



Performance Evaluation and MLP Prediction of Flax- and Graphene Oxide-reinforced Polyester Composites

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ABSTRACT

This research examines the mechanical properties of composites made from flax fiber and polyester resin. Hybrid composites were produced by integrating flax fiber, known for its exceptional tensile and flexural strengths, with graphene oxide nanoparticles (nGO) and polyester resin. The flexural and ultimate tensile strengths of the composites were predicted using a multilayer perceptron (MLP) regression model, a type of artificial neural network (ANN). The composite material FGO-1, comprising 40 wt.% flax fiber, 1 wt.% graphene oxide nanoparticles, and 59 wt.% polyester resin, exhibited outstanding mechanical properties. The FGO-1 sample showed improvements in flexural modulus (46.80%), flexural strength (50.80%), tensile modulus (32%), and tensile strength (37.83%). The energy absorption rate was 32.69%, and its impact resistance exceeded that of the other composite formulations by 8.75%. The ANN model successfully predicted these strengths, achieving R^2 values of 0.89 and 0.98 for flexural and tensile strengths, respectively. Microstructural analysis using a scanning electron microscope (SEM) was conducted alongside tensile, flexural, impact, and interlaminar shear strength tests to evaluate the composite's performance.

Keywords: Flax fiber; Polyester resin; nGO; Artificial intelligence; Natural fiber composite.

1. INTRODUCTION

Composites are increasingly used in engineering applications owing to their favorable combination of strength, stiffness, and light weight. Among them, natural fiber composites have become important due to their sustainability, biodegradability, and potential to replace synthetic materials. Flax fiber, in particular, is widely studied because of its good mechanical performance, renewable availability, and compatibility with various polymer matrices. Surface treatments and nanofillers are commonly incorporated to improve fiber-matrix bonding, thermal stability, and overall mechanical behavior, enabling natural fiber composites to meet the demands of automotive, aerospace, and structural applications (Alipour *et al.* 2021; Almeida *et al.* 2025). Flax-based composites are extensively reported. PP composites with 10 wt.% treated flax and 7.5 wt.% Al_2O_3 achieved superior dispersion and strength (Aruna *et al.* 2025). Nano- TiO_2 -coated flax fibers exhibited increased tensile, flexural, and interlaminar shear strength (ILSS) by up to 24% with reduced water absorption (Prasad *et al.* 2021). PLA (polylactide) reinforced with alkali-treated flax fibers,

5% epoxidized palm oil, and 0.5% graphene showed improved flexibility and thermal stability (Jiyas *et al.* 2024). Kenaf reinforced with PES (polyethersulfone) coating and nanosilica improved ILSS and chemical resistance under compression molding (Iman *et al.* 2024). Flax combined with SiCw (whiskers) and SiC mesh achieved high tensile and flexural values through improved bonding (Murugan *et al.* 2020). Hybrid epoxy composites with glass/flax and ZnO nanofillers at 0.3 wt.% showed a peak flexural strength of 475.56 MPa (Meravi and Panchore, 2024a). Optimization via response surface methodology (RSM) identified a 300 gsm flax mat, 5 wt.% TiO_2 , and 15 min cryogenic treatment as the optimal configuration (Mohammed *et al.* 2024).

Hemp, jute, and kenaf fiber composites also showed significant potential. Hemp/epoxy with graphene oxide achieved a flexural strength of 790 MPa, though excess filler caused agglomeration (Hallad *et al.* 2022). Hemp/flax composites reinforced with basalt powder and SiO_2 exhibited tensile strength of 134.21 MPa and strong damping, making them suitable for aerospace applications (Velmurugan *et al.* 2025). Jute fibers treated

with carboxylated graphene oxide improved conductivity, thermal stability, and strength (Chowdhury *et al.* 2025).

Other natural fibers have also been studied. GO-reinforced sedge/epoxy composites achieved higher impact resistance with reduced delamination (Neuba *et al.* 2025). *Calotropis gigantea* composites with 4.5 wt.% SiO₂ retained strength after water exposure and improved ILSS (Velmurugan *et al.* 2023). Polyester composites hybridized with marble dust and kenaf fibers showed improved wear resistance and mechanical strength, with ANN models successfully predicting wear beyond the tested ranges (Nayak and Satapathy, 2022). Graphene derivatives play a key role in improving composite behavior. Silane-GO-treated cellulose in natural rubber composites increased strength by 16.95% and reduced rolling resistance by 42.26% (Li *et al.* 2024). GO-modified jute/epoxy composites offered high performance with reduced environmental footprint (Islam *et al.* 2023). Composites with 5 wt.% graphene and 25 μ m particles showed optimal mechanical performance, reaching 59 MPa tensile and 236 MPa flexural strength (Kamatchi *et al.* 2023).

Structural, morphological, and reusability characteristics were validated via FTIR and SEM (Mayakannan *et al.* 2022). Artificial intelligence and predictive modeling approaches have been used to accelerate material development. A deep multilayer perceptron achieved over 87% accuracy in predicting tensile, flexural, modulus, and density parameters of natural fiber composites (Sathish *et al.* 2023). Loofa/Al₂O₃/Al-SiC composites' mechanical and thermal properties were also accurately predicted using ANN techniques (Mohit *et al.* 2023b).

Although significant progress has been made in the development of natural fiber and hybrid polymer composites, research integrating flax fibers with graphene oxide (GO) nanoparticles remains notably scarce. In particular, studies exploring the combined enhancement of mechanical properties and predictive modeling for flax-GO reinforced polyester composites are limited. To address this research gap, the present work focuses on fabricating GO-modified flax fiber polyester composites and evaluating their mechanical behavior, including tensile strength, flexural strength, and ILSS. In addition to experimental characterization, an MLP-based predictive model is employed to estimate the mechanical properties, enabling the correlation of microstructural improvements with data-driven performance prediction. This dual approach aims to demonstrate both the material enhancement achieved through GO incorporation and the methodological innovation offered by AI-assisted

prediction models. Overall, the study establishes a pathway for developing sustainable, high-performance composites supported by accurate computational intelligence frameworks.

2. MATERIALS AND METHODS

2.1 Materials

The amalgamation of flax fiber, recognized for its robust flexural and tensile capabilities, with GO nanoparticles and polyester resin yields a hybrid composite. Flax fiber (40 wt.%), polyester resin, and nGO (~50 nm) were used in this study. All materials were procured from local suppliers in Tamil Nadu, India. Flax fiber exhibited several characteristics, including a density of 1.5 g/cm³, a Young's modulus ranging from 10 to 30 GPa, a bundle width of 2 to 10 mm, and a tensile strength between 400 and 980 MPa. The compressive strength, Young's modulus, and density of polyester resin were 28.25 to 78.83 MPa, 0.9 to 0.92 GPa, and 1.11 g/cm³, respectively. Composites derived from renewable fibers, as opposed to synthetic materials, present a more sustainable alternative, hence reducing environmental impact.

2.2 Fabrication Process

The required quantities of flax fiber, nGO, and polyester resin were ascertained using the rule of mixtures and the fundamental equations (Eqs. 1-4). A glass rod was employed to mix the hardener with the polyester resin in a basin. The flax-nGO polyester composite samples were fabricated via the hand layup method due to its simplicity, cost-effectiveness, and flexibility in material arrangement (Meravi and Panchore, 2024b). Four samples were made for each arrangement. The initial phase in the fabrication process was applying a release film to the mold's surface. The hardener was introduced after the amalgamation of the nGO with the polyester resin. After layering the flax fiber plies within the mold, the resin mixture was applied in a drizzle over them. An amalgamation of epoxy resin nGO was utilized on the initial layer of flax before the lamination of the subsequent layer. A 40 kg weight was applied to the mold for 24 hours to ensure that the samples cured and hardened enough. The curing process enabled the composite panels to be removed from the mold and conform to specifications. Specimens were produced for multiple ASTM-standard tests, and the fabrication process is illustrated in Fig. 1. Table 1 presents the comparative volumes of flax fiber, nGO, and polyester resin.

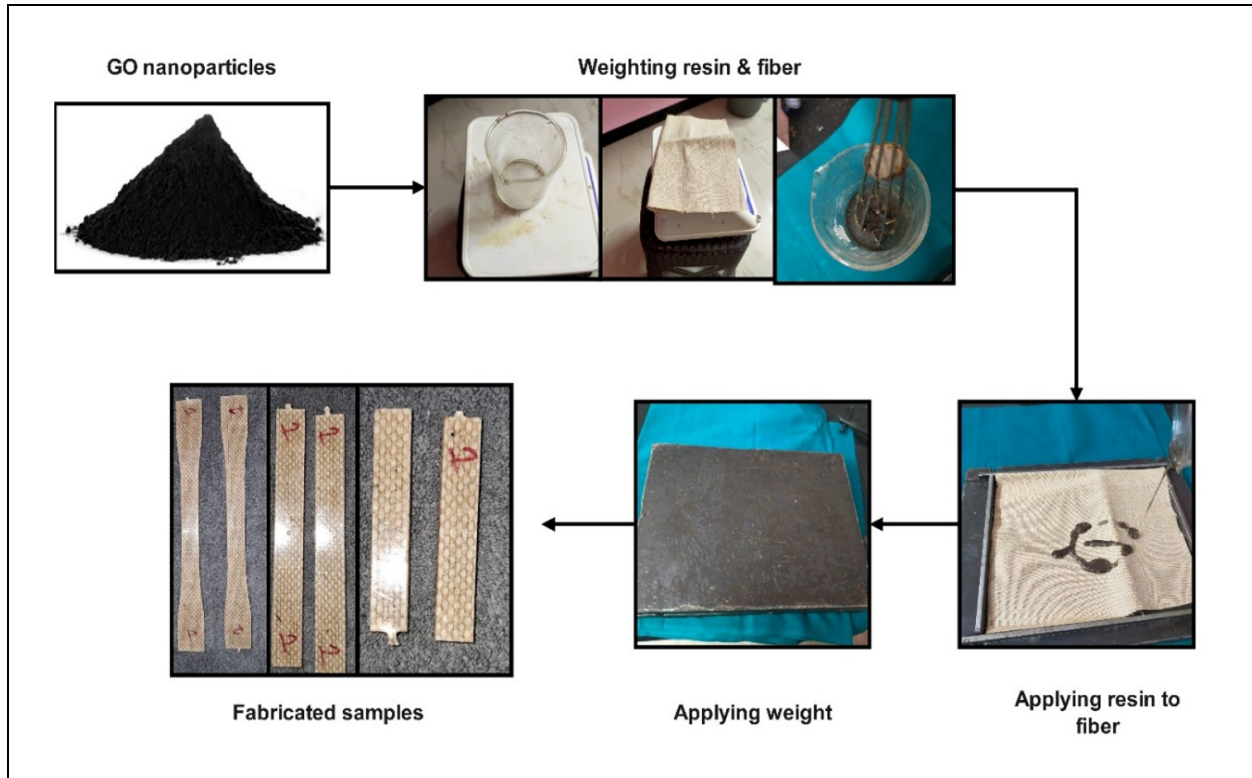


Fig. 1: Fabrication process of the composite sample

Table 1. Different weight percentages of composite samples

S. No.	Wt.% of Flax Fiber	Wt.% of nGO	Wt.% of Polyester Resin	Specimen Code
1	40	1	49	FGO-1
2	40	3	47	FGO-2
3	40	5	45	FGO-3
4	40	7	43	FGO-4

$$\rho_c = \frac{1}{\frac{\text{Wt.\% of flax fiber}}{\rho_A} + \frac{\text{Wt.\% of nGO}}{\rho_B} + \frac{\text{Wt.\% of polyester resin}}{\rho_F}} \quad \dots (1)$$

$$V_A = \frac{\text{Wt.\% of flax fiber} \times \rho_c}{\rho_A} \quad \dots (2)$$

$$V_{GO} = \frac{\text{Wt.\% of GO} \times \rho_c}{\rho_B} \quad \dots (3)$$

$$V_P = \frac{\text{Wt.\% of polyester resin} \times \rho_c}{\rho_P} \quad \dots (4)$$

where, ρ_c , ρ_F , ρ_{GO} , and ρ_P are the densities of the composite configuration, flax fiber, nGO, and polyester resin, respectively. V_F , V_{GO} , and V_P are the volume fractions of flax fiber, nGO, and polyester resin, respectively.

2.3 Experimentation

This study employed a FIE (UNITEK - 94100) Universal Testing Machine (UTM) equipped with a 5 kN load cell (Fig. 2) to perform tensile, flexural, and interlaminar shear strength (ILSS) tests (Gaddala *et al.* 2025). Composite specimens ($250 \times 25 \times 3$ mm) underwent tensile testing at a rate of 2 mm/min, adhering to the specifications outlined in ASTM D3039M-14. A three-point bending test was conducted to evaluate flexural strength, adhering to the specifications of ASTM D-790-03. The testing velocity was established at 2 mm/min. The flexural specimens measured $127 \times 12 \times 3$ mm (Sahayaraj *et al.* 2021). A $60 \times 12 \times 3$ mm specimen was utilized to assess ILSS in compliance with ASTM D2344-00. Five samples for each test were used, and the average values along with standard deviations were calculated for analysis.

Specimens were fabricated to dimensions of $64 \times 12 \times 3$ mm in compliance with ASTM D-256-10 and evaluated for impact performance with an Izod impact tester (Almeida *et al.* 2025). The Rockwell hardness was assessed utilizing a 0.25-inch ball indenter under a 60 kg load, employing a tester calibrated to ASTM D785-10 standards. The fractured specimens from mechanical tests were cut into $\sim 10 \times 10$ mm pieces and ultrasonically cleaned in ethanol to remove debris. The samples were then air-dried and sputter-coated with a thin layer (~ 10 nm) of gold to ensure conductivity. Microstructural

examination was carried out using a ZEISS SEM operated at an accelerating voltage of 30 kV, with magnifications ranging from 500 $\times$ to 5000 $\times$, depending on the fracture features of interest. The analysis focused on interfacial bonding, fiber pull-out, voids, and matrix cracking.

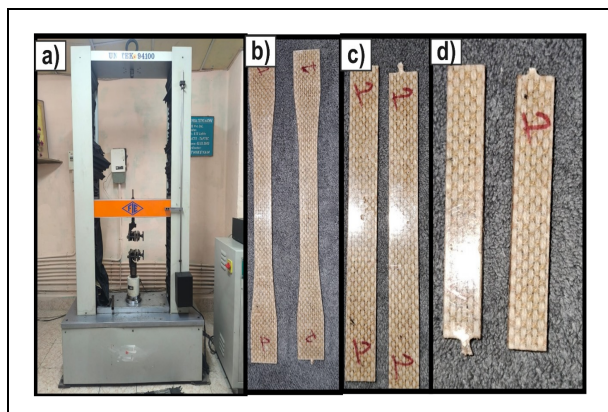


Fig. 2: Pictorial representations of: (a) UTM, (b) tensile specimen, (c) flexural specimen, and (d) ILSS specimen

2.4 Machine Learning Models

An MLP regression model was implemented to predict the tensile and flexural strengths of the composites. The dataset consisted of 200 experimental data points with three input variables (flax fiber wt.%, nGO wt.%, and polyester wt.%) and two output variables (tensile and flexural strengths). The network architecture comprised one input layer with three neurons, two hidden layers with 16 and 8 neurons, and one output layer with two neurons (Fig. 3). Rectified Linear Unit (ReLU) was used as the activation function for the hidden layers, while a linear activation function was applied at the output layer. Training was performed using the Adam optimizer with a learning rate of 0.001, a batch size of 16, and 500 epochs. Data were divided into 80% training and 20% testing subsets. Model evaluation was based on standard regression performance metrics.

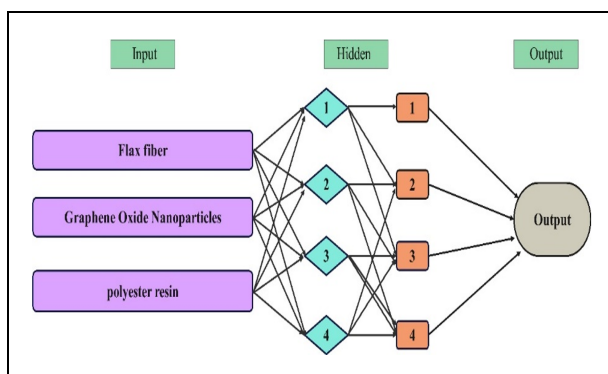


Fig. 3: Structure of the MLP network

3. RESULTS AND DISCUSSION

3.1 Tensile Test Results

Relative to the other composites, the FGO-1 samples exhibited the highest levels of stiffness and tensile strength. The tensile strength and stiffness of FGO-2 samples were lower than those of FGO-1, despite a greater concentration of nGO. FGO-3 samples characterized by a higher concentration of nGO exhibited reduced stiffness and diminished tensile strength compared to FGO-2. FGO-4, a composite with the highest proportion of nGO and the lowest amount of polyester resin, possessed the lowest tensile strength and stiffness. Multiple samples of flax-nGO polyester composites were evaluated for tensile strength and tensile modulus, as illustrated in Fig. 4(a, b). The tensile modulus and tensile strength of the FGO-1 sample were approximately 20%, 12%, and 32% superior, along with tensile strength of 17.21%, 24.59%, and 37.83% respectively, than those of the FGO-2, FGO-3, and FGO-4 samples. Similarly, a cellulose nanofiber-GO hybrid filament achieved a high tensile strength of 439.4 MPa and a Young's modulus of 23.9 GPa (Kim *et al.* 2021).

The increased cellulose content and relatively low microfibril angle, both of which enhance the fiber's tensile strength, are evidenced by the higher proportion of flax fibers in the FGO-1 sample. The FGO-1 specimens were enveloped on both surfaces by a mat of flax fibers surrounding the nGO. The flax fibers exhibited higher nGO concentrations than the central region of the composite. The FGO-1 composite surpassed traditional composite configurations in modulus, fracture strain, and tensile strength.

As the core thickness of a composite material increases, the load is distributed over a broader surface area of the material. If the core material's strength is inadequate to bear this increased load, the composite's overall tensile strength will diminish. This explains the decline in tensile strength and modulus observed in the FGO-2, FGO-3, and FGO-4 specimens as the nanoparticle content increased, which concurrently reduced the load-bearing capacity of the core.

However, the percentage of elongation at break significantly decreases with increasing filler loading, as shown in Fig. 4(a). Polymer chains cannot glide or move freely within a matrix containing fillers, as these additions create physical barriers. The composite's ductility and elongation at break are adversely impacted, as the polymer's capacity to absorb strain diminishes.

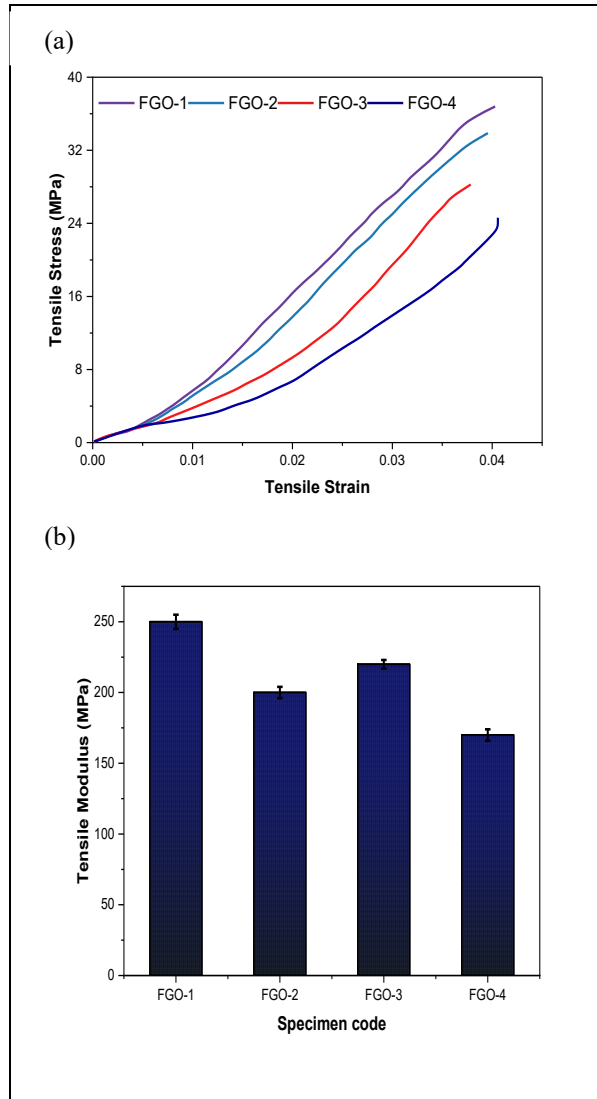


Fig. 4: (a) Tensile stress vs. strain curves for various composites subjected to tensile test, and (b) tensile moduli

3.2 Flexural Test Results

The stress-strain curves shown in Fig. 5(a) are indicative of an enhancement in flexural stiffness as the ratio of nGO decreases from FGO-4 to FGO-1. According to these tendencies, FGO-4 has the most flexibility, whereas FGO-1 demonstrates the greatest stiffness. Furthermore, FGO-1 exhibits the strongest strength, whereas FGO-4 demonstrates the lowest, as the flexural strength escalates from FGO-4 to FGO-1. Fig. 5(a, b) compares the flexural modulus and strength of several flax-nGO polyester composite specimens. Specifically, the flexural modulus of the FGO-1 sample is approximately 14.89%, 31.91%, and 46.80% more than that of FGO-2, FGO-3, and FGO-4, respectively.

Increasing the core thickness in composites results in a more extensive distribution of the applied

load across the core region. This redistribution enlarges the load-bearing region, so imposing greater stress on the core material, despite first appearances of advantage. The flexural performance will be significantly compromised if the core material has sufficient strength to withstand this stress. The composites FGO-2, FGO-3, and FGO-4 exhibit this phenomenon distinctly, as their flexural strength and modulus diminish with an increase in core thickness. The composite's expanded load area subjects the core material to excessive stress beyond its capacity. The matrix's bending load-bearing capability diminishes when it becomes excessively saturated, impairing its ability to bond with and support the reinforcing fibers effectively. The structural damage indicates that the core material lacks sufficient strength to adequately support loads under high flexural stresses, hence compromising the composite's durability.

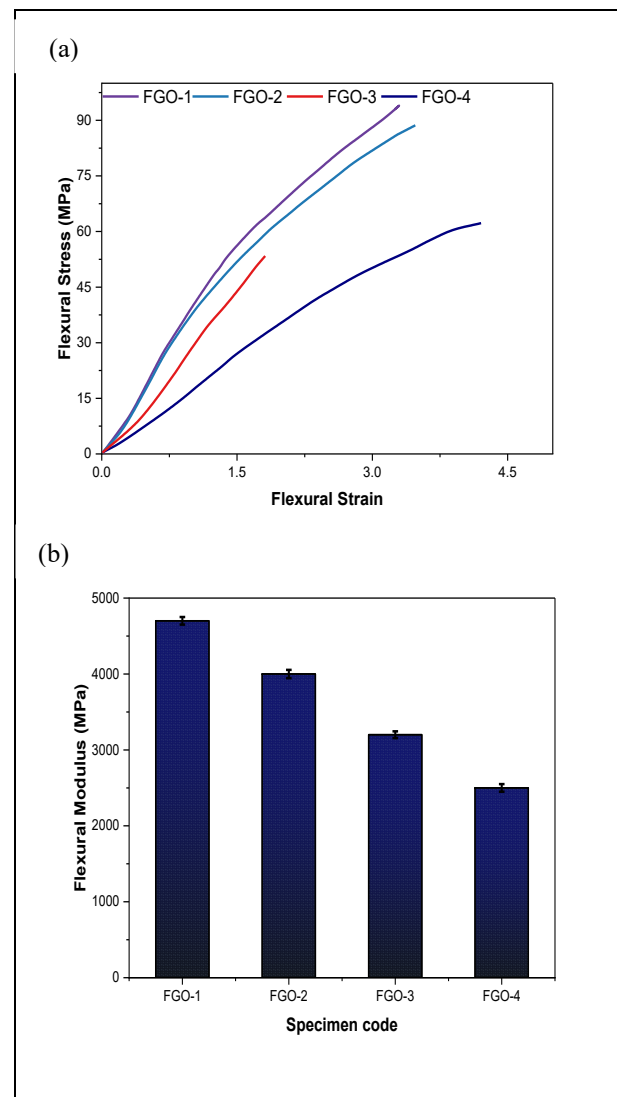


Fig. 5: (a) Flexural stress vs. strain curves for various composites subjected to flexural test, and (b) flexural moduli

The outstanding flexural properties of FGO-1 arise from the balanced structural synergy between flax fiber and the polyester matrix. The flax fibers can endure bending loads efficiently due to the encasing and supportive nature of the innately rigid polyester matrix. The external layers of the composite, which endure the majority of the bending force, maintain their shape due to the structural integrity of flax fibers. The efficacy of this reinforcement is significantly contingent upon the adhesion of the nGO and polyester resin. The composite's stiffness and flexural strength are reduced due to weak points resulting from insufficient interfacial bonding. To achieve optimal mechanical performance, it is crucial to enhance the fiber-matrix interaction. Likewise, the optimal 0.5 wt.% graphene nanoplatelets (GNPs) incorporated into flax/epoxy composites achieved the best tensile and flexural properties. Beyond this threshold, reinforcement declined due to GNP agglomeration (Alipour *et al.* 2021).

3.3 Impact Test Results

Fig. 6 (a, b) illustrates the impact strength and absorbed energy of the flax-nGO polyester composite specimens. The absorbance energy in the FGO-1 sample is approximately 13.46% greater than in the FGO-2 sample, 25% greater than in the FGO-3 sample, and 32.69% greater than in the FGO-4 sample. Its impact strength is approximately 6.25% more than that of FGO-2, 12.5% greater than FGO-3, and 18.75% greater than FGO-4. These findings indicate that FGO-1's enhanced material composition and structural integrity contribute to its superior impact performance. The impact strength of a composite correlates with the core material's capacity to absorb and distribute impact energy, the skin material's resistance to fracture, and the quality of the interfacial bonding between the two components. The FGO-1 sample exhibited enhanced composite strength and stiffness attributable to the augmented quantity of flax fiber in the outer layers. Due to its remarkable toughness, flax fiber can endure impacts and inhibit the propagation of cracks. Furthermore, the flax fibers create a robust interfacial contact that enhances energy absorption and impact resistance, while reducing localized damage and facilitating uniform energy distribution throughout the composite.

The optimal combination of cellulose and hemicellulose in FGO-1 enhances its effectiveness by facilitating the proper dispersion of polyester within the nGO. Enhancing the compatibility between the matrix and reinforcement significantly improves the composite's structural integrity and impact resistance. Conversely, samples FGO-2, FGO-3, and FGO-4 exhibit diminished impact strength and absorbed energy. The elevated core material (nGO) composition is responsible for this

reduction; nGO lacks the necessary robustness and rigidity to absorb and distribute impact energy uniformly.

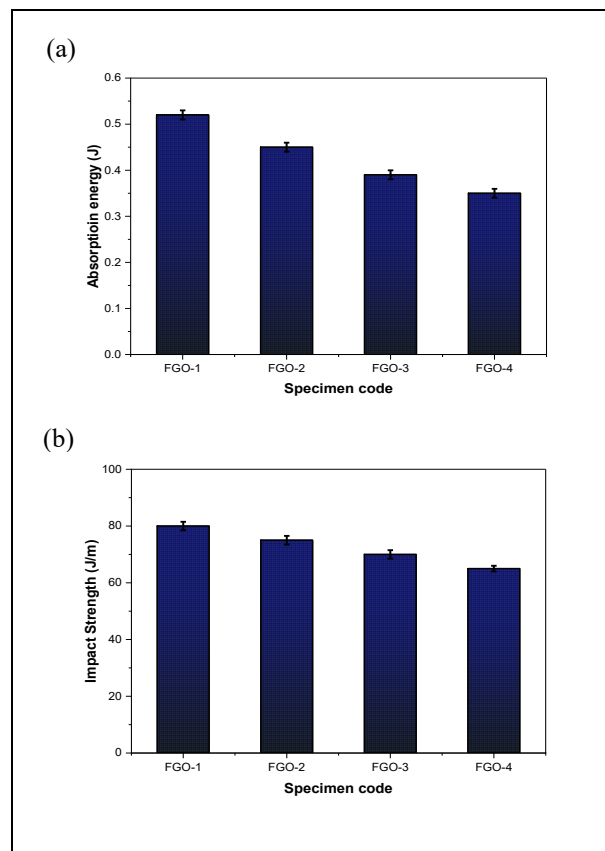


Fig. 6: (a) Absorbed energies for various composites subjected to impact test, and (b) their impact strengths

3.4 Interlaminar Shear Strength (ILSS) Test Results

Fig. 7 (a, b) displays the ILSS of various flax-nGO polyester composites. Relative to FGO-2, FGO-3, and FGO-4, the FGO-1 sample has superior load-bearing capability, exceeding them by approximately 26.66%, 46.6%, and 60%, respectively. Similarly, FGO-1 has superior structural integrity and bonding as demonstrated by its ILSS, which is roughly 12.15% greater than FGO-2, 32.5% greater than FGO-3, and an impressive 50% greater than FGO-4. Similarly, angora fiber composites incorporated with 4.5 wt.% nano-titanium oxide particles showed improved ILSS and hardness. Results showed significant strength improvement with hybrid laminates achieving 37.89 MPa ILSS compared to 28.27 MPa for non-hybrids (Praveenkumar *et al.* 2024).

The FGO-1 sample's material composition is characterized by a reduced proportion of (nGO) and an increased percentage of flax fiber, which contributes to its enhanced ILSS. These composites improve adhesion between the particles and fibers, resulting in superior

load transfer and reduced delamination under stress. The structural function of flax fiber, characterized by its rigidity and high tensile strength, maintains the stability of and aids in its resistance to shear stresses. Conversely, the FGO-2, FGO-3, and FGO-4 samples exhibit diminished load-bearing capacity and interlaminar shear strength (ILSS). The elevated flax fiber composition may be responsible for this, as it diminishes the capacity to attach to the outer layer. The composite's load-bearing capability is reduced due to delamination resulting from shear stress and inadequate interfacial adhesion. These samples illustrate the critical significance of adhesion quality on ILSS, as their inadequate interfacial bonding restricts their capacity to distribute loads equally.

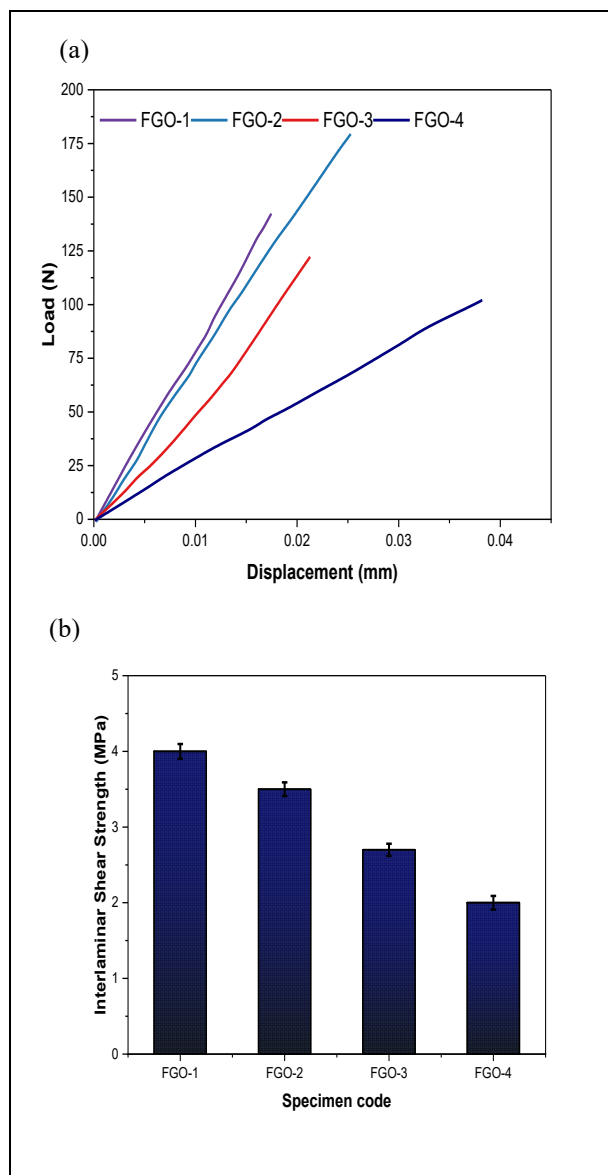


Fig. 7: (a) Load-displacement curves of the composites and (b) their ILSS values

3.5 Rockwell Hardness Number

Fig. 8 illustrates the Rockwell hardness values of various flax-nGO polyester composite specimens, demonstrating considerable variation in their indentation resistance. The FGO-1 sample exhibited remarkable hardness with indentation resistance around 15.38%, 23.07%, and 26.92% superior to FGO-2, FGO-3, and FGO-4, respectively. The enhanced material composition of the FGO-1 sample, characterized by an increased proportion of flax fiber and a reduced fraction of nGO, primarily accounts for its superior performance. The woven structure of flax fibers is crucial for enhancing the hardness of the composite. Flax fibers significantly enhance the composite's resistance to localized deformation under load owing to their superior tensile strength, rigidity, and durability. The uniform load-bearing capacity of the composite is attained through the even distribution of fibers within the matrix and the increased ratio of the flax fibers in FGO-1.

The FGO-2, FGO-3, and FGO-4 samples exhibit reduced hardness values due to a higher concentration of nGO in their cores. Graphene oxide nanoparticles possess higher mechanical strength compared to flax fibers. The uniform dispersion of fibers within the polyester matrix significantly enhances the hardness of the FGO-1 sample. To prevent localized deformation resulting from weak regions, the fibers must be adequately spread to reinforce the matrix. The enhanced mechanical performance and elevated hardness of the composite result from the synergistic features of the FGO-1 fiber and matrix components. Table 2 shows the comparative analysis of the composite samples.

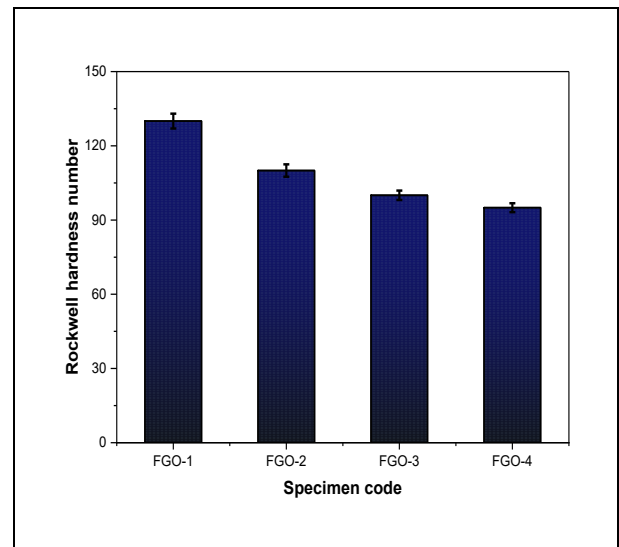


Fig. 8: Rockwell hardness values of various flax-nGO-polyester composites

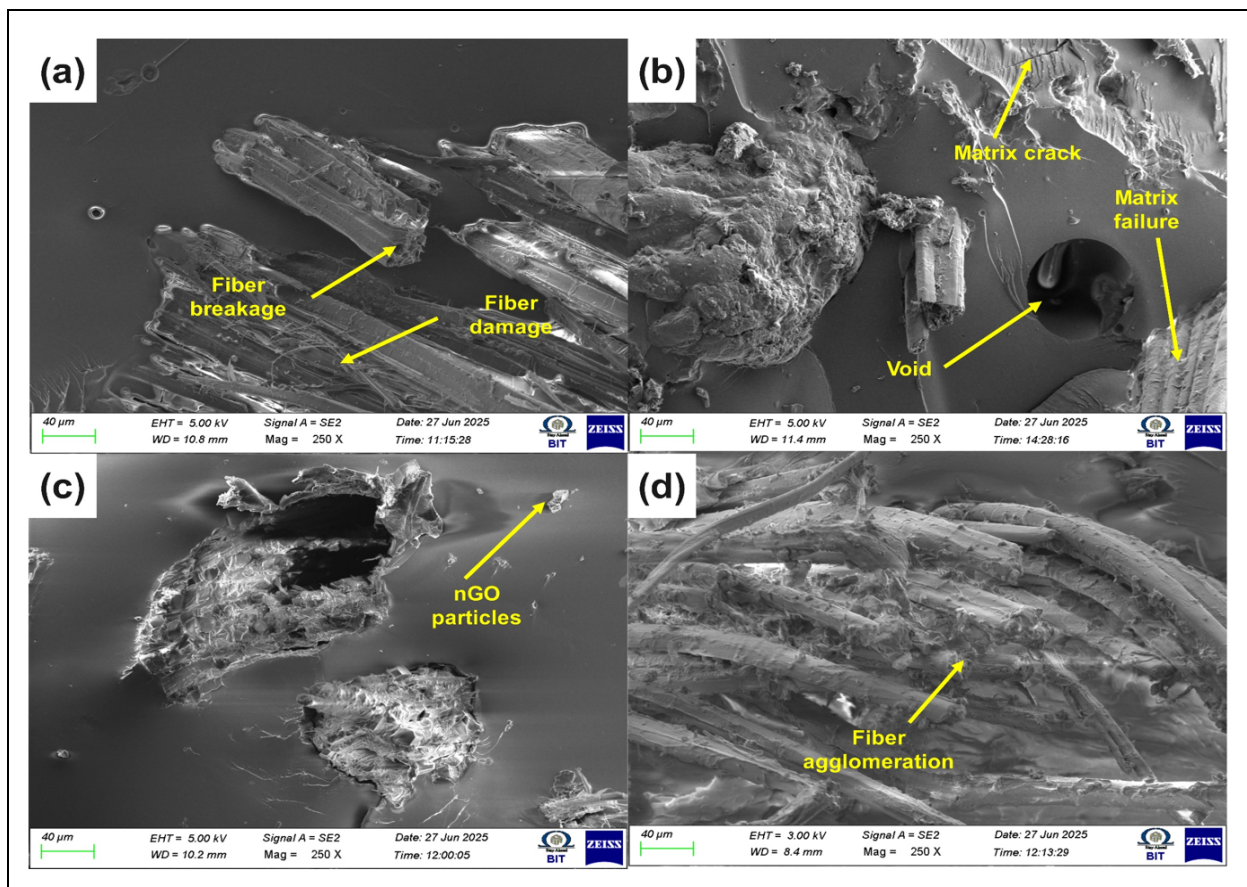
Table 2. Comparative mechanical properties of the composite samples

Property	FGO-1 vs. FGO-2	FGO-1 vs. FGO-3	FGO-1 vs. FGO-4
Tensile strength (%)	+17.21	+24.59	+37.83
Flexural modulus (%)	+14.89	+31.91	+46.80
Impact absorbed energy (%)	+13.46	+25.00	+32.69
ILSS (%)	+26.66	+46.60	+60.00
Hardness (%)	+15.38	+23.07	+26.92

3.6 SEM Analysis

The SEM images display the fracture morphology of flax/nGO-reinforced epoxy composites with varying nGO contents.

Fig. 9(a) depicts the microstructure of the FGO-1 composite, consisting of 40 wt.% flax fiber and 1 wt.% nGO. The image reveals minimal fiber fracture and uniform fiber dispersion. The fine dispersion of nGO improves fiber-matrix adhesion, enhancing mechanical performance through effective load transfer and reduced interfacial defects. Fig. 9(b) shows the FGO-2 composite (40 wt.% flax, 3 wt.% nGO), where signs of fiber debonding and matrix discontinuity emerge. The inadequate nGO distribution results in weaker fiber-matrix bonding, indicating that the nGO content is insufficient to support structural coherence at the interface. Fig. 9(c) depicts the FGO-3 composite with 5 wt.% nGO and 40 wt.% flax. Pronounced fiber pull-out and poor matrix encapsulation are visible, suggesting that excessive nGO begins to hinder matrix flow and interfacial wetting, weakening the composite's structural integrity. Fig. 9(d) illustrates the FGO-4 sample with a higher nGO content with 40 wt.% fiber. A significant presence of porosity and fiber agglomeration is evident, leading to severe disruption in fiber-matrix interaction. The void formation caused by clustering reduces matrix continuity and results in stress concentration zones, ultimately degrading the mechanical properties of the composite. SEM analysis revealed strong fiber-matrix bonding and reduced delamination (Harak *et al.* 2024).

**Fig. 9: SEM images of fractured samples under load: (a) FGO-1, (b) FGO-2, (c) FGO-3, and (d) FGO-4**

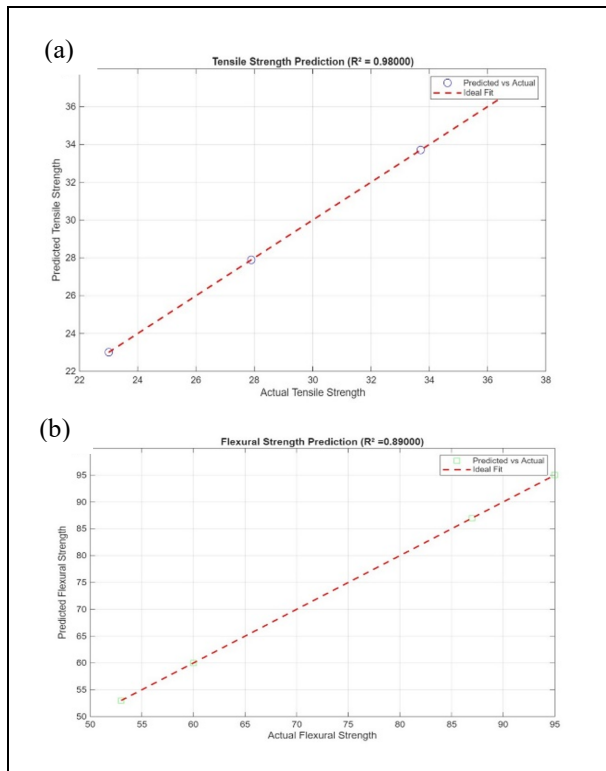


Fig. 10: Predicated vs. experimental: (a) tensile strength and (b) flexural strength

3.7 Machine Learning Model Results

Fig. 10 (a, b) illustrates the disparity between the anticipated and observed tensile and flexural strengths. The findings indicate that the ANN model accurately predicts material strengths, with R^2 values of 0.98 for tensile strength and 0.89 for flexural strength. The interaction coefficients, nearing 1, underscore the robust model correlation and predictive capability, signifying an excellent alignment with the experimental data (Supriya *et al.* 2024b). The reliability of the model is further substantiated by the regression curve, which demonstrates a robust correlation between the expected target values and the network's output, as well as a favorable alignment with the best-fit line.

Iterative fine-tuning and weight adjustments were employed to enhance the model's performance following its training on a dataset of 200 data points, owing to which the projected values closely aligned with the experimental observations. Neural networks, employed in this study, excel at predicting complex material behaviors due to their ability to comprehend non-linear correlations and interactions among many input factors. Moreover, the fiber content emerged as the most influential factor affecting the composite's flexural and tensile strengths, as indicated by the feature importance analysis.

4. CONCLUSION

This study evaluated the mechanical properties of flax-GO polyester composites, specifically their tensile, flexural, impact, and interlaminar shear strengths, underscoring the composite's potential as a sustainable and mechanically superior alternative for automotive interior panel applications. Graphene oxide nanoparticles and flax fibers were incorporated into the composites at varying weight percentages, and their mechanical properties were assessed in accordance with ASTM standards.

- The mechanical characteristics of the FGO-1 sample, including 1 wt.% nGO and 40 wt.% flax fiber, surpassed those of alternative combinations. Its tensile modulus exceeded that of FGO-4 by 7 wt.%, FGO-3 by 5 wt.%, and FGO-2 by 3 wt.%. Its tensile strength was elevated.
- The flexural testing findings indicated that FGO-1 exhibited a superior flexural modulus and enhanced flexural strength compared to FGO-2, FGO-3, and FGO-4, with respective improvements of 14.89%, 31.9%, and 46.80%.
- Regarding energy absorption and impact strength, FGO-1 demonstrated significant superiority over the other samples during impact testing. Moreover, the ILSS test results indicated that FGO-1 exhibited a 26.66% superior load-bearing capability, a 46.6% enhanced shear strength, and a 60% increased shear strength in comparison to FGO-2, FGO-3, and FGO-4. Corroborating these findings, SEM analysis demonstrated enhanced fiber dispersion and a reduction in flaws inside the FGO-1 sample.
- The ANN model accurately predicted both the tensile and flexural strengths of the materials, with R^2 values of 0.98 and 0.89, respectively. The model has great prediction accuracy and a strong relationship, as indicated by interaction coefficients close to 1.
- This study illustrates the potential of eco-friendly flax and nGO composites with improved mechanical properties, based on credible forecasts from ANN models. However, further investigation is required to enhance the composites' applicability in realistic environments; this work solely evaluates their mechanical properties, neglecting their thermal stability and moisture resistance.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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