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Experimental Investigation on the Effect of Prestressing Level on Tensile Properties of Prestressed Glass Fiber Reinforced Polyester Laminates

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A B S T R A C T

This paper experimentally investigates the effect of prestressing levels on the tensile properties of prestressed glass fiber reinforced polyester laminates. A test rig was developed to apply and maintain controlled tensile stress applied to the glass fibers during molding, creating prestressed laminates. Five different prestressing levels of 10%, 20%, 30%, 40%, and 50% were studied. Tensile tests, following ASTM D3039, were conducted on standard specimens with a 29% fiber volume fraction to evaluate the influence of prestressing level on tensile strength, modulus, and energy absorption. Results showed that prestressing significantly enhances the tensile characteristics of the laminates. Even at the lowest prestressing level of 10%, there were notable improvements of 31%, 21%, and 39% in tensile strength, modulus, and energy absorption, respectively. An optimal prestressing level of approximately 28% yielded the highest gains, with substantial increases of 46.5% in tensile strength, 39% in modulus, and 59.5% in tensile energy absorption. Exceeding this level resulted in a decrease in performance, although properties remained superior to non-prestressed laminates. Empirical equations were developed to represent the relationships between the prestressing level and the studied tensile characteristics. These findings suggest that prestressing is a promising method for improving the tensile characteristics of glass fiber reinforced polyester without increasing weight or dimensions. This makes it a valuable material for applications requiring high strength and lightweight properties, such as building facades, automotive body panels, aircraft fuselage panels, marine boat hulls, and wind turbine blades.

1. Introduction

Fiber reinforced polymer (FRP) composites are widely used in various engineering applications, including cladding for other materials, tissue engineering, casting molds, car bodies, aerospace, wind turbine blades, marine, construction, retrofitting of existing structures and sustainable engineering [1-4]. Compared to traditional materials, FRPs have impressive characteristics, such as corrosion resistance, lightweight, and high strength [5]. The mechanical characteristics of FRP composites are influenced by various factors, including constituent material properties, fiber volume percentage, manufacturing procedures, and fabrication methods [6,7]. Fiber reinforced polymer (FRP) composite laminates possess the capacity for customization to satisfy distinct requirements through the selection of various fibers and resins. This capability allows precise control of the material's properties, including strength, stiffness, weight, and economic expenditure. [8,9]. Owing to their exceptional properties, such as strength, stiffness, and cost-effectiveness, glass fiber reinforced polymer (GFRP) composites, which are composed of polyester resin and glass fiber, have become a popular choice. [10]. Thermal expansion mismatch during curing creates residual stresses that can weaken the composite [11,12]. Additionally, GFRP manufacturing methods can introduce defects such as fiber waviness, and voids [13]. Applying a pre-tension during GFRP manufacturing is a promising technique to reduce these defects [14]. To improve the performance of GFRP composites, a fiber prestressing technique is used. It involves applying a specific load to the fibers before the resin cures to create compressive stress in the cured resin [15-17]. The applied load is maintained throughout the curing process in the elastic method, while in the viscoelastic method, the load is applied before the molding stage [18-19]. The elastic method is generally preferred for applications requiring high performance [20]. A study by Al-Hassany et al. [21] found that a deadweight-prestress method using glass fiber and polymer resin led to increased stiffness and total elongation in the resulting composite. A low-intensity pre-load treatment effectively enhanced the tensile characteristics of a glass fiber-epoxy composite with a 10% fiber volume fraction. The greatest improvement was observed at a preload value of 10N. Nawras et al. [22] observed that prestressing glass fiber composites improved fatigue life by 43% at a prestress level of 50MPa for woven glass fiber type E with polyester resin. Additionally, prestressing of knitted glass fiber with the same resin improved their stiffness and fracture resistance by about 10-20% [23]. Mohamed et al. [24] demonstrated that applying a specific tension of 60 MPa during the preparation of FRP composites significantly improved their strength. Compared to non-prestressed materials, these composites exhibited increases of 28.6% in tensile strength, 100.4% in compression strength, and 26.1% in flexural strength. Mohamed et al. [25] investigated the impact of fiber pretension on glass fiber/vinyl-ester composite rebars, the results showed that pre-tensioned rebars had improved fiber alignment and reduced void content. The highest gain in tensile characteristics, as well as reduced moisture absorption and surface deterioration, were demonstrated by rebars with a pretension of 30 MPa. Chen et al. [26] have developed a technique to counterbalance the thermal residual stress that occurs during the curing process of polymeric composites. They used a prestress level of 90 MPa, which increased the impact strength and elongation at the break by 11% and the tensile strength by 15%, respectively. This indicates an overall enhancement in toughness for the composite material. Abdullah and Hassan [27] introduced the jack prestress method and studied how altering the level of pretension affects the durability of a carbon fiber reinforced composite laminate. This method involves using a jack to apply the required tensile force for prestressing, followed by curing the composite in an oven. There are ongoing efforts to enhance the durability of glass fiber reinforced polymer composites. This is being achieved by enhancing the materials used to make the composites and by improving the manufacturing processes [28-30]. Since the cost of producing the GFRP is divided between the materials and the fabrication, the emphasis on upgrading manufacturing methods is still justified to enhance the GFRP composite's total functionality.

This study experimentally investigates the effect of unidirectional fiber prestress on the tensile characteristics of prestressed glass fiber reinforced polyester (PGFRP) laminates, including tensile strength, modulus, and energy absorption capacity. Consequently, identify the optimal prestressing level for maximizing the tensile characteristics of PGFRP. A custom laboratory rig was designed and developed to provide a predetermined constant tension to the fiber filaments throughout the molding and curing of PGFRP laminates. The PGFRP laminates were fabricated with five different prestressing levels of 10%, 20%, 30%, 40%, and 50%, beside a control laminate for comparison, while maintaining a constant fiber volume fraction of 29%. Tensile tests were performed on specimens following ASTM D3039.

2. Materials and prestressing technique

2.1. Materials

This study used glass fiber filaments, type E, sourced from Jushi Group, Egypt, and a commercially available polyester resin to produce PGFRP specimens. The density of both the glass fiber and polyester resin was determined using the ASTM D792-20 standard. Methyl Ethyl Ketone Peroxide (MEKP) was used as a curing agent for the polyester resin in a 1:100 volume ratio, as recommended by the manufacturer.

To evaluate the ultimate strength of tension of the polyester resin, three test specimens were prepared according to ASTM A370. The ultimate strength of tension of both the glass fiber filaments and polyester resin was experimentally measured following ASTM D3379. Each experiment was repeated three times with different specimens. The average property values for the composite's constituent materials are summarized in Table 1.

Table 1: The characteristics of polyester resin and the glass fiber

	Glass fiber	Polyester resin
Density (g/cm^3)	**2.490**	**1.124**
Ultimate strength (kN/ cm^2)	**86.05**	**4.134**
Tensile modulus (kN/ cm^2)	**1464.92**	**216.43**

2.2. Fiber prestressing rig

A pre-tensioning rig designed for applying a controlled uniaxial pre-tensile force to glass fiber filaments is shown in Figures 1 and 2. The rig designed as an open mold and consists of two vertical side guides and three horizontal bases, manufactured from hollow rectangular cross-section steel ducts. The upper and lower bases are rigidly attached to the side guides, while the middle base can slide freely along their vertical tracks. A fine-pitch screw jack mechanism, located between the lower and middle bases, generates the pre-tensile stress. Two digital load cells suspended from the upper base and connected to the ends of the fiber filament accurately measure the applied pre-tensile load. This configuration ensures that the glass fiber filaments remain consistently parallel and evenly spaced throughout the molding process.

2.3. Calculation of required pre-tension force

Under uniaxial tension applied along a principal axis of the composite material, the applied load translates to normal stress, denoted by σ_1. Since the composite material is orthotropic, it deforms similarly to an isotropic material when loaded in uniaxial tension along one of its principal axes [21]. The normal stress in the composite material can be calculated as the following equation:

$$\sigma_1 = \sigma_f + \sigma_m \quad (1)$$

Where σ_f and σ_m are the stresses in the fiber and resin, respectively. Since the uncured matrix has negligible stiffness and is assumed to carry no stress (σ_m=0), the normal stress (σ_1) in the composite material becomes equal to the stress in the fiber. This can be expressed as follows:

$$\sigma_1 = \sigma_f \quad (2)$$

It is imperative to keep the pre-tensile stress during matrix curing below the glass fiber's elastic limit (σ_{fe}) This ensures efficient transfer of the pre-tensile stress to the treated matrix as compressive stress and minimizes losses. Therefore, the prestressing level is typically chosen as a percentage of the ultimate tensile strength of the fiber filaments. The required pre-tension force (F) can be found by applying the following formula:

$$F = \text{Prestressing level} \times \sigma_{fe} \times A \quad (3)$$

To determine the cross-sectional area of the fiber filament (A), the dry weight of three randomly chosen glass fiber filament specimens with a known length of L = 470 mm was measured. The volume of each specimen was then calculated using the glass fiber density reported in Table 1. Finally, the average value of the cross-sectional area was utilized.

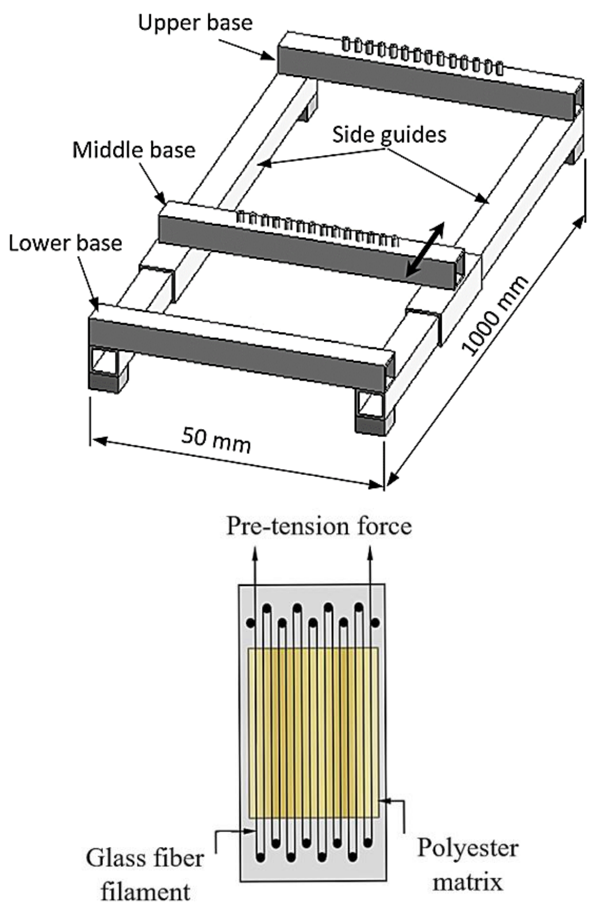

Figure 1: Schematic of the uniaxial fiber prestressing test rig

3. Production of PGFRP specimens and test method

3.1. Manufacturing PGFRP composite laminates

The production of PGFRP laminate utilizes the hand layup method at room temperature adhering to ASTM D3039. This method offers a cost-effective way to produce composite parts in small quantities. To ensure the necessary prestressing, a specific tension load is applied to the aligned glass fiber filaments and maintained throughout the curing of the matrix material. Glass fiber mats are used to achieve a fiber volume fraction of approximately 29% The laminate is then compressed between two rigid wooden plates using screw bolts to ensure uniform laminate thickness and remove any trapped air. Melinex sheets are placed between the wooden plates and the PGFRP laminate to facilitate demolding after curing and to contribute to a smooth surface on the finished PGFRP laminate. The compressed state is maintained for approximately 24 hours to ensure that the resin system completely cures. Five distinct PGFRP laminates with different prestressing levels of 10%, 20%, 30%, 40%, and 50% were produced, along with an additional control laminate fabricated without any prestress for comparison purposes. The final dimensions of all laminates are 150 mm in width, 400 mm in length, and 2.5 mm in thickness, as shown in Figure 3.

Figure 2: Image showing the uniaxial prestressing test rig used to prepare the PGFRP laminates

Figure 3: Manufactured prestressed glass fiber reinforced polyester composite laminate

3.2. Preparing PGFRP specimens

To investigate the effect of different levels of fiber prestressing on the tensile characteristics of PGFRP composite laminates and determine the optimal prestressing level, five test specimens were cut from each fabricated PGFRP laminate, resulting in five sets of test specimens with prestressing levels of 10%, 20%, 30%, 40%, and 50%, resulting in a total of 25 specimens. Additionally, five non-prestressed control specimens were obtained. All the specimens were of the same dimensions (30 mm width, 400 mm length, and 2.5 mm thickness) as depicted in Figure 4. The preparation process followed the ASTM D3039 standard [31], which specifies dimensions and testing procedures for tensile testing of the polymeric composite materials.

Figure 4: Manufactured prestressed glass fiber reinforced polyester composite test specimens

3.3. Tensile test and measurement setup

Figure 5 shows the equipment used for the tensile tests. Tensile tests were performed on PGFRP specimens with varying prestressing levels to evaluate their tensile characteristics, including tensile strength, modulus, energy absorption, and failure strain.

The tests were conducted on a universal testing machine according to ASTM D3039 standards. The crosshead speed was kept at 0.2 mm/min, and the tests took place at room temperature. To measure the strain, an extensometer with a gauge length of approximately 250 mm was attached to the specimen. This gauge length provides a representative region for strain measurement, ensuring accurate strain measurement and compliance with the standard. Each specimen was gradually loaded until failure occurred. The loads and the corresponding displacements were recorded. Five replicates were performed for each prestressing level to ensure data reliability.

4. Results and Discussion

The variation of the resulting displacement of the test specimens with the applied tensile load for the 0% (control) and 10% prestressing levels are shown in Figures 6 and 7. The figures depict that the force-displacement behaviors for the five tested specimens in each case were nearly identical. This consistency in behavior highlights the uniformity of the material's properties and the homogeneity of the PGFRP specimens produced.

Figure 5: Tensile test and measurement setup

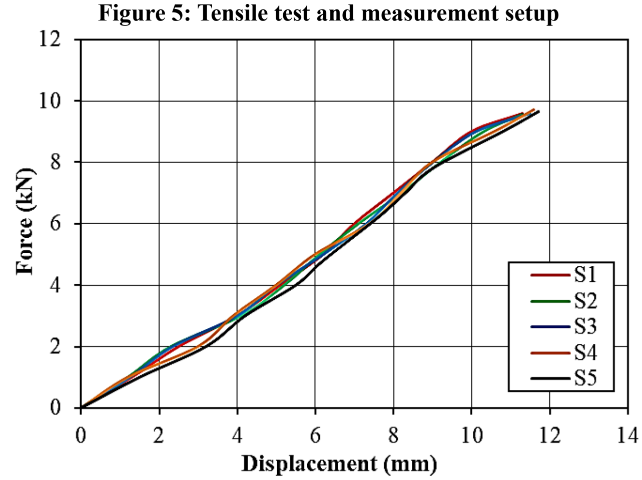

Figure 6: The relationship between applied load and displacement for five control specimens, labeled S1 to S5

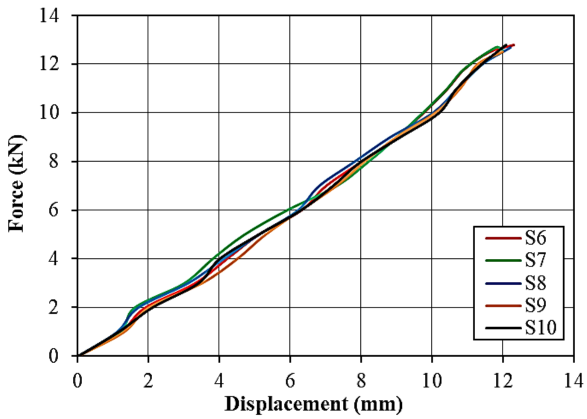

Figure 7: The relationship between applied load and displacement for five 10% prestressing level specimens, labeled S6 to S10

The average of the recorded measurements of the five specimens for each prestressing level were calculated and the results are illustrated in Figure 8, which depicts the variation of average displacements with the average applied tensile loads for different prestressing levels. The force-displacement relationship exhibited nearly linear behavior, with a sudden break occurring at specimen failure. The solid lines on the graph indicate a linear fit. The average values of displacement and force at failure were utilized to calculate the strength and strain of the specimens for comparison purposes.

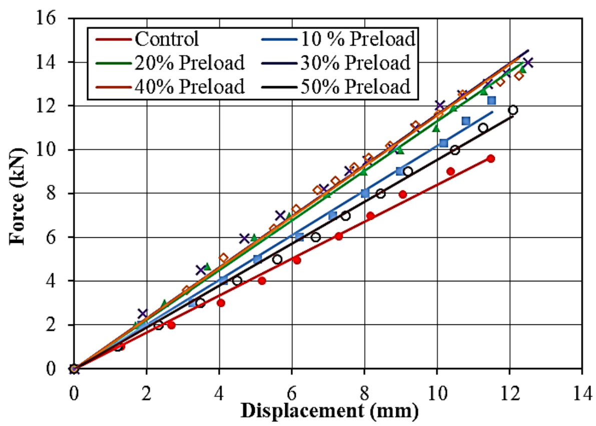

Figure 8: Variation of the average force and average displacement for different prestressing levels

Referring to Figure 9 it is evident that all PGFRP specimens displayed a brittle fracture mode during tensile testing. The failure of the specimens was characterized by matrix cracks, fiber fractures, and separation into two pieces, with the failure occurring mainly within the middle third of the specimens. The absence of extensive debonding (separation of fibers from the polyester matrix), suggests strong adhesion at the fiber-polyester interface in the manufactured specimens. This indicates good load transfer between fibers and the matrix, as debonding typically occurs at weak interfaces.

Figure 9: The failure mode of the tested PGFRP specimens

Figure 10 illustrates the variation in strength of tension of the PGFRP with the applied prestressing level. The tensile strength of the PGFRP shows a marked improvement as prestressing levels rise compared to the non-prestressed case. For instance, when the prestressing level is increased to 10%, the tensile strength increases from about 127 MPa to 170 MPa. This indicates a significant reinforcement effect from the prestressing process.

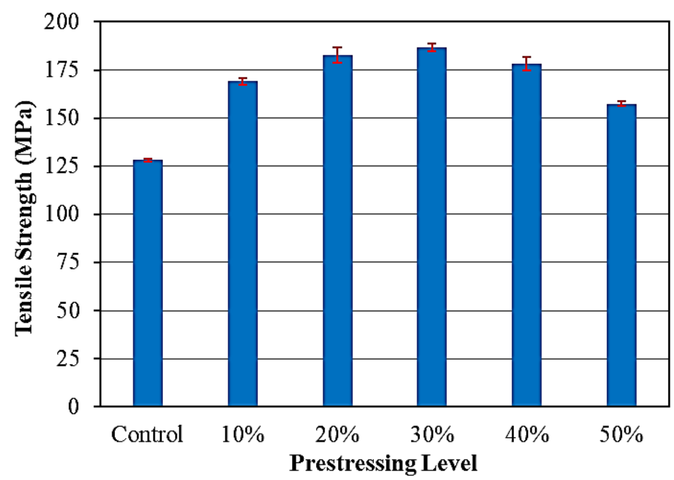

Figure 10: Variation of the tensile strength of the PGFRP with prestressing levels

The tensile modulus was determined by calculating the slope of the linear region in the stress-strain curve for each prestressing level. Figure 11 illustrates the variation of the tensile modulus with the prestressing levels. The tensile modulus of the PGFRP enhances as the prestressing levels increase. Even at the lowest applied prestressing level, the modulus rose from about 2700 MPa to 3500 MPa when the prestressing level reached 10%.

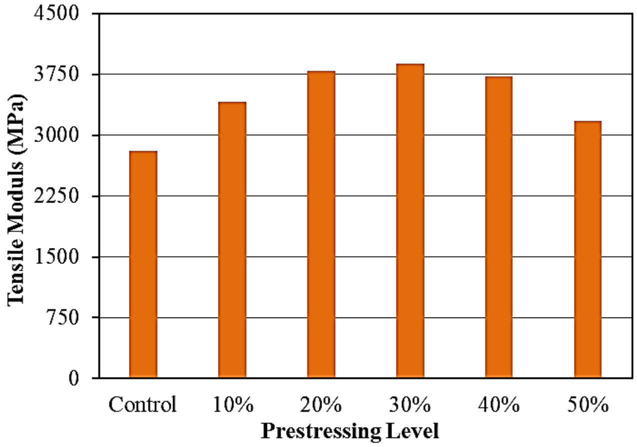

Figure 11: Variation of the tensile modulus of the PGFRP with prestressing levels

Prestressed PGFRP laminates show significantly improved tensile energy absorption (TEA) compared to their non-prestressed counterparts, as demonstrated in Figure 12. TEA is a crucial property for materials utilized in applications requiring impact or shock resistance. By increasing TEA capacity, prestressing broadens the potential applications of PGFRP laminates in structural and industrial fields. Additionally, prestressing results in increased fracture strain in PGFRP, as illustrated in Figure 13. This improvement can be traced back to the compressive stress induced in the polyester resin by prestressing, which delays or prevents crack initiation. As a result, the tensile strength and overall fracture toughness of the material are enhanced.

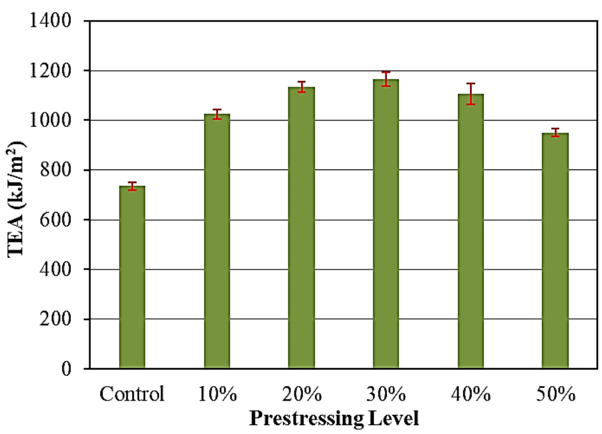

Figure 12: Variation of the TEA of the PGFRP with prestressing levels

Figures 14, 15, and 16 illustrate the variances of the strength of tension, tensile modulus, and energy absorption of the PGFRP with the prestressing levels. These properties are expressed as percentages relative to the non-prestressed case. it can be remarked that the relationships between these properties and the prestressing level are not straightforward. Therefore, a curve fitting analysis was conducted on each relationship to approximate and obtain empirical equations describing the tensile characteristics of PGFRP dependent on the fiber prestressing level. The curves demonstrate a smooth trend, indicating high consolidation and bonding of the composite components,

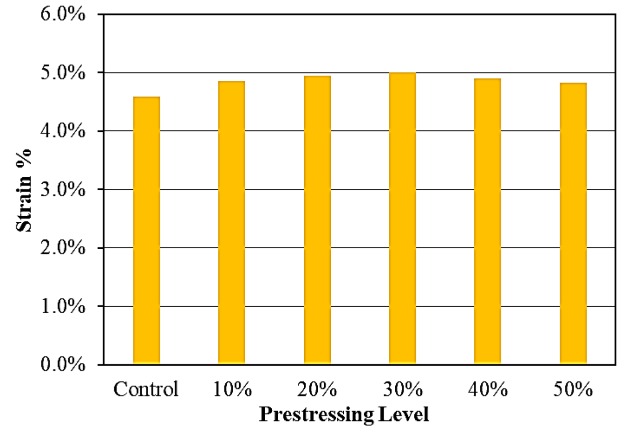

Figure 13: Variation of the fracture strain of the PGFRP with prestressing levels

Figures 14, 15, and 16 illustrate the variances of the strength of tension, tensile modulus, and energy absorption of the PGFRP with the prestressing levels. These properties are expressed as percentages relative to the non-prestressed case. it can be remarked that the relationships between these properties and the prestressing level are not straightforward. Therefore, a curve fitting analysis was conducted on each relationship to approximate and obtain empirical equations describing the tensile characteristics of PGFRP dependent on the fiber prestressing level. The curves demonstrate a smooth trend, indicating high consolidation and bonding of the composite components,

Referring to Figure 14, it can be remarked that the strength of the PGFRP increased by about 31% compared to the non-prestressed case when the prestressing level was raised to 10%. This improvement continued smoothly until the prestressing level reached around 28%. Beyond this value, the relative tensile strength began to decrease as the prestressing level increased, reaching a minimum of 23% at 50% prestressing. Furthermore, the relationship between the relative tensile strength and prestressing level shows that tensile strength is maximized by 46% at a prestressing level of 28%. Based on the fitted curve, the correlation between the relative tensile strength of the PGFRP laminates and the prestressing level (X) can be represented by the following equation:

$$\text{Relative tensile strength\%} = 502.49X^3 - 934.19X^2 + 387.9X \quad (4)$$

Figure 15 shows that the relative tensile modulus follows a similar trend to the relative tensile strength as the prestressing level increases. The most significant improvement in modulus, which is 39%, occurs at approximately 28% prestressing level. This behavior can be explained by the impact of prestressing on fiber alignment. Moderate prestress straightens the fibers in the PGFRP composite, reducing microscopic waviness. Straighter fibers are stiffer and can carry higher loads, resulting in an overall increase in the tensile modulus. Based on the fitting curve, the correlation between the relative tensile modulus of the presented PGFRP laminates and the prestressing level (X) can be represented by the following equation:

Relative tensile modulus% $= -218.53\ X^3 - 337.22\ X^2 + 249.85X$ (5)

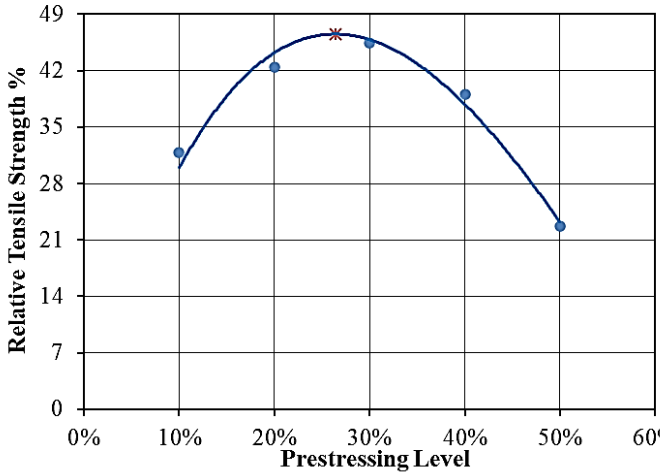

Figure 14: Variation of the relative tensile strength of the PGFRP with prestressing levels

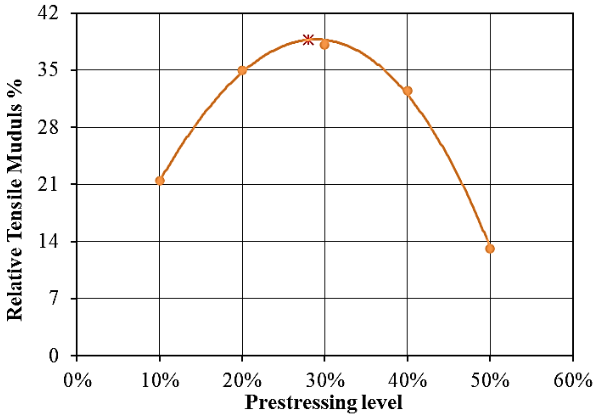

Figure 15: Variation of the relative tensile modules of the PGFRP with prestressing levels

Figure 16 shows the effect of prestressing on the relative tensile energy absorption of PGFRP. The relative TEA smoothly increases with higher prestressing levels, reaching a maximum enhancement of 59% at the optimum prestressing level of 28%. However, further increases in prestressing lead to a decline in relative TEA. There are two opposing forces that affect this behavior. Prestress helps to reduce micro-cracks and voids within the PGFRP, making it stronger, allowing it to absorb more energy before failure. However, excessive prestressing can harm the material's structure and cause the fibers to separate from the matrix, these issues make the material less able to absorb energy. When the prestressing goes beyond the optimal value (28%), the damage to the material's structure outweighs the benefits of closing the micro-cracks, resulting in a decrease in the material's ability to absorb energy. Based on the fitting curve, the correlation between the relative tensile energy absorption of the presented PGFRP laminates and the prestressing level can be represented by the following equation:

Relative tensile energy absorption% $= 484.98X^3 - 1072X^2 + 474.05X$ (6)

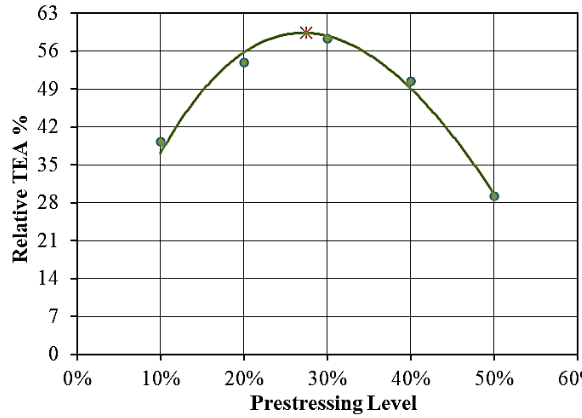

Figure 16: Variation of the relative TEA of the PGFRP with prestressing levels

5. Conclusions

This study demonstrates the effectiveness of fiber prestressing technique to improve the tensile properties glass fiber reinforced polyester laminates while maintaining the same weight and dimensions. The improvements observed were attributed to reduced fiber waviness and compression residual stress inside the treated polyester matrix. The following concluding remarks can be derived from the findings acquired:

1. Tensile strength improved by 23-46.5%, modulus by 13-39%, and energy absorption by 29-59.5% compared to the non-prestressed case.
2. A lower prestressing level of 10% led to greater improvements in tensile properties (9% for strength, 8% for modulus, and 10% for energy absorption) compared to a higher level of 50%.
3. The optimum prestressing level of 28% maximizes the improvement of PGFRP tensile properties, achieving increases of 46.5% in strength, 39% in modulus, and 59.5% in energy absorption.
4. Excessive prestressing may lead to damage to the composite structure or cause debonding between fibers and the matrix. The appropriate prestressing value is crucial for maximizing benefits.
5. The introduced empirical equations provide a suitable tool for estimating the prestressing level and predicting its effects on the tensile properties of PGFRP laminates.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] D. C. William, Materials science and engineering: an introduction. John wiley, 2014.

[2] O. Fraile-Martínez et al., “Applications of polymeric composites in bone tissue engineering and jawbone regeneration,” Polymers (Basel), vol. 13, no. 19, p. 3429, 2021.

[3] A. Meshref A, M. AA, E.-G. MA, and A. WY, “Wear behavior of hybrid composite reinforced with titanium dioxide nanoparticles,” Journal of Advanced Engineering Trends, vol. 39, no. 1, pp. 89–101, 2020.

[4] N. E. Elzayady and E. I. Elghandour, “Fracture resistance of composite structurs from hemp bio-fibers,” Journal of Advanced Engineering Trends, vol. 40, no. 2, pp. 137–147, 2021.

[5] B. Parveez, M. I. Kittur, I. A. Badruddin, S. Kamangar, M. Hussien, and M. A. Umarfarooq, “Scientific advancements in composite materials for aircraft applications: a review,” Polymers (Basel), vol. 14, no. 22, p. 5007, 2022.

[6] S. G. Advani and K.-T. Hsiao, Manufacturing techniques for polymer matrix composites (PMCs). Elsevier, 2012.

[7] N. Khodadadi, H. Roghani, E. Harati, M. Mirdarsoltany, F. De Caso, and A. Nanni, “Fiber-reinforced polymer (FRP) in concrete: A comprehensive survey,” Constr Build Mater, vol. 432, p. 136634, 2024.

[8] T. J. Reinhart, “Overview of composite materials,” in Handbook of composites, Springer, 1998, pp. 21–33.

[9] M. F. Mahmoud and A. Elnaby, “Experimental investigation of the relief time for fiberglass/epoxy composites with volume fraction 30% and 40%,” Port-Said Engineering Research Journal, vol. 24, no. 1, pp. 141–147, 2020.

[10] T. W. Clyne and D. Hull, An introduction to composite materials. Cambridge university press, 2019.

[11] B. Benedikt, M. Kumosa, P. K. Predecki, L. Kumosa, M. G. Castelli, and J. K. Sutter, “An analysis of residual thermal stresses in a unidirectional graphite/PMR-15 composite based on X-ray diffraction measurements,” Compos Sci Technol, vol. 61, no. 14, pp. 1977–1994, 2001.

[12] M. Mohamed, S. Brahma, H. Ning, and S. Pillay, “Development of beneficial residual stresses in glass fiber epoxy composites through fiber prestressing,” Journal of Reinforced Plastics and Composites, vol. 39, no. 13–14, pp. 487–498, 2020.

[13] A. S. Hadi and J. N. Ashton, “On the influence of pre-stress on the mechanical properties of a unidirectional GRE composite,” Compos Struct, vol. 40, no. 3–4, pp. 305–311, 1997.

[14] X. Lin et al., “Durability of viscoelastic fibre prestressing in a polymeric composite,” Polymers (Basel), vol. 15, no. 4, p. 811, 2023.

[15] S. Mojtahedzadeh and Y. Rostamiyan, “Effect of pre-stress on tensile strength of glass fiber epoxy composite,” Journal of Innovative Research in Engineering Sciences; Vol, vol. 3, no. 3, 2017.

[16] L. I. U. Zhendong, X. Zheng, F. A. N. Wenjing, W. Fei, S. Ahmed, and Y. A. N. Leilei, “An alternative method to reduce process-induced deformation of CFRP by introducing prestresses,” Chinese Journal of Aeronautics, vol. 35, no. 8, pp. 314–323, 2022.

[17] P. Choudhari, V. Kulkarni, and S. Khandal, “Review on efforts to improve the mechanical performance of Fiber-Reinforced Polymer (FRP) composites under the Marine Environment,” Journal of The Institution of Engineers (India): Series C, vol. 105, no. 1, pp. 241–269, 2024.

[18] Y. Qin and K. S. Fancey, “Drop weight impact behaviour of viscoelastically prestressed composites,” Compos Part A Appl Sci Manuf, vol. 131, p. 105782, 2020.

[19] X. Chang, X. Wang, C. Liu, Z. Wu, and M. Noori, “Anchoring and stressing methods for prestressed FRP plates: State-of-the-art review,” Journal of Reinforced Plastics and Composites, p. 07316844241258864, 2024.

[20] N. H. Mostafa, Z. N. Ismarrubie, S. M. Sapuan, and M. T. H. Sultan, “Fibre prestressed polymer-matrix composites: a review,” J Compos Mater, vol. 51, no. 1, pp. 39–66, 2017.

[21] M. O. A. Al-hassany, “The effect of unidirectional pre-load on tensile characteristics of E-glass fiber and epoxy composite,” Mater Today Proc, vol. 42, pp. 2510–2515, 2021.

[22] N. H. Mostafa, Z. N. Ismarrubie, S. M. Sapuan, and M. T. H. Sultan, “Effect of fabric biaxial prestress on the fatigue of woven E-glass/polyester composites,” Mater Des, vol. 92, pp. 579–589, 2016.

[23] N. H. Mostafa, Z. N. Ismarrubie, S. M. Sapuan, and M. T. H. Sultan, “Effect of equi-biaxially fabric prestressing on the tensile performance of woven E-glass/polyester reinforced composites,” Journal of Reinforced Plastics and Composites, vol. 35, no. 14, pp. 1093–1103, 2016.

[24] M. Mohamed, M. M. Selim, H. Ning, and S. Pillay, “Effect of fiber prestressing on mechanical properties of glass fiber epoxy composites manufactured by vacuum-assisted resin transfer molding,” Journal of Reinforced Plastics and Composites, vol. 39, no. 1–2, pp. 21–30, 2020.

[25] M. Mohamed, H. Ning, and S. Pillay, “Manufacturing of prestressed glass fiber reinforced polymer rebars and effect of fiber pretension on durability of rebars after conditioning in alkaline solution,” J Compos Mater, vol. 56, no. 26, pp. 4011–4024, 2022.

[26] H. Chen et al., “Elastic fibre prestressing mechanics within a polymeric matrix composite,” Polymers (Basel), vol. 15, no. 2, p. 431, 2023.

[27] O. A. Abdullah and A. K. F. Hassan, “Effect of prestress level on the strength of CFRP composite laminate,” Journal of Mechanical Science and Technology, vol. 30, pp. 5115–5123, 2016.

[28] R. O. Ogunleye and S. Rusnakova, “A review of prestressed fibre-reinforced polymer matrix composites,” Polymers (Basel), vol. 14, no. 1, p. 60, 2021.

[29] L. I. U. Zhendong, X. Zheng, F. A. N. Wenjing, W. Fei, S. Ahmed, and Y. A. N. Leilei, “An alternative method to reduce process-induced deformation of CFRP by introducing prestresses,” Chinese Journal of Aeronautics, vol. 35, no. 8, pp. 314–323, 2022.

[30] A. Jokūbaitis and J. Valivonis, “An analysis of the transfer lengths of different types of prestressed fiber-reinforced polymer reinforcement,” Polymers (Basel), vol. 14, no. 19, p. 3931, 2022.

[31] As. M. ASTM, “ASTM D3039-standard test method for tensile properties of polymer matrix composite materials,” Book ASTM D3039-standard test method for tensile properties of polymer matrix composite materials (ASTM International, 2017), vol. 360, 2017.