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Metal Matrix Composites: Emerging Trends in Microstructure, Performance, and Application-Driven Design

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Abstract: This editorial summarises the Special Issue “Advances in Metal Matrix Composites: Structure, Properties and Applications,” which brings together one review and eight research articles on metal matrix composites (MMCs) formed from diverse matrix and reinforcement combinations, including copper–diamond, aluminium–silicon, aluminium–iron, magnesium–erbium, and tungsten–copper systems. The contributions span thermal conductivity modelling, ultrasonic stir casting, particle dispersion during fabrication, solid-state sintering, controlled thermal expansion alloys, phase stability under heat treatment, and fibre-reinforced composite mechanics, collectively addressing microstructure, mechanical performance, wear behaviour, and thermophysical properties. Findings highlight how reinforcement type, particle or fibre content, processing route, and heat treatment govern hardness, strength, friction, and wear resistance, with applications relevant to automotive, aerospace, electronics, and energy sectors. The issue underscores the breadth of achievable property combinations in MMCs and points to recyclability and sustainable processing as continuing priorities for the field.

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I. INTRODUCTION

Compared to other composites, metal matrix composites (MMCs) have numerous unique properties. These unique qualities are the product of distinct matrix and reinforcing element combinations. The mechanical response, thermophysical property, chemical behavior, electrical property, and wear property of MMCs have received substantial interest. Because qualities can be adjusted to meet specific needs, this development occurred. Wide range of uses in various sectors drove the production of such materials. Automotive, aerospace, electrical, and electronic engineering are among these applications. Recyclability is essential for a sustainable culture. If civilization relies on these minerals, it must solve the difficulty.

The Special Issue "Advances in Metal Matrix Composites: Structure, Properties and Applications" [1] collects the latest research in the subject. These materials are continually changing, therefore there are numerous conceivable combinations. We welcome contributions on material modelling, microstructure characterization, wear testing, and mechanical and thermophysical performance of materials at ambient and elevated temperatures. Articles on MMC sustainability, whether they involve composite or matrix and reinforcement recycling, are required. This rule ensures MMCs are eco-friendly.

II. AN OVERVIEW OF PUBLISHED ARTICLES

A summary and commentary on Special Issue articles are available on this site. These papers are in this Special Issue. This collection comprises metal matrices, reinforcements, a review, and eight research articles. This set has a review. Thus, each composite system has several exciting applications and is well-suited for them. Table 1 highlights key article features.

Chen et al. examined most copper-diamond composite research [2]. Its application demands higher heat conductivity. However, developing a copper-based diamond composite with good thermal conductivity was difficult. Copper matrix was utilized because diamond particles were water-resistant. The copper/diamond interface must be changed to increase wettability. For the reasons above. One can change the copper matrix by coating (alloying) diamond particles or injecting carbon-containing active elements. Both methods work. This study calculates Copper–Based Diamond Composites' thermal conductivity theoretically or using process variables. Both are explored in this paper. Copper-based diamond composites have evolved technologically, says this study. Introduction to copper-based diamond composite thermal conductivity theory. The document includes theoretical calculations. This essay thoroughly discusses interfacial thermal conductivity factors. Analysis in article. Finally, copper and diamond composition difficulties and future study subjects should be examined.

Table 1 List of the Articles Included in this Special Issue.

Article	MMC Matrix	MMC Reinforcement	Investigations
Chen et al. [2]	Copper (Cu)	Diamond particles	Literature review
Ghahremani et al. [3]	Aluminum-silicon (Al-Si)	Silicon oxide nanoparticles (SiO_2np)	Microstructure Wear
Golla et al. [4]	Aluminum-iron (Al-Fe)	Titanium carbide particles (TiCp)	Mechanical properties Wear
Du et al. [5]	Aluminum-silicon (Al-Si)	Silicon carbide particles (SiCp)	Microstructure Transfer efficiency
Hirsch et al. [6]	Aluminum-silicon (Al-Si)	Silicon carbide particles (SiCp)	Mechanical properties Heat treatment
Lewis et al. [7]	Aluminum (Al)	Silicon (Si)	Thermophysical properties
Yin et al. [8]	Magnesium-erbium (Mg-Er)	Nickel and zinc phases (Ni, Zn)	Microstructure Heat treatment
Zhuo et al. [9]	Tungsten-copper (W-Cu)	Tungsten fibers (Wf)	Mechanical properties

Metal matrix nanocomposites were employed by Ghahremani et al. Physical qualities make these materials popular in technology and medicine. Only aluminum-based composites matter in some MMNCs. Few applications suit this pricey metal due to its low wear. Due to low cost. But employing ceramics like carbon allotropes to strengthen aluminium and its alloys could overcome these limitations. This work creates a nanocomposite material from molten aluminium alloy A356 and varying weight percentages of silica (SiO2) nano particles. Ensures desired consequences. Weight percentages are 0.125, 0.175, 0.225, 0.275, 0.375. Ultrasonic power treatment altered material microstructure, hardness, and wear. Heat treatment altered them. Microstructural and XRD analysis of monolithic and composite materials. Wear testing was done on everything. A 1 m/s sliding speed was used to oscillate the load between 60N, 80N, and 100N. Also, sliding distance was raised from 1,000 to 2,000 meters. Wear mechanisms were determined on eroded surfaces. Wear debris and EDS were analysed. Samples with 0.125 weight percent demonstrated 50% lower friction and 68% lower wear. This was noticed during the implementation process. The hardness of 0.125 weight percent samples increased by 52%. Delamination caused little wear, but abrasion caused most.

Golla et al. [4] focused on construction materials. TiC-added Aluminium Matrix Composites are their speciality. Ultrasonic stir casting improved mechanical and tribological properties. In density and hardness (VHN) tests, titanium carbide particles at weight fraction percentages of 0.0, 2.0, 4.0, 6.0, and 8.0 wt% were examined. Wear resistance and ultimate tensile strength (UTS) were assessed by ASTM. The composite's microstructure and elemental phases were examined using FESEM and XRD. Metal matrix composites with 8% TiC reinforcement outperformed the base alloy. Results showed this. The material possesses 32% higher hardness, 68% higher UTS, and 80% higher yield strength than pure aluminium alloy. Each improvement was compared to pure aluminium alloy. The specimens' tensile fracture results showed dimples. The study showed fragility-indicating holes and fissures. These composites were dry-sliding wear tested with a pin-on-disk wear indicator. The testing process included these tests. As TiC particles grew, composite friction decreased. Results confirmed the drop. A composite of six weight percent has one of the lowest friction coefficients, 0.266. The least frictional composite. FESEM and EDXS examined worn pin surfaces. After TiC reinforcement particles were introduced to the matrix alloy, Al-6TiC composites had better wear resistance and friction. This might be the conclusion. This supports the wear test by showing adhesion at lower loads and ploughing at higher loads. More weight causes delamination.

Due to brake disc materials, Du et al. [5] examined lightweight SiC-particle-reinforced aluminium composites. This study examined brake disc materials. For electric cars, these materials may replace cast iron in braking discs. Electric vehicles benefit substantially. This study investigates how SiC particle size and matrix alloy composition effect particle transmission and dispersion. Study seeks this information. Next, a stirring head was used to assess its surroundings and performance using a water model. This assessed stirring head performance. The study examined particle motion and dispersion in molten aluminium systems. The goal was to learn. Thermal pretreatment enhances reinforcing particle wetting. Clustering often happens before reinforcing particles enter the melt. Reinforcing particle soaking has improved. Early clustering always affects particle dispersion and transfer efficiency. This applies regardless of transfer. Particle contact with the melt's oxide skin on top is also important for both qualities. The study indicated that particle size and matrix alloy chemical composition affect transfer efficiency. This was discovered. This discovery was significant. Rare earth elements (RE) in the matrix alloy influenced particle dispersion and clustering of smaller particles. Additional agents from RE. Smaller particles clustered well. To swiftly break clusters, carbides must be introduced to the melt with appropriate stirring. Cluster meltdown has begun. A precise action is needed to achieve the goal.

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Hirsch et al. [6] explore cast aluminium powder solid-state sintering. Every feature has its own traits. Considerations for these qualities are numerous. These include RHS and spark plasma (field-assisted) sintering, which yield exceedingly thin bulk material microstructures. Two microsintering methods. This produces higher-performance material qualities like strength and ductility during manufacture than typical alloy processes. This work studied the mechanical properties of RHS-sintered age-hard enable A357 (AlSi7Mg0.6) cast alloy and SiCp/A357: aluminium matrix composite. This examined alloy mechanical characteristics. For tribological applications requiring high strength and good wear behaviour, the AMC was reoriented. Due to these benefits. This was for exceptional performance.

The asphalt mixture contains 35% coarse particles (d50 = 21 µm). It was done to succeed. The effects and synergy of heat treatment and particle reinforcement in compression at room temperature and 350 degrees Celsius were studied. Compare and comparison were done. When evaluated independently, high particle count strengthened approximately half as much as precipitation hardening. When effects were calculated, this appeared. Precipitation hardened ambient-temperature crushed particles. Compressive deformation at high temperatures caused simultaneous recrystallisation, precipitation, and temperature-activated recovery. Recovery mechanisms existed. When these processes began, material conditions affected their occurrence and interaction. Thermal deformation rearranges SiC reinforcement particles. This reorganisation evenly dispersed reinforcement throughout the dispersion and scarcely fractured particles. These materials strengthen secondary thermo-mechanical AMCs.

Lewis et al. [7] explore novel technologies and lightweight materials to handle component coefficient of thermal expansion (CTE) mismatch-induced heat load and interfacial stresses. This is due to global decarbonisation and increased electronics package power densities. The writers like the researchers' novel approaches and lightweight materials. Aluminium and silicon sound intriguing.

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Features include strong heat conductivity, lightweight construction, and CTE compliance. These materials could help the aerospace, automotive, electric vehicle, consumer electronics, military, and space industries. Thermal management is considered when these sectors design goods. This study describes the high-performance hypereutectic Al–Si AyontEXTM alloy family. These alloys were made via powder metallurgy. The alloys in question are particularly reliable due to their high thermal conductivity (CTE) of 17 µm/(m·◦C) during thermal cycling. Their contact temperature (CTE) is 13 µm/(m·◦C) under thermal and mechanical stress, indicating remarkable thermal and mechanical stability. This alloy is employed in structural heat sinks, reflecting optics, and instruments. Below are key performance connections between Al–Si alloy microstructure, physical properties, and mechanical properties..

Nickel (Ni) and zinc (Zn) affect the development of long-period stacking ordered (LPSO) phases and their structure and thermal stability in Mg97Er2Ni1 and Mg97Er2Zn1 alloys, according to Yin and colleagues [8]. Researchers wanted to discover how transition metals affect LPSO phase formation. Both alloys have α-Mg and LPSO phases in their as-cast form. It's in both alloys. A twenty-hour heat treatment at 540 ◦C dissolves the block-shaped and lamellar LPSO phases in the α-Mg matrix. Reprecipitation of lamellar LPSO phases occurs in Mg97Er2Zn1 alloy after lowering temperature from 540 ◦C to 400 ◦C and cooling. Nickel affects LPSO phase thermal stability more than zinc, according to the comparison. Because nickel matters. Zinc presence causes LPSO to develop a pin-like lamellar structure in the α-Mg matrix. Nickel prevents LPSO. The Mg97Er2Ni1 alloy's LPSO phase has a high melting temperature of 605 ◦C. The scientific literature lists this as the highest LPSO phase temperature. Maintaining the LPSO phase area fraction in Mg97Er2Ni1 alloy requires a 100-hour heat treatment at 500 ◦C without deviations. LPSO grains form 18R-type crystals without phase dissolution or allotropic structural change after 100 hours at 540 degrees Celsius. Transition metal elements regulate LPSO phase stability and form, as revealed by these findings. These results suggest a way to change LPSO phase morphology in magnesium-based alloys. These results suggest this approach.

Zhuo et al. [9] examine toughened tungsten–copper composites. Due to its full properties, tungsten–copper (W-Cu) composites with tungsten fibre (Wf) are used in electronic packaging. However, the links between fibre concentration, aspect ratio, and orientation and material mechanical performance are unknown. The numerical simulation and experimental studies were utilised to develop a three-dimensional microstructural mechanism model and investigate Wf/W-Cu composites' tensile properties and mechanism. Data shows the fibre aspect ratio essential value is 7.6. This fibre data was found. Fibre tensile fracture produces failures above this value, while fibre pullout causes failures below. From 1% to 6% fibre concentration enhances composite material tensile and yield strength by 9.6% and 10.2%, respectively. Because composites contain more fibre. Fracture reduces elongation 18.6%. The difference is big. Fibre orientation angles can be changed from 0 to 90 degrees to change characteristics. Toughness, like strength, ranges from 0 to 90 degrees. Short fibre interface toughening involves pullout, deflection, and fracture bridging. These are interface-related steps. Long-fiber composites are strengthened and prolonged by load transmission and fibre bridging. The damage multiplication mechanism governs multiscale mechanical behaviour based on fibre properties. Damaged fibres do this. Innovative high-performance fibre composites and extreme-condition technical applications will result from the research. These new concepts will optimise Wf/W-Cu composite composition and structure.

III. SUMMARY

This Special Issue "Advances in Metal Matrix Composites: Structure, Properties and Applications" features research and review articles related to metal matrix composites. A variety of matrix materials can be combined with reinforcements, creating unique and tailored properties which make the materials particularly attractive products. Here, the authors of the review article and eight research articles that form this Special Issue do effectively capture this diversity of possibilities, in exploring various combinations of metal matrices and reinforcements. So each article highlights various kinds of application and/or industry fields in which the particular composite system is well suited to and of interest to us.

L.L. and A.J. as Guest Editors of this Special Issue (SI) "Advances in Metal Matrix Composites: Structure, Properties and Applications" would like to express their deep appreciation to all the authors who provide valuable work for publication in the current SI and to all the anonymous reviewers who contribute their professional views for peer evaluation process.

➢ *Conflicts of Interest:*

The authors declare that they have no conflicts of interest.

IV. CONCLUSION

Taken together, the nine contributions confirm that the performance of metal matrix composites is governed jointly by reinforcement selection, processing route, and post-processing heat treatment, rather than by any single factor in isolation. The reviewed systems demonstrate that tailored combinations of matrix and reinforcement can simultaneously improve strength, wear resistance, and thermal management, supporting continued adoption across automotive, aerospace, electronics, and energy applications. Future work in the field should keep sustainability and recyclability central to processing decisions as these materials move further into industrial use.

REFERENCES

[1]. Crystals|Special Issue: Advances in Metal Matrix Composites: Structure, Properties and Applications. Available online: https://www.mdpi.com/journal/crystals/special_issues/XVXRA49BMD (accessed on 8 May 2025).

[2]. Chen, K.; Leng, X.; Zhao, R.; Kang, Y.; Chen, H. Progress in the Copper-Based Diamond Composites for Thermal Conductivity Applications. *Crystals* 2023, *13*, 906.

[3]. Ghahremani, A.; Abdullah, A.; Fallahi Arezoodar, A.; Gupta, M. An Investigation on the Enhanced Wear Behavior of Ultrasonically Stirred Cast A356/SiO_2np Nano-Composites. *Crystals* 2023, *13*, 722.

[4]. Golla, C.B.; Babar Pasha, M.; Rao, R.N.; Ismail, S.; Gupta, M. Influence of TiC Particles on Mechanical and Tribological Characteristics of Advanced Aluminium Matrix Composites Fabricated through Ultrasonic-Assisted Stir Casting. *Crystals* 2023, *13*, 1360.

[5]. Du, A.; Lattanzi, L.; Jarfors, A.E.W.; Zheng, J.; Wang, K.; Yu, G. On the Efficient Particle Dispersion and Transfer in the Fabrication of SiC-Particle-Reinforced Aluminum Matrix Composite. *Crystals* 2023, *13*, 1621.

[6]. Hirsch, S.J.; Berndt, N.; Grund, T.; Lampke, T. Combined Effect of Particle Reinforcement and T6 Heat Treatment on the Compressive Deformation Behavior of an A357 Aluminum Alloy at Room Temperature and at 350 °C. *Crystals* 2024, *14*, 317.

[7]. Lewis, P.; Tarrant, A.; Frehn, A.; Grensing, F.; Nicholson, J.; Farrah, N.; Acreman, M. Aluminium-Silicon Lightweight Thermal Management Alloys with Controlled Thermal Expansion. *Crystals* 2024, *14*, 455.

[8]. Yin, J.; Liu, Y.; Zhu, G.Z. Microstructural Evolution and Thermal Stability of Long Period Stacking Ordered Phases in $Mg_{97}Er_2Ni_1$ and Mg97Er2Zn1 Alloys. *Crystals* 2024, *14*, 1092.

[9]. Zhuo, L.; Xie, Y.; Xu, H.; Luo, B.; Liu, N.; Chen, B.; Wang, H. Multi-Scale Numerical Simulation of Short Tungsten Fiber Reinforced Tungsten–Copper Composites: Influence Mechanisms of Fiber Parameters. *Crystals* 2025, *15*, 209.