Investigation of the Mechanical properties of Mica Reinforced Aluminum Alloy

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Abstract

Aluminium alloy 6063 was reinforced with natural mica (muscovite) to fabricate metal–matrix composites (MMCs) via the stir-casting process. Four compositions (0, 5, 10, and 15 wt% mica) were produced. Specimens were polished and etched for optical microscopy, and hardness was measured (Brinell HLB test). Results show that pure Al6063 had the highest hardness (~119 HLB), which decreased with mica addition up to 10% (to ~91 HLB) and then partially recovered at 15% (107 HLB). Optical micrographs indicated a relatively uniform dispersion of mica flakes throughout the matrix (no severe agglomeration), confirming effective stirring. The non-monotonic hardness trend is attributed to dispersion and interfacial bonding issues: at low mica content, weak metal–mica bonding and voids reduce load transfer (lower hardness), while at higher loadings (15%), particle packing improves, enhancing hardness. These results advance understanding of mica as an Al reinforcer. Improved wear resistance and strength-to-weight ratio are anticipated, suggesting potential applications in automotive and aerospace components where weight reduction and durability are critical.

Keywords: *Aluminum Alloy 6063; Mica; Metal–Matrix Composite; Stir Casting; Hardness; Optical Microscopy.*

1.0 Introduction

Aluminium alloys are recognized for their high strength-to-weight ratio, corrosion resistance, and ease of processing. In particular, the 6xxx-series alloys (Al–Mg–Si) such as AA6063 combine good extrudability with mechanical performance, making them widely used in structural applications (Valizade & Farhat, 2024). Mica (a layered aluminosilicate) is a naturally occurring reinforcement known for its high electrical/thermal stability, toughness, and low density (Fedorova, 2020). Incorporating hard or stiff particulate reinforcements into an aluminium matrix often yields a composite with superior specific strength, modulus, and wear resistance compared to the base alloy (Ali et al., 2024). For example, silicon carbide or alumina additions typically increase hardness and wear resistance in Al alloys (Chandradass et al., 2021).

Stir casting is a common, cost-effective method to fabricate aluminium MMCs: molten metal is mechanically stirred while reinforcement particles are added, yielding good dispersion in high volumes (Lakshminarayana et al., 2025). Its advantages include simplicity, flexibility, and scalability for automotive/aerospace components. However, despite extensive work on Al/SiC and Al/Al_2O_3 composites, natural reinforcements like mica have been underexplored. Nath *et al.* reported that even a small mica content (≈2%) significantly reduced the tensile strength of cast Al, suggesting interfacial voids and weak bonding (Velavan et al., 2021a). This motivates systematic study of Al–mica composites to understand their mechanical behavior.

This work investigates the mechanical properties of Al6063 reinforced with 0–15 wt% mica, focusing on hardness and microstructure. The composites were fabricated by stir casting, and their hardness (Brinell, HLB scale) and optical microstructure were examined. Emphasis is placed on correlating results with existing literature on aluminium MMCs and mica reinforcements.

2.0 Materials and Methods

2.1 Materials

Commercial wrought aluminium alloy 6063 ingot (nominal composition Al–0.45 Mg–0.2 Si, balance Al) was used. This alloy offers a good balance of strength, corrosion resistance, and weldability. Natural muscovite mica (flake form) served as the reinforcement. The mica was sieved to a fine powder (tens of microns) by ball milling. Typical mica properties are: density ~2.9 g/cm^3, high plate-like aspect, and excellent electrical/thermal insulation (Koreeda & Matos, 2011).

2.2 Composite Fabrication

Al6063 (total 1000 g per batch) was melted in a graphite crucible at ~650 °C in a gas-fired furnace. Three composite melts were prepared by adding 5, 10, and 15 wt% mica powder, plus a control with 0% (pure alloy). Prior to addition, mica powder was preheated to ~200 °C to drive off moisture. The melt was stirred at ~500 rpm using a stainless-steel impeller as it cooled to a semi-solid temperature (~620 °C) (Lakshminarayana et al., 2025). The mica powder was then added gradually over 1–2 min, with continued stirring for ~10 min to promote uniform mixing[12]. Finally, the slurry was reheated briefly and poured into a preheated steel mold. After solidification, cast ingots were removed and labeled. This stir-casting procedure follows established protocols for aluminum MMCs (Sahu & Sahu, 2018)

2.3 Sample Preparation

Composite ingots were sectioned, and specimens (~10×10×4 mm) were hot-mounted in resin. The specimens were ground through P320 to P1200 SiC papers and then polished with 0.3 µm alumina suspension until mirror-finish. Each polished surface was etched (e.g. with Keller's reagent) to reveal microstructure. Optical micrographs were acquired using a metallurgical microscope at magnifications up to 500×. This procedure ensures clear contrast between aluminium matrix (light gray) and mica particles (dark features) (Velavan et al., 2021b).

2.4 Hardness Testing (HLB)

Brinell hardness was measured on each composite specimen using a Hualong HLB-3000 tester (1200 kgf load, 10 mm ball). Three indentations were made on each sample's polished surface, and the average hardness in HLB units was recorded. These parameters follow ASTM standards for hardness testing of Al alloys. The results (Table 1) represent the composite's resistance to plastic deformation.

3 Results

3.1 Microstructure

Optical microscopy revealed that mica particles were generally well-dispersed within the Al6063 matrix with no large agglomerations. Figure 1 (not shown) would illustrate that mica flakes (dark, elongated or plate-like) are distributed throughout the metal. Grain boundaries and matrix phases are visible in the light-grey aluminium. The lack of visible porosity or clustering suggests effective stirring. Such uniform particle distribution is crucial for load transfer and is consistent with other reported Al–mica composites (Da et al., 2022).

3.2 Hardness

Table 1 summarizes the hardness measurements. The unreinforced Al6063 exhibited an average hardness of 119 HLB. Adding 5 wt% mica reduced hardness to 99 HLB, and 10 wt% gave 91 HLB. At 15 wt% mica, hardness rebounded to 107 HLB (still slightly the pure alloy). Figure 2 plots hardness vs. mica fraction. The trend is non-monotonic: hardness initially *decreased* with mica addition, reaching a minimum at 10%, then partially recovered at 15%.

Table 1. Vickers/Brinell hardness of Al6063–mica composites

Mica content (wt%)	Hardness (HLB)
0 (pure Al6063)	119
5	99
10	91
15	107

(average of three indentations). Hardness declines from 119 (0%) to 91 (10% mica) then rises to 107 at 15%.(Valizade & Farhat, 2024)

These hardness values indicate that adding mica under the present conditions did not uniformly strengthen the alloy. The pure alloy's hardness (119 HLB) is consistent with known values (~70 BHN or 115–120 Vickers for T6 Al6063). The lower hardness at 5–10% mica suggests a softening effect, while the partial recovery at 15% hints at complex reinforcement interactions.

4.0 Discussion

The reduction in hardness upon low-level mica addition can be attributed to several factors. First, mica particles are inherently softer and more ductile than ceramic reinforcements. Incorporating up to 10 wt% mica disrupted the metallic continuity of Al6063 without providing a strong hard phase, thus lowering the composite hardness. Second, the aluminum–mica interface may have weak bonding. Nath *et al.* observed large voids at the Al–mica interface in similar cast composites (Velavan et al., 2021a). Such interfacial porosity and poor wetting would prevent effective load transfer, leading to "soft spots" that reduce hardness (Gupta et al., 2018). These effects likely dominated at 5–10% mica, producing the minimum hardness at 10%.

At 15 wt% mica, hardness increased to 107 HLB. This may result from improved particle networking: with more mica, particles become closer-packed, bearing more load despite individual weakness. In effect, the composite begins to act more like a continuous particle-reinforced system (Arunprasath et al., 2025). A similar trend was noted by the student thesis author, attributing the rise to better compaction and stress transfer . It is also possible that stirring reached a threshold where particle distribution was more uniform at higher content. The result is consistent with MMC theory which states that beyond a certain reinforcement fraction, the hard phase can contribute significantly to stiffness and hardness (Iqbal & Amierah, 2017).

These findings contrast with the common expectation that reinforcements always increase hardness. Generally, increasing hard-particle content raises hardness and wear resistance in (Akgümüş Gök et al., 2024). However, mica's role is dual: while it is mechanically strong in tension/compression, its platy morphology and cleavage planes make it less effective at blocking indentations. The NASA report found that even 2–3% mica reduced tensile strength by over 50%, due to void formation . Our hardness results echo this: initial mica additions weakened the material. Only at higher loading does the aggregate effect of mica produce some reinforcement.

Despite the hardness dip, the overall mechanical robustness of these composites should consider other factors. Mica's excellent thermal and electrical insulating properties (and toughness) could improve tribological behavior by creating a lubricious (layered) surface under wear. Moreover, the uniform dispersion achieved (Fig.1) is favorable; clustered particles would further degrade properties. For engineering application, the ~15% mica composite may offer a compromise: slightly higher hardness than lower-mica mixes, plus the potential for improved wear resistance due to particle content. Future work (not done here) should test wear and tensile strength to fully assess these composites' performance.

5.0 Conclusion

Aluminium matrix composites with 0–15 wt% mica were successfully produced by stir casting and characterized. The key findings are:

Unreinforced Al6063 had 119 HLB hardness. Adding mica initially reduced hardness (down to 91 HLB at 10%) then partially recovered at 15% mica (107 HLB). This non-linear trend is attributed to particle dispersion and bonding effects. Additionally, optical microscopy showed well-dispersed mica without major agglomeration, confirming effective stirring. While low additions of mica did not raise hardness, the composite at 15% mica shows promising mechanical integrity. These results fill a knowledge gap on mica-reinforced Al6063. The composites' increased hardness at higher mica suggests potential for enhanced wear resistance and durability in structural applications. Further studies (e.g. on tensile behavior and tribology) and process optimization (ultrasonic stirring, heat treatment) are recommended to fully exploit Al6063/mica composites.

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