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A Critical Review of Mechanical and Wear Resistance Characterizations on Developed Aluminium Matrix Composite Reinforced With MgO Particulates

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Abstract

Aluminium matrix composites (AMCs) have garnered significant attention due to their extensive applications in diverse engineering sectors, including aerospace, automotive, marine engineering, and mineral processing. The incorporation of ceramic reinforcements, such as oxides and carbides, into these composites substantially augments their mechanical attributes. These ceramic materials contribute to the enhancement of various properties, including strength, hardness, and durability. Moreover, the improved thermo-mechanical characteristics, wear resistance, sustainability, and cost-efficiency render these composites highly versatile. Specifically, composites formulated through the amalgamation of aluminium and magnesium oxide (MgO) particulates offer an optimal balance between lightweight construction and a high strength-to-weight ratio. The primary objective of this review study is to conduct a comprehensive analysis of AMCs reinforced with MgO particulates. This analysis encompasses the methods of synthesis, the mechanisms contributing to material strengthening, and a focused examination of the impact of MgO reinforcement on mechanical and wear resistance properties.

Keywords: Aluminium Matrix Composites, Magnesium Oxide, Reinforcement, Mechanical Properties, Wear Resistance

1 Introduction

Aluminium, the most abundant metal, exhibits a plethora of desirable attributes such as malleability, light weight, and excellent corrosion resistance [1, 2]. Aluminium alloys primarily consist of aluminium, augmented with additional elements like copper, iron, silicon, magnesium, and zinc [3, 4]. These alloys are characterized by their lightweight nature and resistance to corrosion [5]. Rohatgi et al. [6] highlighted the versatility of aluminium alloys, which come in various tempers and serve as a broad range of manufacturing materials. Aluminium alloys are categorized into different series based on their alloying elements and properties. For instance, 1xxx series alloys are composed of high-purity aluminium, while 2xxx series alloys are copper-reinforced and exhibit considerable toughness. The 3xxx series contains manganese and offers excellent workability and strength. The 4xxx and 5xxx series are alloyed with silicon and magnesium, respectively, and possess good weldability and corrosion resistance. The 6xxx series includes silicon and magnesium, and the 7xxx series is primarily zinc-based, offering excellent strength and higher ductility [7, 8]. The burgeoning interest in Aluminium Matrix Composites (AMCs) is primarily focused on these aluminium alloys [9]. Various forms of ceramics, such as fibers, particulates, or whiskers, are used for reinforcement.

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Among these, particulate-based AMCs have gained prominence due to their enhanced mechanical properties, including improved microhardness, strength, and wear resistance over pure alloys [10, 11]. Factors such as the method of synthesis, size, shape, and chemical affinity between the matrix and reinforcement materials influence the microstructure and properties of AMCs [12]. Heat treatment techniques, such as aging, are employed to optimize the mechanical properties of these alloys [13]. The formation of strong chemical bonds at interfaces and the wetting of reinforcement by melted materials are considered crucial phases in AMC production [14]. Magnesium Oxide (MgO) serves as an exemplary reinforcement due to its wide range of refractory properties, excellent corrosion resistance, and thermal conductivity [15–17]. AMCs reinforced with ceramic particles exhibit superior mechanical properties compared to the base alloy [18]. These composites are characterized by low density, high microhardness, enhanced strength, and excellent wear and corrosion resistance [19]. Applications of Al-MgO based composites span various industries, including electronics, automotive, and aerospace, owing to their unique advantages [20]. Previous studies have primarily focused on aluminium as the matrix material, exploring its lightweight nature, environmental resistance, and generous mechanical properties [21]. Extensive research has been conducted in this domain over the past decades, as advancements in composite behaviors involve the mixture of more than two materials without amalgamation effects [22]. To evaluate the mechanical properties of various AMCs, common approaches include the rule of mixtures, microhardness testing, tensile strength testing, and wear resistance testing [23]. However, fully harnessing the potential of MgO-reinforced AMCs remains a challenge due to factors like inhomogeneous dispersion properties of the reinforcements, cost considerations, and the high demand for the resulting material's desirable properties.

2 Fabrication Methods

This review aims to shed light on the enhancement of mechanical properties, such as microhardness, tensile strength, and compressive strength, as well as tribological performance, notably wear resistance, through the incorporation of MgO particles. The focus is primarily on the fabrication techniques of Aluminium Matrix Composites (AMCs), specifically powder metallurgy and stir casting methods [24–26].

2.1 Processing Methodology

AMCs can be manufactured through various states: solid [24], liquid [25], and vapor [26]. Solid-state methods are categorized into powder metallurgy, which involves powder blending and consolidation, and foil diffusion bonding, which employs long fibers to form a matrix [27]. Liquid-state methods include electroplating and electroforming [28], stir casting [29], pressure infiltration [30], squeeze casting [31], spray deposition [32], and reactive processing [33]. Semi-solid state processes involve semi-solid powder processing, while vapor deposition methods include physical vapor deposition [34, 35]. Additionally, in situ fabrication routes are also employed for AMC production [36]. Liquid-state manufacturing routes are popular due to the effective distribution of particulates in the melted metal [37]. These methods are cost-effective, with stir casting, squeeze casting, and pressure infiltration being the most commonly used [38]. On the other hand, solid-state techniques like powder metallurgy (P/M) are also prevalent [39]. AMCs are primarily developed either through Liquid Metallurgy (L/M) or P/M routes. Stir casting is a favored L/M method, offering an efficient way to produce modern composites at a low cost [40]. Conversely, the P/M method provides a good distribution of particles in the pure alloy and has the advantages of high tolerance and minimal need for secondary machining processes [41]. Sahoo et al. [42] outlined the three crucial steps in the P/M process: blending or mixing, compaction, and sintering. Stir casting is frequently employed due to its cost-effectiveness and suitability for mass production [43]. The selection of appropriate process variables, such as stirrer speed and pouring and pre-heated temperatures, is crucial for synthesizing high-quality composites [44]. Hashmin et al. [45] emphasized that the cost of developing AMCs using the stir casting process is significantly lower compared to other methods. Owing to its flexibility, usability, and commercial viability, stir casting remains the most extensively researched method for AMC production.

2.2 Stir Casting Technique

The stir casting process is employed for the fabrication of innovative components. Initially, the base matrix is superheated above its melting point and then cooled to a temperature lower than the liquidus to maintain the mechanism. Concurrently, preheated particles are introduced into the slurry and mixed with the matrix alloy using a mechanical stirrer. This stirring can be performed on a continuous or semi-continuous basis. The slurry temperature is then elevated to reach a fully molten state, with stirring continuing for an average duration of 5 minutes at speeds ranging from 300 to 550 revolutions per minute. Subsequently, the molten material is superheated once more before being poured into a permanent mold to achieve the desired component shape, as illustrated in Figure 3 [46]. Composites reinforced with particles have been found to exhibit significant improvements in high-temperature properties, as studied by Nripjit et al. [46]. On the other hand, in situ methods for AMCs involve the formation of reinforcement particles within the aluminum matrix during the fabrication process. This approach enhances particle distribution and interface bonding but may require additional steps or specialized materials. Consequently, the overall cost could be impacted when compared to more conventional methods like powder metallurgy or stir casting.

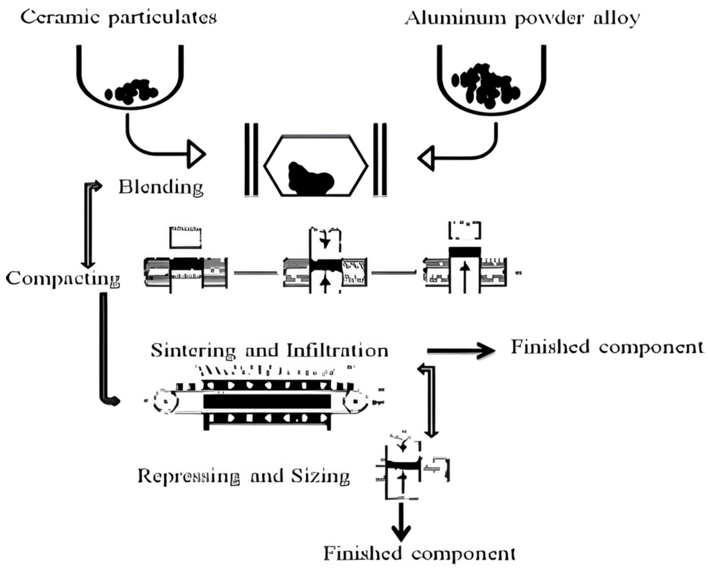

Figure 1: Powder metallurgy method.

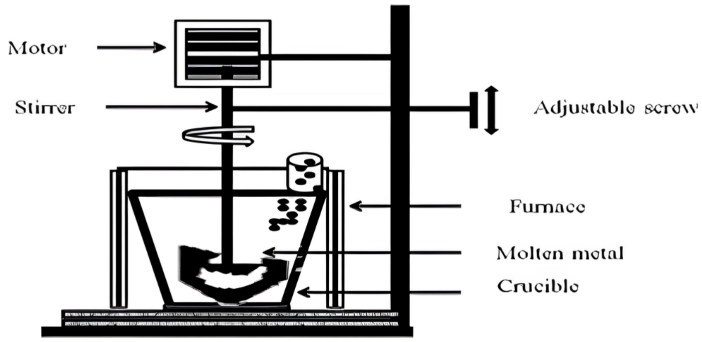

Figure 2: Stir casting method.

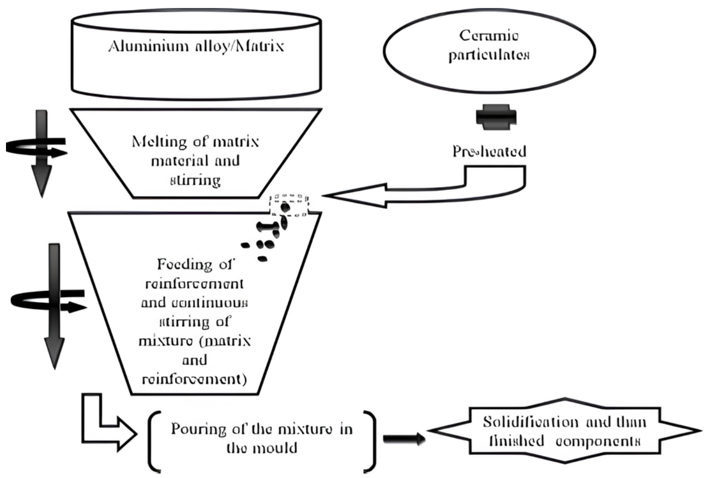

Figure 3: Stir casting procedure.

3 Mechanical Properties

This section aims to investigate the mechanical properties of Al-MgO based composites, which have garnered considerable attention for their potential to improve material attributes. The current study builds upon the extensive body of research in this area, with the intent of contributing new insights. Future research directions that could extend the current findings are also outlined. Various tests have been conducted to evaluate the mechanical properties of metal matrix composites, which utilize aluminum as the base metal and ceramic materials such as Al_2O_3, SiC, and MgO as reinforcements. A significant reduction in grain size has been observed both before and after the addition of reinforcement [47]. In the present study, A356.1-based composites with varying concentrations of MgO nanoparticles (1.5, 2.5, and 5 vol.%) were fabricated at different casting temperatures (800°C, 850°C, and 950°C) using the melt stirring method.

The results indicate that increasing the volume percentage of MgO nanoparticles initially enhances the bulk density of the samples, peaking at 2.5% MgO for all three casting temperatures. This suggests an optimal combination of MgO content and casting temperature may exist for maximizing bulk density while minimizing agglomeration and pore formation. In this context, the highest density was achieved at 850°C [48]. Furthermore, AA 5050/MgO nanoparticle composites with varying volume fractions of MgO (10, 20, 30%) were synthesized using the stir casting process. The tensile strength of the composite was found to decrease with an increase in MgO content, and matrix fractures occurred in composites containing a high volume fraction of 30% vol. MgO [49].

This section also elaborates on the mechanical properties of various aluminum-based composites reinforced with MgO and other materials. For instance, AA 6061 hybrid composite samples were synthesized via the stir casting route, incorporating 1% and 2% wt of Al_2O_3 and MgO. These reinforced composites exhibited notable improvements in microhardness and Ultimate Tensile Strength (UTS) compared to pure AA 6061 [50]. Similarly, A356/MgO-based materials with varying MgO volumes (5, 10, 15, 20%) demonstrated a gradual enhancement in mechanical properties. Specifically, Brinell hardness values ranged from 80.60 to 110.22 BHN, and UTS values increased from 264.96 to 316.11 MPa. Additionally, toughness values ranged from 6.37 to 12.29 J [51]. Another study by Muharrem Pul in 2013 focused on Al-MgO composites with 5, 10, 15% reinforcement. The Brinell hardness values of these samples increased to 50.2, 52.1, 56.4 HB, although the rupture strength values decreased with increased MgO content [52]. Furthermore, Al/MgO composites with 5, 10, 15% reinforcement by volume showed an increase in porosity values (3.99, 4.16, 4.42%). Despite this, the effective thermal conductivity of these composites increased [53]. ZTA/Zirconia toughened alumina composites were also studied, incorporating a 4/1 ratio of Al_2O_3 and aluminum alloy (YSZ). These composites, reinforced with 0.2-0.9 wt.% MgO, exhibited densities ranging from 4.32 to 4.47 g/cm^3 and Vicker hardness values between 1635 and 1694 HV. However, the fracture toughness values decreased from 3.8 to 3.02 MPa-m$^{1/2}$ [54]. The literature consistently suggests that MgO reinforcement enhances both the mechanical and wear resistance properties of composites. These quantitative findings underscore MgO's potential to improve key material properties, making it valuable for various industrial applications. The enhancements in tensile strength, modulus of elasticity, and other mechanical properties indicate the potential for improved structural performance, leading to stronger and more durable materials.

Table 1: Mechanical behaviors of various MgO reinforced composites.

Aluminum alloys	Reinforcement (MgO)	Method	Mechanical properties	Summarized	Reference
AA 7075	5% and 10% (Nano-particulates)	Stir casting	Brinell microhardness: 92.07 HB, Tensile Strength: 137.042 N/mm^2	Microhardness and tensile strength enhanced with MgO	Prasad et al., 2017 [55]
Pure aluminum	MgO (0.5, 1, 2, 3 wt.%)	Powder metallurgy	Relative Density: Cu+0.5wt.%MgO 91.52%	Relative densities decreased and microhardness increased with MgO	Gozde et al., 2016 [56]
A 356	MgO 1.5, 2.5, 5 vol.%	Stir casting and Powder metallurgy	Brinell microhardness varies	Microhardness and compressive strength improved with MgO	Abdizadeh et al., 2014 [57]
A 356	MgO (0, 5, 10, 15, 20 vol.%)	Stir casting	Brinell microhardness: 75.33 HB, Tensile strength: 232.23 MPa	Increase in microhardness, tensile strength, and toughness with MgO	Kumar et al., 2016 [58]
A356.1	MgO (1.5, 2.5, 5 vol.%)	Powder metallurgy	Brinell microhardness: About 45 HB	Composites containing 5% MgO showed maximum strength	Baghchesara et al., 2012 [59]
Pure aluminum	MgO (various sizes)	Vacuum Infiltration	–	Fracture strength increased with particle size	Calin and Citak, 2018 [60]

4 Tribological Properties

This section discusses the tribological properties of various aluminum-based composites reinforced with MgO and other materials. For example, AA 2219/MgO/Graphite (Gr) hybrid composites were manufactured using melt stirring. The weight content of MgO varied from 0.5%, 1%, to 1.5%, while the graphite content was consistently maintained at 1%. The wear rates of these composites were significantly influenced by MgO particles and were dependent on load, sliding displacement (SD), and speed. Optimal conditions resulted in a wear of 143.28 μm, confirmed by a test that yielded 148-μm wear [61]. AA LM13-MgO composites were synthesized via the stir casting process, with MgO reinforcement ranging from 2–10 wt.%. The wear rate decreased with increasing MgO content, under test conditions varying from 20 to 60 N load at a constant speed of 3.456 m/s [62]. Further, Al (ENAW1050A)/MgO composites with 5–15% reinforcement exhibited varying wear behavior. The wear test was conducted under loads ranging from 10–30 N at a sliding speed of 0.2 m/s. The hardest sample, with 15% MgO reinforcement, exhibited the most wear, while the Al/5% MgO composite showed the least wear under a 10 N load [63].

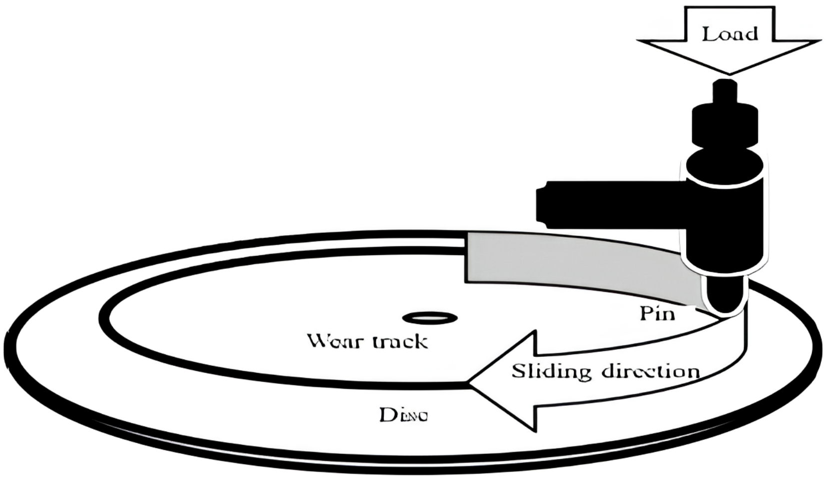

Figure 4: Pin-on-disc set-up.

A study by Manikandan et al. in 2015 focused on AA 6061-MgO composites. These were reinforced with MgO particulates ranging from 1.0 to 2.5 wt.% using the Powder Metallurgy (P/M) technique. The maximum microhardness value of 161.6 VH was achieved with the AA 6061-2%wt.MgO composite. Wear tests conducted under a load of 30 N, at a velocity of 1 m/s and sliding distances ranging from 200–2000 m, showed that 2%wt. MgO led to a wear loss decrease to 0.1292g, indicating enhanced wear resistance [64]. Wear mechanisms in MgO-reinforced composites can be broadly categorized into adhesive, abrasive, and erosive wear. Each of these mechanisms has distinct characteristics and implications for the wear behavior of the composites.

Table 2: Mechanical and Wear Resistance Properties of Various MgO Reinforced Composites

Aluminum Alloys	Reinforcement (MgO) and Method	Mechanical Properties	Wear Resistance Properties (ASTM G-99 standard)	Reference
AA430	SiC+MgO (2.5%, 5%, 7.5 wt.%) Method: Stir casting	Vickers microhardness: 49–61 HV, UTS: 133.21–153.65 MPa	Specific wear rate less than base alloy	[65]
AA 7075	MgO (3, 6, 9 wt.%) Method: Stir casting	Significant increase of hardness	Dry sliding wear: Unreinforced alloys have more wear	[66]
AA 7068	MgO (0, 1, 2, 5%) Method: P/M	Vickers microhardness: 33–68 HV	Enhanced wear resistance	[67]
Pure aluminum	MgO (10, 20, 30, 40vol.%) Method: Vacuum infiltration	Highest microhardness: 71HB, Highest tensile strength: 139 MPa	Lowest wear volume for Al-20%MgO	[68]
Pure aluminum	TiO2+MgO (3, 6, 9, 12 wt.%) Method: P/M	Brinell microhardness: 153–164 HV	Decreasing wear rate for Al/nano-MgO	[69]

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Table 2 – continued from previous page

Aluminum Alloys	Reinforcement (MgO) and Method	Mechanical Properties	Wear Resistance Properties (ASTM G-99 standard)	Reference
A356.1	MgO (0.5, 1, 1.5, 2 wt.%) Method: Stir casting	Brinell microhardness: 98.41 BH	Improved wear resistance	[70]
Pure aluminium	MgO (5, 10, 15 vol.%) Method: P/M	Brinell microhardness: 50.2–56.4 HB	5%MgO reinforced Al-specimens are worn the less	[71]
A 336.0	MgO+RHA Method: Stir casting	Increased hardness with MgO	Minimum wear rate for Al- alloy-10%RHA	[72]
AA 2024	MgO+Al2O3+Gr Method: P/M	Brinell microhardness: 85–111.2 HB	Highest wear resistance for AA 2024/10% Al2O3/ 3%MgO/1.5%Gr	[73]
AZ91 alloy	MgO+Al2O3 Method: In-situ	HV: 64%, YS: 43%, strain hardening: 115%	Highest wear resistance for AZ91-6.5%-composite	[74]
Pure aluminum	MgO (0, 1.5, 2.5, 3.5, 4.5 wt.%) Method: P/M	HV: 16.3%, CS: 13.5%	Optimum properties for Al–5wt.%/Gr–2.5wt.% nano–MgO	[75]
(Sn–Sb–Cu)	MgO+ Al2O3+ FeCr2O4 Method: P/M	–	Mass wear loss affected by FeCr2O4	[76]
ZK60	MgO (0.5% vol.) Method: P/M	Yield Strength: 386–426 MPa, Tensile strength: 419–456 MPa, Elongation: 8.5–9.5%	–	[77]

4.1 Adhesive Wear

Adhesive wear occurs when two contacting surfaces experience molecular attraction and bonding, leading to material transfer from one surface to another. In the context of pin-on-disc tests, adhesive wear can result in material transfer from the pin (the composite) to the disc (a counterpart material). The presence of MgO particles in the composite can act as barriers that reduce the tendency for adhesive wear. These particles enhance the load-bearing capability of the composite and minimize material transfer between the pin and the disc. Consequently, MgO-reinforced composites exhibit improved resistance against adhesive wear.

4.2 Abrasive Wear

Abrasive wear involves the removal of material from a surface due to the presence of hard particles or abrasive agents between the contacting surfaces. This type of wear is particularly relevant in pin-on-disc test setups, especially when the pin or disc undergoes repeated sliding contact with abrasive contaminants. Factors such as particle size, hardness, and concentration significantly affect the abrasive wear behavior. MgO particles, known for their wear resistance, contribute to the reduction of abrasive wear. The hardness and wear resistance of MgO particles can mitigate the abrasive effects of contaminants, thereby enhancing the composite's overall wear resistance.

4.3 Erosive Wear

Erosive wear is caused by the impact of solid particles or liquids on a surface, resulting in material removal. This type of wear is particularly relevant in specific applications, such as in industrial or environmental conditions where the composite may be exposed to high-velocity particles or corrosive liquids. MgO reinforcement, due to its inherent hardness and wear resistance, can offer a level of protection against erosive wear. Thus, it can be inferred that MgO-reinforced composites exhibit enhanced wear resistance due to the mitigating effects of MgO particles on adhesive, abrasive, and erosive wear mechanisms. The specific wear behavior is influenced by various factors, including the size, hardness, and concentration of MgO particles, as well as the testing conditions and environmental factors.

5 Impact of MgO Reinforcement on Aluminum Matrix Composites

Magnesium Oxide (MgO) is a widely used reinforcement material in Aluminum Matrix Composites (AMCs) due to its affordability, ease of incorporation, and beneficial impact on mechanical and wear resistance properties. The various advantages of using MgO as a reinforcement in AMCs are as follows:

- **Cost-Effectiveness:** MgO is often readily available and relatively low in cost. Its ease of incorporation into alloy production processes minimizes additional processing costs.
- **Mechanical Properties:** The addition of MgO particulates enhances tensile and compressive strength. The strong bond between the MgO particles and the aluminum matrix contributes to increased hardness and stiffness.
- **Wear Resistance:** MgO reinforcement significantly reduces the wear rate of AMCs. Its hardness and abrasion resistance minimize material loss during sliding or contact with abrasive surfaces. Additionally, MgO can lower the friction coefficients.
- **Environmental Resistance:** The presence of MgO offers protection against erosion in harsh environments.
- **Toughness:** MgO enhances the material's toughness and its ability to resist crack propagation.
- **Customizability:** The impact of MgO reinforcement can be tailored by adjusting factors like particle size, volume fraction, and distribution.
- **Comparison with Other Reinforcements:** The choice between MgO, Silicon Carbide (SiC), or Aluminum Oxide (Al_2O_3) depends on the application requirements. MgO offers good thermal stability and moderate wear resistance, SiC is ideal for high-temperature and high-wear applications, and Al_2O_3 is preferred for applications requiring excellent corrosion resistance, electrical insulation, and high hardness.

6 Discussions

The analysis of Aluminum Matrix Composites (AMCs) for various mechanical and tribological tests, as detailed in Table 1 and Table 2, reveals that reinforced-based composites consistently demonstrate superior performance compared to monolithic alloys. Among the studied materials, hybrid composites emerge as the most capable. The investigation into Al-MgO based composites has yielded several significant findings, offering valuable insights into composite fabrication, the role of reinforcement, challenges in traditional methods, and the influence of wetting-agents. A fundamental aspect for successfully fabricating Al-MgO based composites lies in achieving a homogenous dispersion of ceramic particulates within the pure alloy matrix. The uniform distribution of both the size and type of MgO particles is essential for the overall success of the composite fabrication process. Conventional stir casting, particularly when working with melted materials at elevated temperatures, poses difficulties in maintaining proper dispersion. These challenges can impede achieving the desired homogeneity and, consequently, the enhancement of material properties. As an alternative to traditional stir casting, electromagnetic stirring has emerged as a potential solution. This technique offers advantages in terms of achieving well-homogeneous dispersed composite materials, overcoming the limitations of conventional methods. Wetting-agents play a crucial role in facilitating strong interfacial bonding between the ceramic particulates and the aluminum matrix. By reducing the sacrificial held angle between the elements, wetting-agents promote effective strengthening within the composite. The presence of porosity within the composite and the level of wettability between the particulates and the pure aluminum alloy are pivotal considerations in the manufacturing process. Addressing these concerns can significantly impact the final material properties. Proper reinforcement achieved through homogeneous dispersion and effective wetting-agents results in a comprehensive enhancement of material properties, including mechanical strength and wear resistance. The findings highlight the potential application of Al-MgO based composites in industries seeking reliable and high-performance materials. Additionally, the scalability of electromagnetic stirring presents an intriguing avenue for industrial production. The findings suggest avenues for further research, such as optimizing the electromagnetic stirring technique, understanding the effects of different wetting-agents, and addressing challenges related to porosity and wettability.

6.1 Applications of AMCs:

In the current landscape, AMCs reinforced with MgO particles find utility in a wide array of applications. For instance, they are instrumental in the automotive sector, particularly in the development of brake components such as discs and pads, offering enhanced braking performance, reduced wear, and superior heat dissipation. Beyond the automotive industry, these composites are invaluable in aerospace for structural components, owing to their high strength-to-weight ratio and thermal stability. They are also suitable for high-temperature applications like jet engines and industrial furnaces. Their corrosion resistance makes them ideal for protective coatings in various industrial settings.

In the biomedical field, the biocompatibility and mechanical strength of Al-MgO composites are being explored for potential use in implants like hip and knee replacements. Additionally, their wear resistance is beneficial for bearings in heavy machinery, reducing maintenance and replacement costs. The lightweight and high-strength properties are advantageous in the production of high-performance sporting goods such as golf clubs and tennis rackets. In the construction sector, these composites serve as robust yet lightweight structural reinforcements. Overall, the versatility of Al-MgO based composites allows them to meet specific challenges across diverse industries, thereby contributing to technological advancements, sustainability, and performance optimization.

6.2 Future research scope for AMCs:

The development of Al-MgO based composites is an area ripe for further research, albeit with its own set of challenges and limitations such as poor wettability, particle agglomeration, and issues related to the reinforcement-matrix interface and processing. Addressing these research gaps necessitates innovative approaches. Computational modeling and simulations could be employed to predict the behavior of these composites under various conditions, thereby optimizing material and processing parameters and reducing the need for extensive experimental work. Another avenue worth exploring is the use of hybrid reinforcements, where MgO particles could be combined with other materials like carbon nanotubes or graphene to achieve synergistic improvements in composite properties. In-situ fabrication methods, where MgO particles are generated within the aluminum matrix during processing, could also be considered to improve particle distribution and bonding. Tailored processing techniques such as spark plasma sintering (SPS) or laser-assisted methods may offer more precise control over fabrication parameters. Additive manufacturing techniques like 3D printing could be leveraged for more intricate designs and controlled deposition of reinforcement materials. Advanced process automation and control systems could also be implemented to ensure consistency and quality in large-scale production. The future of Al-MgO composites is promising, with potential applications spanning diverse sectors. Key areas for future research include advanced fabrication techniques, the development of multi-functional materials, biomedical applications, and energy-efficient transportation solutions. These avenues not only offer the potential for technological advancements but also open up new possibilities for sustainability and performance optimization across various industries.

7 Conclusion:

The extensive literature review conducted in this study has elucidated several key aspects concerning the impact of reinforcement materials on the mechanical and tribological properties of Aluminum Matrix Composites (AMCs). Firstly, AMCs can be effectively fabricated using both powder metallurgy and stir casting techniques. The stir casting method, in particular, offers advantages in terms of cost-effectiveness and suitability for mass production. Secondly, the mechanical and wear-resistant properties of these composites are significantly enhanced with the incorporation of magnesium oxide particles. This suggests that composites with binary reinforcement could serve as better alternatives to those with single reinforcement. Thirdly, the study establishes a positive correlation between microhardness and wear resistance, indicating that AMCs with higher hardness values are likely to demonstrate reduced wear rates and superior performance under abrasive and erosive conditions. Fourthly, the potential applications of AMCs are vast, extending to sectors such as aerospace and marine industries where enhanced mechanical and wear-resistant properties are crucial. Lastly, the use of magnesium oxide as a reinforcing agent in AMCs holds considerable promise for construction materials, enhancing their structural integrity, durability, and overall performance. These reinforced composites meet the current demands in the construction and automotive sectors, including applications in engine components, brake parts, and suspension systems, and are well-positioned to address future challenges.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

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Author Contribution

Hartaj Singh: Conceptualization and Writing–original draft; **Kapil Singh**: Data creation; **Sachit Vardhan** Validation and Visualization; **Sanjay Mohan Sharma** Supervision and Writing-reviewing and editing.

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