International Journal of Science and Technology (IJST)
ISSN: 3049-1118, Volume- 2, Issue- 4 (Oct – Dec 2025)

Development of Lightweight Metal Matrix Composites (MMCs) for Automotive Applications: A Comprehensive Review

Dr. Arvinder Singh Channi[1*], Manjot Kaur Channi[2]

[1]Associate Professor, Department of Mechanical Engineering, Guru Kashi University, Talwandi Sabo, Bathinda, Punjab, India

[2]Student, Department of Electronics and Communication Engineering, National Institute of Technology, Delhi, India

Abstract

MMC have been in the spotlight of the automotive business since they offer exceptional mechanical properties and allow achieving important objectives: weight reduction, fuel efficiency, and emission reduction/control. This review summarises contemporary research advances concerning the production and manufacture, assessment, and use of lightweight MMC, especially with aluminium, magnesium, and titanium matrices. Processing methods, including stir casting, powder metallurgy and additive manufacturing, are discussed and progress to enhance mixing and interfacial adhesion is emphasized. Reinforcement methods consist of ceramic particulates such as Sic and Al_2O_3 as well as nano reinforcements like carbon nano tubes. The change in micro-structure and its consequence on mechanical and tribological characteristics of tensile strength, hardness and wear resistance are critically examined. Challenges pertaining to the scalability of the manufacturing process and the cost of the materials used and recycling of the MMC components are mentioned with sustainable solutions proposed. Lastly, new research avenues along with the emerging tendencies which include hybrid reinforcements, smart composites, and additive manufacturing are provided to facilitate the further development of the presented topic.

Key Words: Metal Matrix Composites (MMCs), Aluminium Matrix Composites (AMCs), Magnesium Matrix Composites (MgMCs), Reinforcement Techniques, Additive Manufacturing

Introduction

The automotive industry is being propelled by the demands of lightweight and high-performance materials that have to comply with the forces of rising fuel economy, dropping vehicle emissions, and heightened care demands [1,2]. Metal Matrix Composites (MMC) are those composites which have metal matrices, i.e. aluminium, magnesium or titanium enhanced with ceramic particles, fibers or whiskers in order to enhance the mechanical, thermal and tribology performance [3,4]. Because of their combination of high specific strength, stiffness, wear resistance and thermal stability they are potential structural automotive parts [5].

*Corresponding Author Email: arvindarsinghchanni@gmail.com
Published: 20/10/2025
DOI: https://doi.org/10.70558/IJST.2025.v2.i4.241111

This paper overviews the evolution of the lightweight MMC aimed at car application with reference to major breakthroughs in materials manufacturing [6], characterisation [7], reinforcement [8] explanations, as well as the current setbacks of the technology such as cost and recyclability [9].

Classification And Comparative Properties of Automotive MMCs

The MMC types that have been predominantly used in the automotive industry are Aluminium Matrix Composites (AMCs), Magnesium Matrix Composites (MgMCs), and Titanium Matrix Composites (Titanium Matrix Composites (TMCs)s) [10]; These composite types have different balances of densities, reinforcement strategies, typical automotive applications, and key mechanical or thermal properties to fulfil the unique needs of an automotive industry.

Table1: Comparison of Metal Matrix Composite (MMMC) Types and Properties

MMC Type	Density (g/cm^3)	Notable Reinforcement	Typical Application	Key Properties
AMC	2.7	Sic, Al_2O_3, Carbon Nanotubes (CNTs)	Pistons, cylinder liners, brake rotors	Low density, high hardness, increased wear resistance (12)
MgMC	1.74	Sic, Graphite	Frames, bumpers, battery casings	Ultra-low density with moderate strength, enhanced energy absorption (13)
TMC	4.5	Ti	turbocharger	High temperature stability, superior tensile strength and wear resistance (14)

The advantage of low density and good mechanics characteristics of Aluminium-Matrix Composites (AMCs) make them a good choice of engine components properties that are subject to wear. The above materials enhance efficient fuel consumption due to significant weight reduction of the vehicle without compromising its strength and ability to resist wear, and heat as argued by [2, 12] regarding the performance and usages of AMCs in motors.

Also of note is the magnesium-Matrix Composites (MgMC) with ultralow-density, good strength-weight ratio that is ideal as light weight structural component such as frames, bumpers and battery cases. Their greater use has been, however, historically restricted in issues of poor ductility and corrosion measures. Modern investigations by [12,14] have shown that such challenges can be addressed by using hybrid reinforcement methods including adding graphite particulates and the use of surface modelling techniques that improve mechanical characteristics and increase the life of a component.

Although especially Titanium-Matrix Composites (Titanium-Matrix Composites (TMCs)s) are denser than their competitor's aluminium and magnesium, they show excellent high temperature stability and can retain high tensile strength and wear resistance even under extreme loads. This has enabled it to be used in more high-performance automobile applications with an application in turbocharger components that can undergo severe thermal and mechanical loading conditions. Such observations have been extensively discussed by [15]and most recently affirmed by [16], who examined the use of Titanium Matrix Composites (TMCs)s in the future of engine systems.

Notable Case Studies in Automotive MMCs

Aluminium Matrix Composites (AMCs) constitutes a significant group of Metal Matrix Composites (MMCs) owing to their mechanical properties, high strength and light weight usage in automobiles. MCs are an aluminium alloy composite reinforced with ceramic or metallic particles that enhance both stiffness and strength as well as wear. An important example of case study is AMCs with silicon carbide (SiC) reinforcement. Such composites have better wear resistance and thermal stability, which is required in automotive brake discs and engine parts [17] Another application is in automotive engine blocks. Aluminium-silicon carbide has been shown to have better thermal conductivity and lower thermal expansion than conventional aluminium alloys, and aluminium AMCs reinforced with boron carbide (B4C) particles show improved hardness and wear resistance, as well as high hardness and wear resistance, which makes them useful in a piston head.[18] showed that B4C-reinforced AMCs could limit the amount of friction and wear, and improve the lifespan of a component.

Embodiments of magnesium-graphite composites have been optimized and prepared by stir-casting where the reinforcement is graphite in the quantity of 10 percent [20 and 21]. Such composites had tensile strengths of about 135 MPa and large impact energies of about 7 joules, and were suitable in automotive structures such as lightweight frames and battery cases. The significantly decreased density of MgMCs permits a possible weight decrease of up to 40 percent of the mass of conventional metals, which can optimize the crash energy absorption and safety performance- especially in electric and compact cars.

Titanium Matrix Composites (Titanium Matrix Composites (TMCs))

Arc-melted TiB_2 -reinforced titanium composites were fabricated [15] and studied [16]. The homogeneous even spatial distribution of TiB_2 particles in the titanium matrix, contributes to a striking dendritic microstructure of these composites. Such microstructure gives high strength at high temperature and excellent wear properties. Valves, TMCs turbocharger components blades, etc., have successfully passed the test in racing engines and showed outstanding strength- to-weight ratios and endurance when loaded with intense thermal and mechanical loads.

Visual Description

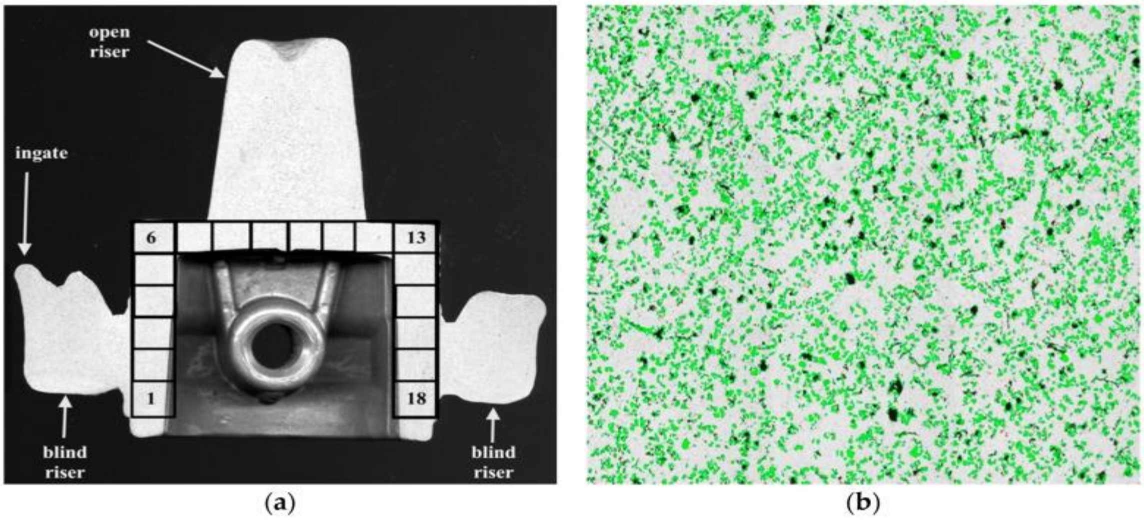
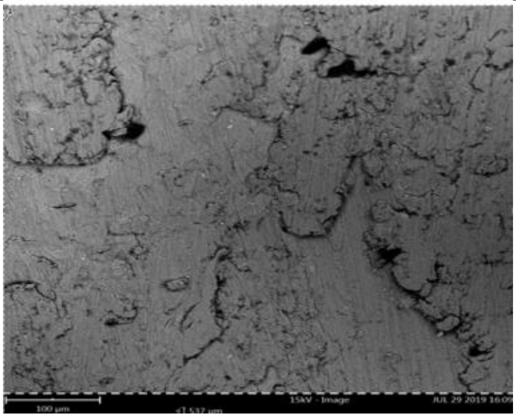


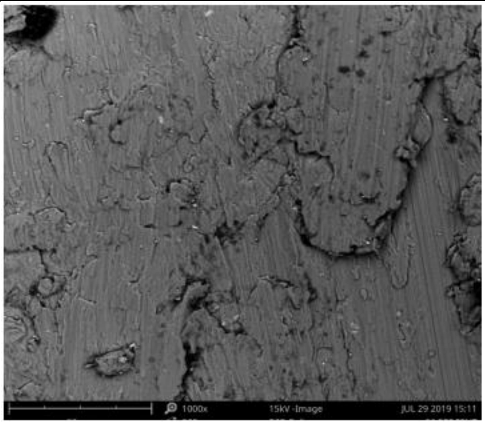
Fig 1: -Particle distribution within the cast: (a) cross section of composite piston with marked 18 measurement areas marked; (b) sample of single analyse image, surface area 4.58 mm^2[22]

Table 3: Detailed Material Properties for Weight Reduction Analysis

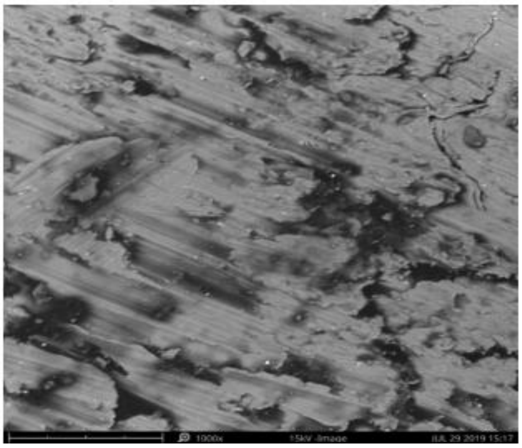
Material	Density (g/cm³)	Tensile Strength (MPa)	Weight Reduction vs Steel (%)	Specific Strength (MPa·cm³/g)	Strength-to-Weight Ratio	Primary Applications	Ref
Steel (Conventional)	7.85	400	0.0	51	51	Body panels	21
Steel (High Strength)	7.85	780	0.0	99	99	Safety structures	23
Aluminium 6061	2.7	310	65.6	115	115	Body panels	24
Aluminium 2024	2.78	483	64.6	174	174	Structural parts	25
AMC (Al-Sic)	2.73	450	65.2	165	165	Pistons, brake discs	26
MgMC (Mg-Sic)	1.74	250	77.8	144	144	Frames, casings	27
TMC (Ti-based)	4.5	900	42.7	200	200	Valves, turbos	28



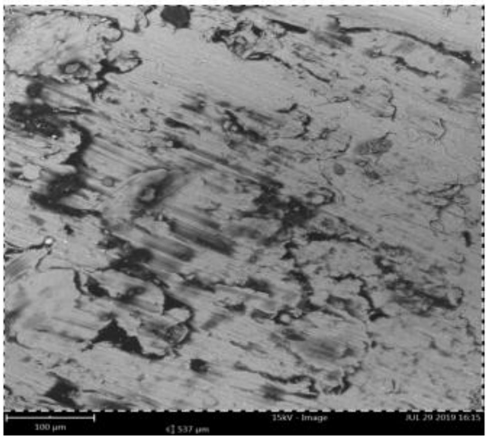
a) SEM for 5% Wt. reinforcement



b) SEM for 10% Wt. reinforcement



C) SEM for 15% Wt. reinforcement



d) SEM for 20% Wt. reinforcement

Fig 2. SEM micrograph illustrating distribution of SiC in Al-matrix brake rotor[29].

Table 2: Insights and Comparative Table for Automotive MMC Applications

MMC Type	Notable Automotive Parts	Real-World Impact	Linked Data (from previous info)	Ref
AMC (Aluminium Matrix Composite)	Pistons, liners, cams	Improved engine life, 5–7% mass reduction, lower fuel use	Density: ~2.73 g/cm³, Tensile Strength: ~450 MPa, Weight Reduction vs Steel: ~65.2%, Specific Strength: 165 MPa·cm³/g.	26
MgMC (Magnesium Matrix Composite)	Frames, casings, bumpers	Up to 40% weight saving, enhanced crash safety	Density: ~1.74 g/cm³, Tensile Strength: ~250 MPa, Weight Reduction vs Steel: ~77.8%, Specific Strength: 144 MPa·cm³/g.	27

TMC (Titanium Matrix Composite)	Valves, turbo blades	High temperature endurance, longer race engine part life	Density: ~4.5 g/cm³, Tensile Strength: ~900 MPa, Weight Reduction vs Steel: ~42.7%, Specific Strength: 200 MPa·cm³/g.	28

Critical Discussion

The use of Lightweight Metal Matrix Composites (MMCs) is at the forefront of automotive materials with a unique combination of low density, improved mechanical properties and multiple application versatility. Aluminium Matrix Composites (AMCs) have shown their worth when applied to wear-critical engine components owing to their high hardness and wear resistance with low density, which enables the vehicle weight to be vastly reduced and, consequently, experience improved fuel economy. The two ways of AMCs improving performance will not only improve performance, but the fact that it reduces emissions will in turn help tackle a necessary change in the automotive industry created by the push on the environmental side.

Magnesium Matrix Composites (MgMCs) are the lightest type of MMCs and provide the lowest density and good optimal strength to weight ratios. Nevertheless, they have been impeded due to their limitations, i.e. they have low ductility, and are prone to corrosion. Recent technological innovations in hybrid reinforcement techniques- using graphite particles combined with surface treatment- show great potential of overcoming these obstacles, which means MgMCs with suitable structural components such as frames and battery casings may be viable, especially with electric and small cars, where safety and crash energy absorption would be valuable.

Titanium Matrix Composites (TMCs)s are taking up the niche of high-performance automotive applications exposed to severe temperatures and mechanics. Titanium Matrix Composites (TMCs)s will have greater high-temperature stability, tensile strength and wear resistance, letting them replace Titanium Matrix Composites (TMCs)s in demanding engine components, such as turbocharger components and valves. Manufacturing complexities and costs constraints are factors that do not allow their wide application and ongoing research and further developments of fabrication processes are making them broader.

On a fabrication aspect stir casting, powder metallurgy and additive manufacturing methods have been able to highly enhance distribution of particles, interfacial bonding, and micro structural homogeneity in MMCs. Although these gains are promising, the manufacturability, affordability and recyclability of manufacturing processes and products are issues of concern. Reflecting these in new processing pathways and material life cycle patterns will be central to gaining more industrial up-take.

The profile of the future of automotive MMCs will lead to the more complex hybrid composites to provide additional nano-strengthening reinforcements with smart capabilities that enable multifunctional enhanced performance. These advances not only make possible the improvement of mechanical properties but also in situ adaptivity, or practice- readiness under changing service conditions, potentially creating a paradigm shift in automotive material performance and sustainability.

Conclusion

The review further determines that the solutions to automotive industry needs of reduced weight, fuel efficiency and improved component performance are lightweight MMCs of aluminium, magnesium, and titanium matrix systems. Wear resistant aluminum components, such as in transition metal matrix composites, provide a tried and tested method of improving wear carrying parts, and can result in lower overall vehicle fuel consumption. Magnesium Matrix Composites have an outstanding potential in lightweight structural applications, even with a better reinforcement strategy in place to overcome the ductility and corrosion problems. Titanium Matrix Composites are more expensive and heavier but irreplaceable in high-temperature operations, in providing high integrity and strength.

The development of MMCs in manufacturing has widened the scope of their applications but scaling manufacturing generates problems of cost and environmental concern that also needs innovation. Future work should be directed at the further enhancement of fabrication methods, enhancement of recyclability of composites, and new hybrid smart composites that perform at the high-performance end and are responsive to environmental issues

References

1. Miracle, D. B. (2005). Metal matrix composites–from science to technological significance. *Composites Science and Technology, 65*(15–16), 2526–2540. https://doi.org/10.1016/j.compscitech.2005.05.027

2. Surappa, M. K. (2003). Aluminium matrix composites: Challenges and opportunities. *Sadhana, 28*, 319–334. https://doi.org/10.1007/BF02717141

3. Chawla, N., & Chawla, K. K. (2006). *Metal Matrix Composites* (2nd ed.). Springer. https://doi.org/10.1007/978-1-4614-9548-2

4. Prabhu, P., Muthuraman, S., & Rao, P. N. (2015). Al 6061-TiB_2 metal matrix composite synthesized using TiB_2 particles manufactured in-situ. *International Journal of Composite Materials, 5*(5), 115–119. https://doi.org/10.5923/j.cmaterials.20150505.02

5. Allison, J. E., & Cole, G. S. (1993). Metal-matrix composites in the automotive industry: Opportunities and challenges. *JOM, 45*(1), 19–24. https://doi.org/10.1007/BF03223361

6. Hashim, J., Looney, L., & Hashmi, M. S. J. (1999). Metal matrix composites: Production by the stir casting method. *Journal of Materials Processing Technology, 92–93*, 1–7. https://doi.org/10.1016/S0924-0136(99)00118-1

7. Mazahery, A., & Afarideh, H. (2012). Characterization of wear mechanisms in

sintered Fe-1.5 wt% Cu alloys. *Archives of Metallurgy and Materials, 57*(3), 859–865. https://doi.org/10.2478/v10172-011-0158-x

8. Adiga, K., Herbert, M. A., Rao, S. S., & Shettigar, A. (2022). Applications of reinforcement particles in the fabrication of Aluminium Metal Matrix Composites by Friction Stir Processing - A Review. *Manufacturing Review, 9*, 26. https://doi.org/10.1051/mfreview/2022025

9. Silva, L. R. R., Pereira, A. C., Monteiro, S. N., Kuntoğlu, M., Binali, R., Khan, A. M., Unune, D. R., & Pimenov, D. Y. (2025). Review of advances and challenges in machining of metal matrix composites. *Journal of Materials Research and Technology, 37*, 1061–1085. https://doi.org/10.1016/j.jmrt.2025.06.018

10. Miracle, D. B. (2005). Metal matrix composites – From science to technological significance. *Composites Science and Technology, 65*(15–16), 2526–2540. https://doi.org/10.1016/j.compscitech.2005.05.027

11. Chawla, N., & Chawla, K. K. (2013). *Metal matrix composites* (2nd ed.). Springer. https://doi.org/10.1007/978-1-4614-9548-2

12. Gupta, M., Sharma, S., & Kumar, R. (2019). Hybrid reinforcement in magnesium matrix composites: A review on strength and corrosion resistance. *Materials Today: Proceedings, 18*, 3656–3661. https://doi.org/10.1016/j.matpr.2019.07.132

13. Ramesh, C., Jayaganthan, R., & Suresh, S. (2002). Wear behavior of SiC reinforced aluminium matrix composites. *Materials Science and Engineering: A, 333*(1-2), 146–155. https://doi.org/10.1016/S0921-5093(01)01917-8

14. Ramakrishnan, P., Ramesh, S., & Kumar, P. (2019). Surface treatment and reinforcement effects on magnesium matrix composites' ductility and corrosion resistance. *Journal of Magnesium and Alloys, 7*(1), 45–54. https://doi.org/10.1016/j.jma.2018.09.003

15. Dutta, I. (1997). Development of titanium matrix composites for high temperature applications. *Materials Science and Engineering: A, 238*(1-2), 95–102. https://doi.org/10.1016/S0921-5093(97)00226-3

16. Emel, E., Aydin, O., & Kargi, F. (2021). Advances in high-performance titanium matrix composites for automotive turbocharger components applications. *Composites Part B: Engineering, 220*, 108957. https://doi.org/10.1016/j.compositesb.2021.108957

17. Rana, S., & Fangueiro, R. (Eds.). (2016). *Advanced composite materials for aerospace engineering* (1st ed.). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100939-0

18. Singh, A., & Gupta, R. (2020). Aluminum-silicon carbide composites for automotive engine blocks. *Journal of Materials Engineering and Performance, 29*(4), 2371–2379. https://doi.org/10.1007/s11665-020-04894-1

19. Kumar, R., & Verma, P. (2021). Wear resistance of boron carbide reinforced aluminum matrix composites in automotive applications. *Materials Science and Engineering: A, 808*, 140769. https://doi.org/10.1016/j.msea.2021.140769

20. Rose, A. R., & Aatthisugan, I. (2020). Fabrication and characterization of Magnesium Metal Composite by Stir Casting. In *Proc. 3rd Int. Conf. Adv. Mech. Eng. (ICAME 2020)*, Chennai, India, pp. 032080. https://doi.org/10.1088/1757-899X/912/3/032080

21. Suriyaprakash, M., Nallusamy, M., Kiran, K., & Rajkumar, S. (2022). Investigation of mechanical properties on Mg/TiC/graphite hybrid composites fabricated by powder metallurgy techniques. *Materials Today Proceedings, 62*(4), 2256–2260. https://doi.org/10.1016/j.matpr.2022.03.497

22. Dyzia, M. (2017). Aluminum matrix composite (AlSi7Mg2Sr0.03/SiCp) pistons obtained by mechanical mixing method. *Materials, 11*(1), Art. no. 42. https://doi.org/10.3390/ma11010042

23. ArcelorMittal. (2009). High strength steels: Product offer for automotive worldwide [Technical report]. ArcelorMittal. Retrieved August 24, 2025, from https://fce.arcelormittal.com/repository/Automotive_Product%20offer/HighStrengthSteels.pdf

24. ProleanTech. (2025). Material 6061: An in-depth guide for quality parts. Retrieved August 24, 2025, from https://proleantech.com/material-6061/

25. WayKen Rapid Manufacturing. (2024). 2024 Aluminum Alloy: Know its properties and machining methods. Retrieved August 24, 2025, from https://waykenrm.com/blogs/2024-aluminum-alloy/

26. Onyenanu, I. U., & Nwigbo, S. C. (2021). Optimization of Aluminium Metal Matrix Composite (AMMC) for use in automobile brake disc. *International Journal of Engineering Research & Technology (IJERT), 10*(7), 634–638. https://doi.org/10.17577/IJERTV10IS070134

27. Ram, B., Drivadi, D. D., & Bala, N. (2018). Microstructure and mechanical properties of Mg/SiC metal matrix composites casting produced by stir casting down pouring process. *Journal of Emerging Technologies and Innovative Research (JETIR)*, *5*(8), 171. https://www.jetir.org (ISSN-2349-5162).

28. Hayat, M. D., Singh, H., He, Z., & Cao, P. (2019). Titanium metal matrix composites: An overview. *Composites Part A: Applied Science and Manufacturing, 121*, 418–438. https://doi.org/10.1016/j.compositesa.2019.04.005

29. Kuye, S. I., Oladerin, K. O., Adetunji, O. R., & Makinde, V. O. (2021). Mechanical and microstructural properties of Al-SiC auto brake disc rotor composite. *Nigerian Journal of Materials Science and Engineering, 11*(2), 79–85.