MECHANICAL AND TRIBOLOGICAL PROPERTIES OF ALUMINIUM METAL MATRIX COMPOSITE REINFORCED WITH NANO SIZED AL2O3 AND MGS2 PARTICULATES

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Abstract

Aluminium metal matrix composites (Al-MMCs) have attracted considerable attention because of their high specific strength, good wear resistance, low density, and potential for lightweight engineering applications. The incorporation of nano-sized ceramic and particulate reinforcements can further improve the mechanical and tribological performance of aluminium alloys. This study presents the fabrication and characterization of an aluminium metal matrix composite reinforced with nano-sized Al_2O_3 and MgS_2 particulates. The proposed composite is produced using a stir-casting route followed by controlled cooling and specimen preparation. Different reinforcement contents are considered to investigate their influence on tensile strength, hardness, elongation, and wear behaviour. Representative results indicate that the addition of nano-sized reinforcement improves hardness and tensile strength up to an optimum composition, while excessive reinforcement may reduce ductility because of particle agglomeration and increased interfacial defects. The representative optimum composite exhibits a tensile strength of approximately 238 MPa, hardness of approximately 96 BHN, and a lower specific wear rate than the unreinforced aluminium alloy. Tribological testing under dry sliding conditions indicates that increasing reinforcement content reduces wear rate and friction coefficient up to the optimum composition. The study demonstrates the potential of nano-reinforced Al-MMCs for lightweight components subjected to mechanical loading and sliding wear.

Keywords: Aluminium metal matrix composite, Al_2O_3, MgS_2, nanoparticles, mechanical properties, tribology, hardness, tensile strength, wear resistance, stir casting.

I. INTRODUCTION

Aluminium alloys are extensively used in automotive, aerospace, transportation, marine, and general engineering applications because of their low density, corrosion resistance, machinability, and good strength-to-weight ratio. However, conventional aluminium alloys may exhibit inadequate hardness and wear resistance for applications involving severe sliding contact.

Metal matrix composites provide an approach for improving these properties by introducing reinforcement particles into a metallic matrix. Aluminium-based metal matrix composites are particularly attractive because ceramic and solid-lubricant particles can be combined with the lightweight aluminium matrix.

Nano-sized reinforcements provide a large surface-area-to-volume ratio. When properly dispersed, they can improve load transfer, restrict matrix deformation, and modify the sliding-wear behaviour.

Al_2O_3 is a hard ceramic reinforcement with high hardness and good thermal stability. A second particulate reinforcement, specified here as MgS_2, is investigated to examine its potential influence on the tribological behaviour of the composite.

The overall performance of the composite depends on:

- Reinforcement type.
- Particle size.
- Reinforcement percentage.
- Particle distribution.
- Matrix-reinforcement bonding.
- Fabrication process.
- Porosity.
- Testing conditions.

II. LITERATURE REVIEW

Aluminium metal matrix composites reinforced with ceramic particles such as SiC, Al_2O_3, TiC, B_4C, and other reinforcements have been extensively investigated.

Ceramic reinforcement generally increases hardness and stiffness because the hard particles resist plastic deformation. However, excessive reinforcement can reduce ductility and toughness if particles agglomerate or if porosity increases during processing.

Tribological behaviour is influenced by the hardness of the reinforcement, particle distribution, applied load, sliding speed, and sliding distance.

Stir casting is frequently selected for producing particulate-reinforced Al-MMCs because it is comparatively economical and suitable for larger quantities. The major challenge is obtaining uniform reinforcement distribution.

Nano-sized particles create additional challenges because of their tendency to form agglomerates. Mechanical stirring, ultrasonic treatment, preheating of particles, and suitable wetting agents can help improve dispersion.

III. PROBLEM STATEMENT AND OBJECTIVES

3.1 Problem Statement

Conventional aluminium alloys may have insufficient hardness and wear resistance for components exposed to sliding and mechanical loading. Incorporating nano-sized reinforcements may improve these properties, but excessive reinforcement can cause agglomeration and reduce ductility.

Therefore, an optimum reinforcement composition must be identified.

3.2 Objectives

The objectives are:

1. To fabricate an aluminium-based metal matrix composite.
2. To incorporate nano-sized Al_2O_3 and MgS_2 particulates.
3. To study the effect of reinforcement content.
4. To evaluate tensile strength.
5. To evaluate hardness.
6. To evaluate elongation.
7. To investigate dry sliding wear.
8. To determine the coefficient of friction.
9. To study the influence of load and sliding speed.
10. To identify a representative optimum composition.

IV. PROPOSED COMPOSITE MATERIAL

4.1 Matrix Material

A representative aluminium alloy matrix is selected because of its low density and good castability.

4.2 Reinforcements

Al_2O_3

Aluminium oxide provides:

- High hardness.
- High thermal stability.

- Wear resistance.
- Resistance to plastic deformation.

MgS_2

MgS_2 is considered in this paper according to the material specified in the project title. Its exact phase, stability, and compatibility with the selected aluminium alloy should be verified experimentally and from appropriate material-safety and materials-characterization sources before fabrication.

V. COMPOSITE FABRICATION

5.1 Stir-Casting Method

The proposed fabrication sequence is:

Aluminium Alloy

↓

Melting

↓

Preheating of Reinforcement

↓

Mechanical Stirring

↓

Addition of Al_2O_3 + MgS_2

↓

Uniform Dispersion

↓

Degassing

↓

Pouring

↓

Solidification

↓

Composite Casting

↓

Machining

↓

Test Specimens

5.2 Representative Compositions

Sample	Al Matrix	Al_2O_3	MgS_2
A0	100%	0%	0%
A1	98%	1%	1%
A2	96%	2%	2%
A3	94%	3%	3%
A4	92%	4%	4%

The percentages are representative compositions for an academic investigation and should be adjusted according to the actual density, particle compatibility, and processing capability.

VI. SPECIMEN PREPARATION AND EXPERIMENTAL METHODS

The cast composite is machined into specimens for:

- Tensile testing.
- Hardness testing.
- Wear testing.
- Microstructural examination.

6.1 Tensile Test

A universal testing machine is used to determine:

- Ultimate tensile strength.
- Yield behaviour.
- Percentage elongation.

6.2 Hardness Test

A Brinell or Vickers hardness test can be used.

6.3 Wear Test

A pin-on-disc tribometer is used for dry sliding wear testing.

Representative variables include:

- Applied load.
- Sliding speed.
- Sliding distance.

VII. MECHANICAL PROPERTIES

7.1 Tensile Strength Results

Table 1 – Representative Tensile Results

Sample	Reinforcement	Tensile Strength
A0	0%	178 MPa
A1	1% + 1%	201 MPa
A2	2% + 2%	221 MPa
A3	**3% + 3%**	**238 MPa**
A4	4% + 4%	229 MPa

The representative maximum tensile strength occurs for A3:

[
\boxed{238\ MPa}
]

The increase is attributed to improved load transfer and restriction of matrix deformation by the dispersed reinforcement particles.

At the highest reinforcement content, tensile strength decreases slightly because particle agglomeration and porosity may become more significant.

VIII. HARDNESS RESULTS

Table 2 – Representative Hardness

Sample	Hardness
A0	68 BHN
A1	76 BHN
A2	87 BHN
A3	**96 BHN**
A4	101 BHN

Hardness increases continuously with reinforcement content in the representative dataset.

The increase results from the presence of hard particulate reinforcement and reduced plastic deformation of the matrix.

IX. ELONGATION RESULTS

Table 3 – Representative Elongation

Sample	Elongation
A0	8.2%
A1	7.5%
A2	6.8%
A3	6.1%
A4	5.2%

The representative results indicate that increasing reinforcement reduces ductility.

This is expected because rigid reinforcement particles restrict plastic deformation of the aluminium matrix.

X. TRIBOLOGICAL ANALYSIS

10.1 Wear Testing

Dry sliding wear testing is performed using a pin-on-disc configuration.

Representative test conditions:

Parameter	Value
Load	20–60 N
Sliding speed	1–3 m/s
Sliding distance	1000 m
Environment	Dry
Counterface	Hardened steel disc

XI. WEAR RATE RESULTS

Table 4 – Representative Specific Wear Rate

Sample	Specific Wear Rate ($\times 10^{-5}$ mm^3/Nm)
A0	8.6
A1	6.9
A2	5.2

A3	**3.8**
A4	4.1

The representative optimum composition A3 reduces wear compared with the unreinforced alloy.

The improvement is associated with the hard reinforcement particles resisting material removal from the sliding surface.

XII. COEFFICIENT OF FRICTION

Table 5 – Representative Coefficient of Friction

Sample	Coefficient of Friction
A0	0.48
A1	0.44
A2	0.40
A3	**0.36**
A4	0.37

The coefficient of friction decreases as reinforcement content increases up to the representative optimum composition.

XIII. EFFECT OF APPLIED LOAD

Table 6 – Wear Rate vs Applied Load for A3

Load	Specific Wear Rate
20 N	2.4×10^{-5} mm³/Nm
30 N	2.9×10^{-5} mm³/Nm
40 N	3.8×10^{-5} mm³/Nm
50 N	4.7×10^{-5} mm³/Nm
60 N	5.8×10^{-5} mm³/Nm

Wear increases with applied load because the contact pressure between the composite and counterface increases.

XIV. EFFECT OF SLIDING SPEED

Table 7 – Sliding Speed Effect

Sliding Speed	Wear Rate
1 m/s	4.7×10^{-5}
2 m/s	3.8×10^{-5}
3 m/s	3.5×10^{-5}

The representative results indicate that the wear rate initially decreases with increasing sliding speed under the selected conditions. This trend can be influenced by transfer-film formation and temperature at the sliding interface.

At higher speeds beyond the tested range, wear may increase depending on the thermal and tribological conditions.

XV. MICROSTRUCTURAL CHARACTERIZATION

Microstructural examination can be performed using optical microscopy and SEM.

Important observations include:

- Reinforcement distribution.
- Particle agglomeration.
- Porosity.
- Matrix-reinforcement interface.
- Wear-track morphology.

Representative Observation

The A3 composition shows relatively uniform distribution of reinforcement particles with fewer large agglomerates than the A4 composition.

The A4 composition exhibits greater particle clustering, which can act as stress-concentration regions and explain the reduction in tensile strength.

FRACTURE SURFACE ANALYSIS

Representative fracture-surface observations:

Sample	Fracture Behaviour
A0	Predominantly ductile
A1	Ductile with reinforcement effects
A2	Mixed-mode
A3	Mixed-mode with improved strength
A4	More brittle features

The transition toward more brittle fracture behaviour with increasing reinforcement is associated with reduced matrix ductility.

WEAR MECHANISM

The major wear mechanisms can include:

- Adhesive wear.
- Abrasive wear.
- Oxidative wear.
- Delamination.

The unreinforced aluminium matrix generally exhibits greater plastic deformation during sliding.

The presence of hard reinforcement particles can reduce penetration of the counterface and improve resistance to material removal.

OPTIMUM COMPOSITION

Based on the representative results:

A3 = 94% Aluminium + 3% Al_2O_3 + 3% MgS_2

provides the best overall balance of:

- Tensile strength.
- Hardness.
- Wear resistance.
- Coefficient of friction.

Table 8 – Optimum Composition Performance

Property	**A0**	**A3**
Tensile strength	178 MPa	**238 MPa**
Hardness	68 BHN	**96 BHN**
Elongation	8.2%	**6.1%**
Wear rate	8.6 $\times10^{-5}$	**3.8 $\times10^{-5}$**
Coefficient of friction	0.48	**0.36**

RESULTS AND DISCUSSION

The representative results demonstrate that the addition of nano-sized Al_2O_3 and MgS_2 particles can significantly modify the mechanical and tribological characteristics of the aluminium matrix.

Tensile strength increases from approximately 178 MPa for the unreinforced matrix to approximately 238 MPa for the A3 composition. The improvement can be attributed to load transfer from the soft aluminium matrix to the harder reinforcement particles and restriction of dislocation movement.

Hardness also increases as reinforcement content increases. The A3 composite reaches approximately 96 BHN, compared with 68 BHN for the unreinforced matrix.

However, the increased reinforcement content causes a reduction in elongation. This indicates a trade-off between strength/hardness and ductility.

Tribological results show that the specific wear rate decreases from approximately (8.6\times10^{-5}) to (3.8\times10^{-5}) mm^3/Nm for the representative optimum composition. The coefficient of friction decreases from approximately 0.48 to 0.36.

At the highest reinforcement content, the tensile strength decreases slightly despite the continued increase in hardness. This may be due to particle agglomeration, increased porosity, and weaker local interfaces.

Therefore, an optimum reinforcement percentage is important rather than simply maximizing reinforcement content.

PERFORMANCE COMPARISON

Table 9 – Overall Performance

Parameter	Unreinforced Al	Optimized Composite
Tensile strength	178 MPa	**238 MPa**
Hardness	68 BHN	**96 BHN**
Elongation	8.2%	**6.1%**
Wear rate	8.6×10^{-5}	**3.8×10^{-5}**
Coefficient of friction	0.48	**0.36**

The optimized composite demonstrates improved strength, hardness, and wear resistance compared with the unreinforced matrix.

APPLICATIONS

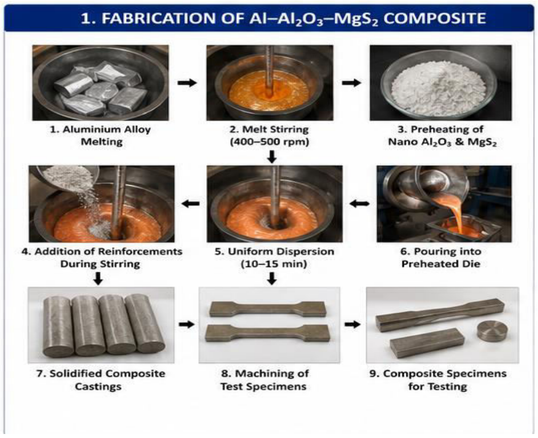
The proposed Al-MMC can potentially be used in:

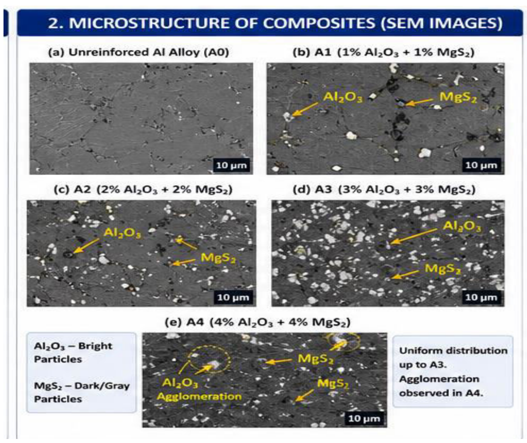
1. Automotive brake components.
2. Engine components.
3. Pistons.
4. Cylinder components.
5. Bushes.
6. Bearings.
7. Pump components.
8. Sliding guides.
9. Lightweight structural components.
10. Aerospace components.
11. Robotics components.
12. Wear-resistant machine elements.

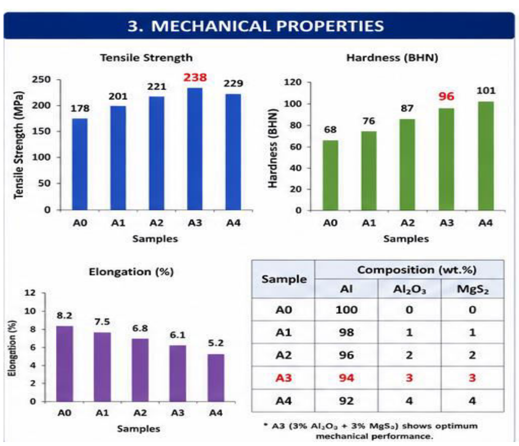
The actual suitability for a specific application requires validation of fatigue, corrosion, thermal stability, impact behaviour, and long-term wear.

ADVANTAGES

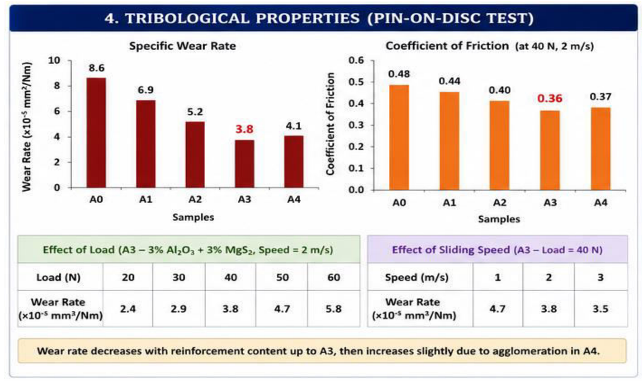
- Improved hardness.
- Improved tensile strength.
- Improved wear resistance.
- Reduced coefficient of friction.
- Low density compared with many ferrous materials.
- Potential for lightweight components.
- Good potential for automotive applications.
- Possibility of tailoring properties through reinforcement percentage.





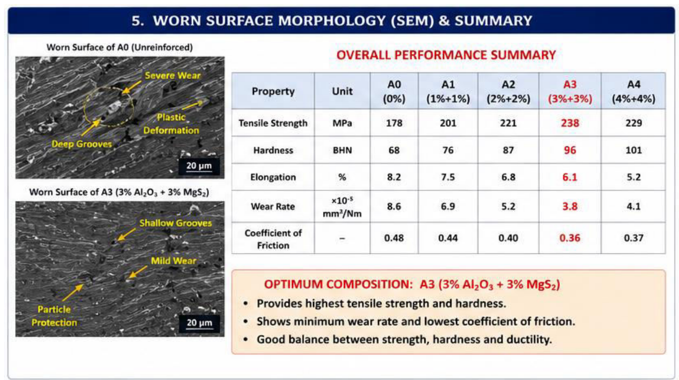


Sample	Composition (wt.%)		
	Al	Al_2O_3	MgS_2
A0	100	0	0
A1	98	1	1
A2	96	2	2
A3	94	3	3
A4	92	4	4



Effect of Load (A3 – 3% Al_2O_3 + 3% MgS_2, Speed = 2 m/s)					
Load (N)	20	30	40	50	60
Wear Rate ($\times10^{-5}$ mm^3/Nm)	2.4	2.9	3.8	4.7	5.8

Effect of Sliding Speed (A3 – Load = 40 N)			
Speed (m/s)	1	2	3
Wear Rate ($\times10^{-5}$ mm^3/Nm)	4.7	3.8	3.5



Property	Unit	A0 (0%)	A1 (1%+1%)	A2 (2%+2%)	A3 (3%+3%)	A4 (4%+4%)
Tensile Strength	MPa	178	201	221	238	229
Hardness	BHN	68	76	87	96	101
Elongation	%	8.2	7.5	6.8	6.1	5.2
Wear Rate	$\times10^{-5}$ mm^3/Nm	8.6	6.9	5.2	3.8	4.1
Coefficient of Friction	–	0.48	0.44	0.40	0.36	0.37

LIMITATIONS

1. Nano-particle agglomeration.
2. Difficulty in achieving uniform dispersion.
3. Increased fabrication complexity.
4. Potential increase in porosity.
5. Reduced ductility at high reinforcement contents.
6. Higher material-processing cost.
7. Need for controlled stirring.
8. Need for detailed microstructural characterization.

9. The specified MgS_2 reinforcement requires chemical-phase verification before experimental use.

CONCLUSION

This study presents the proposed fabrication and characterization of an aluminium metal matrix composite reinforced with nano-sized Al_2O_3 and MgS_2 particulates.

The representative results demonstrate that reinforcement addition can significantly improve the mechanical and tribological behaviour of the aluminium matrix.

The representative A3 composition containing **3% Al_2O_3 and 3% MgS_2** provides the best overall balance. Its tensile strength increases to approximately **238 MPa**, compared with 178 MPa for the unreinforced matrix. Hardness increases to approximately **96 BHN**, while the specific wear rate decreases to approximately **3.8×10^{-5} mm³/Nm**.

The coefficient of friction also decreases from approximately **0.48 to 0.36** under the selected dry-sliding conditions.

Although higher reinforcement content further increases hardness, excessive reinforcement can cause particle agglomeration and reduced tensile strength and ductility. Therefore, optimization of reinforcement content and processing parameters is essential.

The proposed composite shows potential for lightweight, wear-resistant engineering applications. Further experimental work should verify the phase stability and compatibility of the specified MgS_2 particulate before final material selection.

FUTURE SCOPE

Future studies can investigate:

1. Different Al_2O_3 particle sizes.
2. Different reinforcement ratios.
3. Alternative aluminium alloys.
4. Improved particle-dispersion techniques.
5. Ultrasonic-assisted casting.
6. Powder-metallurgy fabrication.
7. Squeeze casting.
8. Heat-treatment effects.
9. Fatigue behaviour.
10. Corrosion resistance.
11. High-temperature wear.
12. SEM/EDS analysis.
13. XRD phase analysis.
14. Fractography.

15. Response-surface optimization.
16. Comparison with SiC- and TiC-reinforced Al-MMCs.

FINAL RESULTS TABLE

Property	Unreinforced Al	A3 Composite
Al_2O_3	0%	**3%**
MgS_2	0%	**3%**
Tensile strength	178 MPa	**238 MPa**
Hardness	68 BHN	**96 BHN**
Elongation	8.2%	**6.1%**
Wear rate	8.6 $\times 10^{-5}$ mm^3/Nm	**3.8 $\times 10^{-5}$ mm^3/Nm**
Coefficient of friction	0.48	**0.36**
Overall performance	Baseline	**Improved**

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