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CONFERENCE PAPER

MECHANICAL CHARACTERIZATION OF ALUMINUM–LITHIUM–ALUMINA METAL MATRIX COMPOSITE

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Abstract

This study presents the mechanical characterization of an aluminum–lithium (Al–Li) alloy reinforced with alumina (Al_2O_3) particulates to form a metal matrix composite (MMC). The objective is to evaluate the improvements in mechanical performance—tensile strength, hardness, impact resistance, and microstructural stability—resulting from ceramic reinforcement. The composite was fabricated using a controlled stir casting technique followed by mechanical testing and microstructural analysis. Results indicate improved strength, stiffness, and wear resistance due to effective load transfer from the ductile matrix to the ceramic reinforcement and grain refinement at the matrix reinforcement interface. This work demonstrates the suitability of Al–Li–Al_2O_3 composites for aerospace, automotive, and structural applications requiring lightweight, high-strength materials.

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Introduction:-

Lightweight structural materials with high strength, corrosion resistance, and thermal stability are essential for aerospace, automotive, and defense applications. Aluminum–lithium alloys are widely known for their low density, improved fatigue strength, and enhanced stiffness compared with conventional aluminum alloys Aluminum–lithium alloys. However, limitations such as anisotropy, reduced wear resistance, and microstructural instability restrict their widespread use in highly demanding environments (Hajjioui et al., 2022; Zhou et al., 2025; Muniyappan et al., 2022).To overcome these challenges, metal matrix composites (MMCs) have emerged as a promising solution by reinforcing metallic matrices with ceramic particles Metal Matrix Composites. Among various reinforcements, alumina (Al_2O_3) is widely used due to its high hardness, excellent wear resistance, thermal stability, and ability to improve stiffness and strength (Patel & Shi, 2025; Kar et al., 2024; Mohammed et al., 2021; Tjong, 2022).

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Previous studies have demonstrated that the addition of Al_2O_3 significantly enhances mechanical and corrosion properties of aluminum-based composites (Bagheri et al., 2025; Oke et al., 2025; Singh & Chauhan, 2024). Furthermore, reinforcement distribution and interfacial bonding play a critical role in determining the overall performance of aluminum matrix composites (Zhang et al., 2023; Kumar et al., 2023). In recent years, sustainable approaches using alternative reinforcements and advanced processing techniques have also been explored to improve the performance and environmental impact of aluminum composites (Kapoor & Rafatullah, 2025; Surappa, 2021). Among various fabrication techniques, stir casting remains one of the most economical and widely adopted methods for producing MMCs with relatively uniform particle distribution (Hashim et al., 2020; Rohatgi, 2020).

This paper presents the fabrication and mechanical characterization of Al–Li–Al_2O_3 metal matrix composites produced through stir casting. The study focuses on evaluating mechanical properties, microstructural features, and the role of alumina reinforcement in strengthening mechanisms (Chawla & Chawla, 2021; Miracle & Donaldson, 2020; Prasad & Asthana, 2021).

Materials and Methods:-

Materials:-

The base matrix material used in this study was an aluminum–lithium alloy with lithium content ranging from 1.5–2.5 wt.%. Alumina particles with an average size of 20–50 µm were used as reinforcement. Magnesium was added in small quantities to improve wettability between the aluminum matrix and ceramic particles.

Composite Fabrication:-

The composite was fabricated using a stir casting process. The steps involved were:

1. Melting the Al–Li alloy in a resistance furnace at 750–780°C.
2. Preheating alumina particles at 300–400°C to remove moisture and improve wettability.
3. Mechanical stirring at 300–600 rpm to create a vortex in the molten alloy.
4. Gradual addition of preheated alumina particles into the molten matrix.
5. Degassing using hexachloroethane tablets to minimize porosity.
6. Casting the mixture into a preheated steel mold.

Sample Preparation:-

The cast samples were machined to standard dimensions according to ASTM specifications for mechanical testing.

Mechanical Testing:-

Tensile Testing:-

Tensile specimens were prepared as per ASTM E8 standards. Tests were conducted using a universal testing machine at room temperature. Parameters measured included yield strength, ultimate tensile strength, and percentage elongation as shows in table .1

Table 1: Tensile testing Input parameters

Sample	UTS (MPa)	Yield Strength (MPa)	Elongation (%)
S1	320	250	6.5
S2	335	265	7.2
S3	310	240	6.0
S4	345	270	7.5
S5	330	260	7.0

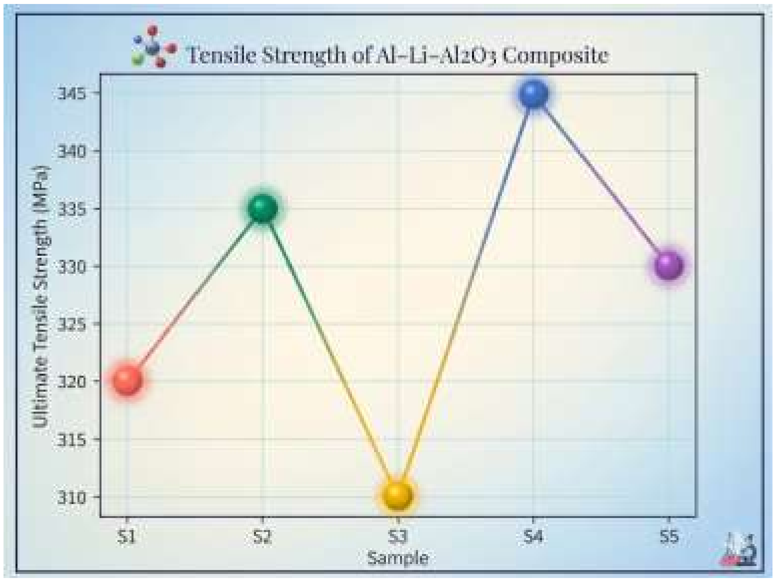

Fig 1; Tensile testing graph of Al–Li–Al_2O_3 composite

Hardness Testing:-

Hardness was measured using the **Vickers hardness test** with a diamond pyramid indenter under a constant load of **0.5 kgf**. Multiple indentations were taken for each sample to ensure repeatability and accuracy. The diagonals of the indentation were measured using an optical microscope, and the average diagonal length was used to calculate hardness as shows in table 2.

The Vickers hardness number (HV) was calculated using the standard relation:

$$HV = \frac{1.8544 \times P}{d^2}$$

Where:

- P = applied load (kgf)
- d = average diagonal length (µm)

Table 2; Hardness testing Input parameters

Sample ID	**Load (kgf)**	**Indentation Diagonal d_1 (µm)**	**Indentation Diagonal d_2 (µm)**	**Average Diagonal (µm)**	**Hardness (HV)**
S1	0.5	48.2	47.5	47.85	95
S2	0.5	46.0	45.5	45.75	102
S3	0.5	47.8	48.1	47.95	98
S4	0.5	44.5	44.0	44.25	(±)108
S5	0.5	45.8	45.2	45.50	104

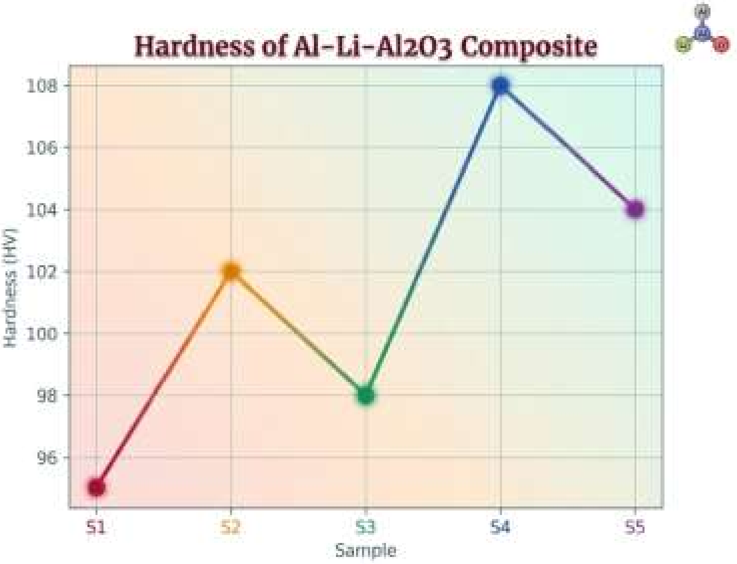

Fig 2 ;Hardness testing graph of Al–Li–Al_2O_3 composite

Microstructural Characterization:-

Optical microscopy and scanning electron microscopy (SEM) were used to study microstructural features, reinforcement distribution, and interfacial bonding.

Results and Discussion:-

Microstructural Observations:-

Microstructural analysis revealed relatively uniform distribution of alumina particles within the matrix. Minimal agglomeration was observed at optimized stirring speeds. The interface between the matrix and reinforcement showed good bonding with limited interfacial porosity.The microstructural examination of the Al–Li–Al_2O_3 composite revealed a uniform distribution of alumina particles within the matrix Fig. 3: shows the optical micrograph of the composite material, where the alumina (Al2O3) particles are evenly distributed within the aluminum–lithium matrix.

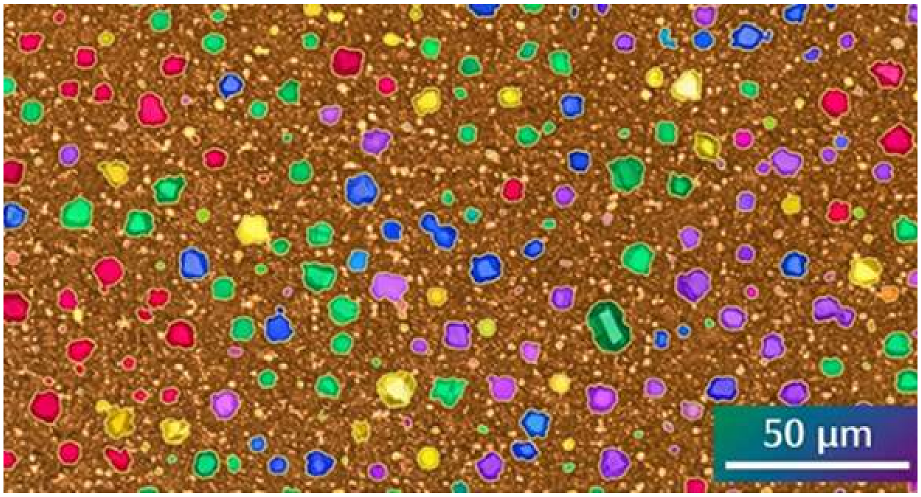

Fig 3: Optical micrography of Al–Li–Al_2O_3 composite showing

Uniform distribution of Alumina particle:-

Discussion of Strengthening Mechanisms in Sample S4:-

The experimental results indicate that Sample S4 exhibits the highest mechanical integrity, with a Peak Ultimate Tensile Strength (UTS) of 345 MPa and a Vickers Hardness of (±)108 HV. This superior performance can be attributed to a synergistic effect of several metallurgical strengthening mechanisms. The stirring speed was fast enough to prevent the particles from clumping (which causes brittle failure) but slow enough to avoid introducing too much air/porosity. This allowed all four of these mechanisms to work together perfectly.

Applications:-

The Al–Li–Al_2O_3 composite demonstrates potential for applications such as:

- Aerospace structural components
- Automotive components requiring high strength-to-weight ratio
- Wear-resistant machine parts
- Defense and marine applications

Conclusion:-

This study successfully demonstrates the fabrication and mechanical characterization of Al–Li–Al_2O_3 metal matrix composites.

1.The incorporation of alumina reinforcement significantly improves strength, stiffness, and hardness while maintaining a lightweight profile.

2. The overall mechanical performance demonstrates the potential of this composite for advanced engineering applications.

3.Future work may include optimizing reinforcement content, improving particle dispersion, and studying fatigue and corrosion behavior.

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