

Analysing the Frictional and Mechanical Behaviour of AL2024 MMC Reinforced with B4C & MoS2 in Brake Pad Systems

Balu Pandurang Patil¹, Mr. P. G. Sarasambi², Prof. Dr. A. D. Desai³,
Prof. Dr. S. D. Shinde⁴, Mr. S. P. Godase⁵

P.G. Student, Department of Mechanical Engineering¹

Professor, Department of Mechanical Engineering³

Assistant Professor, Department of Mechanical Engineering^{2,4,5}

Shree Ramchandra College of Engineering, Lonikand, Pune, Maharashtra, India

Abstract: *The performance of brake pad systems is crucial for the safety and efficiency of automotive applications. This study investigates the impact of reinforcements, namely Boron Carbide (B4C) and Molybdenum Disulfide (B4C), on the frictional and mechanical behaviour of Aluminium 2024 (Al2024) Matrix Composites (MMCs) used in brake pads. Al2024 is a widely employed material in various engineering applications due to its excellent strength-to-weight ratio, but its tribological performance in brake systems can be enhanced by incorporating reinforcements. The study aims to evaluate the improvements in friction, wear resistance, and mechanical properties of Al2024 when reinforced with varying concentrations of B4C and B4C. A series of experiments are conducted, including pin-on-disk tribological testing and tensile, hardness, and impact tests, to assess the influence of these reinforcements on the overall performance of brake pads. The results suggest that B4C significantly enhances the wear resistance and hardness of Al2024 MMCs, while B4C provides improved lubricating properties, reducing friction and enhancing the material's durability. The synergistic effects of both reinforcements in the Al2024 matrix demonstrate a potential pathway for the design of high-performance brake pad materials. This research contributes to the development of advanced materials for automotive brake systems, improving safety and performance under high-stress conditions.*

Keywords: Friction and wear analysis, Pin on disc, Performance Optimization, Finite Element Analysis

I. INTRODUCTION

The performance and reliability of braking systems are critical factors in automotive and aerospace applications, where efficient energy dissipation and durability are paramount. The choice of brake pad materials significantly influences factors such as wear resistance, coefficient of friction, thermal stability, and mechanical strength. Traditional brake pad materials, such as metallic and ceramic composites, have been widely used, but increasing demand for lightweight, high-performance alternatives has driven research in to advanced metal matrix composites (MMCs). Aluminum 2024 (Al2024) is a lightweight, high-strength alloy known for its excellent mechanical properties, making it a promising candidate for brake pad applications. However, its tribological performance, particularly in terms of wear resistance and frictional stability, requires enhancement to meet the rigorous demands of braking systems. Reinforcing Al2024 with hard ceramic and solid lubricant materials can improve its overall tribological and mechanical characteristics, leading to improved performance and longevity.

In this study, Boron Carbide (B4C) and Molybdenum Disulfide (B4C) are selected as reinforcements for the Al2024 matrix. B4C, being one of the hardest known materials, enhances wear resistance, hardness, and load-bearing capacity. B4C, a widely used solid lubricant, reduces friction and enhances self-lubrication, thereby improving the stability of



the braking system under varying operating conditions. The synergistic effects of these reinforcements are expected to enhance the overall frictional and mechanical behaviour of Al2024 MMCs, making them a viable alternative to conventional brake pad materials.

This research aims to analyse the impact of different weight fractions of B4C and B4C on the tribological and mechanical properties of Al2024 MMCs. The study involves a comprehensive experimental evaluation, including wear tests, friction analysis, hardness measurements, and mechanical strength assessments. The findings will contribute to the development of high-performance, pad materials with improved durability, frictional efficiency, and thermal stability.

II. LITERATURE SURVEY

Mohammed Hussein et al. (2024) through the use of the stir casting technology. The matrix material was aluminium alloy, which was melted in a muffle furnace along with ceramic reinforcing particles at a temperature of about 700°C. Ceramic particles were evenly distributed throughout the molten alloy by constant stirring at 400 rpm for ten minutes, which was essential for improving the composite's qualities. The addition of 6.5% TiO₂ using stir casting produced notable improvements in a number of mechanical attributes. Using X-ray diffraction (XRD) methods.

Somayaji et al. (2023) produced composites reinforced with graphite fillers composed of Al6082 in order to analyze its morphology using XRD. They discovered that in every filler combination, there was a significant aggregation of graphite particles or non-uniform dispersion

Reddy et al. (2022) analysed the mechanical and tribological behaviour of Al2024 composites reinforced with varying weight fractions of B4C and B4C. The results showed that increasing the B4C content enhanced hardness and wear resistance, while B4C improved friction stability and reduced wear rates. The study suggested that a specific combination of the enforcements could optimize the performance of Al2024 MMCs for high-performance brake pad applications.

Kumar et al. (2021) conducted a study on the tribological behaviour of Al-based metal matrix composites (MMCs) reinforced with B4C. Their findings indicated that the addition of B4C significantly improved wear resistance and hardness while maintaining a stable coefficient of friction. The study highlighted that their enforcement acted as a load-bearing phase, reducing material loss under high-stress conditions, making it suitable for braking applications.

Patel et al. (2020) investigated the self-lubricating effects of B4C in aluminium composites. The research demonstrated that B4C acted as a solid lubricant, reducing friction and improving wear performance. The study concluded that an optimal concentration of B4C enhanced the tribological properties of aluminium alloys, making them more suitable for applications where controlled friction and wear resistance are critical, such as brake pad systems.

Sharma et al. (2019) explored the combined effects of ceramic and solid lubricant reinforcements in Al-MMCs. Their experimental analysis revealed that the hybrid reinforcement of B4C and B4C resulted in a balanced improvement in hardness, wear resistance, and friction control. The study emphasized that while B4C increased the material's load-bearing capacity, B4C facilitated smooth sliding, reducing friction-induced temperature rise and wear.

M. Anthony Xavier & S. Venkatesan (2019) noted Aluminium-based metal matrix composites were created for lightweight applications, mainly in the automotive and aerospace industries. The creation and characterisation of aluminium alloy 7050 matrix composites enhanced with graphene nanoparticles are the main subjects of this study paper.

B.M. Muthamizh Selvan et al. (2018) By using an in-situ stir casting technique, composite materials with an aluminium alloy 8011 matrix and 0, 4, and 8 weight percentages of ZrB₂ reinforcements were created. X-ray diffraction and scanning electron microscopy examination were used to look for the reinforcements and make sure they were distributed uniformly. Using a pin-on-disc wear tester in accordance with Taguchi's orthogonal array design, experiments were carried out to examine the impact of dry sliding wear parameters, such as sliding distance, percentage reinforcement, load, sliding velocity, and temperature, on wear rate and coefficient of friction. Statistical methods were



also employed to examine the tribological behaviour of synthetic composites. Analysis of variances was used to establish significance and the parameters' impact on the response, and Gray relational analysis.

III. PROBLEM DEFINITION

Conventional aluminium alloys struggle with excessive wear and abrasion when subjected to high-friction automotive environments and Pure aluminium or standard alloys lack the necessary hardness and thermal stability required for advanced automotive applications. while aluminium alloys offer a high strength-to-weight ratio and good corrosion resistance, they exhibit poor tribological performance, specifically low hardness and a high susceptibility to wear, seizure, and galling during mechanical operation. Components such as engine blocks, pistons, and brake rotors are subjected to high loads and temperatures. Standard alloys often fail to meet the required durability and friction standards for these high-stress environments.

IV. OBJECTIVES

- 1) To fabricate Aluminium alloy 2021 reinforced with B4C MMCs through Powder metallurgy technique.
- 2) To do comparative study about friction & wear behaviour of Al, Mg, Zn, Cu existing brake pad materials used in market.
- 3) To simulate the real time parameters of automobile Brake such as sliding velocity, contact pressure and temperature.
- 4) To Evaluate Tribo-mechanical properties of existing Brake pad material and novel composites.

V. METHODOLOGY

1. The study of these composites typically involves a systematic approach to fabrication and characterization. material Preparation and Synthesis Matrix Material Aluminium 2024 is used for its high strength-to-weight ratio Reinforcement: Boron Carbide (B4C) particles (typically 1–15 wt.%) are chosen for their exceptional hardness (28–37 GPa) Liquid metallurgy technique, specifically stir casting, is used to ensure homogeneous distribution of particles in the molten Al2024 matrix.
2. In Mechanical Testing Hardness Test Vickers hardness testing is performed to determine the increase in surface resistance due to reinforcement, often showing a substantial increase in hardness over raw Al2024. Tensile Testing Evaluates ultimate tensile strength (UTS) and yield strength (YS), showing enhancement due to the uniform dispersion of ceramic particles.
3. Impact Test Measures toughness to ensure the material can withstand braking forces without fracturing. Setup: A pin-on-disk tribometer is used to simulate brake pad sliding against a brake rotor. Parameters Tests are conducted under varying loads (e.g., 10–40 N), sliding speeds (1–3 m/s), and temperatures to mimic real-world braking. Measurements Specific wear rate, coefficient of friction (COF), and wear resistance are determined. significantly reduces the wear rate and stabilizes the COF.

VI. EXPERIMENTAL RESULTS AND DISCUSSIONS

6.1 Sliding Wear Response

The findings show that aluminium alloys consistently demonstrate a decrease in wear rate across several test cycles. As a result, the Al2021 alloy matrix is suggested as an optimal choice for the intended applications. This recommendation is backed by test data indicating that Al2021 surpasses other materials, including Al, Mg, Zn, and Cu, in terms of wear rate and coefficient of friction



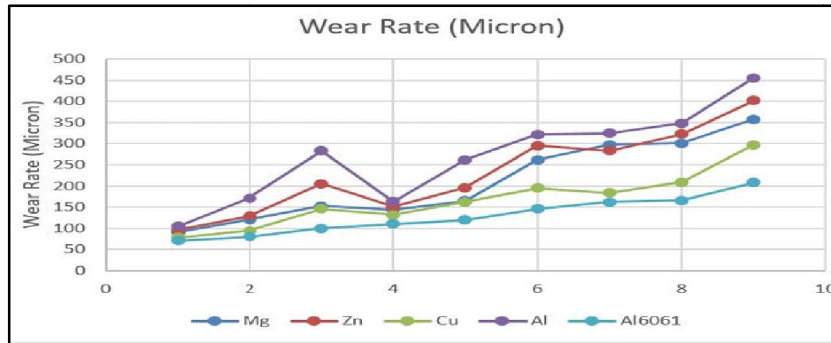


Fig. 6.1 Wear rate of different materials

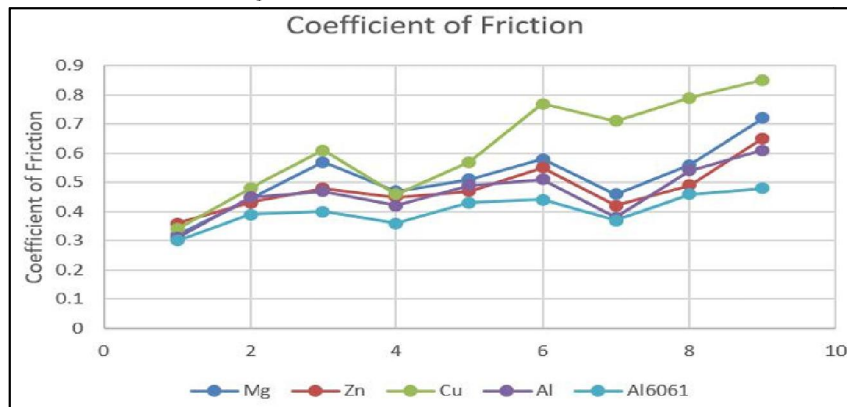


Fig. 6.2 COF of different materials

a) Tensile Strength

The tensile strength and elongation percentages of the Al6061+TiO₂ composites are shown in table 5.5, respectively. In contrast to pure Al6061, which claims a strength of 309 MPa, Al6061+3% TiO₂, Al6061+6% TiO₂, and Al6061+9% TiO₂ report strengths of 315, 333, and 351 MPa, respectively.

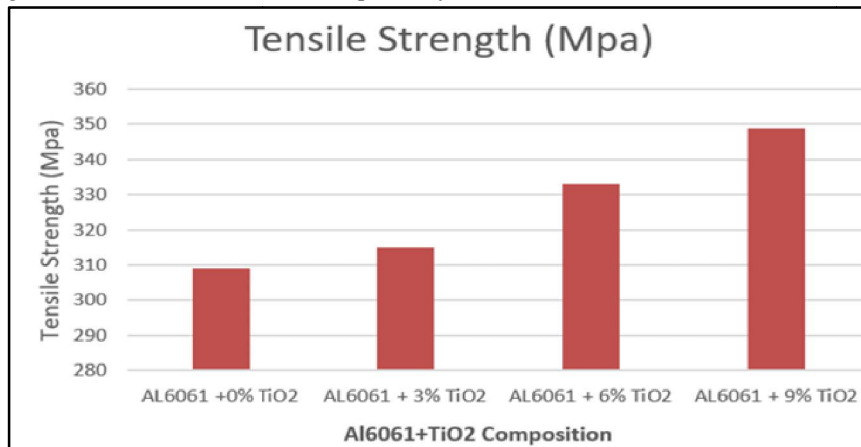


Fig. 6.3 Tensile Strength of TiO₂ Composition

b) Compressive Strength

The compressive strength of Al6061 is 103 MPa, while that of Al6061+3% TiO₂, Al6061+6% TiO₂, and Al6061+9% TiO₂ configurations report compressive strengths of 113, 164, and 193 MPa, respectively.



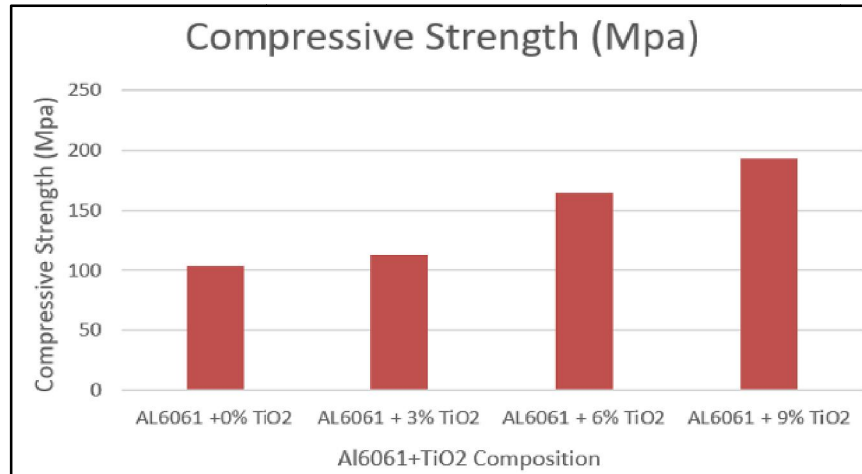


Fig. 6.4 Compressive Strength of TiO2 Composition

c) Hardness (BHN)

It was interestingly found from the testing findings that the composites' hardness steadily increased as the amount of TiO2 increased. AL6061 displays a hardness of 80 BHN. AL6061+3% TiO2, AL6061+6% TiO2, and AL6061+9% TiO2 configurations, respectively, report BHN values of 109, 111, and 125.

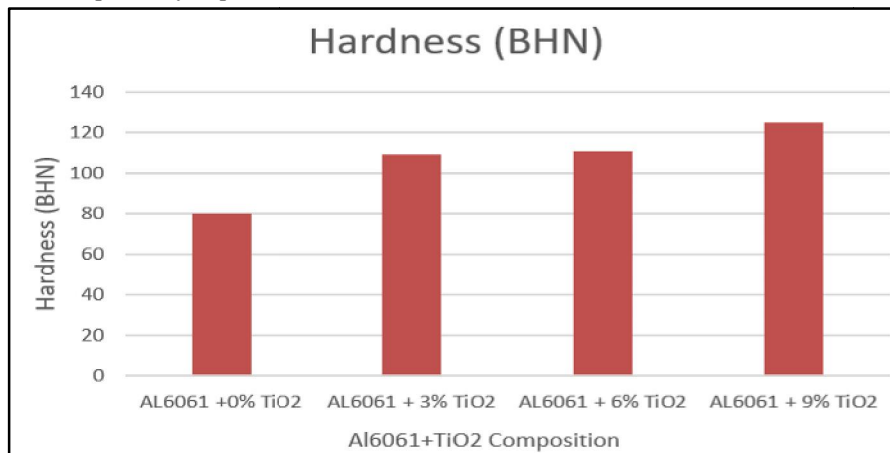


Fig. 6.5 Hardness (BHN) of TiO2 Composition

VII. CONCLUSION

Various tribological and mechanical tests conducted on Al2024+B4C metal matrix composites, along with other brake pad materials, led to the following conclusions.

1. The aluminium alloy (AL2021) reinforced with 6% B4C particulate was manufactured using the powder metallurgy process, demonstrating excellent mechanical and tribological properties.
2. The experimental results for sliding wear and coefficient of friction(COF) of the proposed Al2021+B4C composite show significant improvements compared to existing brake pad materials.
3. Increasing the B4C content from 0% to 9% in the AL2021 alloy enhances its tensile strength by 21%, compressive strength by 27%, and hardness by 38%. However, adding more than 9% B4C results in a noticeable decline in mechanical properties.



4. The composite containing 9% B4C exhibits the highest wear resistance, as well as superior COF, tensile strength, hardness, and compressive strength.

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