The Scientific Bulletin of VALAHIA University
MATERIALS and MECHANICS –Vol. 22, No. 26

DOI 10.2478/bsmm-2026-0004

GLASS FIBER-REINFORCED POLYMER MATRIX COMPOSITES: FIBERS, MATRICES, MANUFACTURING AND APPLICATIONS

Sofia SLAMNOIU-TEODORESCU[1], Liviu OLTEANU[2*], Rodica Mariana ION[3,4,5], Ion Valentin GURGU[2], Adrian CATANGIU[1]

[1]Valahia University of Targoviste, Faculty of Materials Engineering and Mechanics, 13, Sinaia Alley, 130004, Targoviste, Romania
[2]Valahia University of Targoviste, Institute of Multidisciplinary Research for Science and Technology, 13, Sinaia Alley, 130004, Targoviste, Romania
[3]Valahia University of Targoviste, Doctoral School of Materials Engineering, 13 Aleea Sinaia, 130004, Targoviste, Romania
[4]ICECHIM, 202 Splaiul Independentei, 060021, Bucharest, Romania.
[5]Academy of Romanian Scientists, 3 Ilfov Street, 050044 Bucharest, Romania.

* E-mail: liviu.olteanu@valahia.ro

Abstract: *Glass fiber-reinforced polymer matrix composites (GFRPs) constitute a major class of structural engineering materials owing to their advantageous balance of specific mechanical properties, low density, corrosion resistance, and comparatively low production cost. Their increasing adoption in sectors such as automotive, aerospace, civil infrastructure, marine engineering, and renewable energy reflects the need for lightweight materials capable of delivering reliable mechanical performance under diverse service conditions. This review provides a systematic examination of GFRPs, with emphasis on the interdependence between constituent selection, processing methodology, microstructural development, and macroscopic properties. Particular attention is devoted to the classification of polymer matrix composites, the physicochemical characteristics of glass fibers as reinforcement, and the distinct roles of thermosetting and thermoplastic matrices in governing composite behavior. The analysis also addresses fundamental reinforcement mechanisms, stress-transfer efficiency at the fiber–matrix interface, and the influence of critical manufacturing parameters associated with both conventional and advanced fabrication techniques. Furthermore, the review evaluates the mechanical, thermal, and durability-related performance of GFRPs, highlighting the role of fiber architecture, interfacial adhesion, and microstructural heterogeneity on in-service behavior. Representative application areas are presented to demonstrate the technological relevance and multifunctional potential of these materials.*

Keywords: *composites materials, epoxy resin matrix, reinforcing fibers, applications polymer matrix composites; manufacturing processes;*

1. INTRODUCTION

1.1 Context and Relevance of the Topic

In the last decades, the polymer matrix composites (PMCs) reinforced with fibers became an essential class of advanced engineering materials, widely recognized for their superior performance compared to conventional materials such as metals and ceramics. Their increasing applications is mainly attributed to their high strength-to-weight ratio, enhanced stiffness, corrosion resistance, and the ability to tailor their properties according to specific application requirements [1], [2].

Among the various types of fiber-reinforced composites, glass fiber-reinforced polymers (GFRPs) represent one of the most extensively used categories due to their relatively low cost, good mechanical performance, and processing facilities. These materials are widely employed in numerous industrial sectors, including automotive, aerospace, construction, marine engineering, and renewable energy systems [3], [4]. The growing demand for lightweight structures, improved fuel efficacity, and reduced environmental impact has further accelerated the development and application of GFRPs. In addition, their compatibility with a wide range of manufacturing techniques, from conventional processes to advanced fabrication methods, enhances their versatility and industrial applicability [5], [6].

Despite these advantages, several challenges remain associated with the use of GFRPs, particularly in terms of long-term durability, environmental degradation, and recyclability. Factors such as moisture absorption, ultraviolet radiation, thermal fluctuations, and chemical exposure can significantly affect the performance and service life of these materials [7], [8]. Therefore, a comprehensive understanding of the relationships between material constituents, processing parameters, and resulting properties is essential for optimizing composite performance and ensuring long-term reliability.

1.2 Objectives of the Article

The present review aims to provide a comprehensive and systematic overview of polymer matrix composites reinforced with glass fibers, with particular emphasis on the interdependence between manufacturing processes, microstructural characteristics, and material properties.

The objectives of this work include the classification and description of polymer matrix composites, the analysis of reinforcement mechanisms and load transfer phenomena, and the evaluation of glass fibers as reinforcing materials. Furthermore, the role of thermosetting and thermoplastic matrices in determining composite performance is examined. In addition, the review addresses conventional and advanced manufacturing techniques, and presents applications of glass fiber-reinforced polymer matrix composites.

2. OVERVIEW OF POLYMER MATRIX COMPOSITES (PMCs)

2.1 Classification and Typology

Polymer matrix composites (PMCs) are heterogeneous materials consisting of a continuous polymer phase (matrix) and a dispersed reinforcement phase, typically in the form of fibers, particles, or layered structures. The matrix plays a fundamental role in binding the reinforcement, transferring loads, and protecting it from environmental influences, while the reinforcement provides strength and stiffness to the composite system [9], [10].

PMCs can be classified according to several criteria, the most common being the type of polymer matrix. From this perspective, composites are generally divided into thermosetting and thermoplastic systems. Thermosetting matrices, such as epoxy, polyester, and vinyl ester resins, are widely used due to their good mechanical properties, dimensional stability, and resistance to chemical and thermal degradation. In contrast, thermoplastic matrices, including polypropylene, polyamide, and polyethylene, offer advantages such as recyclability, impact resistance, and shorter processing times [6], [9].

Another important classification is based on the type of reinforcement. Composites reinforced with continuous fibers exhibit superior mechanical properties, particularly along the fiber direction, and are typically used in high-performance structural applications. On the other hand, composites reinforced with short or discontinuous fibers are easier to process and more suitable for complex geometries, although they generally exhibit lower mechanical performance [11], [16]. Particle-reinforced composites represent another category, where fillers are used to enhance specific properties such as stiffness, wear resistance, or thermal stability [3].

From a structural standpoint, PMCs can also be categorized into laminated composites, sandwich structures, and hybrid systems. Laminated composites consist of multiple layers with different fiber orientations, allowing for tailored anisotropic properties. The sandwich structures combine lightweight cores with strong outer skins, providing high stiffness-to-weight ratios. Hybrid composites incorporate different types of fibers or matrices to achieve a balance between performance and cost [12], [13].

The versatility of PMCs, resulting from the wide range of available matrices, reinforcements, and architectures, makes them highly adaptable materials suitable for diverse engineering applications [2], [10].

2.2 Reinforcement Mechanisms and Load Transfer

The mechanical performance of polymer matrix composites is primarily governed by the interaction between the matrix and the reinforcement phase. In fiber-reinforced composites, the load applied to the material is predominantly carried by the fibers, which possess significantly higher strength and stiffness compared to the polymer matrix. The matrix, in turn, ensures the transfer of stress between fibers and maintains their alignment and distribution within the composite [9], [10].

The efficiency of load transfer depends strongly on the quality of the fiber–matrix interface. A strong interfacial bond enables effective stress transfer from the matrix to the fibers, leading to improved mechanical performance. Conversely, weak interfacial adhesion may result in debonding, fiber pull-out, and premature failure of the composite material [14], [15].

In the case of discontinuous fiber composites, the concept of critical fiber length is essential for achieving efficient load transfer. The shorter fibers cannot fully develop their reinforcing potential, leading to reduced mechanical properties. Therefore, the fiber length, orientation, and distribution play a crucial role in determining the overall behavior of the composite [11], [16].

Continuous fiber composites, on the other hand, exhibit superior load-bearing capacity, especially when the fibers are aligned in the direction of the applied load. However, their performance is highly anisotropic, meaning that properties vary depending on the loading direction. This characteristic must be carefully considered in the design of composite structures [9], [10].

Additionally, several micromechanical models have been developed to describe load transfer mechanisms in PMCs, including the rule of mixtures and shear-lag theory. These models provide useful insights into the relationship between constituent properties and the overall behavior of the composite material [8], [10].

3. GLASS FIBERS AS REINFORCEMENT MATERIAL

3.1 Types and Chemical Composition

The glass fibers are among the most widely used reinforcement materials in polymer matrix composites due to their favorable balance between mechanical performance and cost. They are typically produced by melting inorganic raw materials such as silica (SiO_2), alumina (Al_2O_3), calcium oxide (CaO), and other metal oxides, followed by extrusion through fine nozzles to form continuous filaments [17], [10].

Depending on their chemical composition and intended application, several types of glass fibers have been developed.

The most commonly used type is E-glass (electrical glass), which offers a good combination of mechanical properties, electrical insulation, and low cost, making it suitable for general-purpose applications. S-glass (structural glass) is characterized by higher tensile strength and modulus, being used in high-performance applications where superior mechanical properties are required. C-glass (chemical-resistant glass) is specifically designed for improved resistance to corrosive environments, particularly in chemically aggressive conditions [17].

The chemical composition of glass fibers plays a crucial role in determining their physical, mechanical, and chemical properties. Variations in the content of silica and other oxides influence factors such as tensile strength, modulus of elasticity, thermal stability, and resistance to environmental degradation. Consequently, the selection of a specific type of glass fiber depends on the requirements of the intended application [17], [18].

3.2 Structural and Mechanical Properties

The glass fibers exhibit a unique combination of mechanical and physical properties that make them suitable for reinforcing polymer matrices. They possess high tensile strength, moderate elastic modulus, low density, and good resistance to corrosion and environmental degradation [19], [4]. Although their stiffness and strength are generally lower than those of carbon fibers, glass fibers offer a significant advantage in terms of cost-effectiveness and ease of processing, which explains their widespread use in industrial applications [3], [9].

The performance of glass fiber-reinforced composites is strongly influenced by several factors, including fiber volume fraction, orientation, length, and distribution within the matrix. Higher fiber content typically leads to increased stiffness and strength, while proper alignment of fibers enhances load-bearing capacity along specific directions [16], [18].

Additionally, the glass fibers exhibit relatively brittle behavior, with limited plastic deformation before failure. This characteristic must be considered in structural design, particularly in applications involving impact loading or cyclic stresses. Despite this limitation, their overall performance remains highly competitive for a wide range of engineering applications [19].

3.3 Fiber–Matrix Interface

The fiber–matrix interface represents a critical region in polymer composites, as it governs the efficiency of load transfer and significantly influences the overall mechanical performance and durability of the material.

A strong interfacial bond ensures effective stress transfer from the matrix to the fibers, thereby maximizing the reinforcing effect. In contrast, weak adhesion at the interface can lead to premature failure mechanisms such as fiber pull-out, debonding, and interfacial cracking [14], [15].

To improve interfacial adhesion, glass fibers are typically treated with surface modifiers, most commonly silane coupling agents.

These agents form chemical bonds between the hydroxyl groups on the glass surface and the functional groups of the polymer matrix, enhancing compatibility and adhesion [17], [15].

The interfacial region is also influenced by factors such as surface roughness, chemical composition, and processing conditions. Optimizing these parameters is essential for achieving improved mechanical performance, resistance to environmental degradation, and long-term stability of the composite material [12], [18].

4. THE POLYMERIC MATRIX OF THE COMPOSITE MATERIAL

The polymeric matrix serves two essential functions: transferring mechanical loads to the reinforcing fibers and protecting against environmental degradation. For these roles, the matrix must possess strong interfacial adhesion with the fibers, sufficient ductility, and high creep resistance [20].

The polymeric matrices represent the most extensively used class of matrices in composite materials, accounting for approximately 75% of current applications. Their mechanical performance is generally lower than that of metallic and ceramic matrices. However, polymer-based systems offer significant processing and economic benefits compared to metallic and ceramic systems. Their relatively low processing temperatures reduce the risk of thermal degradation in the reinforcing phase. Additionally, the polymeric matrices are easier to process and are more cost-effective and available than metallic or ceramic alternatives. The main drawback is their comparatively low upper service temperature, which usually does not exceed 200 °C [21].

The polymer matrices in composite materials exhibit considerable diversity. They are broadly classified by molecular structure, processing behavior, and service performance into thermosetting polymers, thermoplastic polymers, and elastomers. This classification provides a clear framework for distinguishing among these polymer matrices (*Fig.1*).

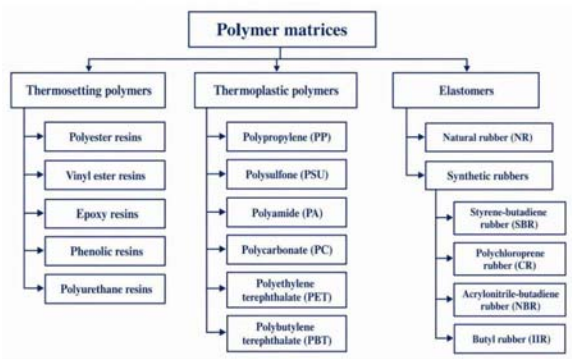

Figure 1. Classification of polymer matrices

4.1. Thermosetting polymers are characterized by covalently crosslinked three-dimensional networks, which impart dimensional stability and good thermal and chemical resistance after curing. Once the curing reaction is completed, they become infusible and insoluble and therefore cannot be remelted by conventional means. This same network structure, while beneficial for in-service performance, is also the principal reason for their limited recyclability. Thermosetting resin systems still dominate continuous fiber-reinforced and high-performance composites, especially where reliable impregnation and structural performance are critical [22].

- *Polyester resins* are widely used because of their low cost, ease of processing, and good chemical/corrosion resistance. Their limitations include intrinsic flammability, relatively high curing shrinkage, and styrene emissions during processing. Accordingly, glass-fiber-reinforced polyester composites are typically preferred for cost-sensitive applications where performance requirements are less demanding than those addressed by epoxy-based systems [23].

- *Vinyl ester resins*, are thermosetting polymers that combine the rapid cure of unsaturated polyester systems with the favorable chemical, mechanical, and thermal characteristics of epoxy-based resins. They are generally recognized for their high chemical and hydrolytic resistance and are widely used in composite applications requiring good corrosion resistance [24].

- *Epoxy resins* are high-performance thermosetting matrices characterized by high mechanical strength, low shrinkage during curing, good thermal stability, strong chemical resistance, and excellent adhesion to fibers. These properties make them suitable for advanced composite applications. However, epoxies are sensitive to moisture, ultraviolet light, and impacts, are susceptible to thermal aging, and are relatively expensive. Epoxy composites reinforced with glass, carbon, or aramid fibers are widely used in aerospace, pressure vessels, and sports equipment [25].

- *Phenolic resins* are distinguished by their excellent fire resistance, thermal stability, and chemical inertness. Despite these advantages, their intrinsic brittleness, moisture sensitivity, and limited processability restrict their broader application in demanding structural systems [26].

- *Polyurethane resins* are significant thermosetting polymers known for their stability, resistance to aging, and versatility in various applications. However, their limited thermal stability and flammability present notable weaknesses. The performance of polyurethane resins is highly dependent on their formulation and processing conditions [27].

4.2. Thermoplastic polymers represent the second major category of matrix materials and have attracted increasing interest due to their recyclability, rapid processing cycles, and virtually unlimited shelf life. Their structural composition, which consists predominantly of linear or slightly branched macromolecular chains, enables repeated softening upon heating and solidification upon cooling without significant chemical modification. These characteristics provide important manufacturing advantages, including easier shaping, shorter cycle times, and the potential for reprocessing by remelting or dissolution.

Even with these benefits, the broader adoption of thermoplastic matrices remains constrained by two main factors: their thermal resistance, which is often lower than that of thermosetting matrices and typically below 150 °C, and their generally weaker interfacial adhesion to reinforcing fibers compared to thermosetting systems. These limitations may reduce load transfer efficiency and affect long-term thermo-mechanical performance [21]. Among the most commonly used thermoplastic matrices are:

- *Polypropylene (PP)* is particularly attractive because of its low cost, good chemical resistance, and moderate thermal stability, typically up to about 110 °C. Its use, however, is restricted by poor impact resistance and combustibility [28].

- *Polysulfone (PSU)* is a high-performance thermoplastic distinguished by excellent resistance to hydrolysis, creep, and chemically aggressive environments, as well as by good electrical insulating properties and thermal stability up to approximately 180 °C. A notable disadvantage of polysulfone is its hygroscopicity, which may influence both processing and in-service behavior [29].

- *Polyamide (PA)* demonstrates resistance to impact, cyclic loading, and exposure to hydrocarbons, which supports its widespread use in engineering applications. Its primary limitation is high moisture absorption, which can alter dimensional stability and reduce mechanical strength [30].

- *Polycarbonate (PC)* is recognized for its high strength, stiffness, and toughness, together with good resistance to greases and oils. However, it is susceptible to degradation in the presence of benzene and alkaline solutions, which limits its use in certain chemically aggressive environments [31].

- *polyethylene terephthalate (PET) and polybutylene terephthalate (PBT)* combine good mechanical properties with low water absorption, limited thermal expansion, and favorable dielectric behavior. demonstrates resistance to impact, cyclic loading, and exposure to hydrocarbons, which supports its widespread use in engineering applications. Its primary limitation is high moisture absorption, which can alter dimensional stability and reduce mechanical strength [32].

4.3. Elastomers is final major category of polymer matrices comprises elastomers, which are a distinct class of polymeric materials characterized by very high reversible deformability, often exceeding strains of 100%, and nearly incompressible mechanical behavior, with a Poisson's ratio close to 0.5. This combination enables elastomers to sustain large elastic deformations and recover their original shape upon unloading. While most elastomers are predominantly organic materials, silicone-based systems are an exception. Typically, elastomers are formulated as multicomponent systems containing a polymeric base, fillers, vulcanizing agents, accelerators, stabilizers, anti-aging additives, and other functional constituents, with the polymer fraction representing only 50–60% of the total composition. Due to their high elasticity, resilience, and flexibility, elastomers are widely used in sealing elements, vibration-damping components, energy-absorption applications, consumer goods, and sports products.

- *Natural rubber (NR)* is obtained from the latex of *Hevea brasiliensis* and, in its raw state, exhibits inadequate mechanical properties and poor solvent resistance for direct industrial use. Accordingly, it must undergo vulcanization, typically by treatment with 2–12% sulfur at temperatures in the range of 120–150 °C, in order to develop suitable physico-mechanical characteristics.

Industrial rubbers typically contain various additives. Curing accelerators such as ZnO and P_2O_5 increase the rate of vulcanization. Carbon black enhances strength and wear resistance, while fillers like chalk, barite, and talc reduce production costs. Plasticizers facilitate processing, and antioxidants inhibit aging. These rubbers exhibit elasticity, fatigue and abrasion resistance, low moisture uptake, and a tendency to swell in oils and gasoline. The typical operating temperature is approximately 80 °C [33].

- *Synthetic rubbers* are produced by polymerization or copolymerization of unsaturated monomers containing multiple double bonds, such as isoprene, butadiene, chloroprene, and methylpropene. By adjusting monomer type, composition, and copolymerization conditions, synthetic elastomers can be engineered to satisfy specific physical, mechanical, and chemical requirements [34].

- *Styrene-butadiene rubber (SBR)* exhibits greater abrasion and aging resistance compared to natural rubber. It remains functional at temperatures up to approximately 100 °C, although it possesses lower elasticity [35].

- *Polychloroprene rubber (CR)* offers superior resistance to moisture, oils, greases, and ozone compared to natural rubber. However, it is less elastic and may degrade when exposed to hot water and fuels [36].

- *Acrylonitrile-butadiene rubber (NBR),* or nitrile rubber, is particularly valued for its excellent resistance to oils and aliphatic hydrocarbons, as well as for its good wear and aging resistance. However, it exhibits limited low-temperature performance, reduced elasticity, and is not resistant to brake fluids[34].

- *Butyl rubber (IIR)* is characterized by very low gas permeability, excellent electrical insulation, good resistance to hot water and steam, and satisfactory aging resistance. Conversely, its relatively low elasticity and poor resistance to oils, greases, and fuels restrict its use in applications involving hydrocarbon exposure [37].

5. THE MANUFACTURING PROCESS OF COMPOSITE MATERIALS

The manufacturing process plays an important role in determining both material development and the characteristics of the final product. In the case of conventional materials, processing usually begins with a simple semi-finished form, such as a rod, ingot, or sheet, which is subsequently shaped into the required configuration. The polymer matrix composites, however, cannot be processed in the same manner. Their fabrication involves a series of specific operations, including reinforcement preparation, fiber cutting, production of reinforced composite parts, and the integration of the constituent materials through techniques such as stamping, pressing, extrusion, and injection [38].

The polymer materials are commonly reinforced with fibres having diameters of approximately 8–12 μm. These fibres may be arranged in woven fabrics or in other preformed textile structures, and can be used as continuous, chopped, single-filament, or multifilament reinforcements. During processing, the reinforcing fibres are incorporated into the polymer matrix in liquid form by techniques such as injection, extrusion, pressing, or stamping, after which the material is cured to obtain the final composite structure. *Figure 2* presents the complete process [39].

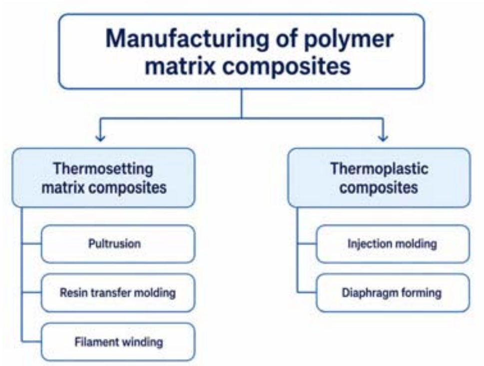

Figure 2. Manufacturing of Polymer Matrix Composites (Adapted from Dhanasekar et al., 2022)[39]

The fiber-reinforced polymer composites are commonly based on thermosetting matrices, particularly unsaturated polyester and epoxy resins. The thermosetting polymers remain widely used because their three-dimensional cross-linked structure provides high dimensional stability together with good solvent and thermal resistance. All the epoxy systems are particularly prominent in high-performance composite applications, while ongoing research continues to improve the durability and thermal performance of thermosetting resins [1].

The thermoplastics consist of linear or branched molecular chains that soften upon heating and solidify again on cooling, which allows repeated thermal processing. Compared with thermosets, the thermoplastic composites generally offer higher toughness, better impact and damage resistance, and shorter processing cycles. These advantages make thermoplastic matrices especially attractive for high-volume manufacturing sectors, particularly the automotive industry [40].

Pultrusion is a manufacturing method in which continuous fiber layers impregnated with resin are pulled through a heated die to produce composite profiles with a constant cross-section and virtually unlimited length. This process is valued for its high production rate, low material waste, and rapid processing, and is commonly applied in vehicle components as well as sporting goods such as ski poles and fishing rods [39].

In resin transfer molding (RTM), a dry fiber preform is first prepared and placed inside a closed matched mold, after which a low-viscosity resin is injected and cured in the mold. The process is well suited to complex geometries and offers good potential for automation and serial production. Typical applications include automotive composite components and, in some cases, large structural parts such as wind turbine blades [41].

The injection molding is a closed-mold process widely used for short-fiber-reinforced polymer composites, particularly where automation, high productivity, and consistent part quality are required. Typical applications include electronic and household products as well as a variety of molded technical components. Diaphragm forming is a thermoforming technique used mainly for thermoplastic composite laminates, where flexible silicone diaphragms assist the shaping of curved components with relatively low-cost tooling. More broadly, the performance of polymer matrix composites depends strongly on the manufacturing and forming processes used to produce the final part [39].

6. APPLICATIONS OF GLASS FIBER-REINFORCED POLYMER MATRIX COMPOSITES

The glass fiber-reinforced polymer matrix composites, commonly referred to as GFRP, are widely used because they combine low density with good specific strength, corrosion resistance, durability, and relatively low manufacturing cost compared with other advanced composite systems [1].

One of the most important application areas is civil engineering, where FRP composites are used for strengthening, rehabilitation, and in some cases new structural components because they offer high strength-to-weight ratio and good resistance to aggressive environments. In construction practice, these materials are used in beams, columns, slabs, bridge elements, and externally bonded reinforcement systems intended to improve the performance of aging infrastructure [42].

Another major field is transportation, especially the automotive and aeronautical sectors, where glass fiber composites are selected to reduce structural weight while maintaining adequate mechanical performance [43].

In the automotive industry, GFRP has been investigated and applied in components such as bumper systems, seat structures, and body parts, mainly because lightweight composite parts can contribute to improved energy efficiency and favorable impact behavior [44].

In the aeronautical sector, glass fiber-reinforced composites are also used in transport-related applications and unmanned aerial vehicle structures, where low weight and design flexibility are especially valuable [43].

A further important application area is the marine industry, where fiber-reinforced composites are used in ships, ship components, offshore systems, and marine renewable-energy structures because of their low weight and strong resistance to corrosion in humid and saline environments [45].

The literature also identifies wind energy as a major application domain, since wind turbine blades are predominantly made of glass fiber-reinforced polymer composites. This widespread use in wind turbines is mainly related to the need for lightweight structures with sufficient stiffness and mechanical reliability under long-term cyclic loading [46].

More broadly, recent review articles describe FRP and GFRP composites as materials with established applications across construction, transport, marine engineering, sport, and energy systems, which confirms their broad technological relevance. Overall, the scientific literature shows that the most representative application fields for polymer matrix composites reinforced with glass fiber are civil construction, transportation, marine engineering, and wind energy, where their combination of low weight, corrosion resistance, and satisfactory mechanical performance offers clear advantages over many conventional materials [47].

6. CONCLUSION

The glass fiber-reinforced polymer matrix composites are a well-established class of materials that combine lightweight characteristics, good mechanical performance, corrosion resistance, and relatively low manufacturing cost. Their extensive use in construction, transportation, marine engineering, and energy systems demonstrates their strong technological and industrial relevance.

The combination of glass fibers with thermosetting or thermoplastic polymer matrices has proven effective in achieving a balanced set of structural and functional properties. Reinforcement architecture, fiber volume fraction, matrix type, and especially fiber–matrix interfacial adhesion play a key role in determining the mechanical, thermal, and durability-related behavior of these composites.

Manufacturing methods significantly influence the final quality and performance of GFRP systems. Both conventional and advanced processing routes can produce composites with tailored properties; however, careful control of fabrication parameters is essential to ensure proper impregnation, structural integrity, and long-term reliability.

Nevertheless, important limitations remain, particularly those related to environmental degradation, long-term durability, and recyclability. Future work should therefore focus on improving interfacial engineering, optimizing processing technologies, and developing more sustainable matrix systems and recycling strategies. Overall, GFRP composites remain a promising solution for the development of lightweight, durable, and high-performance materials suited to modern engineering applications.

REFERENCES

[1] De B., et al., A comprehensive review on fiber-reinforced polymer composites: properties and applications, Progress in Materials Science, 2024.

[2] Mahboubizadeh S., et al., Advancements in fiber-reinforced polymer composites: manufacturing and applications, Journal of Materials Science, 2024.

[3] Alzahrani M.M., et al., Recent advances in fiber-reinforced polymer composites for structural applications, Materials Today Communications, 2025.

[4] Cao Z., et al., Review of key manufacturing technologies for fiber-reinforced polymer composites, Composite Structures, 2025.

[5] Dong S., et al., Durability of thermoplastic glass fiber-reinforced composites under environmental exposure, Composite Structures, 2024.

[6] Dong C., et al., Mechanical behavior of continuous glass fiber-reinforced composites, Journal of Materials Engineering and Performance, 2024.

[7] Kaboré M.W., et al., Recycling strategies for glass fiber-reinforced polymer composites, Polymers, vol. 17, 2025.

[8] Yavuz İ., et al., Mechanical performance of glass fiber-reinforced composite systems, RSC Advances, 2024.

[9] Supian A.B.M., et al., Mechanical properties of hybrid glass fiber-reinforced composites: recent developments, Polymer Composites, 2024.

[10] Mohanraj C.M., et al., Recent progress in fiber-reinforced polymer hybrid composites, Journal of Reinforced Plastics and Composites, 2025.

[11] Kaufmann J., et al., Natural and hybrid fiber composites: classification and applications, Advanced Materials Interfaces, 2025.

[12] Somaiah A., et al., Characterization and properties of glass fiber-reinforced polymer composites, Materials Today: Proceedings, 2024.

[13] Dudás C., et al., Effect of glass fiber reinforcement on composite performance, Materials, 2024.

[14] Dudás C., et al., Interfacial behavior in glass fiber-reinforced composites and its effect on mechanical properties, Materials, 2024.

[15] Chen X., et al., Advanced surface modification techniques for glass fiber-reinforced polymer composites, Journal of Reinforced Plastics and Composites, 2024.

[16] Thomason J.L., Influence of fiber length and distribution on composite performance, Composites Part A, 2024.

[17] Antony Leo F., et al., A review of glass fiber reinforced composite materials – advancements and challenges, Journal of Polymer and Composites, vol. 13, pag. 635-656, 2025.

[18] Kychkin A.K., et al., Durability of basalt- and glass fiber-reinforced polymer composites under extreme conditions, Polymers, vol. 17, 2025.

[19] Zhang H., et al., Fatigue behavior and damage mechanisms of glass fiber-reinforced polymer composites, Composite Structures, 2024.

[20] Cosmeleata G., et al., Materiale compozite cu matrice polimerica, Vol I, Editura Printech, 2006.

[21] Bolundut I.L., Tehnologia materialelor plastice si compozite, Editura Junimea, Iasi, 2019.

[22] Post W. et al., A Review on the Potential and Limitations of Recyclable Thermosets, Polymer-Plastics Technology and Materials, 2020.

[23] Mishra S. et al., Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites, Composites Science and Technology, Volume 63, Issue 10, 2003.

[24] Alia C. et al., Characterization of the chemical structure of vinyl ester resin in a climate chamber under different conditions of degradation, Polymer Degradation and Stability, Volume 153, 2018.

[25] Xu, X. et al., Aramid Fiber-Reinforced Plastics (AFRPs) in Aerospace: A Review of Recent Advancements and Future Perspectives, Polymers, Volume 17, Issue 16, 2025.

[26] Asim, M. et al., A Review on Phenolic Resin and its Composites, Current Analytical Chemistry, Volume 13, Issue 3, 2017.

[27] Conget P. al., A comprehensive review on polyurethane modified asphalt: Mechanism, characterization and prospect, Journal of Road Engineering, Volume 3, Issue 4, 2023.

[28] Hossain T. al., Research and application of polypropylene: a review, Discover Nano, Volume 19, Issue 2, 2024.

[29] Simionescu, S. et al., Polymeric Membrane for Verteporfirin Purification, Materiale Plastice 54 (1), 14, 2017

[30] Venoor V. et al., Understanding the Effect of Water in Polyamides: A Review, Polymer Reviews, Volume 61, Issue 3, 2021.

[31] Raquez J.M., et al., A review of filled and pristine polycarbonate blends and their applications, Express Polymer Letters, Volume 11, Issue 2, 2017.

[32] Lobke De Vos et al., Poly(alkylene terephthalate)s: From current developments in synthetic strategies towards applications, European Polymer Journal, Volume 161, 2021.

[33] Alarifi, I.M., A comprehensive review on advancements of elastomers for engineering applications, Advanced Industrial and Engineering Polymer Research, Volume 6, Issue 4, 2023.

[34] Liu, G., et al., Systematic investigation of the degradation properties of nitrile-butadiene rubber/polyamide elastomer/single-walled carbon nanotube composites in thermo-oxidative and hot oil environments, Polymers, Volume 16, Issue 2, 2024.

[35] Basfar, A.A., et al., Influence of different curing systems on the physico-mechanical and thermal aging properties of SBR and NR rubber vulcanizates, Radiation Physics and Chemistry, Volume 63, Issue 1, 2002.

[36] Mandlekar, et al., A review on specialty elastomers based potential inflatable structures and applications, Advanced Industrial and Engineering Polymer Research, Volume 5, Issue 1, 2022.

[37] Smejda-Krzewicka, A., et al., The new elastomeric compounds made of butyl rubber filled with phyllosilicates, characterized by increased barrier properties and hydrophobicity and reduced chemical degradation, Molecules, Volume 29, Issue 6, 2024.

[38] Nilesh S.G., Fiber-reinforced polymer matrix composites for improved defence armor - A comprehensive review, Smart Materials in Manufacturing, Volume 3, 2025.

[39] Dhanasekar S. et al., Study of Polymer Matrix Composites for Electronics Applications, Journal of Nanomaterials, 2022.

[40] Stewart R., Thermoplastic composites - recyclable and fast to process, Reinforced Plastics, Volume 55, Issue 3, 2011.

[41] Rajak D.K., et al., Manufacturing Technologies of Carbon/Glass Fiber-Reinforced Polymer Composites and Their Properties: A Review, Polymers, Volume 13, Issue 21, 2021.

[42] Pendhari, S. S., Kant, T., and Desai, Y. M., Application of polymer composites in civil construction: A general review, Composites Structures, 2008.

[43] Saftoiu, G.V. et al., Glass Fibre-Reinforced Composite Materials Used in the Aeronautical Transport Sector: A Critical Circular Economy Point of View, Sustainability, 2024.

[44] Mohammadi, H. et al., Lightweight Glass Fiber-Reinforced Polymer Composite for Automotive Bumper Applications: A Review, Polymers, 2022.

[45] Rubino, F. et al., Marine Application of Fiber Reinforced Composites, Journal of Marine Science and Engineering, 2020.

[46] Xu, M. et al., Recovering glass fibers from waste wind turbine blades: Recycling methods, fiber properties, and potential utilization, Renewable and Sustainable Energy Reviews, 2024.

[47] Ion, RM et al., Filmogene film with composite polymer for the retention of degradation products on pictorial surfaces and process for obtaining it, RO 132767 (B1) /2019