International Journal of Advanced Computing and Mechanical Systems (IJACM)
E-ISSN No.: xxxx-xxxx www.ijacm.com
Volume Number: 1 Issue Number: 1 pp: 33- 38 Publication Month: Dec-2025

Frictional Stability and Surface Integrity of Aluminum-Based Composite Materials

S. Karthivelan[1,*], M. Arunprasath[1], V. Magesh Kumar[1]
[1]*Department of Mechanical Engineering, Satyam College of Engineering & Technology, Kanyakumari, Tamil Nadu, India*

C*orresponding Author* E-Mail: karthivelan.s@outlook.com

ABSTRACT

This research focuses on the fabrication and performance evaluation of aluminum alloy–based metal matrix composites reinforced with titanium dioxide (TiO_2) nanoparticles, developed to improve mechanical strength and wear resistance for advanced engineering and automotive applications. Aluminum alloys are widely used due to their low density, favorable strength-to-weight ratio, corrosion resistance, and high thermal conductivity. The addition of TiO_2 nanoparticles is intended to further enhance these characteristics, particularly under tribological loading conditions. The composites were produced using the powder metallurgy technique, which involves blending aluminum alloy powders with TiO_2 nanoparticles, followed by compaction and sintering to obtain a dense and uniformly reinforced structure. Mechanical characterization was carried out through tensile, hardness, and impact tests to evaluate the influence of TiO_2 reinforcement. The results indicate notable improvements in tensile strength and hardness, confirming effective bonding between the aluminum matrix and ceramic nanoparticles. Enhanced impact strength suggests improved energy absorption capability. Tribological performance was examined under varying loads and sliding speeds. The TiO_2-reinforced composites exhibited significantly improved wear resistance compared to unreinforced aluminum, primarily due to the hard ceramic nature of TiO_2, which acts as a protective layer against surface damage. Scanning electron microscopy (SEM) analysis revealed reduced surface degradation and wear mechanisms, validating the role of TiO_2 in lowering wear rates and enhancing surface integrity.

Keywords: Wear behavior, Coefficient of friction, Metal matrix composites, Tribological testing, Mechanical performance

I. INTRODUCTION

Aluminum alloys, particularly AL6061, are increasingly considered for brake pad applications because of their lightweight nature, excellent thermal conductivity, and favorable mechanical properties. Despite these advantages, unreinforced aluminum alloys often fail to meet the stringent wear and frictional requirements of modern braking systems. To overcome these limitations, the incorporation of ceramic nanoparticles such as titanium dioxide (TiO_2) has gained considerable attention [1-3].

TiO_2 is a hard, chemically stable ceramic material known for its excellent wear resistance and thermal stability. When used as a reinforcement in aluminum matrices, it significantly improves mechanical strength and tribological performance. This study investigates the mechanical and wear behavior of AL6061 aluminum alloy reinforced with TiO_2 nanoparticles for brake pad applications. The composites were fabricated using powder metallurgy, a technique known for producing materials with

doi: https://doi.org/10.5281/zenodo.18234813

uniform reinforcement distribution and reduced porosity [3,4]. A comparative assessment was conducted between conventional brake pad materials and the developed metal matrix composite (MMC) brake pads. Mechanical tests, including tensile and hardness measurements, along with wear tests under different operating conditions such as load, sliding speed, and temperature, were performed. The study aims to understand how TiO_2 nanoparticles influence wear resistance, friction stability, and thermal behavior in MMC brake pads.

II. LITERATURE REVIEW

Previous studies have demonstrated the effectiveness of TiO_2 as a reinforcement in aluminum matrix composites. Researchers have employed various fabrication techniques, including stir casting and powder metallurgy, to achieve uniform dispersion of TiO_2 particles within aluminum alloys [5,6]. These investigations consistently report improvements in hardness, tensile strength, and wear resistance with increasing TiO_2 content. Several authors [7,8] have highlighted that nano-sized TiO_2 particles form strong interfacial bonding with the aluminum matrix, which enhances load-bearing capacity and reduces material removal during sliding. Comparative studies on different ceramic reinforcements such as SiC, Al_2O_3, and TiO_2 indicate that TiO_2-reinforced composites often exhibit superior wear resistance and stable friction behavior, particularly at elevated temperatures.

Microstructural analyses using SEM and XRD techniques reveal that homogeneous particle distribution plays a crucial role in improving tribological performance. Protective oxide layers formed during sliding further reduce surface damage and improve thermal stability, making TiO_2-reinforced aluminum composites suitable for automotive brake applications.

III. OBJECTIVES

- To fabricate AL6061 aluminum alloy composites reinforced with TiO_2 nanoparticles using powder metallurgy.
- To compare the friction and wear behavior of conventional brake pad materials such as aluminum, magnesium, zinc, and copper.
- To simulate real automotive braking conditions by varying sliding speed, load, and temperature.
- To evaluate and compare the tribo-mechanical properties of conventional brake pads and developed MMC brake pads.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

4.1 Sliding Wear Behavior

The wear test results demonstrate that aluminum alloys show a consistent reduction in wear rate over repeated test cycles. Among the tested materials, AL6061 exhibited superior wear resistance and lower coefficient of friction compared to aluminum, magnesium, zinc, and copper. This confirms the suitability of AL6061 as a matrix material for brake pad applications (Fig. 1 & 2).

4.2 Tensile Strength

The tensile strength of pure AL6061 was recorded at 309 MPa. With the addition of TiO_2 reinforcement, the tensile strength increased to 315 MPa for 3% TiO_2, 333 MPa for 6% TiO_2, and 351 MPa for 9% TiO_2.

doi: https://doi.org/10.5281/zenodo.18234813

The results clearly indicate that increasing TiO_2 content enhances tensile performance due to improved particle-matrix bonding (Fig. 3).

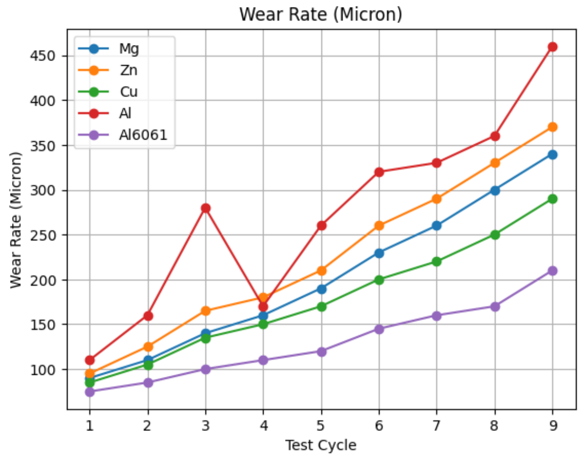

Figure 1: Comparative Wear Performance of Selected Materials

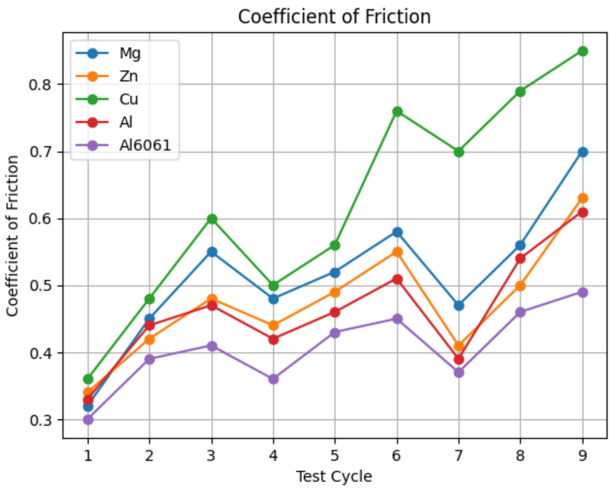

Figure 2: Comparative COF Performance of Selected Materials

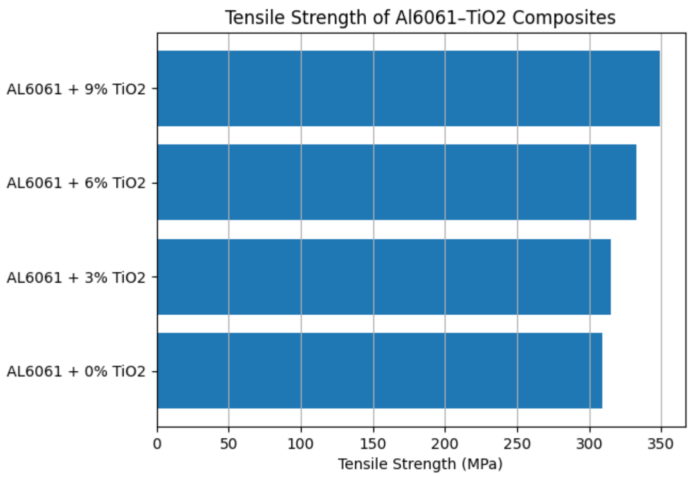

Figure 3: Comparative Tensile strength Performance of Selected Materials

doi: https://doi.org/10.5281/zenodo.18234813

4.3 Compressive Strength

Pure AL6061 exhibited a compressive strength of 103 MPa. The composites reinforced with 3%, 6%, and 9% TiO_2 showed compressive strengths of 113 MPa, 164 MPa, and 193 MPa, respectively. The substantial improvement is attributed to the presence of hard ceramic particles that restrict plastic deformation (Fig. 4).

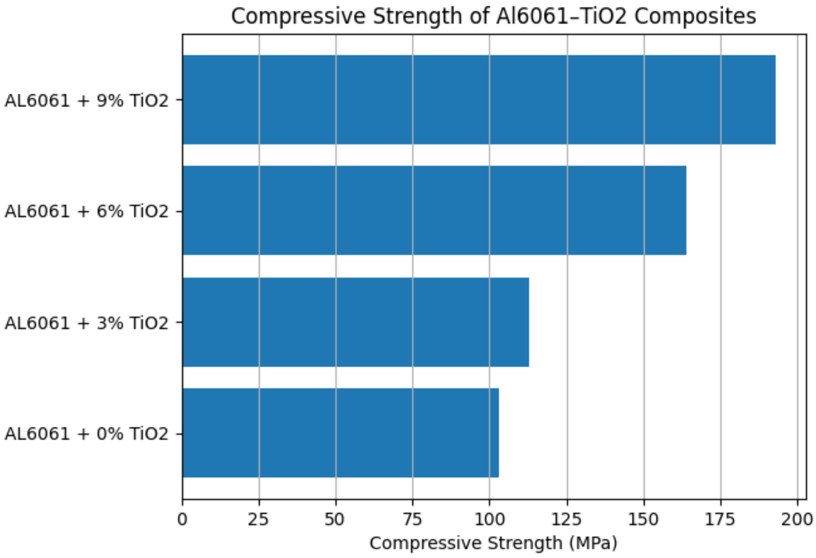

Figure 4: Comparative Compressive strength Performance of Selected Materials

4.4 Hardness

Hardness measurements revealed a progressive increase with increasing TiO_2 content. Pure AL6061 showed a hardness of 80 BHN, while the composites with 3%, 6%, and 9% TiO_2 recorded hardness values of 109, 111, and 125 BHN, respectively. The enhancement is due to the resistance offered by TiO_2 particles against localized deformation (Fig. 5).

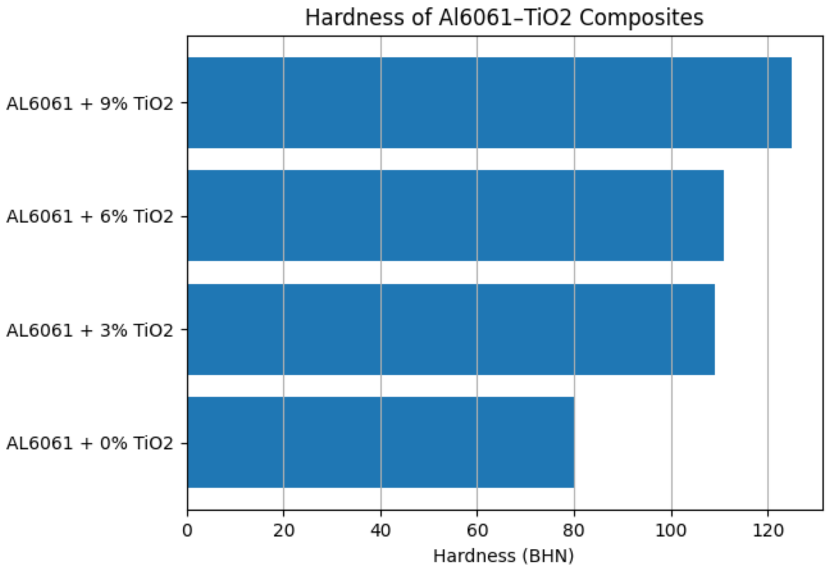

Figure 5: Comparative Hardness Performance of Selected Materials

doi: https://doi.org/10.5281/zenodo.18234813

V. FINITE ELEMENT ANALYSIS

Finite element analysis (FEA) was conducted to evaluate stress distribution within the composite specimen bars. The maximum stress values were observed in regions consistent with experimental failure locations. Comparison between experimental and FEA results showed minimal deviation, with a variation of approximately 1%. Overall discrepancies remained below 10%, indicating strong agreement and validating the structural safety of the composite design (Fig.6).

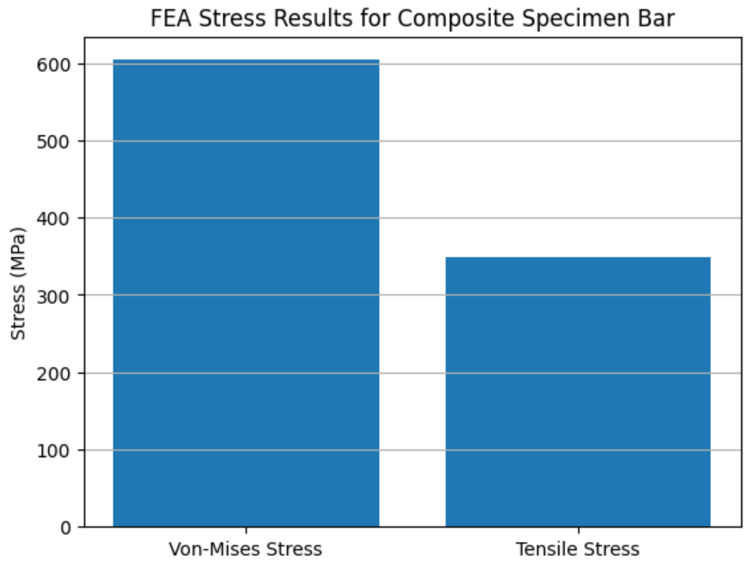

Figure 6: Stress comparison of composite specimen bar obtained from finite element analysis

VI. CONCLUSION

Based on mechanical, tribological, and numerical analyses, the following conclusions can be drawn:

- AL6061 aluminum alloy reinforced with TiO_2 nanoparticles was successfully fabricated using the powder metallurgy technique.
- The composite containing 6%–9% TiO_2 demonstrated superior mechanical and wear properties compared to conventional brake pad materials.
- Increasing TiO_2 content up to 9% resulted in improvements of approximately 21% in tensile strength, 27% in compressive strength, and 38% in hardness.
- The composite with 9% TiO_2 exhibited the highest wear resistance and most stable coefficient of friction.
- Finite element analysis results closely matched experimental findings, confirming the reliability and safety of the composite brake pad design.
- Overall, TiO_2-reinforced AL6061 metal matrix composites show strong potential as high-performance brake pad materials for automotive applications.

doi: https://doi.org/10.5281/zenodo.18234813

VII. REFERENCES

[1] A. Singh and P. Kumar, "Development and wear behavior of aluminum-based metal matrix composites reinforced with nano-TiO_2 for automotive applications," Journal of Tribology and Material Science, vol. 32, no. 4, pp. 205–215, 2018.

[2] M. Gupta and Q. Wang, "Influence of ceramic reinforcements on the tribological performance of aluminum alloy brake pads," Tribology International, vol. 144, Art. no. 106123, 2020, doi: 10.1016/j.triboint.2020.106123.

[3] R. Kumar and D. Patel, "Comparative analysis of conventional brake pads and AL6061–TiO_2 metal matrix composites in automotive applications," Materials Today: Proceedings, vol. 18, pp. 4150–4157, 2019, doi: 10.1016/j.matpr.2019.06.340.

[4] V. Sharma and T. Rao, "Enhancement of tribological properties of AL6061 using nano-TiO_2 reinforcement for brake pad applications," Journal of Advanced Materials Research, vol. 1175, pp. 58–65, 2021, doi: 10.4028/www.scientific.net/JAMR.1175.58

[5] A. Ali and S. Ibrahim, "Effect of TiO_2 reinforcement on the mechanical and wear properties of aluminum matrix composites," International Journal of Automotive and Mechanical Engineering, vol. 19, no. 3, pp. 8303–8314, 2022, doi: 10.15282/ijame.19.3.2022.14.0650.

[6] M. Hussein, R. Gundlapalle, M. K. Kumar, and S. Lakhanpal, "Advancing aluminum-based composite manufacturing: Leveraging TiO_2 reinforcement through stir casting technique," in Proc. Int. Conf. Futuristic Trends in Engineering, Science & Technology (ICFTEST), E3S Web of Conferences, vol. 507, 2024.

[7] A. Somayaji, M. Nagaral, C. Anjinappa, and M. Alkahtani, "Influence of graphite particles on the mechanical and wear characterization of Al6082 alloy composites," ACS Omega, vol. 8, no. 3, 2023, doi: 10.1021/acsomega.3c01313.

[8] B. Saleh et al., "Review on the influence of different reinforcements on the microstructure and wear behavior of functionally graded aluminum matrix composites by centrifugal casting," Metals and Materials International, pp. 1–28, 2019.

doi: https://doi.org/10.5281/zenodo.18234813