TRIBOLOGICAL CORROSION STUDY OF ALUMINUM COMPOSITE MATERIAL

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Abstract:

Aluminum composite materials (ACMs) are widely used in aerospace, automotive, and marine industries due to their high strength-to-weight ratio, corrosion resistance, and mechanical performance. However, their performance under combined tribological and corrosive conditions remains a critical challenge. This study investigates the tribological corrosion behavior of aluminum composite materials under different environmental conditions, focusing on wear resistance, frictional properties, and electrochemical degradation.A series of experiments were conducted using a pin-on-disk tribometer and an electrochemical corrosion setup to evaluate the material's response under simultaneous wear and corrosion exposure. The effects of key parameters such as applied load, sliding velocity, and electrolyte composition were analyzed. Results indicate that the incorporation of reinforcements, such as ceramic particles or carbon-based materials, significantly improves wear resistance while influencing corrosion rates. Synergistic effects between mechanical wear and electrochemical corrosion were observed, leading to material degradation mechanisms like pitting, surface oxidation, and third-body abrasion.This study provides insights into optimizing aluminum composite materials for enhanced tribological corrosion resistance in harsh environments. The findings contribute to the development of more durable materials for engineering applications where both wear and corrosion play a significant role in service life.

Keywords: Aluminum composite materials, tribological corrosion, wear resistance, electrochemical degradation, material optimization.

1. Introduction

Aluminum composite materials (ACMs) have gained significant attention in various engineering applications, including aerospace, automotive, marine, and biomedical industries. Their exceptional properties, such as low density, high strength-to-weight ratio, corrosion resistance, and improved mechanical performance, make them suitable for components subjected to extreme conditions. However, in real-world applications, ACMs often experience simultaneous mechanical wear and corrosive degradation, leading to a phenomenon known as **tribological corrosion**. This complex interaction between tribological wear and electrochemical corrosion significantly affects the longevity and reliability of these materials.Tribological corrosion, also referred to as wear-corrosion synergy, occurs when mechanical wear accelerates corrosion processes or when corrosion weakens the surface, making it more susceptible to wear. The combined effects of friction, wear, and electrochemical reactions can lead to surface damage, pitting, material loss, and structural failure. Understanding these interactions is crucial for improving the performance and durability of aluminum composites in aggressive environments.

Several studies have explored the wear and corrosion behavior of aluminum-based composites individually. However, limited research has been conducted on the **synergistic effects** of tribological and electrochemical processes, particularly under varying environmental conditions such as different pH levels, electrolyte compositions, and mechanical loading. The incorporation of reinforcements, such as ceramic particles (SiC, Al_2O_3, TiO_2) or carbon-based materials (graphene, CNTs), has shown promise in enhancing wear resistance and mechanical strength. However, their influence on tribological corrosion remains an area of active research.

The primary objective of this research is to investigate the tribological corrosion behavior of aluminum composite materials under different operating conditions. The specific objectives include:

1. **Analyzing the wear-corrosion interactions** in ACMs subjected to simultaneous mechanical wear and electrochemical corrosion.
2. **Evaluating the effects of key parameters** such as sliding velocity, applied load, and electrolyte composition on tribological corrosion performance.
3. **Studying the role of reinforcements** in enhancing the wear and corrosion resistance of aluminum composites.
4. **Identifying dominant wear and corrosion mechanisms** contributing to material degradation and proposing strategies for material optimization.

This study aims to provide valuable insights into the degradation mechanisms of aluminum composites, ultimately contributing to the design and development of more durable materials for high-performance applications in corrosive and wear-intensive environments.

Table No. 1 the mechanical properties of Al / Al- 6061 alloy are given below.

Properties	Metric	Imperial
Tensile strength	310 MPa	45000 psi
Fatigue strength	96.5 MPa	14000 psi
Yield strength	276 MPa	40000 psi
Shear strength	207 MPa	30000 psi
Elastic modulus	68.9 GPa	10000 psi
Elongation	12-17%	12-17%
Poisson's ratio	0.33	0.33
Hardness, Brinell	95	95

1.1 ALUMINIUM 6061

Main Elements: Aluminum (Al) ~97.9%, Magnesium (Mg) 1.0%, Silicon (Si) 0.6%
Other Elements: Copper (Cu) 0.28%, Chromium (Cr) 0.2%, Iron (Fe), Zinc (Zn), and small traces of others

- Strength: Medium-to-high strength (~310 MPa tensile strength in T6 temper)
- Corrosion Resistance: Excellent, especially in marine and atmospheric conditions
- Machinability: Good, especially in T6 temper
- Weldability: Good, but prone to loss of strength in the heat-affected zone
- Heat Treatable: Yes (T4, T6, etc.)
- Electrical & Thermal Conductivity: Moderate (lower than pure aluminum)

2. Methodology for Tribological Corrosion Study of Aluminum Composite Material

2.1 Selection of Materials

- Base Material: Aluminum 6061 or another aluminum alloy.
- Reinforcement: Possible reinforcements include SiC, Al_2O_3, B_4C, or Graphene at different weight percentages.
- Processing: Fabrication methods like stir casting, powder metallurgy, or spray deposition can be used to develop the composite.

2.2 Sample Preparation

- Prepare test specimens according to ASTM G99 (for wear) and ASTM G31 (for corrosion) standards.
- Common sample dimensions: Ø 10 mm × 30 mm or 20 mm × 20 mm × 5 mm.

- Surface Finishing: Polished with emery papers (400, 600, 800, 1200 grit) and cleaned with acetone.

2.3 Tribological Testing (Wear Study)

- Test Equipment: Pin-on-disc tribometer (ASTM G99).
- Test Conditions:
  - Load: 10-50 N
  - Sliding velocity: 0.5-2 m/s
  - Sliding distance: 500-2000 m
  - Track Diameter: 50-100 mm
  - Environmental Medium: Dry & corrosive (NaCl solution, H_2SO_4, etc.)
- Data Recorded: Coefficient of friction (COF), wear rate, and material loss.

2.4 Corrosion Testing

- Test Equipment: Electrochemical Workstation (Potentiostat/Galvanostat).
- Methods Used**:**
  - Potentiodynamic Polarization (PDP)
  - Electrochemical Impedance Spectroscopy (EIS)
- Test Conditions**:**
  - Electrolyte: 3.5% NaCl (to simulate seawater corrosion)
  - Scan Rate: 1 mV/s
  - Electrode Setup: Reference (Ag/AgCl), Working (sample), Counter (Pt electrode)
  - Immersion Time: 24-72 hours

2.5 Tribo-Corrosion Testing (Combined Study)

- Performed in a Pin-on-Disc machine or a reciprocating wear tester with an electrochemical cell.
- In-Situ Measurements: Wear volume, open circuit potential (OCP), COF.
- Compare wear loss in air vs. wear loss in corrosive environments**.**

2.6 Microstructural and Surface Analysis

- Scanning Electron Microscopy (SEM)**:** For wear track and corrosion product examination.
- Energy Dispersive X-ray Spectroscopy (EDS): To analyze elemental composition.
- X-ray Diffraction (XRD): To identify corrosion products like Al_2O_3 or Al $(OH)_3$**.**
- 3D Profilometry: To measure surface roughness and wear volume.

2.7 Data Analysis & Conclusion

- **Compare wear rates in** dry, wet, and corrosive **conditions.**
- **Evaluate** synergistic effects **of wear and corrosion.**
- **Optimize reinforcement percentage for best tribo-corrosion resistance.**

Mix the reinforcement with the matrix material using mechanical stirrer as a vortex is known as stir casting. It is a helpful technique for making metal matrix composites because of its low cost mass production, adaptability, implicity, almost net shaping and ease of control over the composite structure

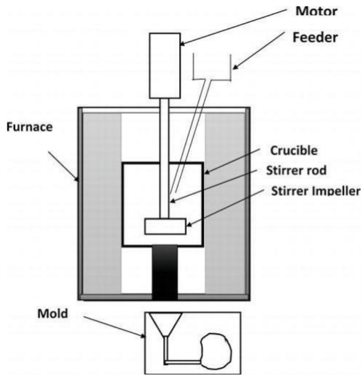


Fig.No.1 Stir casting

The furnace, reinforcement feeding, and mechanical stirrer are the three main components of the stir casting arrangement shown in Figure. In the furnace, the materials are heated and melted. For bottom pouring furnaces, stir casting is more suitable. This is done to prevent the solid particles from sinking to the bottom once the properly mixed solution has been poured. Mechanical stirrers are employed to generate a vortex that will mix the reinforcing materials supplied to the melt. A stirrer is made consisting of an impeller blade and a stirring rod. Impeller blades can be of a variety of sizes, shapes, and designs. When the flat blade has three numbers, axial flow occurs in the crucible and requires less energy. This stirrer is connected to a motor with variable speed Impeller blades can be of a variety of sizes, shapes, and designs. The motor with variable speed is connected to this stirrer. he stirrer's spinning speed controlled by the motor regulator. The feeder is also linked to the furnace so that reinforcing powder may be fed into the melt. You can fill a permanent mound, a sand mound, or a lost-wax mound with the mixed slurry

The picture illustrates the stir casting method, highlighting its various steps in this process. The matrix material is liquefied in the bottom half of the furnace, while reinforcements undergo preheating at a precise temperature in a separate furnace to eliminate moisture impurities and other contaminants. Once the matrix material has melted at a specific temperature and mechanical steering has commenced to generate a vertex, the reinforcement particles are introduced into the system following this, the reinforcement is maintained within the system for a designated duration. After being poured into a heated mound, the molten liquid cools naturally before becoming solid. Processes including heat treatment, machining, testing, and inspection are also done after casting. Been completed. There are several different impeller blade geometries.

The initial stage in this procedure is to melt the matrix material. For further testing, the material is now formed into cylindrical rods and melted into tiny sheets. The sheet has a 2mm thickness and a 5cm-by-5cm cross section. This sheet has an oxidizing coating on it. Additionally, the material is examined for its mechanical qualities (wear test, tensile test).

3. RESULTS

3.1. Tensile Analysis

Fig No. 2 Specimens after the tensile test

The tensile test is a crucial mechanical characterization method in the tribological corrosion study of aluminum composite materials. It evaluates how the material behaves under uniaxial tensile stress, particularly when exposed to corrosive environments and wear conditions.

3.2 specimen Preparation

- Material: Aluminum composite (e.g., Al6061-SiC, Al7075-B_4C, Al-Al_2O_3)
- Fabrication Method: Stir casting, powder metallurgy, or spray deposition.
- Standard: Specimens prepared as per ASTM E8/E8M (Standard for tensile testing of metals).
- Dimensions:
  - Gauge length: 25–50 mm
  - Diameter: 6–10 mm (cylindrical)
  - Thickness: 2–4 mm (flat samples)
- Surface Preparation:
  - Polished using emery papers (400–1200 grit)
  - Cleaned with acetone or ethanol

3.3 Corrosion Exposure Before Testing

To study tribo-corrosion effects, specimens are pre-exposed to corrosive environments:

◈ Salt Spray Test (ASTM B117) – Exposure to 3.5% NaCl solution **for** 24–72 hours

◈ Electrochemical Corrosion Test (ASTM G31) – Potentiodynamic polarization in a corrosive electrolyte

◈ pH Variation Studies – Samples immersed in acidic (H_2SO_4), neutral (NaCl), and alkaline (NaOH) solutions

Table No. 2 Tensile Analysis

Composition	Peak Load (FMAX) kN	Disp. At Fmaxin mm	Breaking Load in kN	Max. Disp. In mm	Ultimate Stress in kN/mm2	Elangation %
0%	22.3	12.1	21.94	12.2	0.182	23.33%
6%	25.48	18.4	9.04	18.5	0.208	30.83%
8%	13.36	8.8	13.04	9.1	0.109	15.17%

Tensile analysis evaluates the mechanical strength, deformation behavior, and fracture characteristics of aluminum composite materials, especially under the influence of tribological (wear) and corrosive environments. Salt Spray Test (ASTM B117) Immersion in 3.5% NaCl for 24–72 hours. Potentiodynamic Polarization Test (ASTM G31) Electrochemical corrosion study in acidic, neutral, or alkaline solutions.Wear & Corrosion Combined Study Specimens subjected to simultaneous tribological wear and corrosion.

3.4 Specimen Preparation & Standard Testing Parameters

- Material: Aluminum matrix composite (e.g., Al6061-SiC, Al7075-B_4C, etc.)
- Manufacturing Process: Stir casting, powder metallurgy, or other fabrication methods.
- Standard Followed: ASTM E8/E8M (for metallic tensile testing)
- Sample Dimensions:
  - Gauge length: 25–50 mm
  - Thickness: 2–4 mm
  - Width/Diameter: 6–10 mm
- Surface Treatment: Polishing with emery papers (400–1200 grit), cleaning with acetone.

The process starts with the chosen matrix material melting and the molten metal is then fed with the chosen reinforcing particles. Then, they are thoroughly mixed by the mechanical stirrer and later on can be casted by the conventional casting methods[1 2]. Stir casting method is one of the most straightforward and economical way to fabricate liquid state composites, the casting techniques offer an advantage over other procedures. Therefore, a crucial stage in the stir casing process was to stir cast the mixture in order to obtain uniform distribution of reinforcement into base alloy. A successful method for improving reinforcement distribution throughout the matrix was fluid stir casting

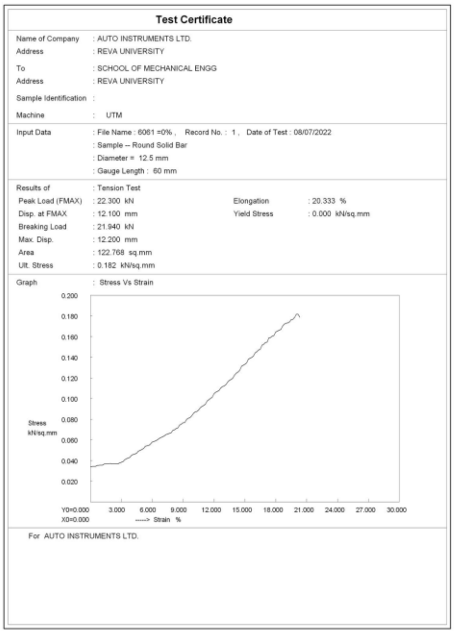


Figure 1: Tensile for 0%

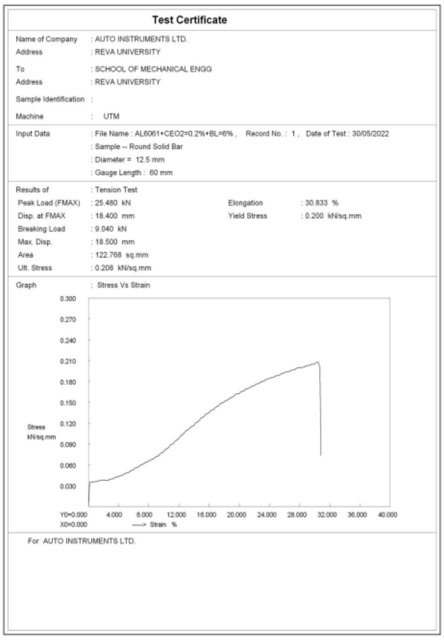


Figure 2: Tensile for 6%

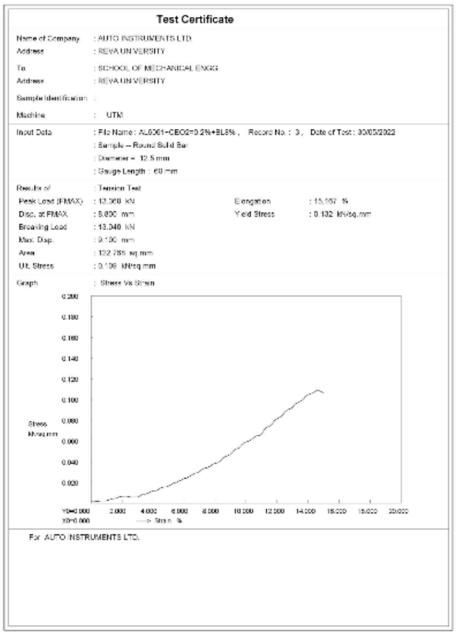


Figure 3: Tensile for 8%

Overall, the data suggests that the addition of beryl to the aluminum composite material affected its mechanical properties in different ways, depending on the beryl composition. The material with 6% beryl composition had higher initial strength and stiffness, but lower ductility and ultimate strength, the material with 8% beryl composition had similar initial strength and stiffness as the material with 0% beryl composition, but higher ductility. Further research can be conducted to optimize the beryl composition for specific applications and to investigate the material's long-term performance and durability.

3.5 Compression Analysis

The results were analyzed and the stress vs strain graph was plotted for 0%, 6% and 8% composites respectively.

Figure 3 Specimens after compression test

Evaluate compressive strength, yield stress, and deformation behavior.Test Standard: ASTM E9 (for metallic materials).Machine Used: Universal Testing Machine (UTM) or hydraulic press.

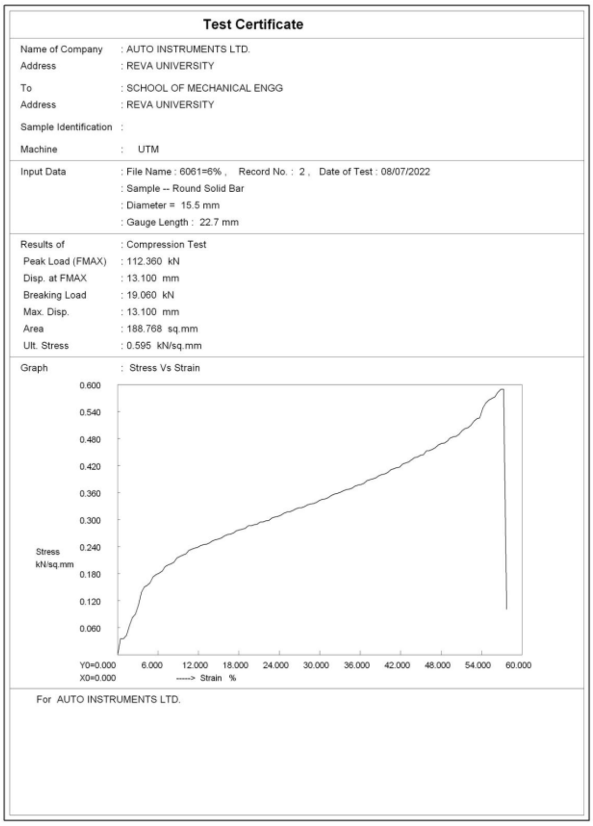
3.6 Test Parameters:

- Load range: 10–100 kN
- Strain rate: 0.5–2 mm/min
- Specimen size: Ø10 mm × 20 mm (cylindrical) or 20 mm × 20 mm × 20 mm (cube).
- Shear cracks: 45° diagonal cracks due to maximum shear stress.
- Splitting fracture: Composite breaks into multiple fragments.
- Debonding: Matrix-reinforcement separation seen in high-stiffness materials.

It is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. Stir casting as shown in fig. is the simplest and the most cost effective method of liquid state fabrication. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies It is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. Stir casting as shown in fig. is the simplest and the most cost effective method of liquid state fabrication. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies stirring. Stir casting is the simplest and the most cost effective

Table 3:- Compression Analysis

Composition	Peak Load (Fmax) in kN	Disp. At Fmax in mm	Breaking Load in kN	Max. Disp. in mm	Ultimate Stress in kN/mm2
0%	119.360	14.300	15.300	14.300	0.632
6%	112.360	13.100	19.060	13.100	0.595
8%	118.6	13.3	118.6	13.3	0.628


Test Certificate

Name of Company : AUTO INSTRUMENTS LTD.
Address : REVA UNIVERSITY
To : SCHOOL OF MECHANICAL ENGG
Address : REVA UNIVERSITY
Sample Identification :
Machine : UTM
Input Data : File Name : 6061=6% , Record No. : 2 , Date of Test : 08/07/2022
: Sample -- Round Solid Bar
: Diameter = 15.5 mm
: Gauge Length : 22.7 mm
Results of : Compression Test
Peak Load (FMAX) : 112.360 kN
Disp. at FMAX : 13.100 mm
Breaking Load : 19.060 kN
Max. Disp. : 13.100 mm
Area : 188.768 sq.mm
Ult. Stress : 0.595 kN/sq.mm
Graph : Stress Vs Strain

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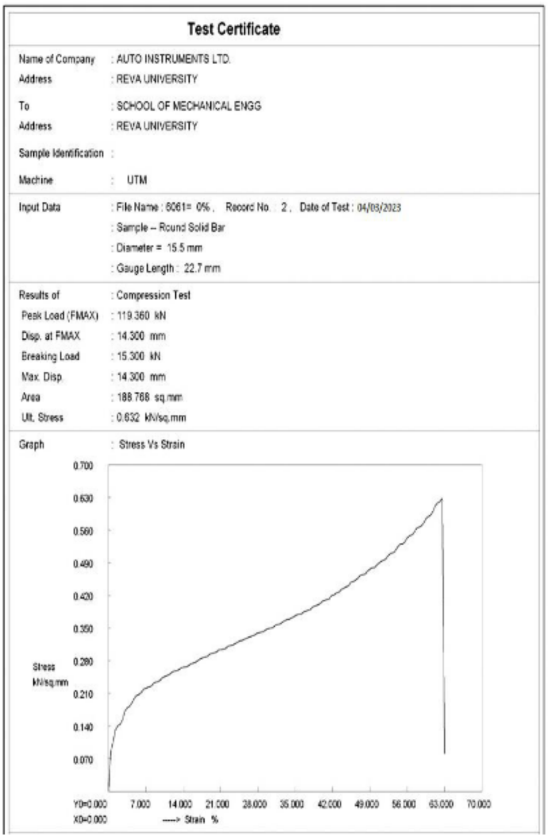
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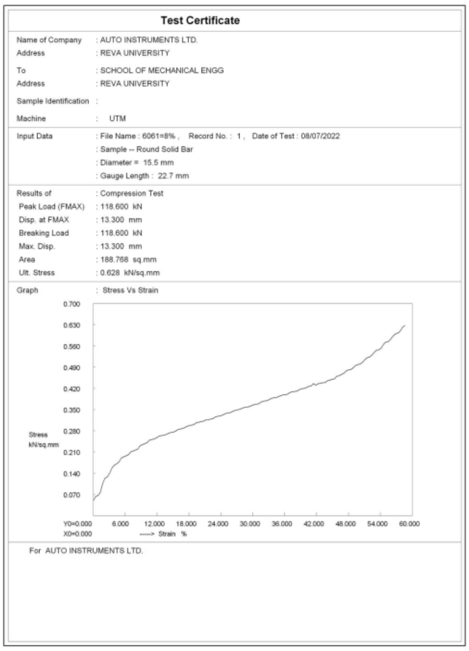
Address : REVA UNIVERSITY
Sample Identification :
Machine : UTM
Input Data : File Name : 6061= 0% , Record No. : 2 , Date of Test : 04/09/2023
: Sample -- Round Solid Bar
: Diameter = 15.5 mm
: Gauge Length : 22.7 mm
Results of : Compression Test
Peak Load (FMAX) : 119.360 kN
Disp. at FMAX : 14.300 mm
Breaking Load : 15.300 kN
Max. Disp. : 14.300 mm
Area : 188.768 sq.mm
Ult. Stress : 0.632 kN/sq.mm
Graph : Stress Vs Strain

Figure 4: Compression for 0%

Figure 5: Compression for 6%



Test Certificate

Name of Company	: AUTO INSTRUMENTS LTD.
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To	: SCHOOL OF MECHANICAL ENGG
Address	: REVA UNIVERSITY
Sample Identification	:
Machine	: UTM
Input Data	: File Name : 6061=8% , Record No. : 1 , Date of Test : 08/07/2022
	: Sample -- Round Solid Bar
	: Diameter = 15.5 mm
	: Gauge Length : 22.7 mm
Results of	: Compression Test
Peak Load (FMAX)	: 118.600 kN
Disp. at FMAX	: 13.300 mm
Breaking Load	: 118.600 kN
Max. Disp.	: 13.300 mm
Area	: 188.768 sq.mm
Ult. Stress	: 0.628 kN/sq.mm
Graph	: Stress Vs Strain

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Figure 6: Compression for 8%

Overall, the data suggests that the addition of beryl to the aluminum composite material had a notable impact on its mechanical characteristics, yet the precise nature of the effect depended on the beryl composition. The material with 0% beryl composition had the highest ultimate stress and breaking load, while the material with 8% beryl composition had the highest peak load and maximum displacement. The material with 6% beryl composition had lower strength and stiffness, but higher ductility. Further research could be conducted to optimize the beryl composition for specific applications and to investigate the material's long-term performance and durability.

3.7 Wear Analysis

Studying the wear and frictional force vs time for different beryl compositions can provide valuable insights into the tribological properties of composite materials. In this case, the study tested composite materials containing different amounts of burial, 0% 6% and 8%. Each sample underwent a 15N load for 600 seconds on a 50mm radius disc spinning at 210 rpm. Results indicated that as a barrel concentration increased, wear rate and frictional force of the composite decreased this is because barrel strength and stiffness improve the mechanical properties of material, reducing deformation, and where during sliding. Moreover, higher barrier concentration enhances lubrication properties leading to a lower frictional force.

In addition, the result showed that, as a testing time increased, the composite materials wear, rate and frictional force decreased. This can be explained by the rubbing action during the tribological test, creating a protective coating on the composite material surface. The protective layer can enhance the material stable logical qualities by lowering the frictional force and wear rate.

Fig 7 Sample for wear Test

In summary, analysing the frictional force and wear over time for different beryl compositions provides important information on the tribological properties of composite materials. According to the experimental findings, the wear resistance and frictional force of the composite material can both be enhanced by raising the concentration of beryl. This finding highlights the importance of testing duration in determining the tribological characteristics of composite material. Future research endeavors could investigate the effects of additional variables, such as matrix type, processing parameters, and ambient circumstances, on the tribological characteristics of composite materials that use beryl reinforcement where frictional force is measured against time for different beryl compositions.

Fig 8: ***FF for4% Beryl***

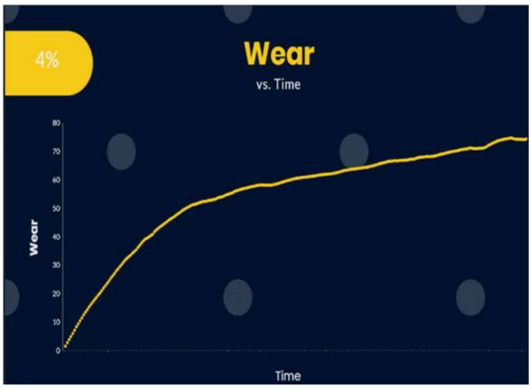
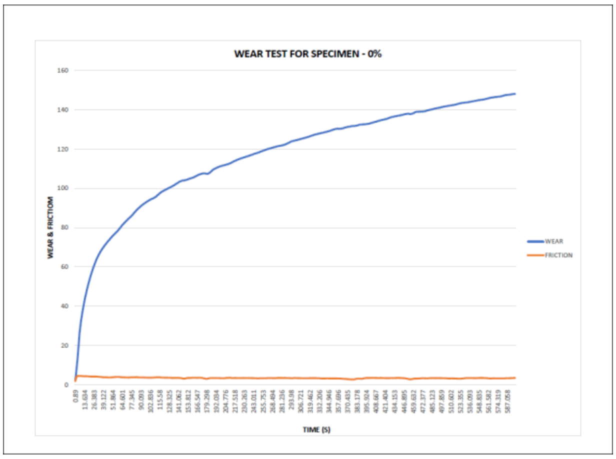


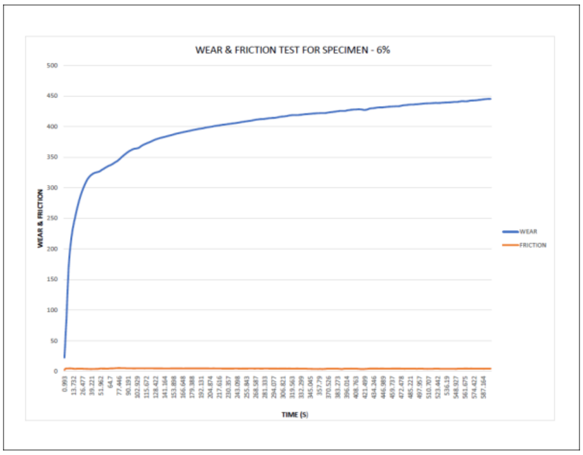
Fig 9: ***Wear for 4% Beryl***

Fig 10: ***FF for 8% Beryl***

Fig 11: ***Wear for 8% Beryl***

Comparing the results of the different beryl compositions, a beryl concentration of 8% a When subjected to a dry sliding wear test, composites containing 0.2% and 8% wt cerium oxide performed exceptionally well, with wear being 7.4% less than that of the base alloy. Increasing the oxide content will improve mechanical and wear properties even more, but not to the same degree as reinforcement. 8% exhibited the lowest wear rate and frictional force. This indicates that a higher concentration of beryl can improve the tribological properties of the composite material. However, it is important to note that the effects of beryl concentration on tribological properties may not always be straightforward and can be influenced by other factors such as the processing conditions and microstructure of the composite material.





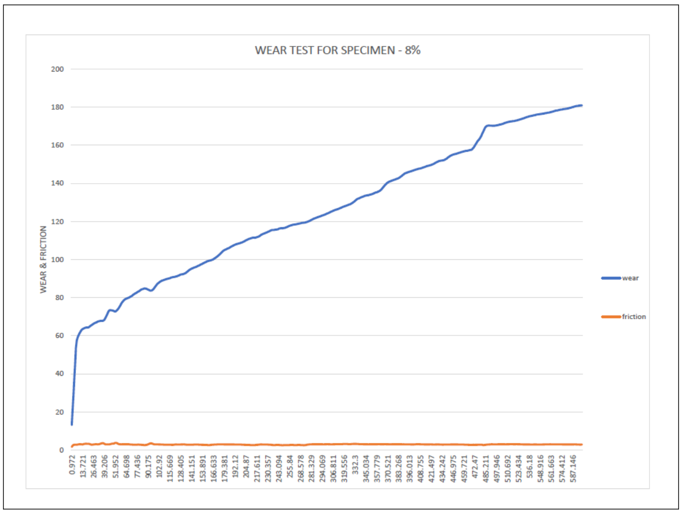


Fig 12: wear test

In addition, the result showed that, as a testing time increased, the composite materials wear, rate and frictional force decreased. This can be explained by the rubbing action during the tribological test, creating a protective coating on the composite material surface. The protective layer can enhance the material stable logical qualities by lowering the frictional force and wear rate.

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4. Conclusion

The present study looked into the impact of beryl concentration on the mechanical, tribological, and corrosion properties of composite materials. The composite materials were prepared by incorporating beryl particles at concentrations of 0%, 6% and 8%. Tensile and compression Tests were conducted to assess the mechanical characteristics, The tribological tests revealed that the wear rate and frictional force of the composite materials. the Various tribological tests were run to look at the composite materials, tribological characteristics, the mechanical properties of the composite materials were enhanced by the addition of beryl particles, as demonstrated by the outcomes of the tensile and compression test, the composite materials, modules of Elasticity and maximum stress Both increased as the concentration of beryl did, suggesting that beryl particles had a reinforcing impact. The results also demonstrated that the composite material with a 8% beryl concentration had the highest modulus of Elasticity and maximum stress, suggesting that the mechanical properties of the composite materials can be enhanced by increasing beryl concentration. This trend can be attributed to the high strength and stiffness of beryl, which can reduce the deformation and wear of the material during sliding. Additionally, the higher concentration of beryl can also improve the lubrication properties of the composite material, resulting in a lower frictional force. Additionally, the data showed that as testing duration increased, the composite materials' wear rate and frictional force decreased, suggesting the creation of a protective layer on their surface. Overall, the studies finding point to the possibility of enhancing composite materials, mechanical, tribological, and corrosion resistance by including beryl particles. The outcomes also imply that the qualities of composite material can be enhanced and better reinforcing can be obtained with higher beryl concentration. It is crucial to remember that other variables, like the composite materials, microstructure, and processing circumstances, may have an impact on how beryl concentration affects a material's characteristics.

To sum up, our study has shed light on how the concentration of beryl affects the mechanical and tribological characteristics of composite materials. The outcomes of the experiment have demonstrated that the addition of beryl particles can improve the properties of composite materials and that a higher concentration of beryl can provide better reinforcement and improve the properties of the composite material. The results of this study can be applied to different kinds of reinforcing materials and matrix materials, and they can be helpful in the production of composite materials with enhanced mechanical, tribological, and corrosion properties. Future studies can investigate the effect of other parameters such as the type of matrix material, processing conditions, and environmental factors on the properties of composite materials with beryl reinforcement.

References:

[1]. Vijayasarathi Prabakaran(2024) Study of tribological performance and corrosion resistance of aluminum alloy 6063 composites enhanced with a combination of silicon carbide and tungsten disulfide particles Results in Surfaces and Interfaces.

[2]. Zhiyuan Guo (2024) Enhancing the tribological and corrosion properties of 2A12 aluminum alloy via micro-arc oxidation and paraffin sealing Colloids and Surfaces A: Physicochemical and Engineering Aspects

[3]. Sodiq Abiodun Kareem (2024) Aluminium matrix composites reinforced with high entropy alloys: A comprehensive review on interfacial reactions, mechanical, corrosion, and tribological characteristics Journal of Materials Research and Technology

[4]. Ashby, M. F. (2011). Metal foams: A design guide. Butterworth-Heinemann.

[5]. Dey, P. K. (2016). Tribology of metal matrix composites: A review. Materials & Design, 90, 986-1005.
[6]. Elanchezhian, C., Aravindan, S., & Arulshri, K. P. (2014). Recent developments in hybrid metal matrix composites: Techniques and their applications. Materials & Design, 57, 185-205.
[7]. Kainer, K. U. (Ed.). (2006). Metal matrix composites: Custom-made materials for automotive and aerospace engineering. John Wiley & Sons.
[8]. Chawla, N., & Shen, Y. L. (1999). Ceramic and Metal Matrix Composites: Routes and Properties. Springer.
[9]. Pradeep, K. G., & Prabhu, N. (2013). Synthesis of Al6061/SiCp Composite by Stir Casting. International Journal of Materials Science and Engineering, 1(1), 1-7.
[10]. Singla, M., Dwivedi, D. D., & Singh, L. (2009). Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite. Journal of Minerals and Materials Characterization and Engineering, 8(06), 455-467.
[11]. Robinson, R. C., & Adams, J. B. (1988). Structure of stir-cast metal matrix composites. Scripta Metallurgica, 22(10), 1501-1506.
[12]. Davis, J. R. (1993). Aluminum and Aluminum Alloys. ASM International.
[13]. Cahn, R. W. (2002). The Coming of Materials Science. Elsevier.
[14]. Deer, W. A., Howie, R. A., & Zussman, J. (2013). An Introduction to the Rock-Forming Minerals. Mineralogical Society of Great Britain and Ireland.
[15]. Hawthorne, F. C., Oberti, R., & Harlow, G. E. (2013). On the classification of amphiboles. The Canadian Mineralogist, 51(2), 325- 341.