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# Recent Wear Resistance Improvement Mechanisms of Aluminum Metal Matrix Composites: A Review

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ABSTRACT

Wear resistance is essential for ensuring the longevity and performance of mechanical components. Researchers are increasingly focusing on composite materials due to their high performance and cost effectiveness. Non-ferrous metals, like aluminum, provide improved wear resistance compared to ferrous metals. However, there is a need for a thorough review that specifically focuses on particle reinforced aluminum metal matrix composites (AMMCs). The purpose of this review is to explore and analyze the wear characteristics of particle reinforced AMMCs. It explores how different reinforcing materials affect the wear behavior of composites. The findings from this review provide valuable insights for improving wear resistance in diverse industries through the design and development of aluminum based composites. These findings also pave the way for future research in this area.

## 1. Introduction

Wear resistance is critical in industries such as automotive, aerospace, and manufacturing, as it ensures reliable performance, extends service life, and reduces maintenance costs. As a result, there is growing interest in developing advanced materials capable of withstanding severe abrasive and erosive conditions. Among these, aluminum metal matrix composites (AMMCs) have attracted significant attention due to their high strength-to-weight ratio, low density, and excellent wear resistance. Compared with conventional ferrous and non-ferrous alloys, AMMCs offer economic, performance, and environmental advantages, including reduced fuel consumption and emissions in transportation applications. Their superior mechanical, thermal, and tribological properties have led to widespread adoption in aerospace, automotive, marine, and structural applications where wear is a major concern [1–7].

Various reinforcements are added to aluminum matrices to enhance their mechanical and tribological properties [8]. Reinforcement particles improve stiffness, specific strength, wear, creep, and fatigue resistance, making composites more durable than conventional engineering materials [9]. Ceramic reinforcements, in particular, significantly enhance wear resistance under different loads, sliding speeds, and distances. Studies show that incorporating SiC and $B_4C$ into aluminum matrix hybrid composites markedly improves hardness, compressive strength, and wear resistance [10]. Although aluminum alloys are widely used in marine, aerospace, and automotive applications due to their low density and good formability, their low hardness and poor tribological performance limit broader use. These limitations are effectively addressed by reinforcing aluminum with particles such as SiC, $Al_2O_3$, graphite, titanium, and other reinforcements [11].

AMMCs are produced using various fabrication routes, including solid-state methods like powder metallurgy and friction stir processing, liquid-state techniques such as stir casting, squeeze casting, and liquid infiltration, and deposition processes like compo casting and spray deposition. These methods provide flexible options for effectively incorporating reinforcements into the aluminum matrix [12–14].

Numerous studies have investigated the wear behavior of particle-reinforced AMMCs, for instance, Chakrapani et al. [15] examined aluminum alloys such as 6061, 7075, and 5058 reinforced with particles like $Al_2O_3$, SiC, fly ash, zircon, and $B_4C$ using various fabrication methods, reporting significant improvements in mechanical and tribological properties, with reinforcement distribution playing a key role. Manikonda et al. [16] highlighted that reinforcements such as $Al_2O_3$, SiC, and graphite enhance aluminum performance cost-effectively, with SiC showing excellent matrix compatibility and wear resistance. Similarly, Sambathkumar et al. [17] reviewed AA7075 composites and confirmed that hard particle reinforcements markedly improve mechanical, tribological, and corrosion properties compared to the base alloy.

While many reviews discuss aluminum matrix composites and their fabrication methods, very few concentrate specifically on AA6061 composites produced through stir casting or powder metallurgy. In addition, existing studies offer limited insight into future research directions in this area. This review fills that gap by focusing on AA6061-based MMCs fabricated using stir casting and powder metallurgy, evaluating the effects of different reinforcements on wear behavior. It also highlights key challenges and suggests future research pathways to support the development of advanced wear-resistant AMMCs.

## 2. Overview of Wear Resistance Enhancement

Wear resistance is a key factor in the performance of MMCs, as it directly influences their durability, reliability, and ability to function under demanding engineering conditions. This section highlights the significance of wear resistance in MMCs, with a focus on aluminum metal matrix composites (AMMCs). It also discusses the role of reinforcements, the impact of fabrication methods, factors that affect wear behavior, and findings from experimental studies on wear performance.

### 2.1 *The Importance of Wear Resistance in MMCs and its Impact on their Performance.*

Wear resistance is vital in MMCs as it directly affects their performance. It allows MMCs to have prolonged service life, enhanced reliability, reduced maintenance and downtime, improved performance in harsh environments, energy efficiency, cost savings, and enhanced product quality. Developing MMCs with superior wear resistance is crucial for optimal performance. Wear-resistant materials (WRMs) have received a lot of attention as a result of their widespread use in industries like military, biomedical, medical, aerospace, automotive, and industrial. As a result, the development of wear-resistant materials has both technical and economic advantages. Indeed, the cost of abrasion on expensive materials can account for a large percentage of the gross national product (GDP) of technologically advanced nations, ranging from 1% to 4%. [18].

As a result, it may be stated that reinforcing improves wear resistance, giving it an advantage in applications where wear resistance is a design criterion. Increasing the volume proportion of reinforcement in composites leads to a higher wear resistance than monolithic alloys or metals [19]. Wear resistance is crucial, and it can be improved by increasing the material's hardness [20]. The addition of reinforcement improved wear resistance, and the reinforcements utilized were harder than the matrix material [21]. Heat-treated alloys and composites have better strength, hardness, and wear resistance, according to research reports [22]. Therefore, developing AMMCs with superior wear resistance is vital for optimal performance.

### 2.2 *Aluminum Metal Matrix Composites (AMMCs)*

Aluminum metal matrix composites have a distinct set of features that make them appealing for a wide range of applications, enhancing performance and improving aluminum's structural capabilities. Aluminum based composites are commonly recognized as very promising structural materials in metal matrix composites (MMCs) due to their outstanding corrosion resistance, wear resistance, specific modulus, and lightweight qualities. These AMMCs are made utilizing a variety of techniques and contain various reinforcement particles such as borides, carbides, oxides, nitrides, and mixtures of these. The inclusion of stable reinforcement particles in AMMCs adds to their superior mechanical properties and wear characteristics. Because of these qualities, it is well-suited for use in the aerospace and automotive industries [23].

In a study by Mohanavel et al. in 2021 [24] aluminum was recognized as an abundant and widely used material that offers versatility as a matrix in composite applications. The addition of ceramic particles to the aluminum matrix increases the composite's hardness, strength, stiffness, creep resistance, fatigue resistance, and wear qualities beyond those of traditional materials. As a result, aluminum composites have grown in popularity across a variety of industries.

Aluminum metal matrix composites (AMMCs) have great properties such as superior erosion and wear resistance, a high strength-to-weight ratio, and cost-effectiveness, making them extremely adaptable for a variety of applications. These composites can be further improved by adding ceramic reinforcements, which improves mechanical and frictional properties. Ceramic reinforcements like SiC, B4C, and $Al_2O_3$ are often used to improve the performance of AMMCs [25].

AMMCs are commonly recognized as the best composites for a wide range of applications in industries including automotive, aerospace, and marine. Due to its outstanding strength-to-weight ratio, increased toughness, great wear resistance, and hardness [26].

Metal matrix composite materials based on 6xxx series aluminum alloy are progressively being used in a wide range of industries, including marine, aerospace, and automotive [27]. Among the 6000 series alloys, 6061 is recognized as having the highest strength. It is commonly referred to as a structural alloy, indicating its suitability for applications that require robust structural support and load-bearing capabilities. The medium-strength aluminum alloy 6061 demonstrates excellent corrosion resistance properties. This makes it highly resistant to damage and deterioration caused by various corrosive environments, such as moisture, chemicals, and atmospheric conditions [28]. AA6061 is a popular aluminum alloy that exhibits good mechanical properties, including high strength, good corrosion resistance, and excellent weldability. To further improve its properties, AA6061 can be reinforced with various types of materials, including inorganic, organic, hybrid, and nanomaterials. Some common reinforcements used in AA6061 composites are SiC, B4C, $Al_2O_3$, and TiC [29]. Aluminum-based composites are versatile and have exceptional characteristics, making them appropriate for a variety of applications.

### 2.3 *Role of Reinforcements in Enhancement of Wear Resistance*

Reinforcements serve an important function in increasing MMC wear resistance. They contribute by resisting micro-cutting actions, restricting plastic deformation, and forming protective layers between the composite and abrasive surfaces. Incorporating suitable reinforcements, such as particles or fibers, improves the overall wear performance of MMCs. Recent research has looked into the mechanical and tribological behavior of various reinforcements in MMCs under dry and lubricated sliding circumstances. Studies have demonstrated that using various reinforcements in MMCs can effectively reduce friction and wear in tribological applications [6]. Reinforced particles resist abrasion and limit distortion in MMCs, resulting in good wear resistance [10]. Various reinforcements are chosen based production cost, product quality, and end application [5]. The employment of lubricant and silicon carbide as a hard reinforcement can considerably boost the desirable qualities of composites, such as wear resistance and strength, when compared to composites that have a single reinforcement, such as SiC or graphite alone [30]. Each reinforcement material possesses distinct metallurgical and economic characteristics suitable for specific engineering applications. Industrial manufacturers have emphasized the use of particulate reinforcement composites due to their cost-effectiveness [31]. Incorporating hard reinforcing materials to MMCs improves their wear performance [32]. The incorporation of SiC &Jute ash in to aluminum leads to an increase wear resistance [33]. Higher reinforcement content improves the mechanical and tribological properties of the composites [34].

The use of hard reinforcement particles in AMMCs improves their wear performance. Increasing the amount of reinforcement particles improves the wear resistance of AMMCs. These reinforcing particles help with wear resistance by preventing micro-cutting action induced by rubbing abrasives and limiting plastic deformation by forming a protective oxide layer between the composite and the opposing abrasive. The applied load in dry sliding wear of AMMCs is directly proportional to the material removal rate. The sliding distance and sliding speed also have predictable impacts on the wear rates of AMMCs. AMMCs can experience a variety of wear processes, such as abrasive, adhesive, delamination, and fretting wear. [7]. However, the addition of reinforcements in the production of (AMMCs) presents several challenges, including the reactivity between the matrix and the reinforcing material, the type of reinforcing material chosen, the volume fraction of the reinforcing material, and the distribution of the reinforcing material within the composite [35].

### 2.4 *Fabrication Techniques for AMMCs*

Several fabrication techniques are employed to produce (MMCs). These methods include stir casting, powder metallurgy, and in-situ synthesis. Each process has advantages and disadvantages for producing desirable MMC qualities, such as wear resistance. Choosing the appropriate fabrication technique is crucial for obtaining MMCs with enhanced wear performance. However, the AMMC are generally fabricated by powder metallurgy route or liquid casting technique, because of the cost effective.

Stir casting, also called vortex method, is a popular liquid state processing technique. Preferred for its simplicity, for complex components, as it ensures desired quality and process efficiency. For bulk production with desired properties. Simple, cost-effective, and offers a pretty consistent dispersion. Operationally simple, cheapest, most efficient, and feasible for producing particle/fiber reinforced composites. Low processing costs and high production rates make it easily customizable and economically viable. Highly attractive due to its availability and cost-effectiveness. The benefits of its flexibility and adaptability to large-scale production. Stir casting has several disadvantages, including inadequate distribution of reinforcement ceramic particles in the metal matrix (agglomerations), porosities in composites during manufacturing, and limited wettability of ceramic particles with molten metal [36]–40]. Stir casting has the drawback of reinforcement segregation, which is challenging to avoid. To overcome this drawback, powder metallurgy is employed [41].

Powder metallurgy (PM) is a solid-state manufacturing method that generates high-quality MMCs with uniform reinforcing distribution. However, it has limits, such as being appropriate mainly for simple-shaped components with little reinforcement content, high cost for producing large and heavy parts due to expensive dies, difficulties in compressing certain metal powders and procuring them, non-uniform density of compacts, lower impact and fatigue strength compared to other methods, and potential health issues from atmospheric contamination in the workplace [42]. Powder metallurgy minimizes defects like porosity, poor wetting, and interfacial energies in composites. Fabricating MMCs using pm is a revolutionary approach in both research and industry. Unlike procedures like as stir casting and squeeze casting, powder metallurgy aids in the resolution of wetting and interface bonding issues between reinforcement and matrix. Researchers routinely use PM to eradicate these flaws and improve the mechanical properties of composites [43]. Solid-state processing below the matrix melting point overcomes the limitations of liquid-state processing in MMCs. pm is a highly preferred and adaptable method for manufacturing MMCs. Compared to other technologies, it provides a more uniform microstructure, high strength, dimensional accuracy, reduced scrap loss, and avoids the requirement for intensive machining processes [44].

### 2.5 *Factors Influencing Wear Performance*

Various factors influence the wear performance of MMCs. The distribution of reinforcements within the material is influenced by stir casting parameters, including temperature, speed, and stirring time. PM parameters that affect the material's microstructure include compaction pressure, sintering temperature, and time. The characteristics of reinforcements, such as particle size, shape, and weight percentage, impact wear resistance. Wear parameters, including load, sliding speed, and sliding distance, also play a significant role in wear behavior. By optimizing these factors, it is possible to improve wear performance and develop materials with increased wear resistance.

AA6061 composite, fabricated using the stir casting route, incorporates different proportions of reinforcement materials such as SiC, $Al_2O_3$, and zirconia sand ($ZrSiO_4$); rice husk ash (RHA). Based on experimental results, wear characteristics are mostly influenced by the size of the abrasive grain. [45].

Wear rate and frictional forces are decreased by AMMCs with fly ash reinforcement. At low speeds and moderate loads, wear starts out mildly and gets worse as the load and speed increase. Adhesion, often referred to as thermally stimulated wear, causes wear cracks to appear on the surface of the composite. Adding fly ash particles to AMMCs at room temperature reduces their cutting and plastic deformation properties. However, plastic deformation during sliding creates a protective layer between 100°C and 200°C, which lowers the wear rate of fly ash reinforced metal matrix composites. [46].

In their comprehensive review, Baliarsingh et al. 2023 [47] investigated the impact of different parameters on the mechanical and tribological properties of MMCs, including fabrication process, type of reinforcement, and content. A longer stirring time was found to have a negative effect on the mechanical qualities, whereas a longer ball milling duration produced positive results. Aluminum alloy's mechanical strength and wear resistance were increased by the inclusion of carbonaceous and ceramic reinforcements. Test circumstances, reinforcement content, and particular combinations of matrix-reinforcement determined how wear process factors affected wear rate (WR) and coefficient of friction (COF).

In this work, an AA8011-BN metal matrix composite's wear performance was examined using a Taguchi orthogonal array design. The experiment included variations in sliding distance, time, applied force, and reinforcement content. The results indicated that, within the specific test range, the weight fraction of the reinforcement had the greatest impact on wear behavior. It was also found that wear behavior was significantly influenced by the sliding distance and the applied force, making them important factors to take into account [48]. Using a Pin-on-disk wear testing apparatus at normal temperature, the dry sliding wear characteristics of aluminum composites were examined. The wear rate in this circumstance is dependent on several characteristics, including as the applied load, sliding distance, sliding velocity, and the presence of reinforcement materials [49].

2.6 *Experimental Studies on Wear Performance*

The wear performance of AMMCs has been studied experimentally. In these investigations, wear rates and the impacts of several parameters on wear resistance are evaluated.

In a study conducted by Arunkumar et al. in 2020 [50] the kind and amount of reinforcing particles utilized, together with the production method, all affect the characteristics of AMMCs, according to a thorough assessment of the literature. SiC is widely utilized due to its availability and its ability to improve composite hardness. Titanium carbide (TiC) is preferred for improved resistance to abrasion. Al2O3 is a cost-effective option, often incorporated using powder metallurgy to achieve optimal particle distribution. Despite availability and cost concerns, B4C is favored for its superior mechanical properties. When it comes to microstructure, mechanical, thermal, and tribological qualities, hybrid composites outperform monolithic composites. Silver (Ag) in the composite has self-lubricating properties, while graphite has good lubricating qualities.

In their study, Chandla et al. 2021 [51] carbides, oxides, nitrides, and several agro-industrial reinforcements (SiC, $B_4C$, TiC, WC, $TiB_2$, $Al_2O_3$, $TiO_2$, $ZrO_2$, $MoS_2$, $Fe_2O_3$, Gr, FA, RM, CNT, and MWCNT) were effectively added to AA6061 MMCs through the casting process, the AA6061 composites' mechanical, tribological, and physical properties were greatly enhanced. In the AA6061 MMC, the addition of solid reinforcements significantly improved tribological parameters such as specific wear rate (SWR), volume wear rate (VWR), wear rate (WR), wear loss (WL), and coefficient of friction (COF). Gr, SiC, $B_4C$, and $Al_2O_3$ particles showed the biggest improvements in SWR and COF among all the reinforcements. Gr reinforcing in particular, with its self-lubricating effect, demonstrated exceptional tribological qualities. The as-cast composites' wear resistance (WR) and COF were improved as a result of the formation of a scratch-resistant layer on their surface.

The study concentrated on hybrid and AA6061-based MMCs. SiC and B4C reinforcements were added to the experiment using the stir casting technique. The analysis of wear performance showed that the specimens with the highest weight percentage of reinforcements exhibited reduced wear rates compared to the others [52]. Using stir-casting, an AA6061 hybrid metal matrix composite (HAMMC) was produced. It was strengthened using a constant 5% weight fraction of fly ash and differing weight fractions of SiC and $Al_2O_3$. The hybrid composite with 20% total reinforcing material demonstrated exceptional hardness, high yield strength, and low wear rate, according to the experimental results [53]. AA6061-SiC composites with different weight percentages of SiC particles are made by using the stir casting technique. Wear tends to reduce with increasing SiC concentrations in these composites, but increases with sliding distance and load. The coefficient of friction (COF) also exhibits a tendency to drop with sliding distance, increase with load, and climb with SiC concentration. Under maximum conditions (3000 m sliding distance), the wear in the AA6061-9 weight percentage SiC composite is 68% less than that of cast AA6061 at a contact load of 30 N. At the same contact force of 30 N, the AA6061-9 wt.% SiC composite's coefficient of friction (COF) is 15% greater than the cast AA6061's [54].

$MoS_2$, SiC, and $B_4C$ used as reinforcement for the aluminum alloy AA6061 MMCs. Double- and triple-reinforced samples have reduced wear loss in comparison to non-reinforced specimens, according to the wear performance of the hybrid composites. A protective B2O3 layer that formed at the contact zone and the existence of solid MoS2 lubricant were blamed for this. The two principal wear mechanisms found in these composites were wear debris and delamination wear [55]. The impact of SiC and SiC/Alumina ($Al_2O_3$) particles with different weight percentages (5 wt%, 7 wt%, and 7 wt% SiC/3 wt% $Al_2O_3$) on the wear, microstructural, and mechanical properties of the composites that were formed was assessed. When compared to cast aluminum alloy, the addition of these reinforcements boosted mechanical strength and wear resistance. The alloy AA6061, which had a SiC/$Al_2O_3$ composite content of 7 weight percent, had the maximum tensile strength, hardness, and wear resistance. It measured 134.3 N/mm2, 35VHN, and 17.27 × 10-5mm$^3$/Nm, respectively. The examination of the optical microscope showed that the reinforcement particles were uniformly distributed throughout the aluminum alloy matrix [56].

The wear characteristics of composites made using AA6061 and SiC via PM method. The green compacts were sintered at temperatures between 610 and 640°C after being uniaxially pressed at 350 MPa of pressure. As the weight % of SiC grew, the composites' wear rate dropped. The reason for this is that a mechanical mixed layer (MML) forms, which aids in preventing direct contact between mating parts [57].

AA6061 with $B_4C$ and SiC as reinforcement materials using a PM procedure. Because of the hardness of $B_4C$ and the advantageous adhesive characteristics between the matrix and SiC, the samples with 9% $B_4C$ and 3% SiC were determined to have the maximum wear resistance [58].

Aluminum alloy 6061 reinforced with SiC and $Al_2O_3$ particles combines the benefits of the reinforcements with the special qualities of the aluminum matrix metal, including high strength, light weight, and ease of machining. Silicon carbide (SiC) offers excellent hardness and wear resistance, while aluminum oxide ($Al_2O_3$) provides good compressive strength and wear resistance [59].

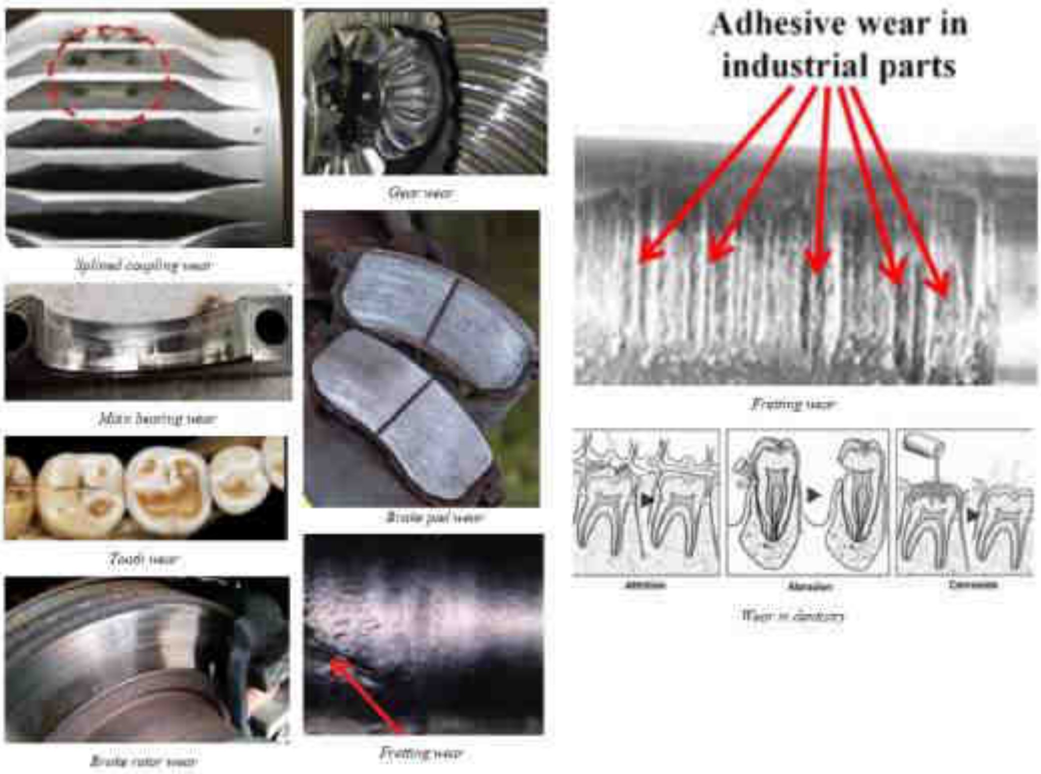


Figure 2.5 Wear in human, and industrial machinery parts.

**3. Existing Challenges and Future Research Directions**

This section discusses the existing challenges in AMMCs and outlines potential future research directions to overcome them.

3.1 *Existing Challenges*

Even though strengthened AMMCs have the potential to improve wear resistance, a number of issues still need to be resolved. Consistent wear resistance in the aluminum matrix depends on the correct dispersion and homogeneous distribution of reinforcing particles. Challenges arise in achieving a homogeneous particle distribution, especially with high-volume fractions of reinforcement. Developing effective processing techniques to ensure uniform dispersion and prevent particle agglomeration is vital. The choice of reinforcing particles greatly impacts the wear resistance of AMMCs. However, selecting the most appropriate reinforcement material for specific applications remains a challenge. Factors such as particle size, shape, composition, and compatibility with the aluminum matrix need to be carefully considered to optimize wear performance

3.2 *Future Research Directions*

To overcome the existing challenges and further enhance the wear resistance of reinforced AMMCs, future research can focus on the following directions. Develop novel processing techniques that enable precise control over the particle distribution and dispersion within the AMMCs, leading to enhanced wear resistance. Explore new reinforcement materials with superior wear resistance properties. Additionally, investigating synergistic combinations of different reinforcement materials can offer unique advantages in terms of wear resistance. By addressing these challenges and exploring these research directions, the field of reinforced AMMCs can continue to advance, offering highly effective wear-resistant materials for a wide range of industrial applications.

**4. Conclusion**

Reinforced AMMCs hold immense potential for enhancing wear resistance in various industrial applications. Through a review of existing literature, the incorporation of reinforcing particles within the aluminum matrix offers significant improvements in wear performance. Increasing the amount of reinforcement enhances wear performance. However, several challenges exist, including, particle distribution, and selection of suitable reinforcing materials. Addressing these challenges requires further research and development efforts. Future studies should focus on advanced processing techniques can be explored to achieve uniform particle distribution and dispersion within AMMCs. Additionally, the development of novel reinforcement materials and the investigation of synergistic combinations can further optimize wear resistance.

**Conflict of interest**
The authors declare no conflict of interest.

**Ethical approval**
This work does not require any ethical statement.

**Reference**


[1] S. Suresh Kumar, S. Thirumalai Kumaran, G. Velmurugan, A. Perumal, S. Sekar, and M. Uthayakumar, "Physical and mechanical properties of various metal matrix composites: A review," in *Materials Today: Proceedings*, Jan. 2021, vol. 50, pp. 1022–1031. doi: 10.1016/j.matpr.2021.07.354.

[2] U. K. Annigeri and G. B. Veeresh Kumar, "Effect of Reinforcement on Density, Hardness and Wear Behavior of Aluminum Metal Matrix Composites: A Review," in *Materials Today: Proceedings*, 2018, vol. 5, no. 5, pp. 11233–11237. doi: 10.1016/j.matpr.2018.02.002.

[3] N. M. S. Kumar *et al.*, "Coatings on Reinforcements in Aluminum Metal Matrix Composites," *Int. J. Met.*, vol. 17, no. 2, pp. 1049–1064, Apr. 2023, doi: 10.1007/s40962-022-00831-8.

[4] A. Chatterjee, P. Roy, A. K. Birru, and G. Sutradhar, "A comprehensive review on tribological and mechanical properties of metal matrix composites," in *AIP Conference Proceedings*, Jun. 2023, vol. 2810, no. 1. doi: 10.1063/5.0146914.

[5] B. Singh *et al.*, "A future prospects and current scenario of aluminium metal matrix composites characteristics," *Alexandria Eng. J.*, vol. 76, pp. 1–17, Aug. 2023, doi: 10.1016/j.aej.2023.06.028.

[6] P. D. Srivyas and M. S. Charoo, "Role of Reinforcements on the Mechanical and Tribological Behavior of Aluminum Metal Matrix Composites - A Review," in *Materials Today: Proceedings*, Jan. 2018, vol. 5, no. 9, pp. 20041–20053. doi: 10.1016/j.matpr.2018.06.371.

[7] N. Idusuyi and J. I. Olayinka, "Dry sliding wear characteristics of aluminium metal matrix composites: A brief overview," *Journal of Materials Research and Technology*, vol. 8, no. 3. Elsevier, pp. 3338–3346, May 01, 2019. doi: 10.1016/j.jmrt.2019.04.017.

[8] K. K. Sadhu, N. Mandal, and R. R. Sahoo, "SiC/graphene reinforced aluminum metal matrix composites prepared by powder metallurgy: A review," *Journal of Manufacturing Processes*, vol. 91. Elsevier, pp. 10–43, Apr. 07, 2023. doi: 10.1016/j.jmapro.2023.02.026.

[9] L. Bhanuprakash, N. Manikandan, L. Varghese, and J. Joseph, "Study on aluminium metal matrix composites reinforced with SiC and granite powder," *Mater. Today Proc.*, Jul. 2023, doi: 10.1016/j.matpr.2023.06.246.

[10] A. Pramanik, "Effects of reinforcement on wear resistance of aluminum matrix composites," *Trans. Nonferrous Met. Soc. China (English Ed.*, vol. 26, no. 2, pp. 348–358, Feb. 2016, doi: 10.1016/S1003-6326(16)64125-0.

[11] P. Singh, R. Walia, and C. S. Jawalkar, "A comprehensive review study on aluminium based hybrid composites with organic and inorganic reinforcements," *Sadhana - Acad. Proc. Eng. Sci.*, vol. 48, no. 1, pp. 1–29, Mar. 2023, doi: 10.1007/s12046-023-02093-4.

[12] J. Lade *et al.*, "A critical review of fabrication routes and their effects on mechanical properties of AMMCs," *Mater. Today Proc.*, Mar. 2023, doi: 10.1016/j.matpr.2023.03.041.

[13] P. V. Reddy, G. S. Kumar, D. M. Krishnudu, and H. R. Rao, "Mechanical and Wear Performances of Aluminium-Based Metal Matrix Composites: A Review," *Journal of Bio- and Tribo-Corrosion*, vol. 6, no. 3. Springer, pp. 1–16, Sep. 01, 2020. doi: 10.1007/s40735-020-00379-2.

[14] S. Sharma, A. Goyal, P. Bharadwaj, A. D. Oza, and A. Pandey, "Application of metal matrix composite fabricated by reinforcement materials – A review," *Mater. Today Proc.*, Mar. 2023, doi: 10.1016/j.matpr.2023.02.287.

[15] P. Chakrapani and T. S. A. Suryakumari, "Mechanical properties of aluminium metal matrix composites-A review," in *Materials Today: Proceedings*, Jan. 2020, vol. 45, pp. 5960–5964. doi: 10.1016/j.matpr.2020.09.247.

[16] R. D. Manikonda, S. Kosaraju, K. A. Raj, and N. Sateesh, "Wear Behavior Analysis of Silica Carbide Based Aluminum Metal Matrix Composites," in *Materials Today: Proceedings*, Jan. 2018, vol. 5, no. 9, pp. 20104–20109. doi: 10.1016/j.matpr.2018.06.377.

[17] M. Sambathkumar, R. Gukendran, T. Mohanraj, D. K. Karupannasamy, N. Natarajan, and D. S. Christopher, "A Systematic Review on the Mechanical, Tribological, and Corrosion Properties of Al 7075 Metal Matrix Composites Fabricated through Stir Casting Process," *Advances in Materials Science and Engineering*, vol. 2023. Hindawi Limited, 2023. doi: 10.1155/2023/5442809.

[18] B. P. Aramide, A. P. I. Popoola, E. R. Sadiku, F. O. Aramide, T. Jamiru, and S. L. Pityana, "Wear-Resistant Metals and Composites," in *Handbook of Nanomaterials and Nanocomposites for Energy and Environmental Applications: Volumes 1-4*, vol. 1, Springer International Publishing, 2021, pp. 731–756. doi: 10.1007/978-3-030-36268-3_177.

[19] U. K. Annigeri and G. B. Veeresh Kumar, "Effect of Reinforcement on Density, Hardness and Wear Behavior of Aluminum Metal Matrix Composites: A Review," in *Materials Today: Proceedings*, Jan. 2018, vol. 5, no. 5, pp. 11233–11237. doi: 10.1016/j.matpr.2018.02.002.

[20] S. J. S. Chelladurai, S. S. Kumar, N. Venugopal, A. P. Ray, T. C. Manjunath, and S. Gnanasekaran, "A review on

mechanical properties and wear behaviour of aluminium based metal matrix composites," in *Materials Today: Proceedings*, Jan. 2020, vol. 37, no. Part 2, pp. 908–916. doi: 10.1016/j.matpr.2020.06.053.
[21] A. Coyal, N. Yuvaraj, R. Butola, and L. Tyagi, "An experimental analysis of tensile, hardness and wear properties of aluminium metal matrix composite through stir casting process," *SN Appl. Sci.*, vol. 2, no. 5, pp. 1–10, May 2020, doi: 10.1007/s42452-020-2657-8.
[22] H. Singh, K. Singh, S. Vardhan, and S. Mohan, "Study on the wear performance of AA 6061 and AA 6082 based metal matrix composites," in *Materials Today: Proceedings*, Jan. 2020, vol. 43, pp. 660–664. doi: 10.1016/j.matpr.2020.12.585.
[23] P. Samal, P. R. Vundavilli, A. Meher, and M. M. Mahapatra, "Recent progress in aluminum metal matrix composites: A review on processing, mechanical and wear properties," *Journal of Manufacturing Processes*, vol. 59. Elsevier, pp. 131–152, Nov. 01, 2020. doi: 10.1016/j.jmapro.2020.09.010.
[24] V. Mohanavel *et al.*, "Mechanical Properties of Titanium Diboride Particles Reinforced Aluminum Alloy Matrix Composites: A Comprehensive Review," *Advances in Materials Science and Engineering*, vol. 2021. Hindawi Limited, 2021. doi: 10.1155/2021/7602160.
[25] R. S. Gill, P. S. Samra, and A. Kumar, "Effect of different types of reinforcement on tribological properties of aluminium metal matrix composites (MMCs) – A review of recent studies," *Mater. Today Proc.*, vol. 56, pp. 3094–3101, Jan. 2022, doi: 10.1016/j.matpr.2021.12.211.
[26] S. Ranjan, J. Karloopia, and P. K. Jha, "Recent Advances in Aluminium-Based Hybrid Metal Matrix Composites: A Review," in *Minerals, Metals and Materials Series*, Springer Science and Business Media Deutschland GmbH, 2022, pp. 53–81. doi: 10.1007/978-3-030-92567-3_4.
[27] A. Yahia Hassan *et al.*, "The electrochemical degradation, wear behavior and machining of metal matrix composites based on 6xxx aluminum alloy with ceramic particulate reinforcements; a brief review," *Mater. Today Proc.*, vol. 80, pp. 377–381, Jan. 2023, doi: 10.1016/j.matpr.2022.10.184.
[28] S. Muniamuthu, J. Udaya Prakash, S. Jebarose Juliyana, and C. Sarala Rubi, "Investigation of mechanical properties of metal matrix composites," *Mater. Today Proc.*, Aug. 2023, doi: 10.1016/j.matpr.2023.07.341.
[29] A. Kareem, J. A. Qudeiri, A. Abdudeen, T. Ahammed, and A. Ziout, "A review on aa 6061 metal matrix composites produced by stir casting," *Materials (Basel).*, vol. 14, no. 1, pp. 1–22, Jan. 2021, doi: 10.3390/ma14010175.
[30] R. Manjunath, D. Kumar, and A. Kumar, "A Review on the Significance of Hybrid Particulate Reinforcements on the Mechanical and Tribological Properties of Stir-Casted Aluminum Metal Matrix Composites," *Journal of Bio- and Tribo-Corrosion*, vol. 7, no. 3. Springer Science and Business Media Deutschland GmbH, pp. 1–11, Sep. 01, 2021. doi: 10.1007/s40735-021-00558-9.
[31] A. Saxena, K. K. Saxena, V. K. Jain, S. K. Rajput, and B. N. Pathak, "A review of reinforcements and process parameters for powder metallurgy-processed metal matrix composites," *Mater. Today Proc.*, Mar. 2023, doi: 10.1016/j.matpr.2023.02.227.
[32] N. Bharat and P. S. C. Bose, "An overview on the effect of reinforcement and wear behaviour of metal matrix composites," in *Materials Today: Proceedings*, Jan. 2021, vol. 46, pp. 707–713. doi: 10.1016/j.matpr.2020.12.084.
[33] A. Coyal, N. Yuvaraj, R. Butola, and L. Tyagi, "An experimental analysis of tensile, hardness and wear properties of aluminium metal matrix composite through stir casting process," *SN Appl. Sci.*, vol. 2, no. 5, pp. 1–10, May 2020, doi: 10.1007/s42452-020-2657-8.
[34] A. Kareem, J. A. Qudeiri, A. Abdudeen, T. Ahammed, and A. Ziout, "A review on aa 6061 metal matrix composites produced by stir casting," *Materials (Basel).*, vol. 14, no. 1, pp. 1–22, 2021, doi: 10.3390/ma14010175.
[35] G. Sundar and N. Rajesh Jesudoss Hynes, "Reinforcement in aluminium metal matrix composites," in *AIP Conference Proceedings*, Aug. 2019, vol. 2142, no. 1. doi: 10.1063/1.5122398.
[36] D. Kumar, S. Angra, and S. Singh, "Mechanical Properties and Wear Behaviour of Stir Cast Aluminum Metal Matrix Composite: A Review," *Int. J. Eng. Trans. A Basics*, vol. 35, no. 4, pp. 794–801, 2022, doi: 10.5829/IJE.2022.35.04A.19.
[37] P. Samal, P. R. Vundavilli, A. Meher, and M. M. Mahapatra, "Recent progress in aluminum metal matrix composites: A review on processing, mechanical and wear properties," *J. Manuf. Process.*, vol. 59, no. September, pp. 131–152, 2020, doi: 10.1016/j.jmapro.2020.09.010.
[38] H. Kala, K. K. S. Mer, and S. Kumar, "A Review on Mechanical and Tribological Behaviors of Stir Cast Aluminum Matrix Composites.," *Procedia Mater. Sci.*, vol. 6, no. Icmpc, pp. 1951–1960, 2014, doi: 10.1016/j.mspro.2014.07.229.
[39] R. Raja, S. Jannet, S. Reji, and C. S. Glen Paul, "Analysis of mechanical and wear properties of Al2O3 + SiC + B4C/AA5083 hybrid metal matrix composite done by stir casting route," *Mater. Today Proc.*, vol. 26, no. xxxx, pp. 1626–1630, 2020, doi: 10.1016/j.matpr.2020.02.340.
[40] A. K. R and T. S. Krishnakumar, "ScienceDirect Casting and characterization of Al6063 / SiC nano composites produced using stir casting method," *Mater. Today Proc.*, vol. 5, no. 11, pp. 23853–23862, 2018, doi: 10.1016/j.matpr.2018.10.177.
[41] A. M. Sankhla, K. M. Patel, and M. A. Makhesana, "Effect of mixing method and particle size on hardness and compressive strength of aluminium based metal matrix composite prepared through powder metallurgy route," *J. Mater. Res. Technol.*, vol. 18, pp. 282–292, 2022, doi: 10.1016/j.jmrt.2022.02.094.
[42] K. S. L. Narayana, M. M. Benal, and H. K. Shivanand, "Effect of graphite on aluminium matrix composites fabricated by stir casting route - A review," *Mater. Today Proc.*, vol. 45, pp. 327–331, 2020, doi: 10.1016/j.matpr.2020.11.051.
[43] G. Manohar, A. Dey, K. M. Pandey, and S. R. Maity, "Fabrication of Metal Matrix Composites by Powder Metallurgy : A

Review," *AIP Conf. Proc.*, vol. 020041, 2018, doi: 10.1063/1.5032003.
[44] D. K. Sharma, D. Mahant, and G. Upadhyay, "Manufacturing of metal matrix composites: A state of review," *Mater. Today Proc.*, vol. 26, no. xxxx, pp. 506–519, 2019, doi: 10.1016/j.matpr.2019.12.128.
[45] A. Ranjan, L. Nagdeve, H. Kumar, and A. Mishra, "Tribological Performance of Aluminium Metal Matrix Hybrid Composites," *Mapan - J. Metrol. Soc. India*, vol. 37, no. 4, pp. 845–858, Dec. 2022, doi: 10.1007/s12647-022-00596-9.
[46] J. Nanda, S. N. Das, A. Choudhury, L. Das, and S. K. Patel, "Wear analysis of aluminum-fly ash hybrid composites," in *Materials Today: Proceedings*, Jan. 2020, vol. 33, pp. 5461–5466. doi: 10.1016/j.matpr.2020.03.259.
[47] S. S. Baliarsingh, D. Das, R. R. Behera, S. Roy, S. Chakrabarty, and K. Mohanta, "Mechanical and tribological properties of aluminium based metal matrix composites: An overview," *Mater. Today Proc.*, Jul. 2023, doi: 10.1016/j.matpr.2023.06.374.
[48] B. S. P. Kumar *et al.*, "Optimization and Wear Properties for the Composites of Metal Matrix AA8011/Boron Nitride Using Taguchi Method," *J. Nanomater.*, vol. 2022, 2022, doi: 10.1155/2022/6957545.
[49] K. Vijaya Bhaskar, S. Sundarrajan, B. Subba Rao, and K. Ravindra, "Effect of reinforcement and wear parameters on dry sliding wear of aluminum composites-A review," in *Materials Today: Proceedings*, Jan. 2018, vol. 5, no. 2, pp. 5891–5900. doi: 10.1016/j.matpr.2017.12.188.
[50] S. Arunkumar, M. Subramani Sundaram, K. M. Suketh Kanna, and S. Vigneshwara, "A review on aluminium matrix composite with various reinforcement particles and their behaviour," in *Materials Today: Proceedings*, Jan. 2020, vol. 33, pp. 484–490. doi: 10.1016/j.matpr.2020.05.053.
[51] N. K. Chandla, S. Kant, and M. M. Goud, "Mechanical, tribological and microstructural characterization of stir cast Al-6061 metal/matrix composites—a comprehensive review," *Sadhana - Acad. Proc. Eng. Sci.*, vol. 46, no. 1, pp. 1–38, Dec. 2021, doi: 10.1007/s12046-021-01567-7.
[52] V. Balasubramani, R. Pandiarajan, B. Stalin, and V. Kavimani, "Mechanical and metallurgical characterization of B4C and SiC reinforced stir casted AA6061 hybrid MMC," *Phys. Scr.*, vol. 98, no. 10, p. 105922, Sep. 2023, doi: 10.1088/1402-4896/acf1dd.
[53] C. H. Gireesh, K. G. D. Prasad, and K. Ramji, "Experimental investigation on mechanical properties of an Al6061 hybrid metal matrix composite," *J. Compos. Sci.*, vol. 2, no. 3, p. 49, Aug. 2018, doi: 10.3390/jcs2030049.
[54] B. N. Venkatesh, U. Hebbal, K. B. Yogesha, M. Mruthunjaya, and G. M. Swamy, "Enhancing Tribological Characteristics of AA6061-SiC Composites via Response Surface Methodology," *J. Inst. Eng. Ser. D*, pp. 1–15, Dec. 2023, doi: 10.1007/s40033-023-00610-7.
[55] A. Abebe Emiru, D. K. Sinha, A. Kumar, and A. Yadav, "Fabrication and Characterization of Hybrid Aluminium (Al6061) Metal Matrix Composite Reinforced with SiC, B4C and MoS2 via Stir Casting," *Int. J. Met.*, vol. 17, no. 2, pp. 801–812, Apr. 2023, doi: 10.1007/s40962-022-00800-1.
[56] J. Chandradass, T. Thirugnanasambandham, P. Jawahar, and T. T. M. Kannan, "Effect of silicon carbide and silicon carbide/alumina reinforced aluminum alloy (AA6061) metal matrix composite," in *Materials Today: Proceedings*, Jan. 2020, vol. 45, pp. 7147–7150. doi: 10.1016/j.matpr.2021.02.143.
[57] S. Orazbayev, M. Gabdullin, T. Ramazanov, Z. Askar, and Z. Rakhymzhan, "Obtaining hydrophobic surfaces in atmospheric pressure plasma," in *Materials Today: Proceedings*, Jan. 2020, vol. 20, pp. 335–341. doi: 10.1016/j.matpr.2019.10.052.
[58] K. Halil, O. I. Ismail, D. Sibel, and Çi. Ramazan, "Wear and mechanical properties of Al6061/SiC/B4C hybrid composites produced with powder metallurgy," *J. Mater. Res. Technol.*, vol. 8, no. 6, pp. 5348–5361, Nov. 2019, doi: 10.1016/j.jmrt.2019.09.002.
[59] M. Karthikraja, K. Ramanathan, S. Selvaraj, and S. Sargunanathan, "Evaluation of mechanical and tribological properties of hybrid AA6061 Al matrix composite," in *Materials Today: Proceedings*, Jan. 2019, vol. 27, pp. 2918–2924. doi: 10.1016/j.matpr.2020.03.516.