

# Mechanical Behaviour of TiO<sub>2</sub> and Graphene Nanoplatelets Reinforced ZE42 Magnesium Alloy Hybrid Composites: A Short Review

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**Abstract:** These key attributes including high specific strength, low density and good manufacturability properties make magnesium alloys (e.g. ZE42 (Mg–Zn–Zr)) appealing as high performance materials for applications in the aerospace and automotive industry directed towards lightweight structures. Consequently, TiO<sub>2</sub> nanoparticles & Graphene Nanoplatelets (GNP) have been widely incorporated as hybrid reinforcement within metal alloys to improve their mechanical properties through the mechanism of grain refinement, and load transfer mechanisms. The review provides a short overview of the new investigations carried out on TiO<sub>2</sub> and GNP reinforced with ZE42 Mg composites by covering all aspects associated with fabrication methods, microstructural development, strengthening mechanisms, mechanical performance as well as knowledge gaps for further research.

**Keywords:** ZE42 magnesium alloy; Titanium dioxide (TiO<sub>2</sub>); GNP; Hybrid composites; Mechanical behavior

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## Introduction

Magnesium alloys have been investigated as the next generation structural materials for automotive, aerospace and portable electronics applications due to their high specific strength with low density in comparison to aluminum or steel alloys and good damping capacity and recyclability. However, their extensive engineering applications may still be hindered by some intrinsic disadvantages like the low ductility, insufficient wear resistance and relatively inferior high-temperature strength [1,2]. Considering these limitations, magnesium alloys (ex. ZE42 (Mg-Zn-Zr)) have been implemented as matrices in hybrid matrix composites (MMCs) reinforced with ceramic and nanocarbon reinforcements, which disproves the lightweight advanced properties along with improved mechanical factors [6].

Considering these constraints, magnesium alloys such as ZE42 (Mg-Zn-Zr) has been used as matrices for the hybrid metal matrix composites (MMCs) reinforced with both ceramic and nanocarbon reinforcements that have been also invalidated lightweight high performance in parallel poor mechanical properties [6]. In terms of reinforcement strategies, it has been shown that the addition of titanium dioxide (TiO<sub>2</sub>) nanoparticles as dispersoids has benefits regarding high hardness and thermochemical stability, while also potentially behaving as effective stress concentrators able to provide an increased deterrent for dislocation motion enhancing therefore strength/stiffness [3-5]. TiO<sub>2</sub> has also been added extensively to various magnesium alloy systems (e.g., AZ91, AZ31), and it contributes significantly to grain

refinement as well as load transfer strengthening mechanisms that have led to significant improvements in hardness, compressive strength and wear resistance [6,7] for Mg–TiO<sub>2</sub> composites prepared via casting or powder metallurgical processes. TiO<sub>2</sub>-nanoparticle reinforced Mg nanocomposites with controlled homogeneous particle distribution fabricated by optimized powder metallurgy exhibit most favorable mechanical properties such as compressive strength can be increased due to Hall–Petch and Orowan strengthening [7, 8]. Simultaneously, carbon-based nanomaterials (e.g., graphene and its derivatives) are also emerging as outstanding reinforcing agents. Due to its high intrinsic tensile strength and Young's modulus, graphene can effectively enhance the mechanical properties when widely distributed within a metal matrix. Low contents of graphene have been observed to improve hardness and compressive strength in Mg composites with the help of mechanisms such as grain refinement and effective load transfer [9,10]. However, this approach is technically difficult because graphene tends to agglomerate and obtain homogeneous graphene by spreading strong interfacial bonding with the Mg matrix.

Therefore, the research and development of hybrid reinforcement systems which introduce a combination of TiO<sub>2</sub> with GNP were initiated with an expectation to complement the merits of hard ceramic particles and excellent mechanical performance from nanocarbon sheets. Specifically, previous studies on hybrid composites of similar nature in different Mg alloy systems (for example AZ91/TiO<sub>2</sub>/graphene) have reported the ability of these combinations to increase hardness, tensile strength and wear resistance compared to both alloys without reinforcement as well as single-phase reinforcement-based composites [1,11]. This addition leads to grain refinement, more effective load transfer and impressive interface strengthening between the matrix and reinforcements. While comprehensive research has been done on Mg-based hybrid composites with different reinforcement combinations, considerable efforts targeting TiO<sub>2</sub> and graphene as the hybrid reinforcements in ZE42 magnesium alloy are still underway. The novel engine application will yield the alloy (i.e., ZE42) to have Zn/Zr content which generates a unique baseline microstructure that interacts differently with the reinforcements compared to those systems such as standard AZ31/AZ91. Understanding the combined play of TiO<sub>2</sub> and graphene in regulating the mechanical behavior like tensile properties, fracture mechanisms, microstructural development and deformation features of ZE42 is crucial for enhancing these hybrid composites for deployment in structural applications.

This paper provides a short review of the mechanical behavior of hybrid composites prepared from TiO<sub>2</sub> and graphene reinforced with ZE42 magnesium alloys. This article provides a short review of problem statements and research gaps. The short review also highlights structure–property correlations and determines knowledge gaps which will pave the way for work leading to tailoring ZE42-reinforced hybrid composites for future advanced lightweight structural applications.

## **Problem Statement**

While magnesium alloys like ZE42 (Mg–Zn–Zr) exhibit high specific strength and light weight, attractive for aerospace and automotive applications, their comparatively low tensile strength, limited ductility, lack of wear resistance, and susceptibility to microstructural instability limit structural application. Recent studies have shown that TiO<sub>2</sub> nanoparticles help to enhance hardness and strength through grain refinement and Orowan strengthening, and GNP is also reported as a ceramic reinforcement by virtue of its excellent mechanical properties for improving the load transfer capability and stiffness. Nevertheless,

most published works are dedicated to single-reinforced Mg alloys (e.g. AZ31, AZ91), and research on hybrid TiO<sub>2</sub> and GNP reinforcement in ZE42 specifically is scarce. However, the contribution of dual reinforcements on microstructural evolution, interfacial bonding and dispersion behavior, tensile property, fracture mechanisms and overall mechanical performance of ZE42 has not yet been adequately addressed. Moreover, limitations like nanoparticle agglomeration, weak matrix–reinforcement interface, as well as processing-derived defects have resulted in discrepancies on the mechanical enhancement reported. Thus, a systematic evaluation is necessary to elucidate the strengthening mechanisms, to optimize reinforcement contents and processing routes, as well as establishing a clear structure–property relationship for TiO<sub>2</sub> and GNP reinforced ZE42 magnesium alloy hybrid composites.

### **Research Gap**

Though many attempts have been made to synthesize and characterize the magnesium matrix composites reinforced with a variety of ceramic nanoparticles, GNP or hybrid systems only very few studies exist on developing a TiO<sub>2</sub> and GNP reinforced ZE42 magnesium alloy hybrid composite. Few studies have been conducted on more specific systems, which remains to be very limited for alloy ZE42 as a matrix material. To ensure homogeneous dispersion, however, the potential of processing parameters is under explored because nanoparticle agglomeration and weak interfacial bonding constitute great challenges in the production of metal matrix nanocomposites. Thus, the interfacial properties and load transfer mechanisms between ZE42 and two reinforcements are not well established limiting the correlation of microstructural evolution with mechanical performance. Additionally, there are few systematic studies performed on high temperature behavior, creep resistance, fatigue performance and long-term structural stability — all primary requirements for aerospace and automotive applications. Furthermore, little data are available on the synergistic effect of TiO<sub>2</sub> and GNP on tribological and corrosion properties in realistic working environments. Moreover, both predictive modeling methods and quantitative evaluations of the synergistic strengthening mechanisms of dual reinforcements in ZE42 are still lacking, underlining that combined experimental-computational efforts are required to maximize the benefits from this hybrid composite system.

### **Conclusion**

Owing to grain refinement and load transfer and synergistic strengthening mechanisms, TiO<sub>2</sub> and GNP hybrid reinforcements greatly enhance the mechanical performance of ZE42 magnesium alloy. Enhancements such as hardness, tensile strength, and wear resistance have been reported; however, homogenous dispersion with strong interfacial adhesion is considered one of the main challenges. Though some limited focused studies indicate promising results of ZE42-based TiO<sub>2</sub>–GNP systems, further research into processing optimization, microstructural control and long-term performance is required to realize their full potential within lightweight structural applications.

## References

1. Y. Amangeldinova and T. Sh. Atabaev, "Investigation of mechanical and wear behaviour of AZ91 magnesium matrix hybrid composite with TiO<sub>2</sub>/graphene," *Materials Today: Proceedings*, vol. 20, no. 3, pp. 237–240, 2020.  
<https://doi.org/10.1016/j.matpr.2019.09.142>
2. M. Rashad, F. Pan, M. Asif, et al., "Effects of graphene nanoplatelets on the mechanical properties of Mg composites," *Journal of Magnesium and Alloys*, vol. 3, no. 1, pp. 1–9, 2015.  
<https://doi.org/10.1016/j.jma.2015.01.001>
3. C. Jiang, L. Gu, H. Xiong, J. Wang, et al., "Review of progress on fabrication technology of Mg matrix composites," *Journal of Magnesium and Alloys*, vol. 12, no. 12, pp. 4768–4807, 2024.  
<https://doi.org/10.1016/j.jma.2024.11.026>
4. S. Hazra, "Enhancing material performance: A review of magnesium-based metal matrix composites," *Journal of Manufacturing Engineering*, vol. 20, no. 1, pp. 7–19, 2025.  
<https://doi.org/10.5555/jme.2025.2001>
5. J.-Y. Ren, G.-C. Ji, H.-R. Guo, et al., "Nano-enhanced phase reinforced magnesium matrix composites: A review of the matrix, reinforcement, interface design, properties and potential applications," *Materials*, vol. 17, no. 10, p. 2454, 2024.  
<https://doi.org/10.3390/ma17102454>
6. Y. Ying, W. Wang, G. You, et al., "Toward high-performance Mg-matrix composites: Recent advances in ceramic reinforcement strategies and processing innovations," *Materials*, vol. 19, no. 2, p. 365, 2026.  
<https://doi.org/10.3390/ma19020365>
7. N. S. Kumar and G. G. Sozhamannan, "Investigating the effect of mechanical properties of magnesium alloy (AZ91D) reinforced with graphene metal matrix composite by stir casting method," *Materials Today: Proceedings*, vol. 64, Part 1, pp. 95–100, 2022.  
<https://doi.org/10.1016/j.matpr.2022.03.143>
8. S. Z. Faris, "Mechanical and microstructural properties of TiO<sub>2</sub>-enhanced magnesium composites prepared by powder metallurgy," *NX Materials*, Article 101470, 2026.  
<https://doi.org/10.1016/j.nxmte.2026.101470>
9. F. Liu, Z. Wang and W. Du, "Microstructure and mechanical properties of magnesium matrix composites reinforced by in situ reduced graphene oxide," *Materials*, vol. 16, no. 6, p. 2303, 2023.  
<https://doi.org/10.3390/ma16062303>
10. S. Hazra, *A Review of Magnesium-Based Metal Matrix Composites*, Ed. S. Hazra, 2025.
11. S. K. Khatkar et al., "Hybrid magnesium matrix composites: A review of reinforcement effects on structure and performance," *Reviews in Advanced Materials Science*, vol. 76, pp. 415–438, 2023.  
<https://doi.org/10.1515/rams-2023-0028>