The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 2026

Volume 40, Pages 304-311

ICBAST 2026: International Conference on Basic Sciences and Technology

Next-Generation Multifunctional Composites: The Role of MXene Nanosheets in Enhancing Fiber-Reinforced Epoxy Polymers

Muhammed Huseyin Guzel
Konya Technical University

Abstract: Fiber-reinforced polymer composites are indispensable in high-performance engineering sectors. This study investigates the potential of MXenes as advanced reinforcing agents for carbon, glass, basalt, and Ultra High Molecular Weight Polyethylene (UHMWPE) epoxy composites. It presents a comparative analysis evaluating the effects of the primary MXene synthesis methods: Direct HF etching method and the Minimally Intensive Layer Delamination (MILD) method using LiF/HCl. Literature synthesis reveals that MXenes significantly enhance Interlaminar Shear Strength (ILSS), flexural modulus, and fracture toughness even at ultra-low concentrations through mechanisms such as crack deflection, bridging, and mechanical interlocking. Notably, interfacial modifications in UHMWPE composites have demonstrated a reported increase in Interfacial Shear Strength (IFSS). Beyond mechanical gains, MXenes provide multifunctional capabilities, including electromagnetic interference shielding and superior resistance to corrosive environments. This study concludes that, despite being an emerging area, the synergy between MXenes and fiber-reinforced epoxy polymers represents a promising approach for the development of next-generation multifunctional composites with high durability.

Keywords: Fiber-reinforced epoxy, MXenes, Nanosheets

Introduction

Composite materials are engineered structures formed by combining two or more components that remain insoluble within each other at the macroscopic level. This combination results in properties superior to those of the individual constituents. Specifically, Fiber-Reinforced Polymer Composites (FRPCs) have replaced traditional metallic materials in critical engineering sectors - such as aerospace, automotive, and defense - due to their lightweight nature, high specific strength, and excellent corrosion resistance. In these systems, the matrix phase binds the reinforcement elements together and facilitates load transfer to the fibers, while the fibers act as the primary load-bearing components, providing strength and stiffness (Guzel & Onal, 2025).

MXenes represent a novel family of two-dimensional (2D) transition metal carbides, nitrides, or carbonitrides with a graphene-like structure. These materials are synthesized by the selective etching of precursor ceramics known as MAX phases, which have the general formula $M_{n+1}AX_n$. In this formula, M represents early transition metals (e.g., Ti, V, Nb), A denotes elements from groups 13 (IIIA) or 14 (IVA) of the periodic table (typically Al or Si), and X stands for carbon or nitrogen (Gan & Xiong, 2025).

During the synthesis process, the A layers are selectively removed and replaced by functional groups which impart a hydrophilic character to the surface. A defining feature of MXenes, distinguishing them from other nanomaterials, is their combination of high metallic conductivity and the ability to form chemical bonds with polymer matrices via these functional groups. Technically, MXenes exhibit an extraordinary Young's modulus, making them ideal candidates for structural composite reinforcement. Furthermore, their high specific surface area allows them to function as multifunctional bridging agents that enhance mechanical interlocking at the interface (Pan et al., 2026).

The integration of MXenes into FRPCs offers the potential to simultaneously enhance mechanical strength, electrical conductivity, and thermal stability. Due to their active surface functional groups, MXenes establish strong interactions between the matrix and the fibers, maximizing load transfer efficiency and minimizing interfacial weaknesses. Additionally, the superior metallic conductivity of MXenes enables the development of multifunctional composites with advanced capabilities, such as Electromagnetic Interference (EMI) shielding and structural health monitoring (self-sensing).

MXene Synthesis Mechanisms and Preparation Methods

The performance of MXene-based structural materials fundamentally depends on the efficiency of the exfoliation process from the MAX phase. In $M_{n+1}AX_n$ phases, the M-A bonds are metallic in nature and significantly weaker than the ionic/covalent M-X bonds. This difference in bond energy allows for the selective removal of A elements using appropriate chemical etchants (Aghamohammadi et al., 2021).

The resulting MXene surfaces are terminated with hydroxyl (-OH), oxygen (-O), and fluorine (-F) groups. These terminal groups dictate the hydrophilic nature and the electrical/mechanical properties of the material. While various techniques - including molten salt etching, alkali-assisted hydrothermal methods, and electrochemical etching - have been developed, two primary methods currently dominate due to their yield and control.

Direct HF Method

The direct HF etching method is one of the common top-down protocols that involves the selective removal of the A group (usually Al) from the MAX phase (Zhao et al., 2019). The protocol is briefly as follows:

MAX phase powder is slowly added to a high-concentration HF solution (typically 40-48 wt%). The reaction is performed in a PTFE beaker at room temperature to manage the exothermic nature of the process. Reaction times typically involve 24 hours of continuous magnetic stirring. A atoms react with the acid to form soluble salts, leaving behind an accordion-like multilayered MXene structure. The suspension is then centrifuged (e.g., 5000 rpm) and washed repeatedly with deionized water until the supernatant reaches a pH of approximately 6.

Several key studies in the literature demonstrate the versatility of the direct HF method in enhancing composite performance. Ding et al. (2021) synthesized Ti_2C MXene nanosheets from Ti_2AlC MAX phase via HF etching and successfully grafted these layers onto carbon fiber surfaces to improve the interfacial properties of epoxy composites. Similarly, Zhao et al. (2019) synthesized $Ti_3C_2T_x$ MXene through HF etching followed by sonication, subsequently coating the resulting nanosheets onto carbon fibers using an electrostatic self-assembly method to enhance the mechanical performance of the epoxy resin. In a more recent application, Kumar et al. (2025) synthesized multilayer MXene by stirring 1g of Ti_3AlC_2 powder in 20 mL of 48% HF solution for 24 hours at room temperature; the product was then modified with silane to improve EMI shielding properties within the epoxy matrix. Furthermore, Pei et al. (2025) utilized 40 mL of HF to etch 2 g of Ti_3AlC_2 powder over a 24 hours reaction period, loading the synthesized MXene onto carbon fiber surfaces to synergistically develop the tribological properties, including wear and friction resistance, of the resulting epoxy composites.

The direct HF method is characterized by several distinct advantages and disadvantages that influence its selection for MXene synthesis. On the positive side, it offers high efficiency in completely removing the A layer from the MAX phase, yielding high-purity multilayer structures. It also features a relatively short reaction time compared to alternative techniques, making it the standard protocol for large-scale production. Moreover, the method results in a distinct accordion-like morphology, which provides a significantly increased surface area that is highly beneficial for various reinforcement applications. Conversely, the method presents significant safety risks, as HF is extremely toxic and corrosive, requiring specialized PTFE equipment and stringent laboratory safety protocols. The aggressive nature of the acid may also induce structural defects or vacancies within the MXene layers. Finally, there is an additional processing requirement, as the resulting product is typically multilayered and necessitates a separate delamination step using chemicals to achieve single-layer separation (Ding et al., 2021).

MILD Method

The Minimally Intensive Layer Delamination (MILD) method avoids direct HF use by generating HF in-situ through the reaction: $LiF + HCl \rightarrow HF + LiCl$ (Liu et al., 2019). The protocol is briefly as follows:

LiF is dissolved in concentrated HCl (6M-12M), followed by the slow addition of MAX phase powder. The reaction is typically conducted at mild temperatures (35-40°C) for 24 to 48 hours. A key advantage of this method is the simultaneous intercalation of Li^+ ions between MXene layers during etching. This expands the interlayer spacing and weakens Van der Waals forces. Upon reaching pH 6 through washing, the resulting clay-like sediment can be delaminated into single or few-layer colloidal suspensions through simple manual shaking or low-energy sonication.

The effectiveness of the MILD method in producing high-quality MXenes is evidenced by several recent studies across diverse composite systems. Yuksel Yilmaz et al. (2024) investigated the integration of 2D nanofillers synthesized via the MILD method into aerospace-grade epoxy composites, highlighting how the resulting high structural integrity significantly enhances both mechanical damping and electrical conductivity. Similarly, Wang et al. (2023) demonstrated that MILD-synthesized and surface-modified MXenes achieve exceptional homogeneous dispersion within the epoxy matrix reinforced with Ultra High Molecular Weight Polyethylene (UHMWPE) fibers, resulting in a substantial increase in Interfacial Shear Strength (IFSS).

Regarding matrix compatibility and functional thresholds, Qian et al. (2022) analyzed the electrical percolation behavior of these nanosheets in epoxy, revealing that the surface hydroxyl groups inherent to the MILD process are instrumental in optimizing matrix-filler synergy. For tribological applications, Song et al. (2024) showed that hybridizing MILD-produced MXenes with TiO_2 nanodot modifications significantly improves the wear and friction resistance of epoxy resins. Furthermore, the role of MXenes in advanced diagnostics was explored by Hu et al. (2025), who utilized MXene/polyurethane (PU) modifications for in-situ damage sensing in Carbon Fiber-Reinforced Composites (CFRCs); they noted that the high conductivity afforded by the MILD synthesis is critical for the precision of electrical signal measurements. Finally, Qu et al. (2025) supported these findings by illustrating how MILD-MXene layers effectively guide crack deflection within the epoxy matrix, thereby enhancing energy dissipation mechanisms as confirmed through rigorous mechanical testing.

The MILD method is increasingly favored due to several technical benefits, beginning with enhanced safety; the life-threatening risks and corrosive hazards of direct concentrated HF are significantly mitigated through precise acidity control. This method also produces high-quality flakes that better preserve the lateral size of the nanosheets and minimize structural defects compared to the HF method. A distinctive advantage is spontaneous delamination, as the intercalation of Li^+ ions during etching allows for layer separation without the need for toxic chemicals or high-intensity sonication.

Furthermore, MILD-synthesized MXenes exhibit superior colloidal stability in water, facilitating a more homogeneous dispersion within epoxy resins and other polymer matrices. However, the method requires a longer reaction time, generally spanning 24-48 hours. There is also a risk of residual impurities, specifically LiCl, remaining between the layers if the washing process is not performed meticulously, which can negatively impact the final composite's dielectric and thermal performance (Liu et al., 2021).

Table 1. Technical comparison of MXene synthesis methods

Feature	Direct HF Method	MILD Method
Etching Agent	Concentrated Hydrofluoric Acid (40-48%)	In-situ generated HF (LiF/HCl)
Safety Level	Low (High toxicity and corrosive risk)	Moderate (Lower acid concentration, safer handling)
Reaction Time	Generally shorter (24 hours)	Longer (24-48 hours)
Delamination	Requires separate intercalants	Spontaneous delamination via Li^+ ions
Nanosheet Quality	Potential for more structural defects	Higher quality, larger lateral size, fewer defects
Morphology	Distinct accordion-like multilayer	Clay-like sediment, easier single-layer yield
Colloidal Stability	Moderate (Requires intensive processing)	High (Superior stability in aqueous media)
Environmental Impact	High due to hazardous waste	Moderate; more controlled acidity

A comparative analysis of these two dominant synthesis routes, focusing on safety, structural integrity, and exfoliation efficiency, is summarized in Table 1. As indicated in the table, the selection of the synthesis route is a critical decision that balances the structural integrity of the flakes against the scalability and safety of the process.

Intercalation and Delamination

The transition from accordion-like multilayer MXene to single nanosheets depends heavily on the chosen synthesis route. In the Direct HF method, post-synthesis intercalation using external organic molecules is mandatory to weaken interlayer bonds. Conversely, the MILD method facilitates in-situ intercalation, where Li^+ ions from the etchant integrate between the layers during the reaction itself. Following these steps, applicable to both methodologies, sonication provides the necessary energy to overcome remaining Van der Waals forces. Literature suggests processing the pH-neutral suspension in an ultrasonic bath for 1.5 to 2 hours. To prevent oxidation, this process must be conducted in an ice bath, ideally under argon gas protection. The final colloidal solution is centrifuged to remove un-exfoliated particles, resulting in high-quality single or few-layer MXene nanosheets (Yilmaz et al., 2024a). The successful exfoliation and stabilization of these nanosheets are prerequisite steps for their effective integration into polymer matrices, where their reinforcing potential varies depending on the type of fiber reinforcement employed.

Performance Analysis of Fiber-Reinforced Epoxy Polymers

This section evaluates various studies focusing on the integration of MXenes into FRPCs through the direct incorporation of these nanosheets into the epoxy resin matrix. The analysis covers the mechanical, interfacial, and multifunctional impacts of MXene modification across four primary reinforcement types: carbon, glass, basalt, and UHMWPE fibers. Detailed findings regarding the synergistic effects of MXenes on these diverse composite systems are presented in the following sections. Carbon Fiber-Reinforced Polymers (CFRPs) are the benchmark for high-performance structural materials; however, their performance is often limited by poor interlaminar properties. The high aspect ratio and surface functionality of MXenes provide a strategic solution to enhance the fiber-matrix interface in these systems.

Duan et al. (2024b) investigated the mechanical performance of Carbon Fiber-Reinforced Epoxy Composites (CFRECs) modified with $Ti_3C_2T_x$ MXene nanosheets. The nanosheets were dispersed into the epoxy resin via a co-blending process, and multilayer composites were subsequently fabricated through layer-by-layer assembly and hot pressing. The results demonstrated that the interlaminar shear strength (ILSS) improved significantly as MXene content increased, achieving a 17.27% enhancement at a 2 wt% loading. This mechanical improvement was attributed to the formation of a strengthened MXene/epoxy matrix layer and the ability of the 2D nanosheets to effectively hinder crack propagation within the interlaminar region. In a other study, Duan et al. (2024a) explored the impact of introducing MXene as a reinforcing phase at both the fiber-matrix interface and within the epoxy matrix. By depositing 0.5 wt% MXene onto the carbon fiber fabric via atomization and dispersing additional MXene into the matrix, the researchers achieved a remarkable 55.58% increase in ILSS. This synergistic reinforcement was credited to improved mechanical interlocking, hydrogen bonding, and Van der Waals interactions at the interface. Furthermore, the crack-bridging effect provided by the MXene nanosheets within the matrix further fortified the composite against structural failure.

Song et al. (2025) examined the mechanical and multifunctional properties of short CFRECs modified with MXene. The short carbon fibers were first functionalized with nitric acid and then coated with MXene layers to create a heterostructured MXene/short carbon fibers reinforcement phase. At an optimum fiber-to-MXene ratio, the flexural strength increased to 113.9 MPa and impact strength reached 18.0 kJ/m^2, representing significant mechanical gains. These improvements were driven by increased surface roughness and strong interfacial bonding, while the study also briefly noted enhanced thermal conductivity and reduced wear rates due to the MXene's lubricious nature. Qu et al. (2025) focused on the mechanical and interfacial properties of MXene-dispersed carbon fiber reinforced epoxy composites at both room temperature and cryogenic temperatures (90°K). The incorporation of just 0.10 wt% MXene resulted in a 13.03% increase in ILSS and a 26.84% boost in Mode-II interlaminar fracture toughness at cryogenic levels. The researchers identified that MXene functional groups facilitate bridging and mechanical interlocking, which are critical for preventing thermal stress-induced microcracking. The study also confirmed a reduction in the coefficient of thermal expansion as a secondary benefit of the modification.

Qin et al. (2025) utilized polydopamine-functionalized MXene nanosheets within an epoxy vitrimer resin to produce bidirectional carbon fiber composites. While the matrix-level tensile and flexural strengths showed a slight decline due to the vitrimer chemistry, the composite-level ILSS increased from 52.1 MPa to 58.5 MPa upon MXene addition. This enhancement was explained by the formation of hydrogen bonds between the matrix and the amine/phenolic hydroxyl groups on the MXene nanosheet, which increased the interfacial contact area. The research also highlighted secondary improvements in thermal stability, flame retardancy, and self-healing

capabilities. Kumar et al. (2025) incorporated silane-modified MXene directly into the epoxy matrix to improve the mechanical and EMI shielding performance of CFRPs. The results revealed that silane-modified MXene provided substantial gains, including a 40% increase in tensile strength, a 30% increase in flexural strength, and a 34.21% rise in short beam strength. The amine groups introduced via silane established covalent bonds with the epoxy, increasing cross-linking density and enabling crack pinning and bridging mechanisms. Beyond mechanical reinforcement, the study emphasized the material's superior EMI shielding efficiency.

Hu et al. (2025) presented a hybrid filler system consisting of 0.1 wt% MXene and 1 wt% PU to enhance the mechanical and damage-sensing performance of CFRPs. The hybrid composite achieved an extraordinary 104% increase in flexural strength and a 79% increase in ILSS, reaching values of 885.7 MPa and 52.2 MPa, respectively. This dramatic improvement resulted from the MXene's 2D morphology causing crack deflection and the PU increasing ductility through hydrogen bonding. The study also noted that the interconnected network formed by these fillers provided a baseline for advanced in-situ damage sensing. Pei et al. (2025) investigated the synergistic effects of loading MXene onto carbon fiber surfaces within a hybrid epoxy matrix containing a rubber phase. While the primary focus was on tribology, the research demonstrated that carbon fibers bear the structural load while MXene nanosheets prevent deep matrix wear. The configuration led to a 55.8% reduction in the friction coefficient and a 96.6% decrease in the wear rate. This study confirms that MXene serves as a dual-purpose additive, acting as an effective solid lubricant while maintaining the structural integrity provided by the carbon fibers. Hu et al. (2025) explored the potential of hydroxylated MXene as a nano-binder to reinforce interfacial bonding and enhance the toughness the matrix in CFRP laminates. By adding only 0.1 wt% hydroxylated MXene, the flexural strength and ILSS increased by 52.9% and 40%, respectively, surpassing the performance of much higher concentrations of carbon nanotube (CNT) or graphene. The primary mechanism involved hydroxylated MXene forming a 3D network that redistributed loads and induced crack branching, which effectively prevented brittle failure. The study highlighted a 62.6% increase in fracture energy, suggesting high resistance to fatigue and impact. Glass fibers provide excellent electrical insulation and cost-effectiveness; however, they often encounter challenges such as moisture absorption and moderate mechanical strength. Consequently, recent research has focused on incorporating MXenes, particularly in hybrid configurations, to bridge these performance gaps.

Priyadarshini et al. (2023) conducted a comparative study on the effects of MXene and graphene within hybrid E-glass and hemp fiber epoxy composites, focusing on the dominant influence of MXene on mechanical and physical properties. Through the application of hand lay-up and vacuum bagging techniques, it was observed that incorporating 1 wt% MXene into the matrix led to a substantial 45% increase in flexural strength and an 11.2% enhancement in tensile strength compared to the neat hybrids. This performance leap is attributed to terminal functional groups on the MXene flakes that stabilize load distribution between the fiber and matrix while increasing rigidity to delay sudden failure. Furthermore, MXene-modified composites exhibited nearly 50% lower water absorption than graphene-based counterparts, proving MXene's role as a superior moisture barrier and environmental stabilizer. Bodduru et al. (2023) investigated the use of MXene, graphene nanoplatelets, and CNTs to enhance the mechanical performance and environmental resistance of sisal/glass fiber hybrid epoxy composites. The results indicated that adding MXene to the hybrid system increased tensile strength from 47 MPa to 67.1 MPa and flexural strength from 64.7 MPa to 86.3 MPa, nearly recovering the baseline performance of pure glass fiber composites. This success is credited to the high 2D surface area of MXene, which facilitates robust mechanical interlocking and efficient stress transfer between the matrix and fibers. Notably, MXene also reduced the void ratio from 17.2% to 10.3%, suggesting improved resin flow and fiber wettability during fabrication, while simultaneously increasing elongation at break by 37%. Tadesse et al. (2025) examined the water resistance and structural stability of hemp/glass fiber hybrid composites modified with MXene and graphene nanofillers. While glass fibers inherently reduce water absorption compared to natural fibers, the study found that MXene plays a critical protective role as a chemical shield in aggressive acidic (HCl) and alkali (NaOH) environments. In these harsh conditions, MXene exhibited superior chemical stability compared to graphene, effectively minimizing matrix degradation and subsequent moisture intake. Fourier-Transform Infrared Spectroscopy (FTIR) analysis confirmed the presence of hydrogen bonding between the fibers and matrix, which, combined with the low porosity provided by the glass fibers, makes these composites highly suitable for marine and heavy industrial applications. Yilmaz et al. (2024b) explored the use of pristine MXene and silane-functionalized MXene to simultaneously improve the mechanical and flame-retardant properties of glass fiber-reinforced epoxy composites. The highest mechanical gains were achieved at a 0.25 wt% loading, where silane-functionalized MXene composites showed a 27.55% increase in flexural strength, a 19.21% increase in tensile strength, and a 12.40% increase in ILSS. The silane coupling agent significantly improved the dispersion of nanosheets and established strong chemical bonds between the epoxy and the MXene flakes. Additionally, the functionalized MXene acted as an effective fire retardant, reducing the burn rate by 25.50% at 0.5 wt% loading, confirming its dual strategic value as a structural and safety-oriented additive.

Basalt fibers are gaining prominence as eco-friendly alternatives to glass fibers, yet their susceptibility to chemical degradation in alkaline environments remains a critical concern. MXenes serve as a dual-purpose additive in basalt-reinforced epoxy, acting as both a mechanical reinforcement and a chemical barrier. Qian et al. (2022) studied a hybrid nanofiller system composed of 2D MXene and CNTs to enhance the mechanical performance and corrosion resistance of Basalt Fiber-Reinforced Polymer (BFRP) composites. The research highlighted a synergistic bridging effect, where CNTs prevent the MXene layers from restacking, creating a nano-rivet network within the polymer matrix. This configuration led to a 53.5% increase in tensile strength and a 43.2% increase in flexural strength compared to pristine BFRP. Most significantly, after 120 days of alkali immersion, the MXene/CNT-modified samples showed negligible changes in mechanical properties, proving that the hybrid barrier tightly encapsulates the basalt fibers to prevent environmental corrosion. Qian et al. (2023) focused on mitigating the poor alkali resistance of BFRPs by incorporating MXene nanosheets into the matrix via the vacuum-assisted resin transfer molding process. At a loading of 0.5 wt%, the flexural strength reached 530.1 MPa, marking a 39.4% improvement due to optimized stress transfer and more tortuous crack propagation paths. In harsh alkali aging tests at 40°C for 60 days, the MXene-reinforced samples maintained structural integrity that was surprisingly higher than that of pristine, unaged BFRP. This superior durability is attributed to a combination of the physical 2D barrier effect, which creates a tortuous path and an increased cross-linking density in the epoxy matrix induced by MXene surface functional groups.

UHMWPE fibers possess extraordinary specific strength but suffer from inherently low surface energy, leading to poor interfacial adhesion with epoxy resins. MXene-based surface modifications offer a promising route to induce chemical reactivity on these inert fiber surfaces. Wang et al. (2023) developed an organic-inorganic hybrid MXene to overcome the inherently poor interfacial adhesion of UHMWPE fibers in epoxy matrices. By chemically modifying MXene with silane, the researchers created a filler that achieves both homogeneous matrix dispersion and strong covalent bonding at the fiber interface. The results were dramatic, with the IFSS increasing by 324% (from 2.13 MPa to 9.04 MPa) and tensile strength rising by 56% to reach 142.7 MPa. The organic phase of the hybrid MXene acts as a stress-absorbing buffer, while the inorganic hybrid MXene phase provides high-strength mechanical resistance. Scanning Electron Microscope (SEM) and micro-bond tests confirmed that this modification shifts the failure mode from simple adhesive separation to a complex process involving crack branching and enhanced energy dissipation.

Summary and Outlooks

This review has comprehensively evaluated recent investigations into the transformative effects of MXenes on the mechanical, tribological, thermal, corrosion, and electrical performance of FRPCs. The summarized literature indicates that MXenes, even at exceptionally low loadings (typically 0.1 to 1 wt%), lead to substantial improvements across all investigated properties. The primary mechanism for these mechanical gains is the presence of active functional groups (-OH, -O, -F) on the MXene surface, which facilitate hydrogen bonding, covalent cross-linking, and superior interfacial load transfer. Furthermore, the 2D layered morphology provides a physical barrier that induces crack deflection and pinning, while also forming self-lubricating transfer films that dramatically reduce wear rates.Despite the significant progress observed in recent years, the application of MXenes in advanced structural composites remains a burgeoning field with several unexplored avenues. Future research should prioritize the following directions to unlock the full potential of these materials:

- While $Ti_3C_2T_x$ is widely studied, other transition metal carbides such as Ti_2CT_x and Nb_2CT_x should be investigated for specific aerospace and defense applications.
- Comprehensive research is needed to directly compare MXenes against other two-dimensional (2D) nanomaterials, such as graphene, molybdenum disulfide (MoS_2), and boron nitride (BN), within identical polymer systems to establish clear performance benchmarks.
- To establish advanced multi-scale reinforcement networks, it is necessary to conduct deeper research into the synergy between MXenes and complementary nano-forms, including 1D carbon nanotubes and 0D nanodots.
- There is a critical need for advanced analytical modeling and molecular dynamics simulations to predict the interfacial behavior and failure mechanisms of various MXene-reinforced fiber systems.

Scientific Ethics Declaration

Conflict of Interest

* The author declares that there is no conflict of interest.

Funding

* The author declares that no financial support was received for the research, authorship, and publication of this article.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Basic Sciences and Technology (www.icbast.net) held in Konya/Türkiye on April 02-05, 2026.

References

Aghamohammadi, H., Amousa, N., & Eslami-Farsani, R. (2021). Recent advances in developing the MXene/polymer nanocomposites with multiple properties: A review study. *Synthetic Metals, 273*, 116695.

Bodduru, K., Singh, L. K., Kassa, M. K., Maddamsetty, A., & Arumugam, A. B. (2023). Influence of MXene, graphene nanoplatelet and multi-walled carbon nanotube on mechanical properties, swelling and flammability behaviour of hybrid sisal/glass fibre reinforced epoxy laminate composites. *Materials Research Express, 10*(4), 045002.

Ding, R., Sun, Y., Lee, J., Nam, J.-D., & Suhr, J. (2021). Enhancing interfacial properties of carbon fiber reinforced epoxy composites by grafting MXene sheets (Ti2C). *Composites Part B: Engineering, 207*, 108580.

Duan, N., Li, Y., Shi, Z., Wang, J., Zhang, C., Tang, X., & Wang, G. (2024a). Effect of adding reinforcing phase to the interface and matrix on the interlaminar shear properties of multilayer-structured composites. *Materials Letters, 360*, 135947.

Duan, N., Li, Y., Shi, Z., Wang, J., Zhang, C., Tang, X., & Wang, G. (2024b). A novel micromechanical model for predicting the shear properties of multilayer Ti3C2Tx MXene/carbon fiber fabric/epoxy composite. *Polymer Composites, 45*(10), 9196–9208.

Gan, Y., & Xiong, Y. (2025). Review of MXene synthesis and applications in electromagnetic shielding. *RSC Advances, 15*(12), 9555–9568.

Guzel, M. H., & Onal, G. (2025). Effect of water aging on the mechanical properties of hybrid carbon/aramid reinforced thermoplastic composites. *Advanced Engineering Materials, 27*(20), 2403025.

Hu, Y., He, X., Liu, Y., Yang, Y., Ma, C., Sun, Z., & Jiang, J. (2025). Multifunctional carbon fiber composites via interface-engineered MXene-polyurethane hybrids: Synergistically enhanced mechanical, in situ damage sensing, and EMI shielding properties. *ACS Applied Nano Materials, 8*(21), 10985–11001.

Hu, Y., Liu, Y., Cui, C., Cai, W., Ma, C., Min, R., Wang, A., Yang, Y., Zhang, S., & Jiang, J. (2025). Hydroxylated MXene as a nano-binder: Concurrently strengthening interfaces and toughening matrix in carbon fiber/epoxy composites. *Composites Science and Technology*, Article 111426.

Kumar, B., Jangra, S., Goyat, M. S., Mishra, Y. K., Kheir, M., Halder, S., & Das, S. (2025). Integrated approach for improving mechanical performance and EMI shielding of CFRE via surface-modified MXene. *Polymer Composites, 46*, S423–S444.

Liu, L., Ying, G., Hu, C., Zhang, K., Ma, F., Su, L., Zhang, C., & Wang, C. (2019). Functionalization with MXene (Ti3C2) enhances the wettability and shear strength of carbon fiber-epoxy composites. *ACS Applied Nano Materials, 2*(9), 5553–5562.

Liu, L., Ying, G., Sun, C., Min, H., Zhang, J., Zhao, Y., Wen, D., Ji, Z., Liu, X., & Zhang, C. (2021). MXene (Ti3C2Tx) functionalized short carbon fibers as a cross-scale mechanical reinforcement for epoxy composites. *Polymers, 13*(11), 1825.

Pan, S., Liu, L., Zhang, K., Wen, D., Wang, J., Qian, C., Xiao, X., He, Y., Ji, Z., & Ying, G. (2026). Review: Preparation and mechanical properties of MXene and its structural composites. *Journal of Materials Science*, 1–41.

Pei, X., He, W., Zhang, Z., Wang, R., Zhang, Y., Wang, Q., & Wang, T. (2025). MXene–CF synergy to improve tribological properties of epoxy resin/carboxyl-terminated butadiene acrylonitrile. *Polymer International, 74*(4), 324–335.

Priyadarshini, S., Soren, S., & Durga, G. (2023). Effect of graphene and MXene as 2D filler material on physico-mechanical properties of hemp/E-glass fibers reinforced hybrid composite: A comparative study. *Polymer Composites, 44*(5), 2685–2696.

Qian, Y., Zhong, J., & Ou, J. (2022). Superdurable fiber-reinforced composite enabled by synergistic bridging effects of MXene and carbon nanotubes. *Carbon, 190*, 104–114.

Qian, Y., Zhong, J., & Ou, J. (2023). Improvement in alkali-resistance of basalt fiber-reinforced polymer by Ti3C2Tx (MXene) modified matrix. *Polymer Composites, 44*(4), 2581–2591.

Qin, Z., Zhang, Y.-R., Wu, S.-G., Gu, S., Liu, C., Wang, Y.-Z., & Chen, L. (2025). MXene-engineered multifunctional epoxy vitrimers: Uniting self-healing, fire safety, and component recyclability in carbon fiber composites. *Chemistry of Materials, 37*(21), 8614–8626.

Qu, D.Y., Guo, F. L., Hou, W.D., Guan, T., Fu, Y.T., Hao, J., Peng, C.-Y., Zhang, Y.-C., Li, Y.-Q., & Liu, S.-T. (2025). Effects of introducing MXene nanosheets on the mechanical properties of carbon fiber reinforced epoxy composite at cryogenic temperature. *Composites Science and Technology, 263*, 111102.

Song, Y., Li, S., Liu, Y., & Zhang, Y. (2025). Heterostructured three-dimension MXene/short carbon fiber to enhance thermal, mechanical and tribological properties of epoxy composites. *Journal of Reinforced Plastics and Composites, 44*(21–22), 2396–2406.

Tadesse, Y. G., Priyadarshini, S., Kassa, M. K., Ali, T. K., Seid, A. M., & Bodduru, K. (2025). Investigating the water resistance and structural stability of hemp-glass fiber polymer composites reinforced with graphene and MXene nanofillers. *Polymer Composites*, *47*(9), 8478-8488.

Wang, K., Shen, L., Zhu, Q., Bo, R., Lu, R., Lu, X., & Fu, Z. (2023). Construction of modified MXene with organic–inorganic structure to enhance the interfacial and mechanical properties of UHMWPE fiber-reinforced epoxy composite. *Chemical Engineering Journal, 452*, 139156.

Yilmaz, A. N. Y., Bedeloglu, A. C., & Yunus, D. E. (2024a). Electromagnetic interference shielding, mechanical, and flame retardant behaviors of Ti3C2Tx-MXene/glass fabric epoxy hybrid composites. *Journal of Alloys and Compounds, 1009*, 176877.

Yilmaz, A. N. Y., Bedeloglu, A. C., & Yunus, D. E. (2024b). Enhancing mechanical and flame retardant characteristics of glass fiber-epoxy laminated composites through MXene and functionalized-MXene integration. *Materials Today Communications, 39*, 108745.

Zhao, X., Qi, S., Liu, J., Han, X., & Zhang, F. (2019). Preparation and mechanical performances of carbon fiber reinforced epoxy composites by MXene nanosheets coating. *Journal of Materials Science: Materials in Electronics, 30*(11), 10516–10523.

Author(s) Information

Muhammed Huseyin Guzel
Technical Sciences Vocational School
Konya Technical University, Konya, Türkiye
ORCID iD: https://orcid.org/0000-0003-3093-3453
*Contact e-mail: *mhguzel@ktun.edu.tr*

*Corresponding author(s) contact email

To cite this article:

Guzel, M. H. (2026). Next-generation multifunctional composites: The role of Mxene nanosheets in enhancing fiber-reinforced epoxy polymers. *The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 40,* 304-311.