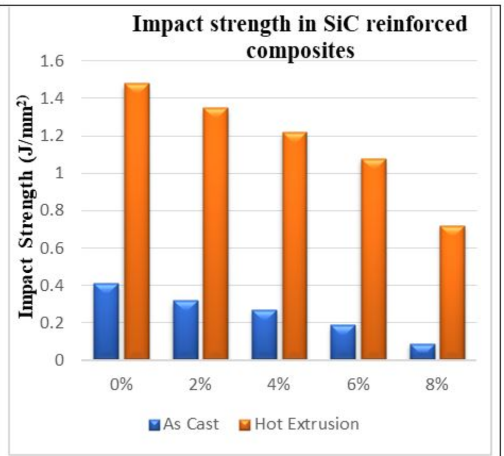


Figure 4: Specimens tested under charpy impact

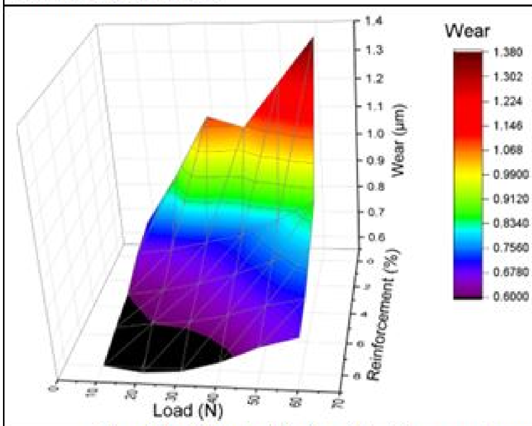


Graph 7: Impact strength of composites with varying percentages of reinforcement in as cast and hot extruded condition

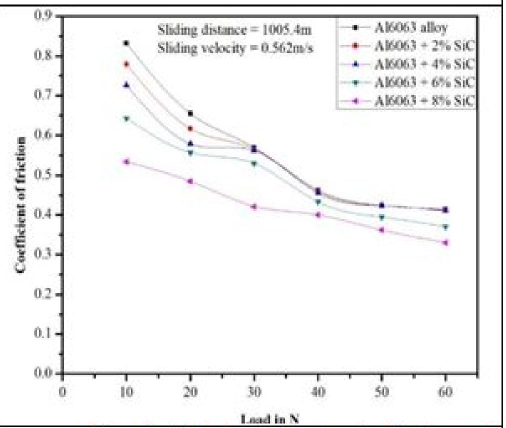
Figure 4 and Graph 7

Adhesive Wear Test

Graph 8: Wear rate of composites in as cast condition under different loads reinforced with silicon carbide reinforcement.



Graph 9: Effect of load and reinforcement on wear rate of SiC reinforced composites in as cast condition.



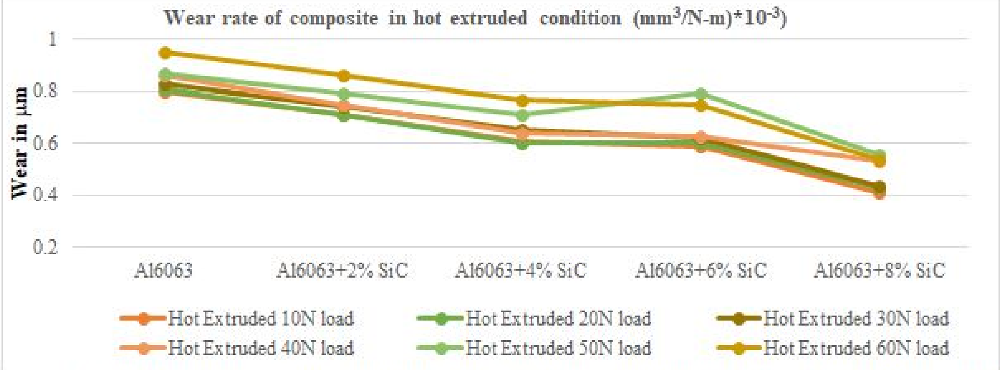
Graph 10: Coefficient of friction of composites by varying weight of SiC reinforcement at different loads in as cast condition.

Graph 8-10

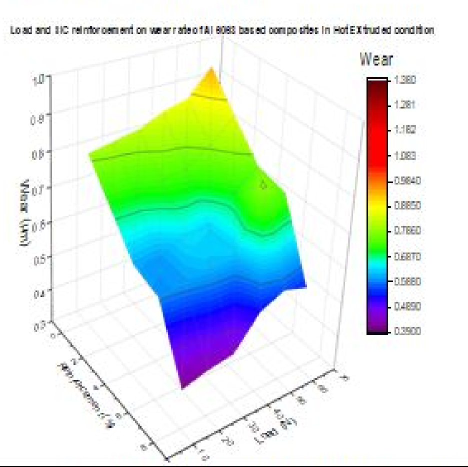
Graphs 8-10 shows the wear rate and coefficient of friction for various loads for composite reinforced with SiC with various weight percentages under as cast conditions. Similar observation made by other studies [24,25]. The graph underline the importance of optimizing the reinforcement content in aluminum 6063 composites to achieve superior wear resistance, particularly under high-load applications. The linear relationships observed provide valuable insights into designing composites for targeted mechanical and wear performance.

Graphs 11-13 shows the wear rate and coefficient of friction for various loads for composite reinforced with SiC with various weight percentages under as cast conditions.

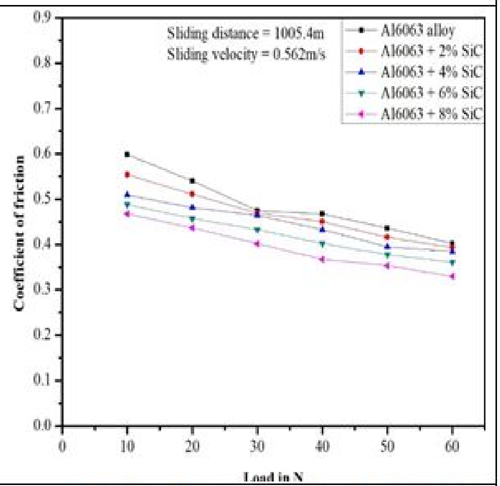
From the above graph 8-13 the wear rate studies for the developed composite system, under both as-cast and hot-extruded conditions. The graphs indicate that as the applied load increases, the wear rate of the composite also increases. This is attributed to higher contact force and increased adhesive forces. Notably, the wear rate shows an almost linear relationship with the applied load. Furthermore, the wear rate decreases linearly with an increase in the percentage of reinforcement. This suggests that higher reinforcement content improves the composite's resistance to wear. In addition, the graphs reveal that the wear rate decreases linearly as the percentage of reinforcement in the composite increases. This implies that the introduction of higher amounts of silicon carbide (SiC) particulates enhances the composite's resistance to wear. The reinforced particles act as barriers, reducing direct metal-to-metal contact and thus mitigating material removal during the wear process. The hot-extruded composite exhibits a marked improvement in wear performance compared to the as-cast condition. This enhanced wear resistance can be attributed to the higher density and more uniform distribution of reinforcement particles achieved during the hot extrusion process. Hot extrusion applies significant pressure and temperature, resulting in a compact microstructure with fewer voids and improved bonding between the matrix and the reinforcement. These structural improvements reduce wear, indicating the formation of a more stable wear surface with less material adhesion and lower susceptibility to wear damage. The coefficient of friction is notably higher in the as--cast condition compared to the hot-extruded composite. In the hot-extruded state, the lower coefficient of friction suggests that adhesive wear mechanisms dominate, with reduced abrasive interactions due to the enhanced material cohesion and reinforcement uniformity. The increased compactness of the composite, achieved under the high-pressure and high-temperature conditions of hot extrusion, minimizes surface roughness and facilitates smoother sliding interactions during wear testing. These findings highlight the significant role of hot extrusion in improving wear performance, making the material more suitable for demanding applications requiring high wear resistance. Consequently, the hot extrusion process significantly enhances the wear resistance and overall performance of the developed composite system. Similar observation made by other studies [26-28].



Graph 11: Wear rate of composites in hot extruded condition under different loads reinforced with Silicon carbide reinforcement



Graph 12: Effect of load and reinforcement on wear rate of SiC reinforced composites in hot extruded condition



Graph 13: Coefficient of friction of composites by varying weight of SiC reinforcement at different loads in hot extruded condition.

Graphs 11-13

Conclusions

The hot extrusion process plays a critical role in enhancing the mechanical properties of Al 6063 composites. It refines the grain structure, producing smaller and more uniform grains, which, according to the Hall-Petch relationship, results in increased strength and toughness due to the greater grain boundary area acting as barriers to dislocation motion. Additionally, hot extrusion significantly reduces porosity and voids, creating a denser and more homogeneous material. For Al 6063 reinforced with SiC particles, the process ensures a uniform distribution of the reinforcement throughout the matrix, minimizing weak zones and improving load transfer, thereby further enhancing the composite's overall mechanical performance.

- **Enhanced Hardness and Wear Resistance:** The incorporation of SiC reinforcement into the Al6063 matrix significantly increases the hardness and wear resistance of the composites. This improvement is more pronounced with higher SiC content.
- **Effect of Hot Extrusion:** Hot extrusion significantly enhances the mechanical properties of the composites compared to the as-cast condition. This process results in a higher density and more uniform distribution of SiC particles, leading to improved hardness and reduced wear rate.
- **Coefficient of Friction:** The coefficient of friction is lower in hot-extruded composites compared to as-cast ones, indicating a dominance of adhesive wear mechanisms. This lower coefficient of friction correlates with the enhanced compactness and structural uniformity achieved through hot extrusion.
- **Maximum Performance at 8% SiC:** The study finds that composites with the highest SiC content (8 wt%) exhibit the greatest improvement in hardness and wear resistance, showcasing the optimal reinforcement level for achieving superior mechanical properties.

Acknowledgments

The author would like to express gratitude to Ghousia College of Engineering, Ramnagaram, for their invaluable support in the fabrication process. Special thanks are also extended to Bharat Technical Labs, Hyderabad, for their assistance, as well as to Middle East College for their ongoing support. Additionally, the author thanks Qeios.com for providing the opportunity to prepare the review version and all reviewers for their valuable comments.

Author Contributions

- **Conceptualization:** Abdul Nazeer, Mir Safiulla,
- **Methodology:** Abdul Nazeer, Mir Safiulla,
- **Fabrication parameters:** Abdul Nazeer, Mir Safiulla,
- **Design of experiments:** Abdul Nazeer, Mir Safiulla, Adeel Suhail, Fiseha M Gunagul,
- **Investigation:** Abdul Nazeer, Mir Safiulla, Adeel Suhail, Fiseha M Gunagul,
- **Data Curation:** Abdul Nazeer, Mir Safiulla, Adeel Suhail, Fiseha M Gunagul,
- **Writing – Original Draft Preparation:** Abdul Nazeer, Mir Safiulla, Adeel Suhail, Fiseha M Gunagul,
- **Writing – Review Editing:** Abdul Nazeer, Adeel Suhail, Fiseha M Gunagul,
- **Supervision:** Mir Safiulla,

Conflicts of Interest or Competing Interests

The authors declare that there are no conflicts of interest or competing interests.

Data and Code Availability

The findings of this study are available from the corresponding author doctorate thesis, but not published.

Supplementary Information

NA

Ethical Approval

This study on the fabrication and testing of composite materials did not involve human or animal subjects and therefore did not require ethical approval.

References

1. William D, Callister Jr (2007) Materials Science and Engineering An Introduction (eight). New York.

2. Razzaq AM, Majid DL, Basheer UM, Aljibori HSS (2021) Research Summary on the Processing, Mechanical and Tribological Properties of Aluminium Matrix Composites as Effected by Fly Ash Reinforcement. Crystals, 11: 1212.

3. Sijo MT, Jayadevan KR (2016) Analysis of Stir Cast Aluminium Silicon Carbide Metal Matrix Composite: A Comprehensive Review. Procedia Technology, 24: 379-85.

4. Kadam MS, Shinde VD (2020) Stir cast aluminium metal matrix composites with mechanical and micro-structural behavior: A review. Materials Today: Proceedings, 27: 845-52.

5. Ashwath P, Xavior MA (2016) Processing methods and property evaluation of Al 2 O 3 and SiC reinforced metal matrix composites based on aluminium 2xxx alloys. Journal of Materials Research, 31: 1201-19.

6. Rajan Verma, Saurabh Sharma, Dinesh Kumar (2017) Analysis of Mechanical Properties of Aluminium based Metal Matrix Composites Reinforced with Alumina and Sic. International Journal of Engineering Research and, V6: 03.

7. Krishna Prasad S, Dayanand S, Rajesh M, Nagaral M, Auradi V, Selvaraj R (2022) Preparation and Mechanical Characterization of TiC Particles Reinforced Al7075 Alloy Composites. Advances in Materials Science and Engineering, 1-11.

8. Miloradović N, Vujanac R, Mitrović S, Miloradović D (2019) Dry Sliding Wear Performance of ZA27/SiC/Graphite-Composites. Metals, 9: 717.

9. Vijaya Ramnath B, Elanchezhian C, Naveen E, Nagarajakrishnan P, Chezhian T, Saleem A, Srivalsan M (2018) Mechanical and Wear Behavior of Aluminium-Zircon Sand-Fly-ash Metal Matrix Composite. IOP Conference Series: Materials Science and Engineering, 390: 012018.

10. Ramesh MDJ, Ravichandran M (2019) Investigation on mechanical properties and wear behaviour of titanium diboride reinforced composites. FME Transactions, 47: 873-9.

11. Singh KK, Singh S, Shrivastava AK (2016) Study of Tribological Behavior of Silicon Carbide Based Aluminum Metal Matrix Composites under Dry and Lubricated Environment. Advances in Materials Science and Engineering, 1-11.

12. Krishnamurthy K, Ashebre M, Venkatesh J, Suresha B (2017) Dry Sliding Wear Behavior of Aluminum 6063 Composites Reinforced with TiB₂ Particles. Journal of Minerals and Materials Characterization and Engineering, 05: 74-89.

13. Sahu MK, Sahu RK (2018) Fabrication of Aluminum Matrix Composites by Stir Casting Technique and Stirring Process Parameters Optimization. In Advanced Casting Technologies. InTech.

14. Hima Gireesh C, Durga Prasad K, Ramji K (2018) Experimental Investigation on Mechanical Properties of an Al6061 Hybrid Metal Matrix Composite. Journal of Composites Science, 2: 49.

15. Jeykrishnan J, Vijaya Ramnath B, Hervin Savariraj X, David Prakash R, Dhinesh Rajan VR, Dinesh Kumar D (2016) Investigation on Tensile and Impact Behavior of Aluminum Base Silicon Carbide Metal Matrix Composites. Indian Journal of Science and Technology, 9.

16. Mohapatra SK, Maity K (2017) Synthesis and characterisation of hot extruded aluminium-based MMC developed by powder metallurgy route. International Journal of Mechanical and Materials Engineering, 12: 2.

17. Mohanakumara KC, Rajashekar H, Ghanaraja S, Ajitprasad SL (2014) Development and Mechanical Properties of SiC Reinforced Cast and Extruded Al based Metal Matrix Composite. Procedia Materials Science, 5: 934-43.

18. Ravichandran M, Balasubramanian M, Anand Chairman C, Marichamy S, Dhinakaran V, Stalin B (2020) Mechanical properties of Fly ash reinforced Aluminium matrix composites. IOP Conference Series: Materials Science and Engineering, 988: 012095.

19. Chakrapani P, Suryakumari TSA (2021) Mechanical properties of aluminium metal matrix composites-A review.

Materials Today: Proceedings, 45: 5960-4.

20. Reddy PS, Kesavan R, Vijaya Ramnath B (2018) Investigation of Mechanical Properties of Aluminium 6061-Silicon Carbide, Boron Carbide Metal Matrix Composite. Silicon, 10: 495-502.

21. Konopka K, Maj M, Kurzydłowski KJ (2003) Studies of the effect of metal particles on the fracture toughness of ceramic matrix composites. Materials Characterization, 51: 335-40.

22. Zhao Q, Liang Y, Zhang Z, Li X, Ren L (2016) Effect of Al content on impact resistance behavior of Al-Ti-B4C composite fabricated under air atmosphere. Micron, 91: 11-21.

23. Chintada S, Dora SP, Kare D (2022) Mechanical Behavior and Metallographic Characterization of Microwave Sintered Al/SiC Composite Materials – an Experimental Approach. Silicon, 14: 7341-52.

24. Rao, T. B. (2018). An Experimental Investigation on Mechanical and Wear Properties of Al7075/SiCp Composites: Effect of SiC Content and Particle Size. Journal of Tribology, 140.

25. Samal P, Vundavilli PR, Meher A, Mahapatra MM (2020) Recent progress in aluminum metal matrix composites: A review on processing, mechanical and wear properties. Journal of Manufacturing Processes, 59: 131-52.

26. Soltani N, Jafari Nodooshan HR, Bahrami A, Pech--Canul MI, Liu W, Wu G (2014) Effect of hot extrusion on wear properties of Al–15wt.% Mg2Si in situ metal matrix composites. Materials & Design, 53: 774-81.

27. Abdollahi A, Alizadeh A, Baharvandi HR (2014) Dry sliding tribological behavior and mechanical properties of Al2024–5wt.%B4C nanocomposite produced by mechanical milling and hot extrusion. Materials & Design, 55: 471-81.

28. Deaquino-Lara R, Soltani N, Bahrami A, Gutiérrez--Castañeda E, García-Sánchez E, Hernandez-Rodríguez MAL (2015) Tribological characterization of Al7075–graphite composites fabricated by mechanical alloying and hot extrusion. Materials & Design, 67: 224-31.