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Wear Behavior of Si_3N_4 Reinforced AA2219 Metal Matrix Composites

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Abstract

In today's manufacturing industries, Metal Matrix Composites (MMCs) are in high demand owing to their valuable properties like high strength-to-weight ratio and resistance against wear. This research evaluates the wear properties of AA2219 matrix composites reinforced using varying amounts (2%, 4% and 6% by weight) of Si_3N_4 particles, fabricated by squeeze casting. Wear performance testing of the developed Aluminium Matrix Composite (AMC) is executed by utilising pin-on-disc equipment subjected to varying conditions of load and speed. The wear rate is reported to rise with increasing normal load and sliding velocity. The study also reveals that the wear rate reduces with increasing reinforcement content.

Keywords: *AA2219, Si_3N_4, Squeeze Casting, Wear, Worn Surface*

1.0 Introduction

Composite materials, which combine distinct constituents, have garnered substantial interest in materials science and engineering owing to their ability to amalgamate the beneficial properties of the individual components. Many aspects, together with the novel material's enhanced strength compared to conventional materials, can impact decision-making[1-3]. A key advantage of composites over monolithic metals is their unique combination of properties not commonly found in traditional materials, such as enhanced resistance to fatigue and improved stiffness-to-weight ratio[1-2,4-6]. Furthermore, composites exhibit enhanced thermal expansion and resistance against corrosion along with good optical, magnetic, wear, besides fracture properties, amongst other combined qualities. The demand for producing MMCs for applications like automotive, aerospace, and defence has substantially increased. There is a need to fabricate composites using simplified manufacturing processes and improved mechanical properties to overcome the limitations of current aluminium-based composites by modifying experimental procedures. Among various metal matrices being studied, Aluminium Metal Matrix Composites (AMMCs) have emerged as the most sought-after materials aimed at lightweight, high-strength applications

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in aerospace/ automotive sectors. AMMCs are commonly preferred against materials owing to their resistance to wear, strength-to-weight ratio besides favourable thermal properties. There are various methods for preparing composites[6-9]. The present study employs squeeze casting because of its mass production ability, simplified process control, enhanced wettability of reinforcements by the molten metal and superior metallurgical quality from solidification under pressure[10,11].

2.0 Literature Survey

Wear resistance is enhanced by including reinforcements in the form of fibres and particulates like B_4C, SiC, Al_2O_3, glass and graphite into aluminium alloys using various manufacturing methods. Researchers increasingly focus on expanding AMC utilisation in aircraft and automobiles. This has enabled producing composites with various ceramic reinforcements, including BN, SiC, ZrO_2, Al_2O_3, B_4C, TiB_2, WC, TiB_2, AlB_2, ZrB_2 and TiC[12-15].

AA2219 is a high-strength, machinable aluminium alloy in the 2000 series. Renowned for its strength, weldability, thermal stability, fatigue resistance and corrosion resistance, AA2219 is a preferred choice in AMMC development. Copper (Cu) is the major alloying element in AA2219, improving strength through solid solution formation and fine precipitation during heat treatment. Copper contributes to the alloy's high strength, making it suitable for applications requiring structural integrity. To further enhance its mechanical and functional properties, researchers have explored various reinforcements. AA2219 is widely used in aerospace, particularly for cryogenic fuel tank storage. Integrating AA2219 with ceramic reinforcements like SiC, Al_2O_3 and Si_3N_4 has produced MMCs with increased resistance against wear which is crucial for high-temperature, abrasive and mechanically loaded applications[16-18].

Silicon nitride (Si_3N_4) is a ceramic commonly used to reinforce materials across aerospace sectors owing to its ability to withstand extreme conditions. Adding Si_3N_4 particles confers several advantages, enhancing overall composite performance. Fabrication methods play a critical role in determining microstructure and properties. Among various techniques, squeeze casting has gained prominence as a hybrid process combining casting and forging features, offering advantages like superior mechanical properties, improved particle distribution and enhanced interfacial bonding, making it preferred for high-performance composite applications. Wear performance is vital for aerospace, automotive and other applications in abrasive, erosive environments. Silicon nitride's hardness and wear resistance make it useful for reinforcing aluminium composites to mitigate deformation and wear issues in automotive applications[19-21].

AA2219 exhibits improved mechanical properties including high strength, reduced weight, good weldability, and enhanced cryogenic performance[22-23]. This study aims to prepare AA2219 alloy reinforced with Si_3N_4 particles and characterise its wear behaviour. Combining AA2219 alloy and Si_3N_4 reinforcement offers a unique opportunity to develop AA2219-Si_3N_4 composites with enhanced strength, hardness, and wear resistance. Si_3N_4 is identified because of its high hardness and wear resistance. When used to reinforce AA2219, Si_3N_4 particles can enhance hardness and wear resistance, acting like a barrier to reduce contact with the matrix and wearing surface[24].

This work aims to examine the effect of reinforcement on the tribological properties of the composite for diverse industrial applications.

3. Materials and Methods

3.1 Materials

The matrix material utilised is Al2219 aluminium alloy ingots. Si_3N_4 particles having a particle size of ≤8 microns were selected as reinforcing materials.

3.2 Preparation of Composites

To begin, a known amount of Al2219 alloy was heated till it was melted by using an induction furnace. The temperature was increased above the melting point of the alloy for preparing a homogeneous melt. Since the Al2219 alloy contains magnesium, a suitable inert gas was used to avoid oxidation.

The reinforcement was preheated to around 250°C to improve wettability during the melting process. Uniform stirring was undertaken to disperse the particulates in the melt. Si_3N_4 particulates and varying weight percentages were manually introduced into the vortex formed at 800rpm stirring speed. For squeeze casting, a hydraulic press was used. The molten composite, prepared by stirring, was pressed under pressure in closed dies. A consistent pressure of around 100MPa was applied for 1 minute.

The sample was allowed to cool and then ejected from the die.

3.3 Wear Test

For wear testing, the samples were evaluated in a dry sliding condition using a pin-on-disk wear machine following the American Society for Testing and Materials (ASTM) G99-04 standard. Sliding pressure was varied by changing the loads. The equipment had an EN24 steel disc of adequate hardness against which the specimen could slide.

The diameter of the disc was around 210mm. Testing was carried out at a constant sliding velocity of 1.5m/s and sliding distance of 2500m, with varying loads of 30, 40 and 50N. The final and initial weights of the pins were measured with a 0.1mg precision electronic balance. The wear rate was determined by the weight loss method. Microstructural analysis was carried out on the wear-tested samples.

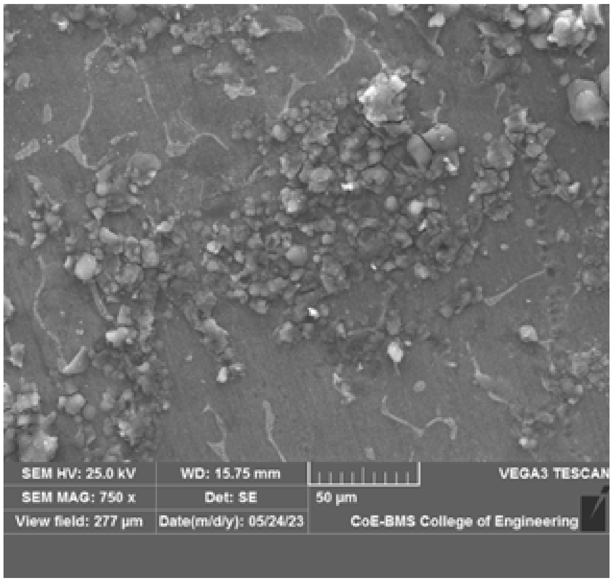

Figure 1. Micrograph of composite reinforced with 6wt.% Si_3N_4.

4. Results and Discussion

4.1 Microstructural Analysis

The processed composites were subjected to Scanning Electron Microscopy. Figure 1 reveals the micrograph of one of the composites prepared. The reinforcements are spread uniformly throughout the composite. The composite's Energy Dispersive X-Ray Spectroscopy (EDS)

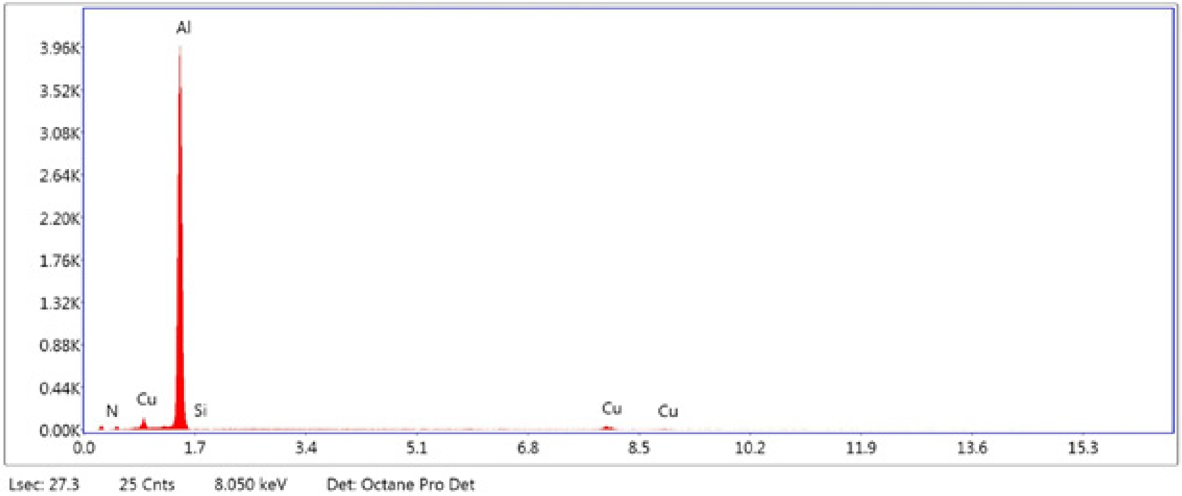

Figure 2. EDS spectrum of composite reinforced with 6wt. % Si_3N_4.

spectrum presents the essential elements existing in the composite (Figure 2).

4.2 Wear Analysis

The wear conduct of the AA2219 + Si_3N_4 composites was evaluated under various conditions to determine the effects of different factors on the material's resistance to wear and abrasion. The plots (Figure 3 (A) to (C)) clearly illustrate how Si_3N_4 content influenced wear properties for tests run at 100, 200, and 300 revolutions per minute with applied loads of 30, 40 and 50N. Increasing the normal load from 30N to 50N leads to heightened wear rates across all tested composites. The application of greater normal loads pushes the Si_3N_4 particles more forcefully into the aluminium matrix, amplifying the abrasive action of the hard reinforcements. This abrasive mechanism, along with increased friction and the production of larger wear debris particles under higher loads accelerates the wear rate proportionally.

The key finding was that increasing the percentage of Si_3N_4 particles from 2% to 6% by weight substantially decreased the rate of wear of the AA2219 composite. The hard ceramic Si_3N_4 particles help protect the softer aluminium alloy by supporting the load and resisting shear forces during sliding contact with a counterface. The uniform dispersion of hard reinforcement enabled consistent wear resistance over the range of sliding velocities by preventing direct metal-on-metal contact

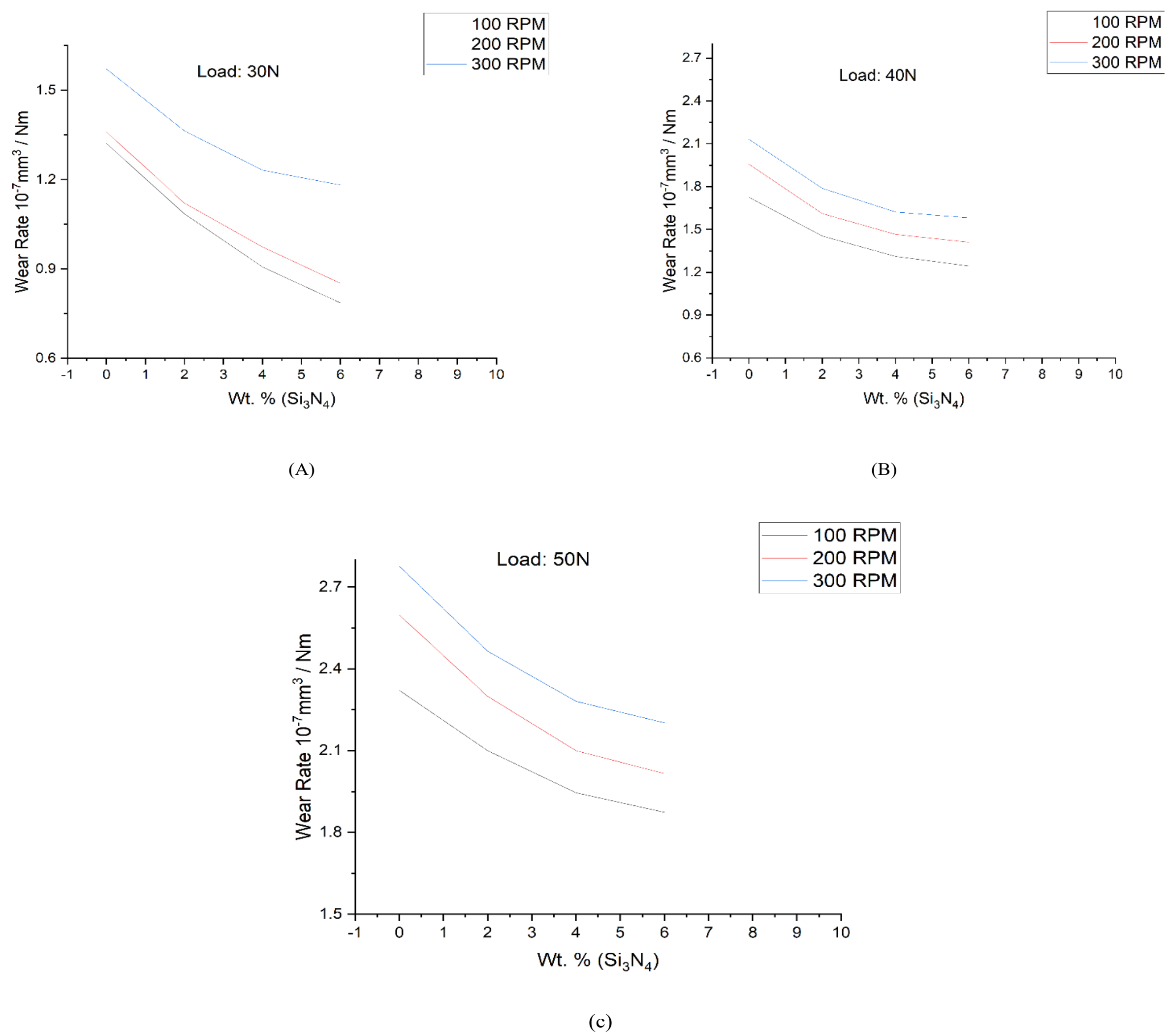

Figure 3. **(A)-(C)** reveals the wear rate of the as-cast alloy and composite at varying loads and speeds.

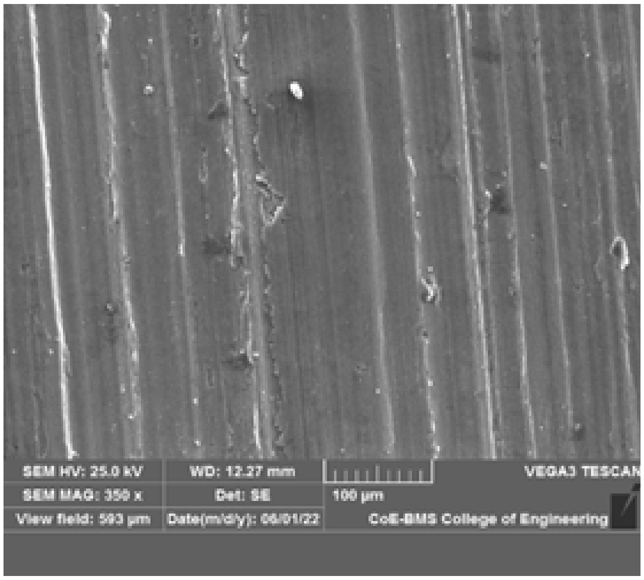

Figure 4. SEM micrograph of worn surface of as-cast alloy subjected to a load of 50 N and 300rpm.

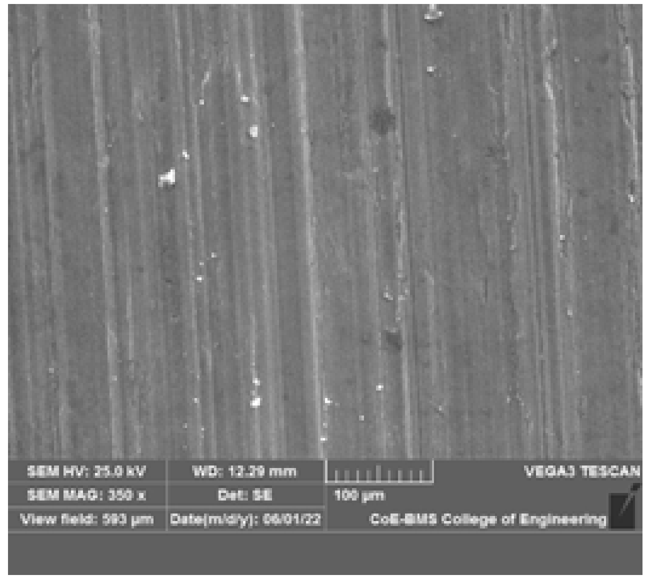

Figure 5. SEM micrograph of worn surface of alloy reinforced with 6wt.% Si3N4 composite subjected to a load of 50N and 300rpm.

during abrasive wear processes. The microstructure images in Figures 4 and 5 provide additional evidence of the wear effects of Si_3N_4 particles at a typical load of 50N. The unreinforced alloy in Figure 4 displays plastic deformation from frictional heating.

The enhanced wear resistance of the composites can be ascribed to two main factors - increased hardness provided by the Si_3N_4 particles, which resists material removal during sliding contact, and the good bonding amongst Si_3N_4 and matrix interfacial bonding, which prevents the detachment of the hard particles over repeated sliding cycles.

The elevated loads generated higher frictional heating and increased plastic deformation on the surface, accelerating the removal of material. The higher hardness of 6 wt.% Si_3N_4 reinforced composite enabled the hard ceramic particles to plough grooves into the opposing surface.

5.0 Conclusion

AA2219 aluminium alloy matrix reinforced with silicon nitride (Si_3N_4) particles demonstrated enhanced properties because of its effective interfacial bonding between the alloy matrix and the ceramic particulates.

- Squeeze casting technique was successfully utilised to synthesise Si_3N_4 reinforced composites.
- The AA2219/Si_3N_4 composites displayed superior resistance to wear as against the cast alloy.
- Applied load and sliding speed were able to influence significantly the wear rate of the composites. The wear rate was dependent on the load-bearing capacity imparted by the hard Si_3N_4 particles

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