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WEAR STUDY OF ALUMINIUM METAL MATRIX COMPOSITES: A BRIEF OVERVIEW

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Abstract
Aluminium metal matrix composites (Al MMCs) with reinforcements like whiskers, particulates, or continuous/discontinuous fibers. These composites can be customized to achieve desired property combinations, including high strength-to-weight ratio, specific strength, specific stiffness, creep resistance, and lower density compared to traditional engineering materials. Aluminium Metal Matrix Composites (Al MMCs) are now preferred materials in various sectors, including aerospace, construction, marine, and automotive industries. This study focuses on dry sliding wear, commonly encountered in these applications. The paper provides a results of how factors like applied load, reinforcement particles, sliding distance, and sliding speed influence the wear properties of different Al MMCs, it also explores the factors contributing to the identified wear patterns on the composite surfaces. A summary has been provided, outlining distinct wear categories in relation to different reinforcement types, loading, speed, and wear conditions.

Keywords: Aluminium metal matrix composites, Dry sliding wear, Sliding distance.

Introduction

About 69% of the mass of metal matrix composites (MMCs) manufactured each year and used in industry is made up of aluminium metal matrix composites (Al MMCs) [7].This is because of their exceptional mechanical, tribological, and physical qualities [7]. Al MMCs have recently been preferred over other commonly used aluminium alloys due to their exceptional strength-to-weight ratio [4]. The purpose of MMCs is to combine the desired metallic matrix characteristics with the qualities of the reinforcing particles [9]. In particular, the aluminium metallic matrix of Al MMCs offers high hardness, modulus, strength, low thermal expansion, and high temperature durability, while the reinforcements give ductility, formability, toughness, and electric and thermal conductivities [8].In terms of the combination of profile features, no monolithic material has yet to rival Al MMCs [1,2]. Al MMCs are now preferred materials for building and construction [4,3,10], structural, thermal management and mild steel bearing applications [5], for the production of parts like cylinder liners, rotating blade sleeves, brake drums, cylinder blocks, gear parts, piston crowns, crankshafts, disc brakes and drive shafts [6–11], aerospace and defence [12–13], and other fields have attracted even more attention [14]. Additional ones include air conditioner compressor pistons [15], energy [16], sporting equipment [10,17], rail transportation [18], precision and optical instruments [19], and others. These application areas highlight the fact that a significant number of the components for which Al MMCs are designed are prone to high wear rates [20].Therefore, research on these composites' wear properties is important in order to better understand how they behave in use. It has been demonstrated that a variety of material and operating conditions influence the wear characteristics of materials in a complex way [21]. An overview of the research conducted by multiple investigators on the effects of x reinforcement, applied load, sliding distance, and sliding speed on the wear properties of Al MMCs is provided in this paper.

The influence of reinforcement particles on the wear characteristics of Aluminium Metal Matrix

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Composites (Al MMCs):

Critical Factors in Wear Performance are the type, nature, shape, and size of reinforcements are crucial factors affecting the wear performance of Al MMCs, requiring careful selection [17,22]. An investigation on the wear behaviour of a hybrid Al2219/Gr/B4C composite revealed that an increase in sliding speed, sliding distance, and applied load led to higher wear

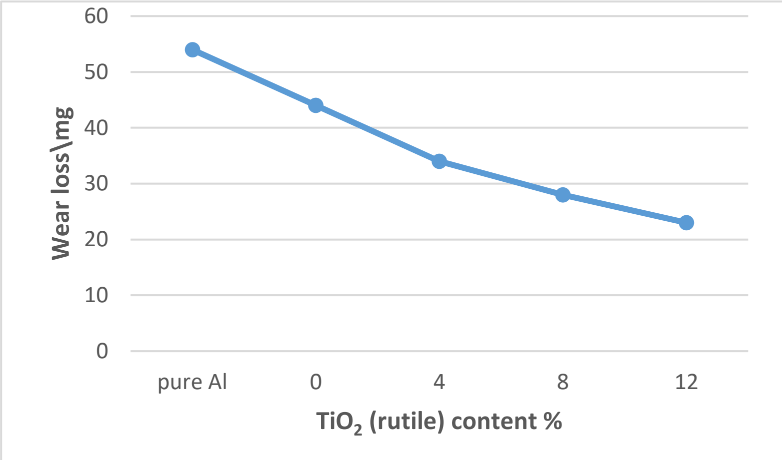


Fig. 1 – Influence of TiO2 (rutile) reinforcement particles on wear of aluminium hybrid composites [24]

rates for the base alloy Al2219, Al2219 with 8% B4C, and the hybridized composite. The hybridized composite exhibited better resistance to wear, attributed to the action of ceramic particle reinforcements, which provided substantial resistance to micro cutting by abrasives.

Effect of Reinforcement on Wear in Other Studies are Kumar et al. [9] studied a composite with AA430 matrix and a combination of SiC. An increase in SiC content led to increased wear resistance and hardness, attributed to oxide phases formed due to the presence of TiO2, resisting micromachining by abrasives. Sarada et al. [23] investigated a hybrid Al MMC, concluding that hybrid reinforcement led to higher hardness and lower wear loss compared to single reinforcement. Incorporation of reinforcements in Al MMCs was reported to restrict

plastic deformation flow, as reinforcements formed a protective layer between abrasive opposing materials and counter faces in the composites [20,25].plastic deformation flow, as reinforcements formed a protective layer between abrasive opposing materials and counter faces in the composites [20,25].

Effect of Particle Size on Wear Behaviour are Sharma et al. [26] investigated the effects of particle size on the wear behaviour of aluminium matrix composites containing sillimanite reinforcement particles. Presence of sillimanite considerably lowered wear loss compared to the base alloy. Increased percentage of reinforcement enhanced wear resistance up to a certain level, beyond which wear resistance started to reduce due to agglomeration of fine particles.

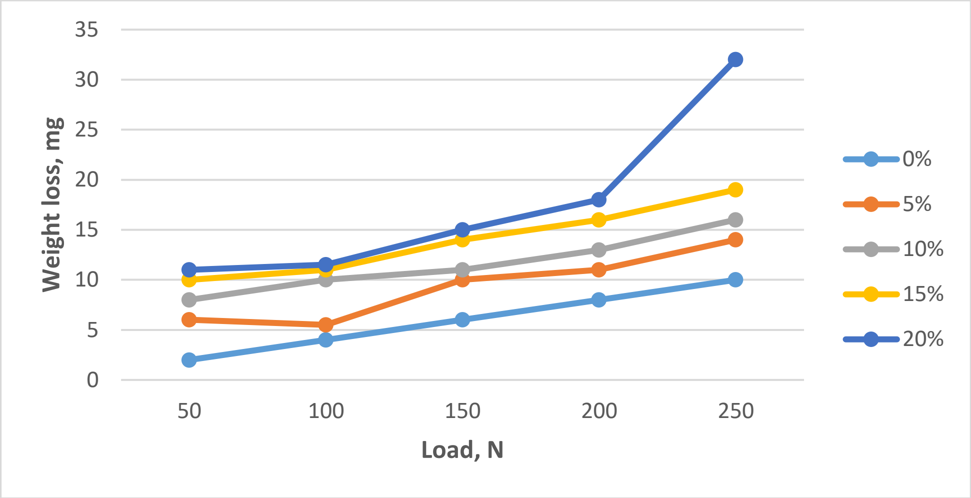
Effect of Specific Reinforcements on Wear and Mechanical Properties are Phanibhushana et al. [27] studied hematite-reinforced Al MMC, finding that the addition of Fe2O3 as reinforcement improved wear resistance and mechanical properties such as hardness and ultimate tensile strength. Mistry and Gohil [15] studied the wear behaviour of AA7075/Si3N4p MMC. Ceramic reinforcement (Si3N4p) acted as a load-bearing material, reducing the tendency for the formation of a mixed mechanical layer on the composite surface and resulting in decreased wear loss.

Influence of applied load on wear characteristics of Al MMCs:

Researchers have explored how applying force affects the wear and tear of metal matrix composites (MMCs). When the load increases, friction between surfaces rises, causing a higher wear rate (Sharma et al. [26]). Madhavarao et al. [28] found that load contributes to 85% of wear in composites, leading to increased temperatures and reduced material hardness. Kumar et al. [29] studied an aluminium

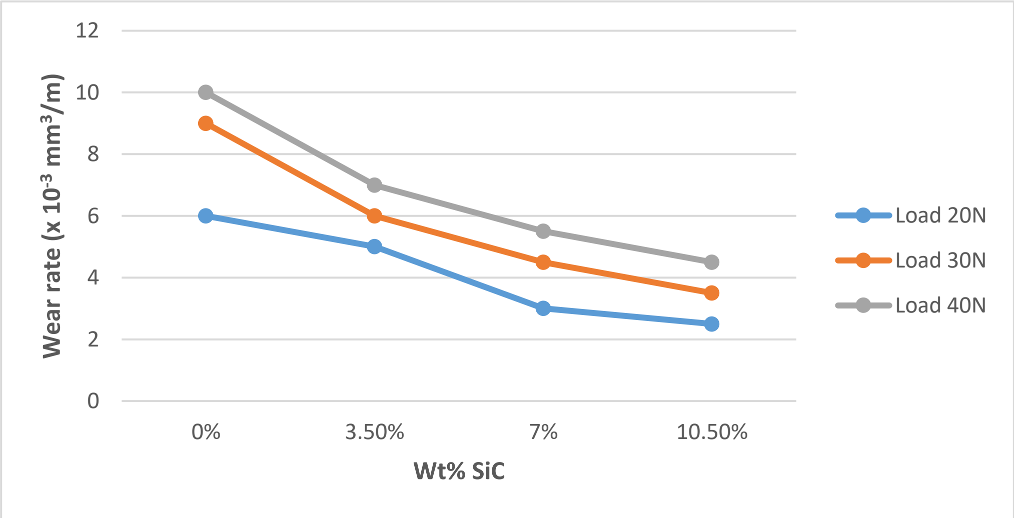
MMC with zinc-aluminium alloy and garnet particles,
discovering that wear rates increased with load. The composite showed delayed severe wear compared to the base alloy due to ceramic reinforcement. Reinforcements in composites were

Fig. 2 – Variation of wear loss of zinc–aluminium based



composites with load [29].

highlighted by Kumar et al. [29] as more beneficial at lower loads. Similar findings were reported by Saravanakumar et al. [30] for AA2219/Gr MMC, where wear increased with load regardless of speed and reinforcement percentage. Other studies on different composites, like Al/SiC MMC [31], Al/B4C MMC [16, 32], revealed a consistent pattern: as load increased, wear rate decreased with better particle



bonding or the formation of a limiting layer.

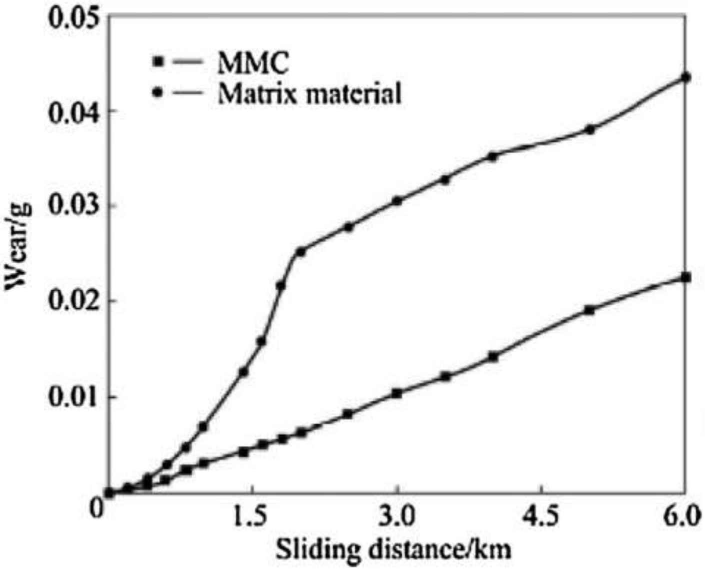
Fig. 3 – Wear rate for AA6063/SiC composite for different applied loads [31]

Krishnamurthy et al. [33] studied Al6063–TiB2 composites, finding that wear increased significantly at higher loads. However, adding TiB2 particles decreased wear rate. These studies collectively emphasize the intricate relationship between applied load and wear rate, offering crucial insights for material engineering applications.

Influence of sliding distance on wear characteristics of Al MMCs:

Looked into how the sliding distance influences wear in metal matrix composites (MMCs). For Al–SiC composites, Singla et al. [34] found that wear rate goes up in a straight line as sliding distance increases due to SiC particles clustering with the aluminium matrix.

Fig. 4 – Wear of Al6061/Al2O3 with increasing



sliding distance [35].

In Aluminium/Alumina/Graphite Al MMC, Radhika et al. [36] discovered the opposite – as sliding distance increased, wear rate and friction coefficient decreased. This was credited to the protective layer formed by graphite and the abrasion resistance of alumina particles. Saraswat et al. [37] studied Al–B4C composites, reporting that as sliding distance increased, so did wear volume, linked to higher friction and temperature softening the matrix.

Sharma et al. [26] explored sillimanite-reinforced Al MMCs, finding that wear rate initially increased (0–500m) due to mechanical welding and fragmentation. Between 500m and 2000m, wear rate decreased with the formation of a protective oxide film. Beyond 2000m, a constant wear rate occurred with the simultaneous formation and removal of a mechanically mixed layer. Pramanik [35] studied Al6061/Al2O3 MMC, revealing a linear relationship with sliding distance, following the Archard law. This was different from the unreinforced alloy, as shown in Fig. 4. These findings provide important insights for material engineering.

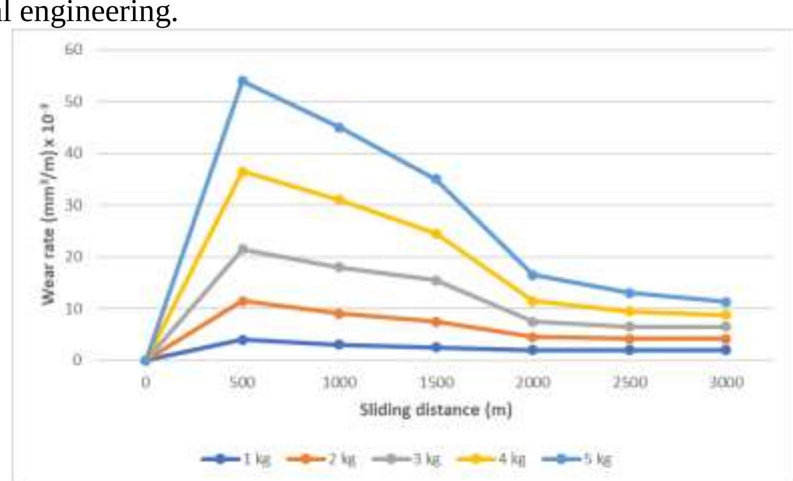


Fig. 5 – Variation of wear rate against sliding distance for 15% sillimanite reinforced Al MMC [26].

Influence of sliding speed on dry sliding wear characteristics of Al MMCs:

Marigoudar and Sadashivappa's research on ZA43-based Al MMC indicated that higher sliding speeds

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increased wear rate but showed reduced material loss with increased reinforcement. Concurrently, Bist et al.'s review on tool wear prediction in friction stir welding of Al MMC observed a direct correlation between wear rate and tool rotation speed. Yet, higher speeds led to increased thermal input, improving composite flow properties, and subsequently reducing tool wear.

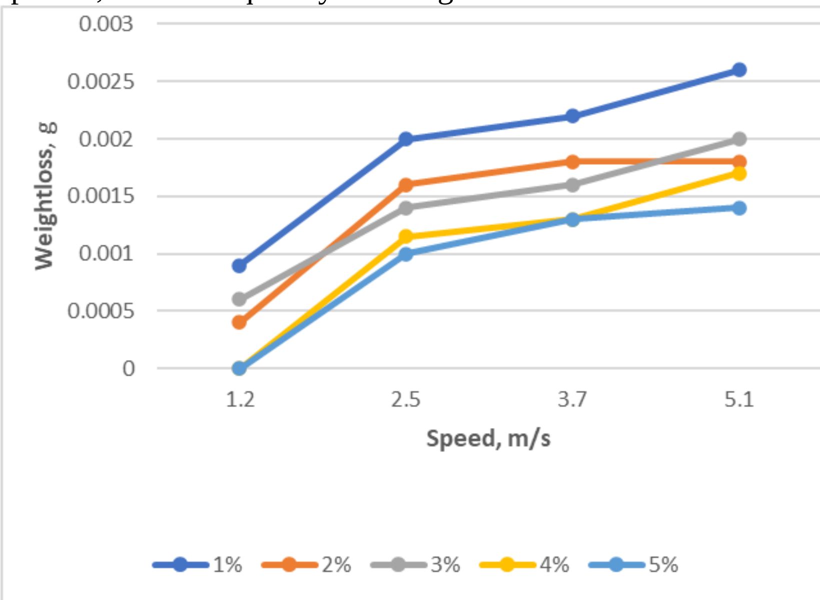


Fig. 6 – Effect of increasing speed on wear loss [38].

Additionally, Ramesh and Keshavamarthy's study on the wear behaviour of hot-extruded Al6061–SiC composite highlighted the influence of slurry speed on wear characteristics.

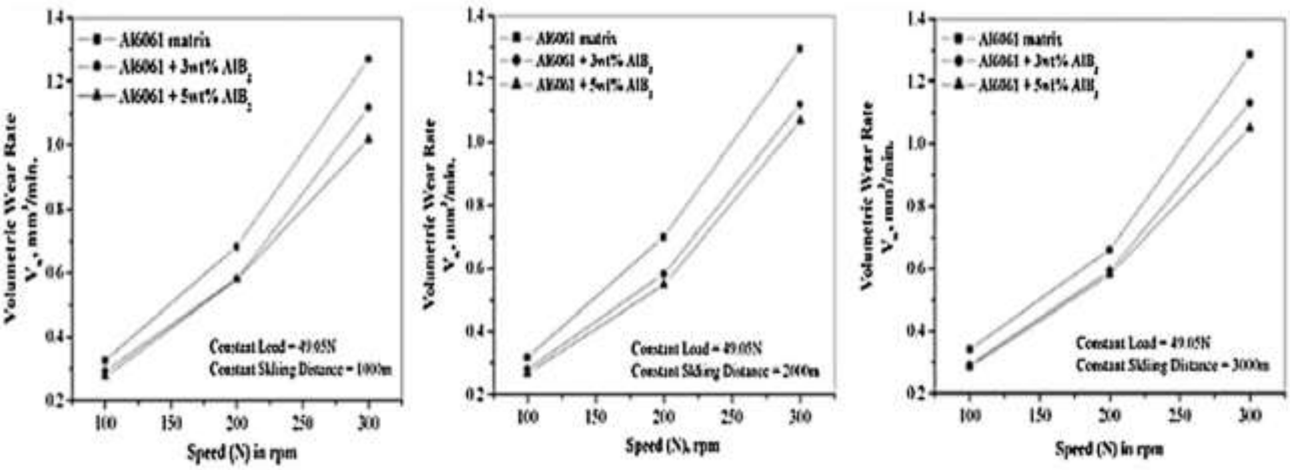


Fig. 7 – Variation of wear rate for Al–AlBr2 composite at different sliding speeds [39]

In the study involving the extruded and cast base alloy, higher rotation speeds increased the slurry erosive wear rate. Conversely, Gargatte et al.(11) found an inverse relationship between sliding speed and the wear rate of Al-5083. At low speeds, wear was high, but as speed increased, wear decreased due to a reduced coefficient of friction and the formation of a protective oxide film between surfaces. However, at higher loads and increased sliding distances, this film was removed, leading to elevated material loss.

Wear mechanisms:

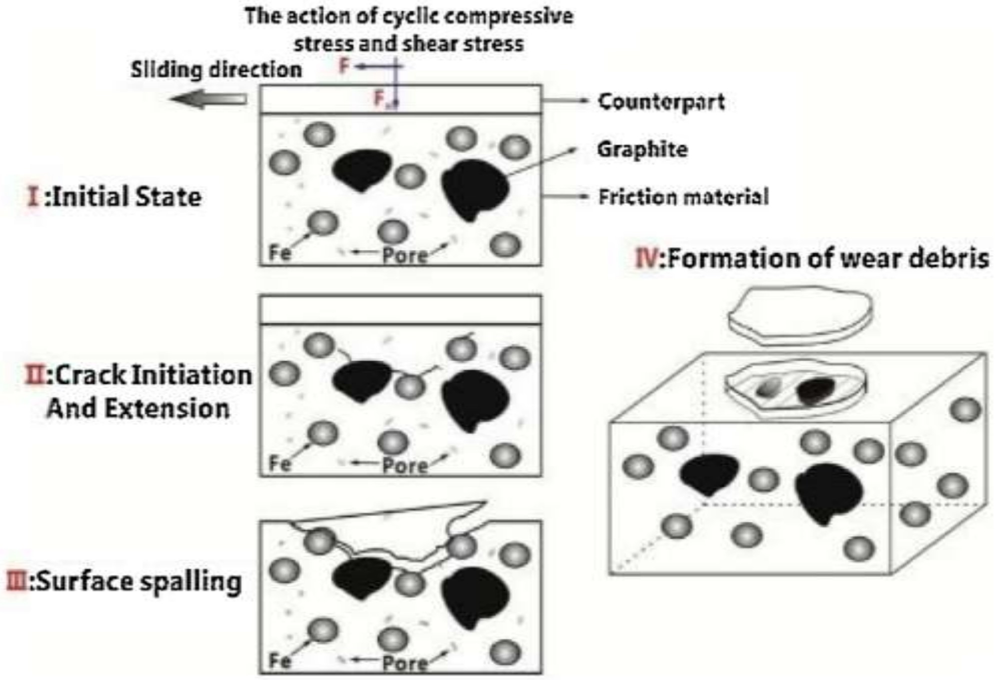
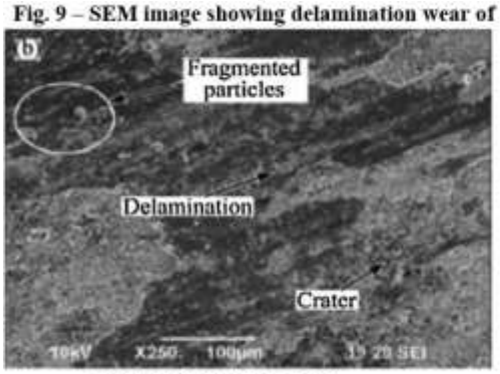


Fig. 8 – Schematic of a delamination wear process [40]

Aluminium Metal Matrix Composites (Al MMCs) are susceptible to several wear mechanisms, including as fretting, adhesion, abrasive, and delamination. This conversation explores how surface morphology is interpreted for every mechanism.

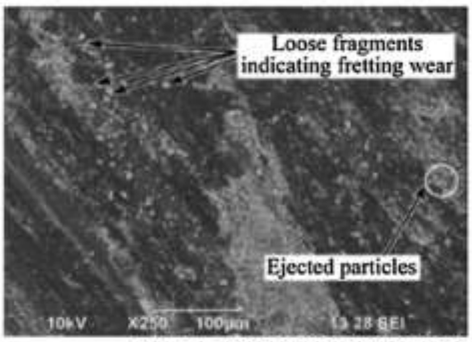
Excessive material breakage that causes craters, pits, deep grooves, and debris resembling flake is the hallmark of delamination. Figure 8 illustrates the linked cracks that Zhou et al. [40] detected in delamination wear as a result of oxidation, surface pollution, and weak particle bonding. Compared to delamination [41], adhesive wear shows less pitting and more prows and plastic deformation [42]. A micro cutting or micro ploughing action is shown by longitudinal or parallel grooves, which are shallower than those found in delamination wear [43]. This is how abrasive wear is detected. Little scratches and loose pieces of oxide waste are visible in fretting wear, which is the result of cyclic.

Fig. 9 – SEM image showing delamination wear of



an Al matrix surface [24]

Fig. 12 – SEM image showing fretting wear



of an Al–15%SiC–8%TiO2 hybrid composite [24

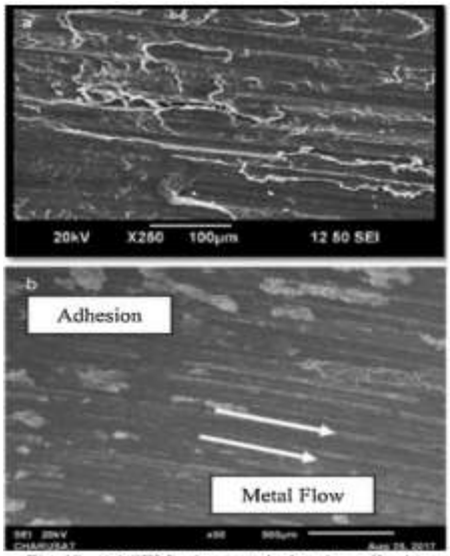


Fig. 10 – (a) SEM micrograph showing adhesive wear of an AA6061 surface [44]. (b) SEM micrographs displaying adhesive wear on (AA7075/Si3N4p) [15].

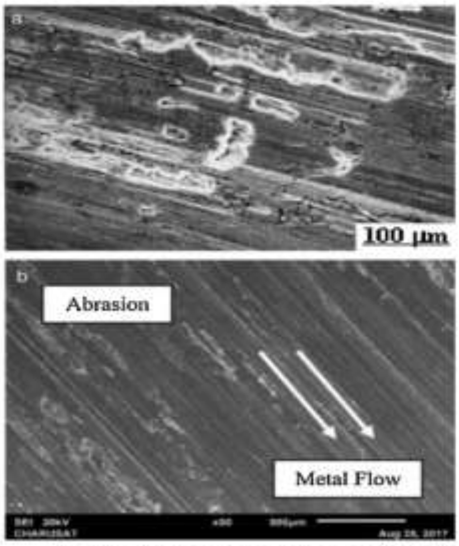


Fig. 11 – (a) SEM image showing abrasive wear mechanism in a zinc–aluminium based Al MMC [29]. (b) SEM micrographs displaying abrasive wear on (AA7075/Si3N4p) [15].

Conclusion:

Based on the review presented, the following conclusions can be derived:

- The wear performance of Al MMCs is improved by the presence of hard reinforcement particles.
- An increase in reinforcement particles results in enhanced wear resistance in Al MMCs.
- Reinforcement particles enhance wear resistance by countering micro cutting actions of rubbing abrasives and restricting plastic deformation through the formation of a protective oxide layer between the composite and the opposing abrasive. The applied load shows a direct proportionality to the rate of material removal in the dry sliding wear of Al MMCs.
- Sliding distance and speed appear to demonstrate consistent patterns in influencing the wear rates of Al MMCs. Further investigation is justified in this regard.
- Wear mechanisms observed in Al MMCs encompass abrasive, adhesive, delamination and fretting wear. Delamination prevails at high loads and in base alloys, while abrasive wear is more likely in low-load conditions for both base alloys and reinforced composites.

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