Tailored Mechanical and Tribological Response of Al–WC Composites Synthesized Via Powder Metallurgy

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Abstract - This study investigates the mechanical and tribological performance of aluminium tungsten carbide (Al-WC) composites fabricated via the powder metallurgy (P/M) route. Pure aluminium was reinforced with varying weight percentages of micro-sized WC particles (0, 3, and 6 wt.%) to evaluate the effects on hardness, density, and erosion wear resistance. Microstructural analysis revealed a uniform distribution of WC particles and refined grain morphology with increasing reinforcement content. The composites demonstrated a significant improvement in hardness, with values rising from 50 Hv for pure Al to 73 Hv for Al-6WC. Erosion wear testing under different impingement angles and velocities showed that WC addition altered the wear mechanism from ductile to brittle, especially at higher impact angles and velocities. Al-3WC exhibited optimal erosion resistance at intermediate conditions, while Al-6WC showed localized embrittlement and particle-matrix debonding at extreme erosive loads. XRD and EDS analyses confirmed the retention of WC phases and their uniform dispersion within the matrix. The study concludes that WC reinforcements enhance the mechanical strength and erosion resistance of Al-based composites, but excessive content may compromise interfacial integrity. Thus, optimizing WC content is critical for tailoring composite performance in dynamic and abrasive environments.

Keywords : Powder metallurgy; Pure Al-WC composites; Erosion wear; Microstructure; Density; Hardness

1. INTRODUCTION

Over the past few decades, metal matrix composites (MMCs), particularly aluminium matrix composites (AMMCs), have emerged as advanced engineering materials due to their superior mechanical, thermal, and wear-resistant properties achieved through ceramic particle reinforcement. While conventional reinforcements such as SiC, B_4C, and TiC have been widely studied, tungsten carbide (WC) offers exceptional hardness, strength, and abrasion resistance, making it a promising alternative. Powder metallurgy, especially flake powder metallurgy, enables uniform particle distribution and improved interfacial bonding, addressing limitations of liquid-state fabrication routes. Although prior research has extensively explored microstructural, mechanical, and tribological behaviour in various AMMC systems, comprehensive studies on Al–WC composites remain limited. Therefore, the present work focuses on evaluating the microstructure, hardness, mechanical performance, and erosion wear behaviour of WC-reinforced aluminium composites fabricated through powder metallurgy, using pure aluminium as the matrix to minimize porosity and processing complexity.

2. LITERATURE REVIEW

S. no	Author	Year	Main Focus	Key Finding
1	P. Balasundar et al**.**	**2024**	Al–nano TiC composite via microwave powder metallurgy	Improved hardness and wear resistance for lightweight applications.
2	**Guoyun Wen et al.**	**2024**	Cu-based composite with TiB_2/B_4C	Enhanced thermal stability and friction performance for braking systems.
3	**Mayank Chouhn et al.**	**2023**	AA7075/SiC functionally	Higher toughness, hardness, and impact strength for

			graded material	aerospace/defense use.

3. METHODOLOGY

In the present study, aluminum metal matrix composites (AMMCs) reinforced with tungsten carbide (WC) were successfully fabricated using the powder metallurgy technique. Commercially pure aluminum powder (99.5% purity, 15.5 µm) was used as the matrix, while WC powder (13.5 µm) served as reinforcement in 0, 3, and 6 wt.% compositions. Uniform mixing was achieved through planetary ball milling with toluene as a process control agent, followed by compaction at 780 MPa and sintering in an argon atmosphere at 550 °C for 1 hour. Mechanical and erosion characteristics were evaluated using Vickers microhardness testing and air-jet erosion testing based on **ASTM G76**. Density behavior was analyzed through theoretical calculations (rule of mixtures) and experimental measurements using Archimedes' principle. Microstructural and phase characterization were performed using optical microscopy (**Leica Microsystems**), SEM/EDS (**Zeiss**), and XRD, confirming the structural integrity and wear performance of the fabricated composites

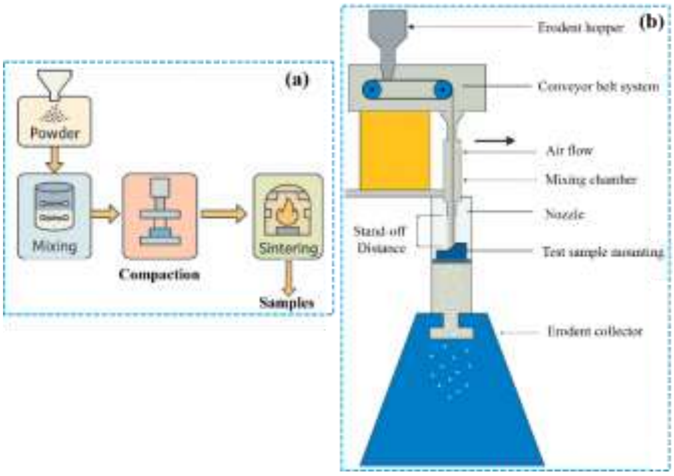

Figure 1. Schematic of **(a)** powder metallurgy process and **(b)** erosion wear tester.

3. CONCLUSIONS

This study demonstrates the controlled mechanical and erosion performance of Al–WC composites fabricated through powder metallurgy with varying WC contents (0, 3, and 6 wt.%). Microstructural analyses confirmed uniform WC distribution and strong interfacial bonding, leading to grain refinement and increased densification, although higher WC levels introduced slight porosity and microcracking. Microhardness improved progressively, reaching 73 Hv for Al-6WC due to dispersion strengthening and dislocation hindrance. Density increased with WC addition but remained marginally below theoretical values because of residual porosity. Erosion resistance was enhanced at lower angles and velocities, while severe conditions caused a ductile-to-brittle wear transition, crack initiation, and reinforcement fragmentation, indicating that WC content significantly governs the wear mechanism and overall durability of the composites.

REFERENCES

1. 1 Sun, H., Saba, F., Fan, G., Tan, Z., & Li, Z. (2025). Strength-ductility synergy in micro-nano reinforced trimodal grained metal matrix composites. *Composites Communications*, 102442.
2. Nosewicz, S., & Jurczak, G. (2025). Role of the interphase zone in the effective mechanical properties and fracture modes of multiphase metal matrix composites at microscale. *Finite Elements in Analysis and Design*, *249*, 104390.
3. Yao, X., Zhang, Z., Zheng, Y. F., Kong, C., Quadir, M. Z., Liang, J. M., & Zhang, D. L. (2017). Effects of SiC nanoparticle content on the microstructure and tensile mechanical properties of ultrafine grained AA6063-SiCnp nanocomposites fabricated by powder metallurgy. *Journal of materials science & technology*, *33*(9), 1023-1030.
4. da Silva, L. R. R., Pereira, A. C., Monteiro, S. N., Kuntoğlu, M., Binali, R., Khan, A. M., & Pimenov, D. Y. (2025). Review of Advances and Challenges in Machining of Metal Matrix Composites. *Journal of Materials Research and Technology*.
5. Cabeza, M., Feijoo, I., Merino, P., Pena, G., Pérez, M. C., Cruz, S., & Rey, P. (2017). Effect of high energy ball milling on the morphology, microstructure and properties of nano-sized TiC particle-reinforced 6005A aluminium alloy matrix composite. *Powder Technology*, *321*, 31-43.

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