Research Article

Development and Characterization of Al-SiC Metal Matrix Composites Through Microwave Processing and Extrusion

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Abstract
Metal matrix composites (MMCs) have garnered significant attention due to their exceptionally lightweight nature, adaptability for a wide range of applications, and exceptional mechanical properties. This investigation delves into the tribological characteristics of aluminum-silicon carbide (Al-SiC) microelectrodes. These MMCs were refined through extrusion after being fabricated using a novel microwave-assisted powder metallurgy process. The impact of reinforcement content on the material's mechanical strength and wear resistance was assessed by varying the weight percentages of SiC (10%, 15%, and 20%). The results indicate that the uniform distribution of SiC within the aluminum matrix significantly enhances the composite's hardness and wear resistance. The addition of 20% SiC resulted in a 28% reduction in the wear rate compared to pure aluminum. In addition, the extrusion procedure improved these properties by aligning the SiC particulates in the direction of extrusion and reducing porosity. This investigation demonstrates that the combination of microwave sintering and extrusion can produce high-performance Al-SiC MMCs with enhanced abrasion resistance and mechanical properties, making them suitable for industrial applications that require lightweight materials and durability.

Keywords: Aluminum-silicon carbide, Metal matrix composites, Microwave sintering, Powder metallurgy, wear resistance

1 Introduction

The demand for materials with exceptional properties and high performance continues to increase as industries endeavor to address the challenges of contemporary applications. In response to this demand, materials scientists have shifted their focus to the development of metal matrix composites (MMCs), which are becoming more popular as alternatives to traditional materials due to their superior mechanical properties and adaptability [1], [2]. A variety of fabrication techniques can achieve the efficient production of MMCs through powder metallurgy (PM). PM facilitates the uniform distribution of reinforcement particles within the matrix, which is essential for achieving the desired material properties [3]–[6]. Nevertheless, PM-processed composites frequently encounter obstacles, including porosity, irregular reinforcement morphologies, and particle agglomeration [7], [8]. While we cannot eliminate these constraints, advancements in microwave processing techniques significantly improve their mitigation.

Microwave radiation, operating within the frequency range of 300 MHz to 300 GHz, presents a distinctive method of material processing. In contrast to traditional heating methods, which rely on conduction, radiation, and convection to transfer heat, microwave heating directly interacts with the material at the molecular level, resulting in the volumetric absorption of electromagnetic energy and its conversion to heat. This results in homogeneous heating and a reduction in the temperature gradient between the material's interior and exterior [9]–[13]. Microwave heating offers a multitude of advantages, such as improved mechanical and physical properties, reduced environmental impact, substantially reduced processing times, rapid heating rates, lower sintering temperatures, and enhanced diffusion processes. Microwave processing is a promising alternative to conventional procedures due to these advantages [14]–[17]. In contrast to conventional sintering methods, microwave processing provides distinct advantages in terms of homogeneity of the resulting material, processing time, and energy efficiency. The conventional method of sintering involves the use of conduction, convection, and radiation to heat materials. This process frequently leads to temperature gradients within the material, which in turn creates irregular microstructures. Conversely, microwave processing generates a more consistent heating profile by heating the material volumetrically through the interaction of electromagnetic radiation with its molecular structure. This results in improved mechanical properties, improved phase distribution, and reduced porosity, which are challenging to achieve through conventional sintering. This distinction emphasizes the novelty of the current study's use of microwave-assisted sintering, which offers a more efficient and effective method of fabricating metal matrix composites.

Extrusion is indispensable in the context of material formation. Extrusion is a process that induces plastic deformation by forcing a metal billet through a die with a reduced cross-sectional area [18]. The interaction of the billet with the die and container in indirect compression extrusion subjects it to compressive forces. This interaction generates high compressive stresses that prevent fracture during the extrusion process [19]. This method is particularly effective in reducing the cast structure of the billet, thereby improving the material's integrity by exclusively applying compressive forces [20]. Response Surface Methodology (RSM) and Genetic Algorithm (GA) are two hybrid approaches that have been used in recent studies to improve the wear behavior of advanced composites. For instance, applying this hybrid method to a new AZ31 magnesium alloy strengthened with 5% yttria-stabilized zirconia (YSZ) significantly slowed down the wear rate. Under optimized conditions, we minimized the ploughing and delamination [21]. Magnesium matrix composites are displacing traditional materials in biomedical, aerospace, and automotive applications as a result of their enhanced properties and lightweight nature. New research using a mixed squeeze and stir casting method has shown that adding silicon carbide (SiC) to magnesium composites makes them 40% harder, 28% stronger, and lowers the rate of wear and tear. The compressive strength also goes up, from 83 to 176 Mpa [22]. Magnesium alloys, including AZ91D, reinforced with alumina and silicon carbide, exhibit improved mechanical properties and reduce the number of microcracks when processed using liquid state techniques. The tensile strength (181 MPa), hardness (85 HV), and impact toughness (21.8 J/mm^2) of these composites were enhanced by the addition of 10 wt% Al_2O_3 and 9 wt% SiC, rendering them suitable for automotive and aerospace applications [23].

Even though a lot of research has been done on aluminum-based MMCs, the current methods of fabrication, like conventional sintering, often lead to problems like porosity, uneven reinforcement distribution, and poor mechanical properties. Furthermore, while numerous investigations have explored SiC reinforcement, only a handful have combined microwave sintering and extrusion to improve the material's mechanical performance, hardness, and abrasion resistance. The novel approach to this study is the integration of a hybrid microwave-assisted powder metallurgy process with extrusion, which enhances the uniform distribution of SiC and the material's mechanical properties. In addition, looking at different SiC percentages (10, 15, and 20%)

gives a fuller picture of the material's tribological behavior. This fills in a gap in current research that doesn't always look at how reinforcement content and process type affect each other. This study comes up with a new idea by making Al-SiC MMCs better at handling heat, being hard, and not wearing down easily. This makes them a good choice for high-performance industrial uses.

This study focuses on the synthesis of aluminum-silicon carbide (Al-SiC) metal matrix composites via microwave sintering, with varying weight percentages of SiC serving as the reinforcing material. After microwave processing, the material undergoes extrusion to reduce its cross-sectional area and enhance its mechanical properties. The main purpose of this study is to compare the tribological properties of microwave-processed and extruded Al-SiC MMCs. This will show how well these methods of making materials improve their performance.

2 Materials and Methodology

2.1 *Materials details*

The reinforcement material in this investigation was silicon carbide (SiC) particles with an average particle size of 23 µm, while the matrix material was 99.5% pure aluminum powder (Al 1100) with an average particle size of 40 µm. The mechanical performance and processability of the composite were balanced by selecting the particle diameters of aluminum (40 µm) and silicon carbide (23 µm). The 40 µm aluminum particles in the matrix material guarantee excellent flowability during blending and compatibility during uniaxial compaction. Furthermore, this particle size enables adequate sintering to take place during microwave processing without promoting excessive grain growth, which could potentially damage the mechanical properties. The 23-µm silicon carbide particles were chosen as the reinforcement to make sure that they were spread out evenly and to improve how well they fit together mechanically with the aluminum matrix. The smaller SiC particles avoid the clustering issues associated with finer particles, leading to enhanced hardness and wear resistance. The composite's SiC content was consistently adjusted within a weight range of 10% to 20%. The purpose of this variation was to evaluate the influence of different reinforcement levels on the composite's properties. Table 1 comprehensively describes the physical and mechanical properties of the aluminum and SiC particles used in the fabrication process. Also, Figure 1(a) and (b) show the microstructural features of the aluminum and silicon carbide particles, focusing on their morphological features that are important for the performance of the composite.

Table 1: Selected materials properties [2].

Material	Materials Properties				
	Density (Kg/m^3)	Elastic Modulus (Mpa)	Tensile Strength (Mpa)	Hardness (VHN)	Melting Temperature (°C)
Al 1100	2800	70×10^3	110	30	640
SiC	3100	400×10^3	-	2800	3100

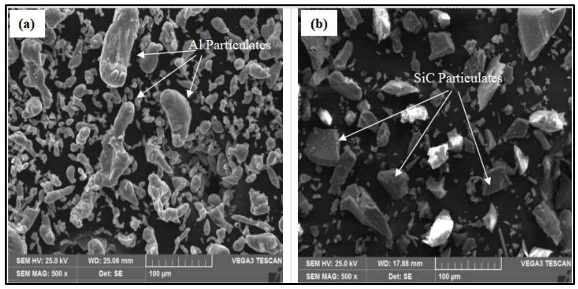

Figure 1: SEM images showing the microstructure of (a) Al powder and (b) SiC powder.

Figure 1(a) displays the scanning electron microscope (SEM) images of the aluminum particles used in the composite fabrication. The SEM analysis shows that the aluminum powder has a mostly nodular shape, as shown by the fact that it doesn't have any sharp edges and the particles are round and come in a range of sizes. This nodular shape is critical because it can affect the powder's flowability and compaction behavior during the fabrication process.

On the other hand, Figure 1(b) presents SEM images of the silicon carbide (SiC) particles used as reinforcement. The SiC particles exhibit a distinct multi-cornered morphology, characterized by well-defined margins and angular corners. This sharp-edged structure significantly improves the mechanical interlocking and bonding between the reinforcement and the aluminum matrix. The multi-cornered SiC particles can effectively embed within the matrix material, making the composite structure stronger overall and making it easier for loads to move through it.

2.2 *Synthesis of Al-SiC composites*

In the present investigation, the powder metallurgy technique has been employed to fabricate metal matrix composites comprising pure aluminum and silicon carbide particles as reinforcement. The synthesis procedure entails blending pure aluminum powder with varying weight fractions (10, 15, and 20% wt.) of silicon carbide powder for 30 min at 200 rpm using a bi-axial mechanical alloying machine. Five samples were prepared and evaluated for each condition (SiC% and process type) to guarantee statistical robustness. Subsequently, the mixed Al-SiC powder compositions are subjected to uniaxial cold compaction, applying a load of 110 kN to form billets measuring 32 mm in diameter and 35 mm in length. These compacted billets are then sintered through a hybrid microwave-assisted two-directional sintering process, as illustrated in Figure 2. The sintering process involves heating the billets for 10 min in a 900W, 2.45 GHz microwave oven, employing an alumina casket as an oxidation barrier layer, to achieve temperatures approaching the melting point of aluminum, as depicted in Figure 3(a). Following the sintering process, colloidal graphite is applied to the sintered billets, which are subsequently subjected to hot extrusion at 300 °C, employing an extrusion ratio of 12.25:1, resulting in the production of rods measuring 10 mm in diameter, as shown in Figure 3(b). These extruded rod samples serve as the basis for further characterization.

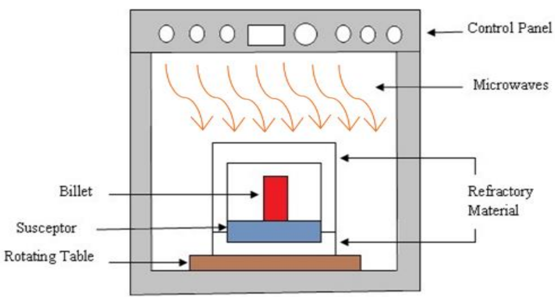

Figure 2: Schematic of the experimental setup

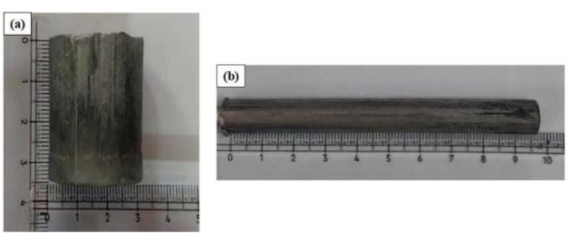

Figure 3: (a) Microwave sintered MMC, (b) Extruded MMC.

3 Tribological Characterization

The specimens were subjected to dry sliding wear testing using a pin-on-disc test device that complied with ASTM G99 criteria and was fitted with an electronic data gathering system. An EN32 hardened steel disc with a 65HRC hardness rating and a Ra value ranging from 2.5 to 3.5 µm was used for the counter surface. The wear tests were executed under various loads, incremented by 10 N, while maintaining a constant velocity of 2 m/s. At intervals of every 3000 meters of testing, the specimens were extracted, subjected to cleaning and drying procedures, and subsequently weighed to determine the mass loss. The wear behavior under escalating loads was investigated by applying loads of 10 N, 20 N, and 30 N during the tests. The wear experiments were conducted in a dry sliding environment at room temperature with a sliding distance of 1000 m. The cylindrical specimen needles utilized had a diameter of 10 mm and a length of 30 mm. The tribological behavior of the composites was captured by perpetually monitoring the temperature and frictional force during the tests. Continuous recordings of friction, temperature and wear parameters were meticulously maintained throughout the testing process.

4 Results and Discussions

In the present work, tribological characterization of Al-SiC MMCs has been carried out both for microwave-processed and extruded specimens. The influence of different percentage compositions of SiC particles has been studied. This section of the article deals with the results of the present work and a brief discussion of the obtained data.

4.1 *Microstructural analysis*

SEM images captured the morphological features of the base alloy and composites that underwent microwave processing, both before and after the extrusion process, in Figure 4(a) and (b), and Figure 5(a) and (b). These images offer valuable insights into the microstructural changes that occur during the fabrication process.

The SEM images of Figure 4(a) and (b) illustrate the microstructure of the aluminum base alloy without the addition of silicon carbide (SiC). The microstructure is relatively uniform, with some inherent grain boundaries prior to extrusion. Following extrusion, Figure 4(b) shows that the grains align and elongate in the direction of extrusion, indicating the microstructure's deformation due to the mechanical process.

Figure 5(a) and (b) depict the microstructure of the aluminum matrix with SiC reinforcement, both before and after the extrusion procedure. The SEM images demonstrate the even dispersion of SiC particulates in the aluminum matrix, a highly desirable characteristic in the development of composite materials. The uniform distribution of reinforcement throughout the matrix significantly enhances the mechanical properties of the composite.

Additionally, Figure 5(b) highlights an important observation: the SEM images of the extruded specimens show the SiC particulates oriented in the direction of extrusion. This alignment implies that the extrusion process has resulted in a preferred orientation of the reinforcement materials within the composite structure. This alignment is critical because it has the potential to impact the composite's anisotropic mechanical behavior, which could result in distinctive mechanical characteristics in specific directions. This consideration is essential when designing and engineering composite materials for applications that require directional mechanical properties.

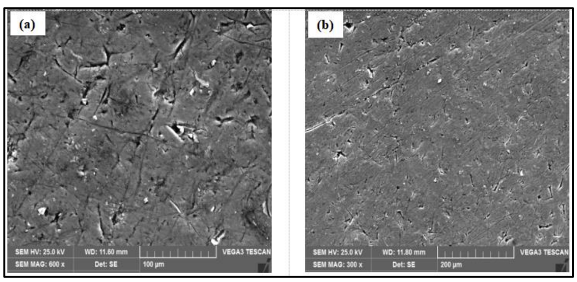

Figure 4: SEM images showing the microstructure of Al without SiC (a) Before extrusion, and (b) After extrusion.

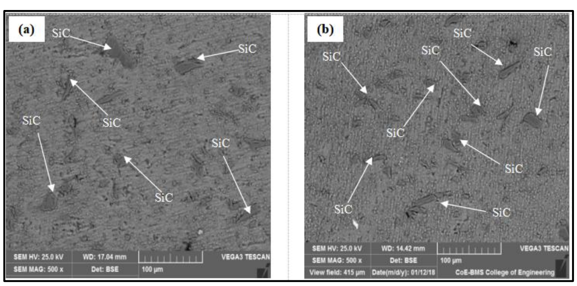

Figure 5: SEM images showing the microstructure of Al with SiC (a) Before extrusion, and (b) After extrusion.

4.2 *X-Ray Diffraction (XRD) analysis*

Figure 6(a) and (b) respectively depict the XRD patterns for the aluminum and SiC particles. The main peaks seen at 2¸ values of about 38.4°, 44.7°, and 65.1° in Figure 6(a) show the (111), (200), and (220) crystallographic planes of face-centered cubic (FCC) aluminum. These peaks validate the purity and structural integrity of the aluminum matrix within the composite, confirming its crystalline structure.

In Figure 6(b), the (111), (220), and (311) planes of silicon carbide (SiC) are shown by separate peaks at 2, values of about 35.7°, 60.1°, and 71.8°. The successful integration of SiC in the composite is verified by these peaks. The sharpness and intensity of these peaks show that the SiC phase is evenly distributed with little clustering, which helps the composite's better mechanical properties.

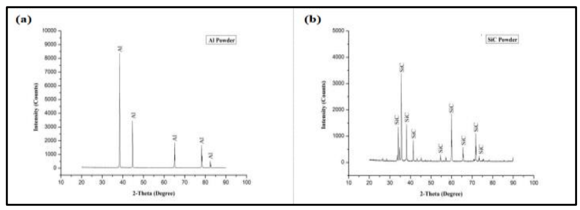

Figure 6: XRD plots of (a) Al powder, and (b) SiC powder.

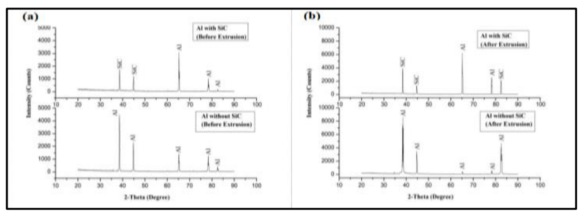

Figure 7: XRD plots of Al without and with SiC (a) Before extrusion, and (b) After extrusion.

Figures 7(a) and (b) show the aluminum matrix's XRD patterns before and after the extrusion process, both with and without SiC. The peaks corresponding to SiC phases are clearly identified. After extrusion, the SiC peaks, particularly at 35.7^0 and 71.8^0, are more pronounced, suggesting that the SiC particles are more evenly distributed and aligned within the aluminum matrix. The extrusion process is responsible for this enhancement, as it refines the microstructure and aligns the SiC particles in the direction of the applied tension.

The process induces microstructural changes that can explain the observed changes in peak intensities after extrusion. The extrusion process results in grain refinement, which affects the diffraction intensities and increases the density of grain boundaries. The alignment of the SiC particles increases the intensity of specific peaks and establishes a preferred orientation of crystallographic planes. The denser structure that results from the reduction in porosity as a result of extrusion is characterized by more distinct and sharper peaks. Moreover, residual stresses generated during extrusion can slightly shift the lattice parameters, contributing to the observed variations in peak intensities. These combined effects offer a comprehensive comprehension of the composite's enhanced mechanical performance and structural integrity following extrusion.

4.3 *Vicker's microhardness*

Figure 8 illustrates a graphical comparison of the Vicker's Hardness Number (VHN) for test specimens that have undergone both extrusion and microwave processing and have various compositions. The VHN experiments are essential for evaluating the mechanical properties of the material, particularly its resistance to plastic deformation.

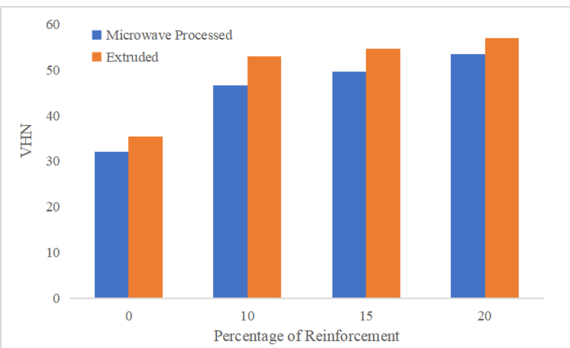

Figure 8: Comparison of VHN values of microwave processed composites and extruded composites.

There is a clear trend in the results shown in Figure 8: the harder the composites get, the more SiC reinforcement that is added. These trends are uniform in both extruded and microwave-processed specimens. SiC particulates' homogenous dispersion within the aluminum matrix is the primary cause of the increase in hardness. The overall hardness of the composite is considerably increased by the formation of strong interfacial bonds between the matrix and the reinforcement significantly increases the composite's overall hardness, which is a critical consequence of this homogeneous distribution.

In addition, the results emphasize an important point: the extruded composite samples are slightly harder than their microwave-processed counterparts, even though the materials used are the same. This increase in hardness in the extruded specimens can be attributed to a decrease in porosity levels that resulted from the extrusion process. A denser microstructure is suggested by a lower porosity, which further enhances the material's hardness properties.

Figure 8 underscores the critical role that fabrication processes and reinforcement distribution play in determining the mechanical characteristics of composite materials. These insights are particularly beneficial for customizing the material's properties to satisfy the specific needs of a particular application, where enhanced mechanical strength and hardness are extremely important.

4.4 *Mass Loss vs. Load*

Figure 9(a) and (b) present a detailed analysis of the variations in mass loss observed in both microwave-processed and extruded composites under various applied loads while maintaining a constant sliding velocity and sliding distance. This analysis is essential for assessing the wear resistance characteristics of the materials.

The data suggests a unique pattern: the mass loss of both the extruded and microwave-processed composites increases as the applied load increases. Furthermore, an increase in the SiC weight percentage from 10% to 20% significantly reduces the mass loss in the extruded composites. The addition of 20% SiC achieved the lowest mass loss, indicating that increased SiC content significantly enhances wear resistance by reinforcing the aluminum matrix and reducing material loss under higher loads. The enhanced hardness and abrasion resistance provided by higher SiC reinforcement levels are the reasons for this improvement.

Intriguingly, the composite's wear resistance increases in proportion to the increase in SiC content. It is possible to attribute this improvement to the superior mechanical properties of SiC, which enhance the composite's resistance to wear-induced degradation. These properties are essential for minimizing material loss during duress, including increased hardness and abrasion resistance.

A critical observation is made when the wear behavior of the extruded composite is contrasted with that of the microwave-processed composites. The composites demonstrate a more uniform distribution of the reinforcing components and reduced porosity levels after the extrusion process. In comparison to their microwave-processed counterparts, the extruded composites exhibit a reduced degradation rate as a result of this structural refinement. The extruded composites exhibit substantially enhanced wear resistance due to the even distribution of reinforcement materials and the reduction in porosity.

The composite materials' wear behavior under varying loads is comprehensively illuminated by the results depicted in Figure 9(a) and (b). SiC reinforcement is essential for improving wear resistance, and the extrusion process further refines the composite structure, resulting in lower wear rates. These discoveries are critical for material optimization in applications where wear resistance is paramount.

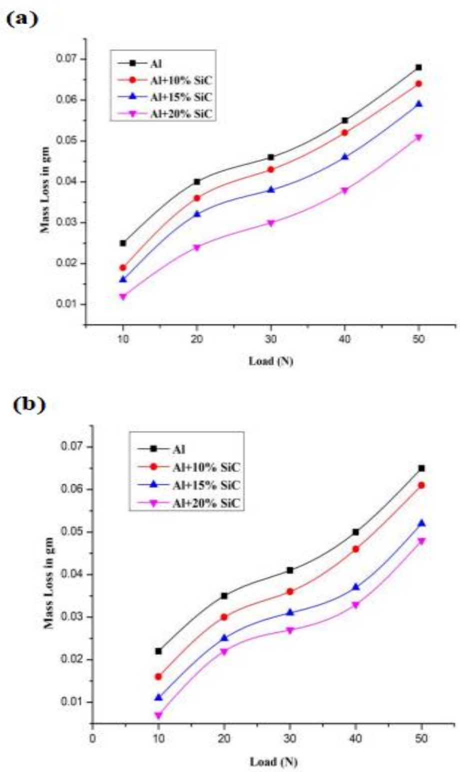

Figure 9: Mass Loss vs. Load result of (a) microwave processed composites, and (b) extruded composites.

4.5 *Wear v/s load*

Figures 10(a) and (b) comprehensively analyze the wear characteristics of pure aluminum and composites with differing weight percentages of SiC under various loads while maintaining consistent operational parameters. These figures provide valuable insights into the materials, and wear resistance performance.

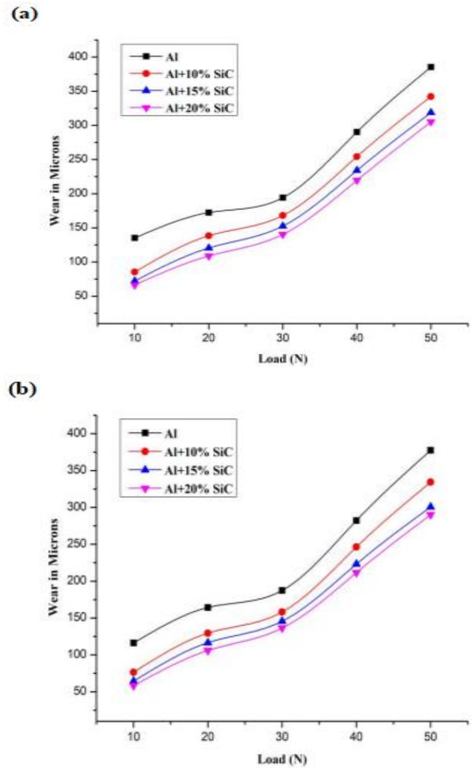

Figure 10: Wear vs. Load result of (a) microwave processed composites, and (b) extruded composites.

The data reveals a distinct trend: wear is most pronounced in pure aluminum and decreases as the SiC content in the composite increases. The trend is consistent for both extruded and microwave-processed composites. The reinforcing effect of the SiC particulates can be attributed to the reduction in attrition with higher SiC content. These particulates fortify the composite structure, making it more resilient to wear-induced degradation.

A noteworthy observation is also revealed by the wear test results: extruded composites exhibit slightly lower wear and mass loss than their microwave-processed counterparts, despite the identical material composition. Furthermore, the degradation rate in both extruded and microwave-processed composites decreases as the SiC content increases from 10% to 20%. A 28% increase in wear resistance was observed in comparison to the base composite, with 20% SiC exhibiting the greatest reduction in wear rate. This improvement comes from the higher SiC content, which makes the load distribution more even and the hardness higher, which lowers material loss and surface deformation.

SiC reinforcement and extrusion significantly influence the wear behavior of the composites under various loads, as shown by the results in Figure 10(a) and (b). The extrusion process further refines the composite structure, resulting in reduced wear and mass loss, while the presence of SiC particulates increases wear resistance. These findings have significant implications for the customization of materials to satisfy specific wear resistance requirements in real-world applications.

4.6 *Frictional Force vs. Load*

Figure 11(a) and (b) comprehensively analyze the frictional force that both microwave-processed and extruded composites encounter under varying loads. The analysis is essential for comprehending the thermodynamic behavior of the materials.

The data suggests that the frictional force is consistently greater in composites than in pure aluminum. This rise in frictional force in the composites is mostly due to the denser SiC particles that get stuck between the surfaces when they slide against each other. These particulates are harder, resulting in a greater frictional force due to the increased resistance.

Additionally, the findings indicate that the frictional force increases in proportion to the burden for all material compositions. The composites' increased frictional force is a sign of their improved capacity to resist erosion and sliding, a critical attribute in applications that prioritize frictional characteristics.

The pictures in Figure 11(a) and (b) show that the SiC particles strengthen the material by making it less likely to stick together. This makes the composites better for uses that need certain tribological properties ability to resist friction. It is crucial to comprehend these tribological features in order to evaluate these materials' applicability for real-world applications that call for particular frictional qualities.

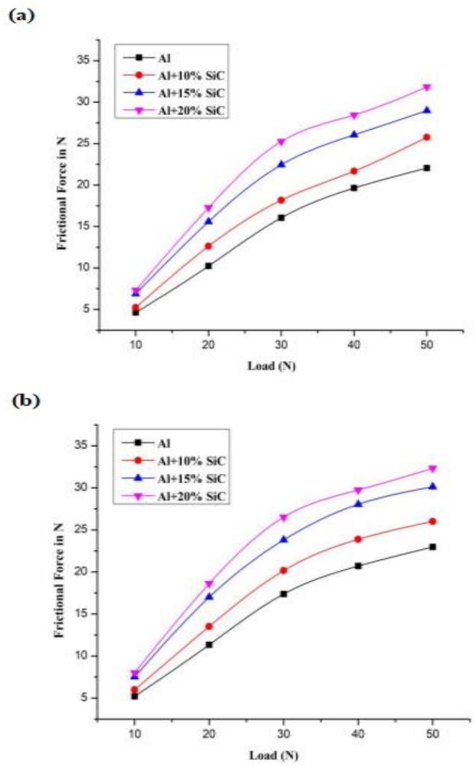

Figure 11: Frictional force vs. Load result of (a) microwave processed composites, and (b) extruded composites.

4.7 *Temperature vs. Load*

Figure 12(a) and (b) depict the temperature variations under various loads for both microwave-processed and extruded composites with varying compositions. This analysis offers crucial insights into the thermal behavior of the materials under operational duress.

Plotting the data reveals a consistent trend: the temperature rises as the applied load increases. This increase is more pronounced in unadulterated aluminum than in composites with SiC reinforcement. Pure aluminum's superior thermal conductivity allows for the transmission of heat to the surface, leading to higher temperature readings.

Nevertheless, the composites, particularly those with a higher SiC content, demonstrate lower temperatures when subjected to the same stresses. The composite materials' lower thermal conductivity in comparison to pure aluminum is the reason for the temperature decrease that occurs as the SiC content increases. The presence of SiC particulates effectively disperses the heat within the material, thereby reducing the overall temperature increase. This behavior is advantageous in applications where thermal management is essential, as it suggests that the composite is capable of maintaining reduced operational temperatures while under load.

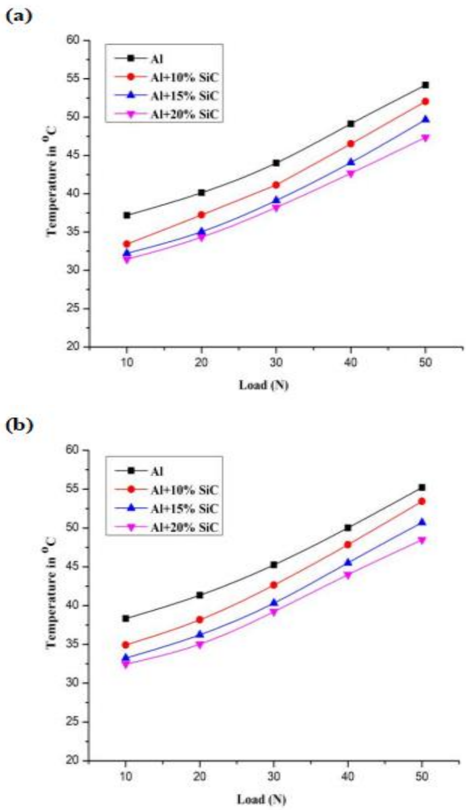

Figure 12: Temperature vs. Load result of (a) microwave processed composites and (b) extruded composites.

The results shown in Figure 12(a) and (b) underscore the significance of SiC reinforcement in regulating the thermal response of composites under varying pressures. These insights are essential for optimizing materials in applications that require thermal stability.

4.8 *Microstructural study of worn surface*

Figure 13(a) and (b) illustrate the worn surfaces of the test specimens through SEM images, which offer crucial insights into the wear mechanisms at work. Figure 13(a) illustrates the worn surface of pure aluminum, highlighting the prominent formation of fissures oriented in the direction of sliding. Tribological contact is the primary cause of these grooves are the direct result of internal plastic deformation caused by the interaction of asperities, which are small imperfections on the contacting surfaces. As the sliding process progresses, plastic flow manifests as a plowing action on the worn surface, leading to the formation of these grooves. The patterns serve as a visual representation of the material's reaction to the mechanical forces and stresses that affect it during the wear process.

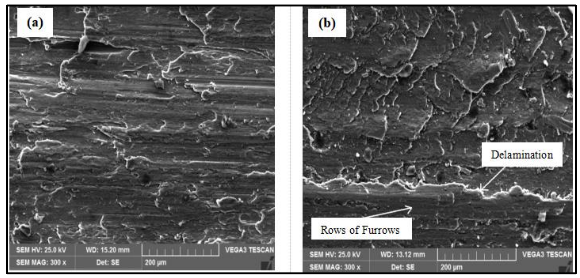

Figure 13: SEM images of worn surface of (a) Al without SiC, and (b) Al with SiC.

On the other hand, Figure 13(b) illustrates the weathered surface of an aluminum composite that has been reinforced with SiC. The specimen's degradation behavior is significantly different from that of the pure aluminum specimen. SiC particulates and secondary phases, particularly at grain boundaries, impede the continuous plastic flow in pure aluminum. This obstruction increases the material's resistance to plastic deformation. Furthermore, Figure 13(b)'s SEM image demonstrates the occurrence of delamination on the weathered surface, a crucial phenomenon for understanding wear resistance.

As a result of the accumulation of plastic deformation under sliding conditions, delamination occurs, resulting in the formation of dislocations and siblings within the material. These dislocations and twins have the potential to propagate through the grains and accumulate at subsurface grain boundaries, where they may initiate fractures. As the sliding process advances, these fractures coalesce to create a continuous intergranular crack that is parallel to the surface. At the same time, the plowing action at the surface generates localized plastically welded zones that bond the deformed surface layers together, thereby contributing to delamination.

These intricate observations provide valuable insights into the mechanisms that regulate the material's response to thermodynamic loading. The interplay between delamination, grain boundary interactions, dislocation generation, and plastic deformation improves our understanding of the wear processes and wear resistance in these materials. In applications where high wear resistance is required, this understanding is critical for informed material design and engineering.

5 Conclusions

This investigation demonstrated the feasibility and effectiveness of fabricating Al-SiC MMCs through extrusion and a microwave-assisted powder metallurgy process. The microstructural analysis demonstrated that the uniform distribution of SiC particles significantly enhanced the mechanical strength of the aluminum matrix. The presence of the SiC phase in the X-ray diffraction analysis demonstrated the effective incorporation of the reinforcement.

The addition of SiC reinforcement significantly improved the wear resistance of the composites. Using 20% SiC reduced the wear rate by up to 28% compared to the base aluminum matrix. The compressive strength increased from 83 MPa to 176 MPa as the SiC content reached 20%, while the hardness increased by 40% as a consequence of SiC reinforcement. The extrusion process further enhanced these properties by reducing porosity and aligning the SiC particles to enhance mechanical performance.

The incorporation of SiC also resulted in an increase in frictional force, which suggests that the material is more resistant to erosion and sliding under duress. Furthermore, thermal analysis revealed that composites with a higher SiC content manifested lower working temperatures, rendering them advantageous for applications that necessitate efficient heat management.

Future research could concentrate on the optimal reinforcement level by examining the impact of SiC content beyond 20% on mechanical and wear properties. Furthermore, exploring various processing techniques and reinforcement materials could enhance the material's efficacy. Research into the behavior of these composites in extreme environmental conditions, such as corrosive environments or high temperatures, has the potential to broaden their applicability to more demanding industrial sectors.

The results show that Al-SiC MMCs can be used as high-performance materials in fields that need better mechanical properties, resistance to wear, and thermal stability. The anticipated applications of these materials include the aerospace, defense, and automotive sectors, with a particular emphasis on components such as engine blocks, brake rotors, heat exchangers, and cutting tools. Furthermore, the development of fabrication processes such as microwave-assisted sintering and extrusion provides these industries with sustainable and energy-efficient manufacturing solutions, rendering them attractive for future industrial applications.

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Author Contributions

The experiments were conducted, the data was analyzed, and the manuscript was composed by H.C. The research work was supervised by S.M.S., who also provided critical insights into the experimental design and made a significant contribution to the interpretation of the results. A.M.H. was instrumental in the manuscript's revision process, which guaranteed the presentation of the findings with clarity and coherence. S.L.M. contributed valuable inputs to improve the quality of the work and was involved in the critical revision of the manuscript, M.P.: provided guidance throughout the research, assisted in the development of the research methodology, and contributed to the final approval of the published version. The final manuscript was reviewed and endorsed by all authors.

Conflicts of Interest

The authors declare no conflict of interest.

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