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THE EFFECT OF EQUI-BIAXIALLY PRE-TENSIONING LOAD ON THE MECHANICAL PROPERTIES OF GLASS FIBER -REINFORCED EPOXY COMPOSITES

Hawraa Ali Nasir[1] and Mustafa Baqir Hunain[2]

[1] Mechanical Engineering Department, Faculty of Engineering, University of Babylon, Iraq, Email: eng954.hawraa.ali@student.uobabylon.edu.iq

[2] Department of Mechanical Engineering, College of Engineering, University of Babylon, Iraq, Email: dr_m_hunain@yahoo.com.

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ABSTRACT

Composite materials are widely used in engineering applications due to their high strength-to-weight ratio and tunable mechanical properties. This research aims to investigate the effect of equi-biaxial pre-tensioning load on the mechanical performance of epoxy composites reinforced with glass fibers at weight fraction of 0.35%. Four pretension load levels (0, 400, 800, and 1200 N) were applied to the fibers prior to fabrication. Tensile, impact, and flexural tests were performed to evaluate the composite behavior. The results showed that preloading significantly improved the mechanical properties, with optimal performance achieved at 800 N. At this level, tensile strength, elastic modulus, and impact strength increased by 50.14, 27, and 49.75%, respectively. and flexural properties also improved, while the flexural stress and modulus increasing by 263.3% and 76%, respectively. In contrast, increasing the pretension load to 1200 N resulted in a reduction in properties. These findings indicate that applying an optimal equi-biaxial pre-tension load during fabrication effectively enhances the overall mechanical performance of glass fiber-reinforced epoxy composites.

KEYWORDS

Equi-biaxially pre-tensioning load; Mechanical properties; Glass fiber reinforced epoxy; Composite fabrication; Property enhancement.

1. INTRODUCTION

A composite material is an incorporation of two or more elements that produces better characteristics than the individual components used alone (Rashid, W.T.,2023). Fiber-reinforced polymer composites offer significant potential for enhancing mechanical performance in engineering applications (Dookhi, M.A. and Tahir, A.A.,2023). There are numerous types of FRP composites, each with its own set of mechanical qualities determined by the production process of the comprising ingredients, fibers and resin. The nature, volume, and orientation of the fibers cause each FRP type to have its distinct features (Shallal, M.A., et al.,2025). The pre-stressing fiber technique enhances the mechanical properties of composites by keeping the fibers under tension during resin curing. After curing, the fibers remain in tension, creating internal compressive stress that improves the composite's performance. (Nacy, S.M.and Yaser, A.S.,2008).

Many studies have been conducted in this field to improve composite characteristic in a variety of ways including varying the ratio between the fiber to resin, fabrication method, along with the components that comprise it (fiber and resin), all of that is able to provide enhanced mechanical characteristic (Al-Dulaimy, A.K.M.A., et al.,2021). (Nacy, S.M.and Yaser, A.S.,2008) studied the effect of fiber pre-stressing on glass fiber/epoxy composites with a fiber volume fraction of 30%. Pre-stressing levels of (0, 2, 4, 6, 8, 10, 15, and 20 MPa) were used during curing, and the specimens were then tensile tested using an INSTRON machine. The results showed a 70% improvement in tensile strength and 46% improvement in ultimate strain at 20 MPa pre-stress level. (Pang, J.W.C.and Fancey, K.S., 2009) investigated the effect of viscoelastic pre-stressing of nylon 6,6 fibers with epoxy and polyester resins. Three-point bending tests showed that the flexural modulus increased by about 50% for samples with high L/h ratios, while the effect was less at low L/h ratios due to shear effects and limited fiber–matrix load transfer. (Bekampiene,P.,et al.,2011) studied the effect of pre-tensioning woven fabrics (cotton and glass) on improving the quality and strength of composite materials. Uniaxial tensile tests were conducted on single-layer composite samples with and without pre-tensioning. The results showed that pre-tensioning by the clamping method improves the quality of the composite parts (smoother surface) and increases the mechanical properties, the tensile strength at break increased by 12% in the warp direction, 58% in the weft direction, and 39% in the bias direction. (Širvaitiene, A., et al.,2013). investigated the effect of pretension on natural fiber composites' tensile and flexural characteristics. The results showed that applying high levels of pretension (ranging from 50% to 70% of the ultimate fiber strength) leads to a significant improvement in flexural strength. At the same time, applying even minor pretension resulted in a significant increase in the tensile strength of the composite materials. (Nishi Y., et al.,2014) studied the effect of tensile pre-stress level on Charpy impact value (auc) of 50 vol.% continuous unidirectional 0-degree oriented carbon fiber reinforced epoxy polymer (CFRP). The results showed that increasing the tensile pre-stress from 0.25 MPa to 17.6 MPa raised the Charpy impact value by 30% at the mid-fracture probability (P_f =50), from 84 to 109 kJ/m². The statistically lowest impact value (P_f =0) also increased by 26%, from 73 to 92 kJ/m², indicating an improved reliability of the specimen's strength. (Hassan, A.K.F.and Abdullah, O.A., 2015) studied a new method for manufacturing pre-tensioned composites using electric jack pre-stress rig (EJPR). Three layers of carbon fibers with a volume fraction of 50% were used. The results demonstrated that the efficiency of the proposed method, with an 85.1% increase in the modulus of elasticity at a tension of 20 MPa, and a 114.9% increase in the tensile strength at the same level. (Nawras, H. M., et al.,2016) investigated the effect of equi-biaxial fabric pre-stressing on the tensile behavior of woven E-glass/polyester reinforced composites. The pre-stressing levels ranged from 0 to 100 MPa. Specimens tested at various orientation angles, from the warp to the bias direction. The results indicated that fabric pre-stressing improved tensile properties, including the elastic modulus and critical stress at first fracture, by 10–20%. Most tensile properties, such as the tensile modulus and critical stress, reached their maximum values at a pre-stressing level of 50 MPa, while the tensile-limited toughness was highest at 75 MPa of pre-stressing. (Mahmoud, M., et al., 2019) developed new approach for manufacturing pre-tensioned glass fiber reinforced polymer (E-glass) composites by using the VARTM technique. Pre-tensioned samples at tensile levels (20,40, 60, 80 and 100 MPa) were prepared, in addition to a control specimen. The results showed reduced fiber waviness, increased fiber volume fraction, and decreased void content, with the best performance at tensile levels of 40 and 60 MPa, where tensile strength increased by 24.2% and 28.6%, compressive strength by 72.5% and 100.4%, and flexural strength by 28% and 26.1%, respectively. (Qin, Y.and Fancey, K.S.,2020) studied the effect of viscoelastic fiber pre-stressing on the impact behavior of polymeric matrix composites. Nylon 6,6 fibers with polyester resin were used to fabricate cross-fiber composite plates (CCPs, 0°/90° layers) and randomly oriented discontinuous fiber plates (RCPs). Drop-weight impact tests at velocities of 1.9–5.8 m/s showed that viscoelastic pre-stressing reduced damage depth by up to 29% in CCPs compared with unstressed controls, though the benefit decreased at higher velocities (>7.7 m/s). At 3.0 m/s, RCPs exhibited a 30% reduction in damage depth compared with 20% for CCPs, with no significant change in debonded area. (Mahmoud, M., et al.,2020) conducted a theoretical and experimental study to reduce residual stresses in polymer matrix during manufacturing. They investigated the effect of fiber pre-stressing on improving tensile strength, and used a theoretical analysis of composites with a 40% fiber volume fraction to determine the optimal pre-stress. The results showed that the optimal compressive stress is approximately 2.5 MPa, and applying this level to composites with 25% and 30% fiber volume fractions achieved the highest tensile strength, confirming the accuracy of the theoretical estimate. (Chen, H., et al.,2023) studied the effect of the elastic fiber pre-stressing (EFP) technique on epoxy composites reinforced with T700 carbon fibers, developing a theoretical model to analyze stresses and their impact on mechanical and dynamic performance. The results showed that the optimal pre-stressing was 90 MPa, increasing tensile strength by 15%, extension at break by 11%, impact strength by 11%, and dynamic flexural modulus by 30%. (Al-Dulaimy, A.K.A. et al.,2020) studied the effect of unidirectional preloading at (5, 8, and 10 N) on the tensile properties of epoxy composites reinforced with E-glass fibers at a fiber volume fraction of 10%. The results showed that preloading increased the maximum strength, percentage elongation, and rapture strength by 38.5%, 45.57%, and 106.2%, respectively, compared to control samples, with 10 N being identified as the optimal preloading level for achieving the best mechanical performance.

Therefore, previous studies on fiber pre-stressing in composite materials have focused mainly on uniaxial loading conditions or on improving a single mechanical property, such as tensile strength or flexural modulus. However, research on the effect of equi- biaxially pre-stressing on glass fiber–reinforced epoxy composites remains limited. The optimum level of this loading has not yet been systematically determined to achieve the best mechanical performance of composites. Based on previous studies, such as (Al-Dulaimy, A.K.M.A., et al.,2021), which used lower pre-tensioning load levels, this work selected four levels (0, 400, 800, and 1200 N) to investigate a wider loading range and determine the optimum level for maximum mechanical performance.

This research aims to study the effect of different levels (0, 400, 800, and 1200 N) of equibiaxial pre-tensioning load on the mechanical properties of epoxy composites reinforced with glass fibers, with a weight fraction of (35wt.%). The mechanical performance will be evaluated through tensile strength, impact strength, elastic modulus, flexural stress, and flexural modulus measurements, with the objective of determining the optimal loading level that achieves the best enhancement in the composite’s mechanical behavior.

2. THE EXPERMINTAL PROCEDURE

2.1. Raw materials

The materials used to prepare the samples consisted of epoxy as a matrix, and glass fiber as the reinforcement material. Quick mast 105 epoxy resin, commercially manufactured by DCP Company, consists of two parts: resin and hardener, mixed at weight ratio of 4:1. The type of fiber used is woven glass fiber. The properties of epoxy resin and the glass fibers are given in Table 1.

Table 1. Properties of epoxy resin and glass fiber used in the current work (Use, M. O. F.), (S. W.,2020)

Property	Epoxy resin	Glass fiber
Tensile strength(MPa)	≥ 25	3450
Tensile modulus (GPa)	3.5	72
Density (g/cm3)	1.1	2.58
Compressive strength(MPa)	≥ 70	-
Flexural strength(MPa)	≥ 50	-
Viscosity	2-5 poise	-
Poisson's ratio	-	0.22

2.2. Mold Design and Fiber Pre-tensioning

A steel mold with dimensions of (50 × 50 cm) as shown in the Fig. 1 was designed and fabricated. The mold consists of two main parts: one is fixed using bolts, while the other is movable through a screw-nut mechanism. As the screw is tightened, it applies tension to the fibers. The applied load is carefully monitored using a mechanical scale, with one end attached to the mold and the other to the screw-nut assembly, ensuring accurate control of the fiber tension during preparation. This system was used to applied controlled tension to the fiber layer. Secondary steel mold with dimensions of (20 × 30 cm) as shown in Fig. 2 was used to cast the final composite plates.

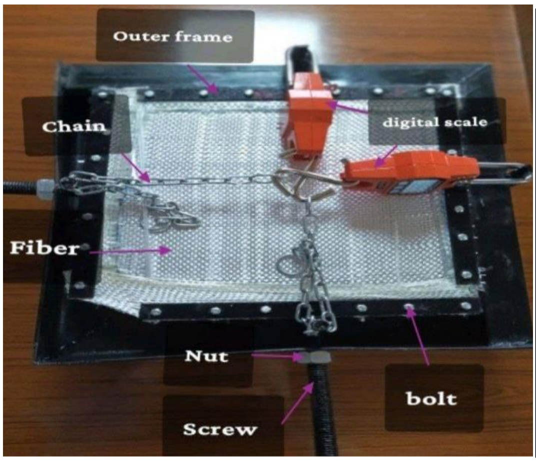

Fig. 1. Biaxial loading frame.

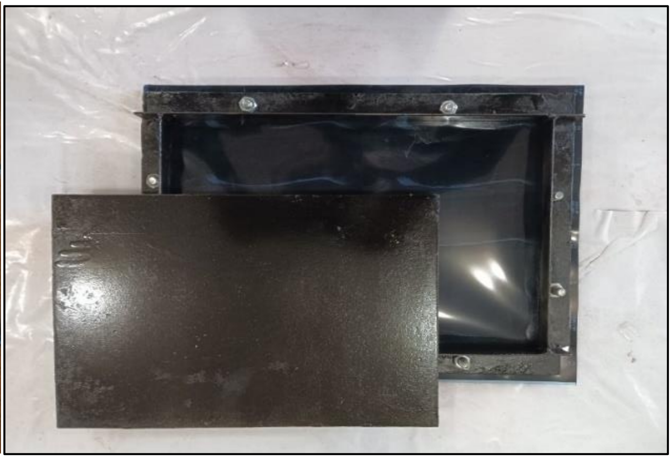

Fig. 2. Manufactured frame.

2.3. Composite Fabrication and Curing

The epoxy resin was mixed with its corresponding hardener at a weight ratio of 4:1, as specified by the manufacturer. The components were thoroughly mixed to achieve a uniform and homogeneous blend, ensuring optimal mechanical performance of the composite material. After mixing, the epoxy-hardener blend was poured over the tensioned fibers within the mold. Special rollers were then used to ensure uniform distribution of the resin and to remove air bubbles generated under the reinforced fibers. The laminate was allowed in the mold to cure at room temperature for 24 hours.

The laminate was left in an oven at 70 °C for 3 hours to achieve proper curing. The specimens from these laminates were cut according to criterion for tensile, flexural, and impact tests. The weight fraction for each sample is calculated according to the ratio of fiber weight to composite weight, which resulted in a fiber weight fraction of 35%.

3. EXPERMINTAL TESTS

3.1. Tensile test

The test sample was prepared as per ASTM (D3039) standard (ASTM, 2014), as shown in the Fig. 3. The tensile test was performed by using Universal Testing Machine Type (WDW-200E) at the room temperature until reaching the specimen fracture. The applied load is (200KN) with speed rate of (2 mm/min). The average of three sample values was reported. Fig. 4 appear composite specimens before tensile test.

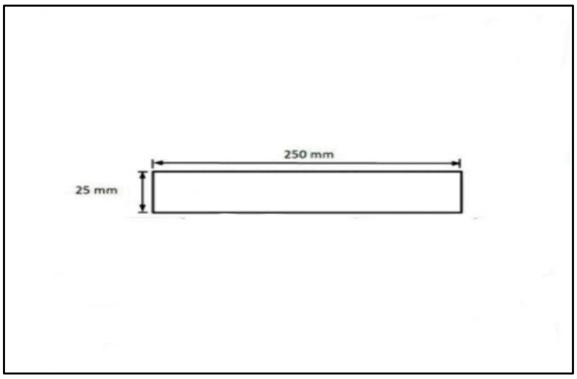

Fig. 3. ASTM D3039 standard dimension.

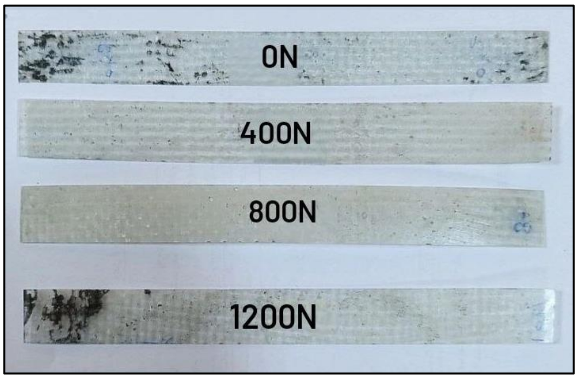

Fig. 4. Testing sample before tensile evalution.

3.2. Impact Test

A Charpy impact tester (Gunt Hamburg Co./ WP400) in the collage of Material Engineering at University of Babylon was used to perform the impact tests. The test was carried out according to ISO179 (ISO 179,2010), as shown in the Fig. 5. This is to determine the impact strength of the material, which is the ability of material to resist to fracture under sudden load. The average of three samples was considered. The samples of this test can be shown in Fig. 6.

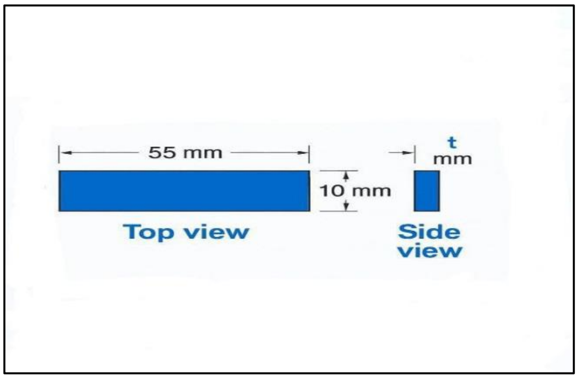

Fig. 5. ISO 179 standard dimension.

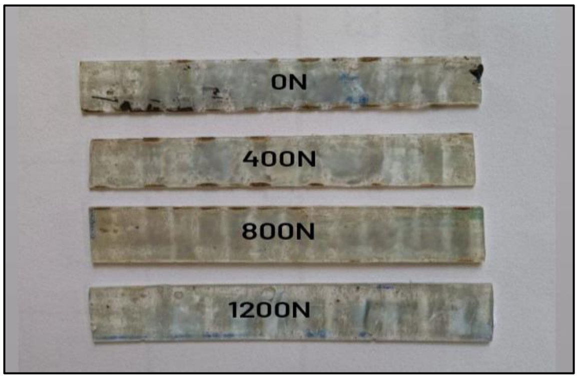

Fig. 6. Impact test samples.

3.3. Flexural Test

The flexural test was performed according to ASTM D790 (ASTM INTERNATIONAL,2002), as shown in the Fig. 7, to evaluate the bending behavior of the composited specimen. A three-point bending tests was utilized using Universal Testing Machine Type (WDW-5E) in the College of Materials Engineering at University of Babylon, with a cross head speed of (1mm/min) at room temperature. The average of three samples was considered. The samples of this test can be shown in Fig. 8. The bending stress, and flexural modulus are calculated based on following equations (Abbas, E.N., et al.,2020).

$$\sigma_{max} = \frac{3P_{max}L}{2bh^2} \tag{1}$$

$$E_f = \frac{mL^3}{4bh^3} \tag{2}$$

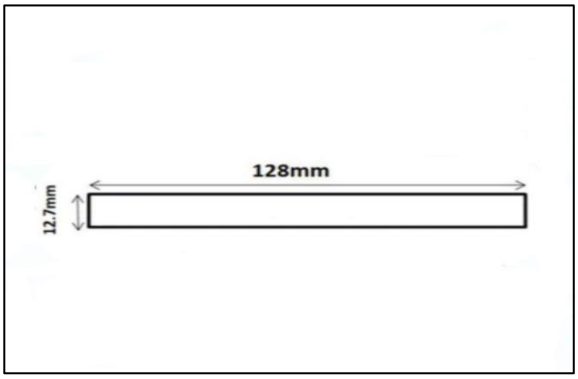

Fig.7. Flexural test sample dimension.

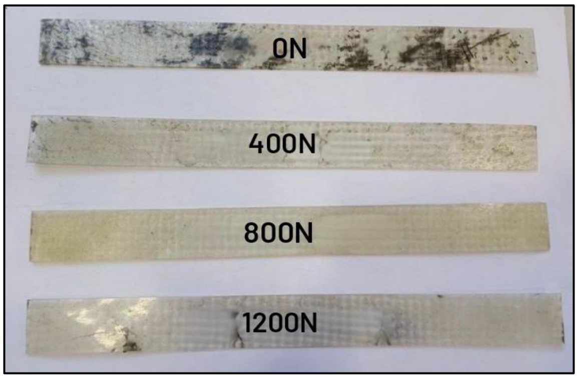

Fig. 8. Bending test specimens.

4. RESULTS AND DISSCUSSION

4.1. Tensile test

To evaluate the effect of fiber pre-tensioning load level on the tensile characteristics of the composite, tensile tests were performed on specimens composed of epoxy reinforced with glass fibers, and Fig. 9 shows the stress-strain curve of the pre-tension load composite samples. The stress-strain curve provides a clear indication of the material's ability to resist deformation under external loading. It is evident from the figure that an increase in the pre-tension load level enhances the stress response while causing only a slight increase in strain. Table 2 summarizes the average value results from the three measurement datasets. Figs. 10 and 11 show the relationships between the pre-tension load levels with both the maximum tensile strength and the elastic modulus. The results presented in Figs. 7 and 8 indicate that the tensile strength and the elastic modulus increase from (134MPa) and (5.8GPa) at zero pre-tension load level to (201.2MPa) and (7.4GPa), respectively, at pre-tension load level of 800N. The increase in tensile strength and modulus of elasticity occurs due to pre-tension load, which causes internal compression in the composite material, which increases the energy required for crack initiation and propagation. Therefore, the composite requires greater forces to fail, which means an increase in the strength of the composite material. In addition, this improvement is due to the reduction of fiber waviness resulting from per-tension load, which allows for increased efficiency of load transfer between fibers and matrix, this agree with the earlier report by (Nawras, H. M., et al.,2016; Al-Dulaimy, A.K.M.A., et al.,2021). A similar trend of improvement is also observed in the study by (Al-Dulaimy, A.K.M.A., et al.,2021), where the maximum tensile strength increased by 38.5% at the highest pre-load (10 N), while our results reached a higher absolute value of 201.2 MPa at 800 N, confirming that pre-tension loading enhances the mechanical properties consistently across both studies, despite differences in absolute values due to variations in sample preparation and pre-tension levels. In contrast, excessive loading at 1200 N led to a decrease in tensile strength to (172MPa). The elastic modulus also decreased compared to the other cases, indicating a deterioration in stiffness. This decrease can be scientifically explained by several reasons: First, excessive load can lead to fiber damage, such as fiber breakage or the appearance of microscopic cracks, which reduces the fibers' ability to transmit loads within the polymer matrix. Second, permanent deformation of the matrix (plastic deformation) or partial separation between the fibers and the matrix (fiber–matrix debonding) can occur, reducing the interaction between the components and weakening the load-bearing properties. Third, excessive loads increase the shear stress at the fiber-matrix interface, facilitating fiber debonding and increasing stress concentration in localized areas, thus degrading mechanical properties, this agree with the earlier report by (Mahmoud, M., et al.,2019). Standard deviation analysis of both tensile strength and elastic modulus showed variations in the dispersion of values between samples under different loading levels. For tensile strength, the standard deviation was highest at the unloaded 0N sample (SD = 1.11), decreased at 400N (SD = 0.53), and increased at 800N (SD = 1.06) before decreasing at 1200N (SD = 0.20), reflecting the stability of results at low and high loads and increased variability at intermediate loads. For elastic modulus, the deviation was lowest at 0N (SD = 0.216), increased at 400N and 800N (SD = 0.536 and 0.454), and then increased slightly at 1200N (SD = 0.510), indicating the influence of preloading on the variability between samples. These results reflect that the variability in mechanical properties is related to the loading level, with variability increasing at intermediate loads and stabilizing or decreasing at maximum loads.

Table 2. Tensile test results of composite material of epoxy reinforced with glass fibers.

Pre-tension load(N)	Tensile strength (MPa)	Average	Improvement in tensile strength (%)	Elastic modulus (GPa)	Average	Improvement in Elastic modulus (%)
	2.813			5.9		
0	4.213	134	0	5.5	5.8	0
	135			6.0		
	175			7.2		
400	176	176.6	31.04	5.9	6.6	13
	175.8			6.7		
	200			6.9		
800	202	201.2	50.14	8.0	7.4	27
	201.6			7.3		
	171.8			6.1		
1200	172	172	28.35	7.0	6.3	8.62
	172.2			5.8		

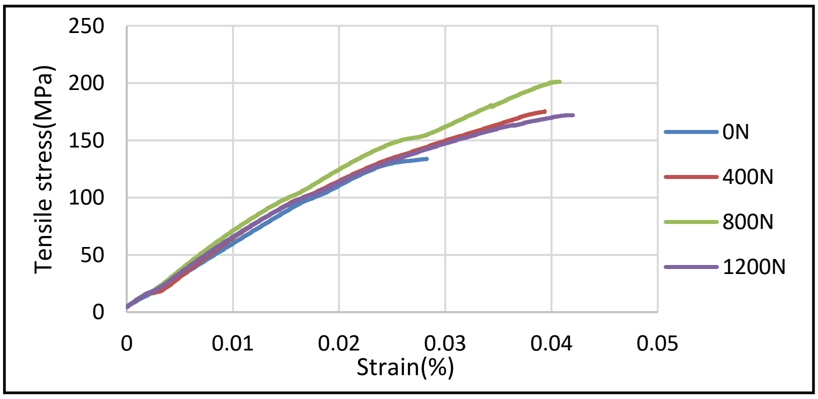

Fig. 9. Stress–strain curves of preloaded glass fiber composite.

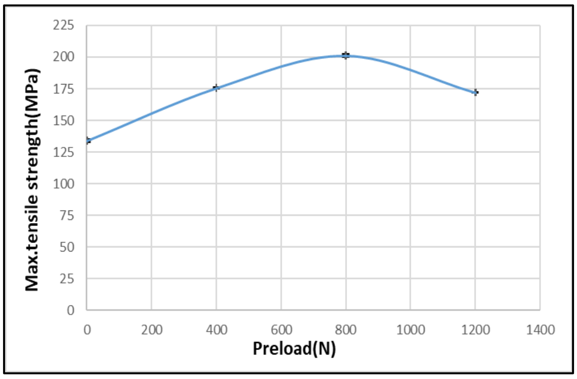

Fig. 10. The pre-tension load and Max. Tensile Strength.

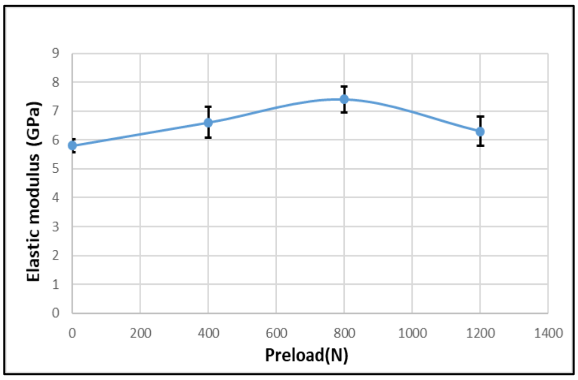

Fig. 11. The pre-tension load and elastic modulus.

4.2. Impact test

A Charpy impact test was performed on samples of a composite material consisting of an epoxy matrix reinforced with glass fibers, in order to study the effect of pre-tensioning load on the material's impact resistance of composite materials as shown in the Fig. 12. The results showed a clear effect of the loading level applied to the glass fibers inside the composite on the impact resistance. Initially, the fiber pre-tensioning load increases the impact strength of the composite material and this trend continues until (800N) of fiber pre-tension load, where it reached a maximum value of ($31.328 kJ/m^2$) compared to the unloaded sample. The increased impact strength is due to the pre-tensioning load of fibers that improved the mechanical performance of the composite material by reducing the fiber waviness and improving the load transfer between the fibers and the matrix, thus increasing its shock resistance, a trend similar to that observed by Nishi et al. (2014) on carbon fiber-reinforced epoxy, where the Charpy impact value increased from 84 to 109 kJ/m² (30% increase) when the tensile pre-stress was raised from 0.25 MPa to 17.6 MPa. When a high pre tension load of 1200 N was applied to the fibers, the impact strength dropped sharply to 17.756 kJ/m². This was due to internal fiber damage and excessive debonding at the fiber-matrix interfaces, which reduced bonding efficiency and weakens the material's energy absorption capacity. Excessive pre-tensioning load also increased stress concentration and crack growth within the material, this agree with the earlier report by (Chen, H., et al.,2023). The results of the standard deviation analysis showed a clear difference in the dispersion of values between samples under different loading levels. The lowest standard deviation was for the unloaded sample, 0N (SD = 0.315), indicating similarity of results and low variability between samples. As the loading increased to 400N and 800N, the standard deviation increased to 0.659 and 0.843, respectively, reflecting increased variability due to the effect of preloading on the distribution of internal stresses or the uneven properties of the matrix and fibers. At the maximum load of 1200N, the standard deviation decreased to 0.699, indicating a convergence of the behavior of the samples as the average impact strength decreased. Overall, the standard deviation analysis reflects that the variability between samples is affected by the loading level, with changes increasing at intermediate loads and decreasing slightly at maximum loads.

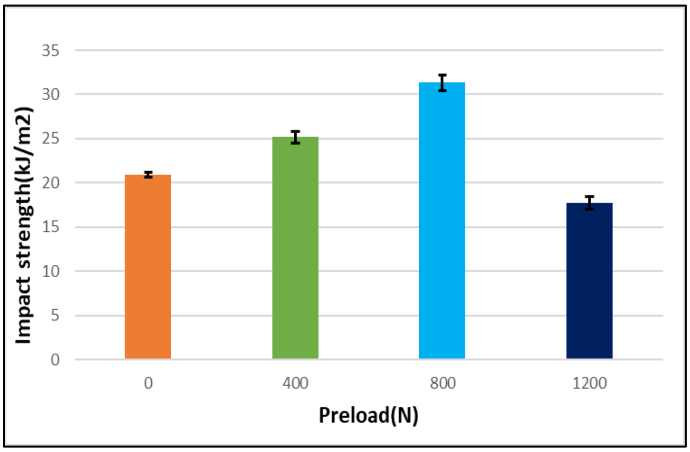

Fig. 12. Impact test results.

4.3. Flexural test

The three-point bending test was performed to calculate the flexural characteristics of composite specimens. Fig. 13 illustrates the effect of different pretension load levels on the load-deformation relationship for a composite specimen. At no pretension load (0 N), the specimen exhibited the lowest load capacity and the largest relative deformation due to the absence of force distribution within the polymer matrix. Increasing the pretension load to 400 N improved mechanical performance, with the maximum load increasing and deformation decreasing due to fiber tension and reduced voids between the fibers and matrix, which enhanced stress transfer. At the optimum pre tension load level (800 N), the specimen achieved the highest load and lowest deformation, reflecting a balanced stress distribution and full utilization of the fiber and matrix strengths. At a very high pretension load (1200 N), the maximum load decreased and deformation increased relatively due to initial cracks in the matrix and partial debonding between the fibers and matrix, which reduced the effectiveness of the fibers in resisting the load.

The flexural stress and modulus of the samples were calculated by Eqs.1 and 2 respectively. Figs.14 and 15 show the results of flexural characteristics of pre-tension load samples. It is clear that both the flexural stress and the flexural modulus increase when fiber pre-tension load increase. This trend continues up to the level of (800 N). The maximum flexural stress(268.86MPa) and modulus (13.2GPa) were observed at the pre-tensioning load level of 800 N. The increase is attributed to the residual stresses generated during the pre-tensioning process, which improves the material's resistance to crack initiation and propagation under bending loads. As a result, higher bending loads and greater fracture energy are required for crack growth, leading to improved flexural resistance of the specimen. The observed enhancement is further attributed to the application of pre-tension load, which subjects the fibers to a pre-tensile condition. This induces a vertical component of tensile force that counteracts the applied bending load during testing. As a result, a greater bending load is required to achieve the same level of deflection, thereby increasing the flexural modulus of the composite material. Comparing these results with (Nawras, H. M., et al.,2015) on glass fiber/polyester composites shows a similar trend, where flexural strength increased from 86.42 MPa at zero pre-stress to 99.38 MPa at 50 MPa pre-stress, and flexural modulus increased from 2.54 GPa to 2.96 GPa. Although the absolute values differ due to differences in fiber type, volume fraction, and preparation method, both studies indicate that moderate pre-tension improves flexural strength and stiffness. The results showed that when a preload of 1200 N was applied, the flexural stress and flexural modulus decreased to 137.97 MPa and 10.6 GPa, respectively. This decrease is attributed to progressive debonding between the fibers and matrix. Increasing the pretension load results in higher shear stresses at the fiber-matrix interface, weakening the bond between the components. When these increased stresses are combined with the external load during the flexural test, further debonding occurs, ultimately reducing the flexural stress and stiffness of the composite, this agree with the earlier report by (Mahmoud, M., et al.,2019). The standard deviation results showed the variability between samples in the flexural tests. For Flexural Stress, the standard deviation was low at 0 N load, reaching 0.16, reflecting high homogeneity between samples. It increased at 400 and 800 N loads, reaching 0.52 and 0.89, respectively, with a slight decrease at 1200 N to 0.78, indicating increased variability in the material response with increasing load. For Flexural Modulus, the standard deviation was low at 0 N load, reaching 0.41, gradually increasing to a maximum value at 800 N before decreasing to 0.63 at 1200 N. This reflects that the stiffness between samples increases with increasing loads, highlighting the importance of standard deviation when evaluating the mechanical properties of composite materials.

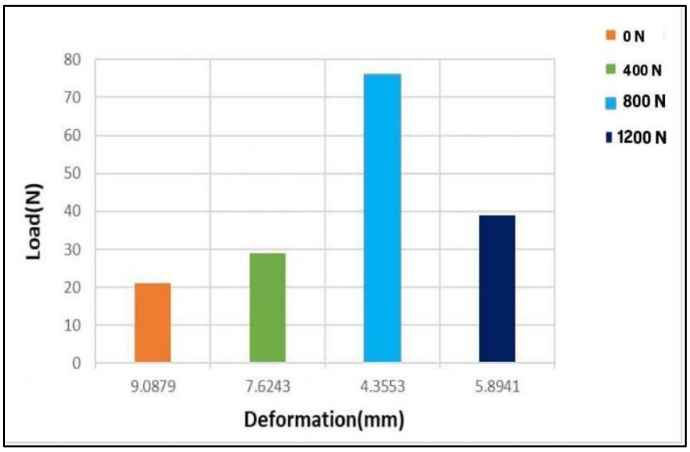

Fig. 13. Load vs deformation relationship of pre-tension load samples.

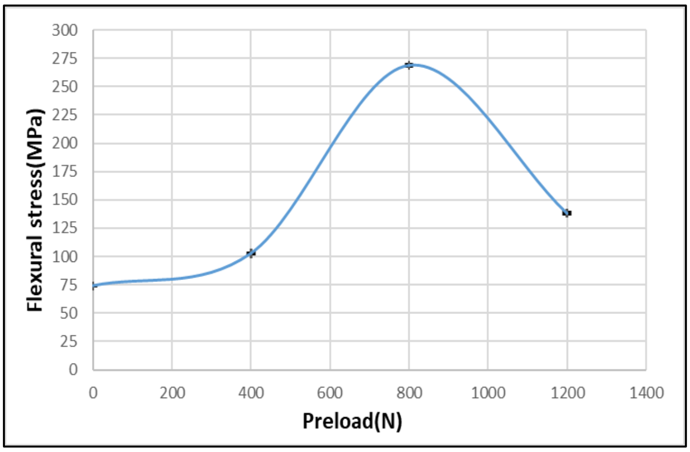

Fig. 14. Flexural stress with different pre-tension load levels.

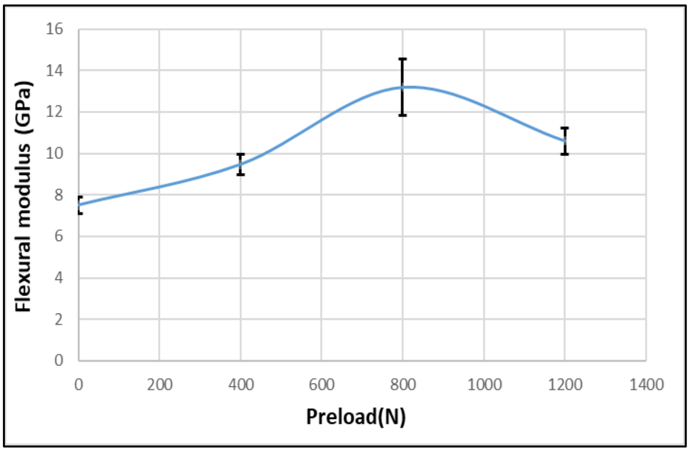

Fig. 15. Flexural modulus with different pre-tension load levels.

5. CONCLUSION

The mechanical properties of glass fiber-reinforced epoxy composites were experimentally investigated under different levels of equi-biaxial pre-tensioning load (0, 400, 800, and 1200 N). Based on the findings, the following conclusions can be drawn:

1. Equi-biaxial pre-tensioning load during the curing process significantly improved all mechanical properties of the composite, including tensile strength, impact strength, and flexural properties.

2. Tensile properties increased with increasing fiber pretension load, reaching a maximum value at 800 N, with tensile strength and modulus of elasticity increasing by 50.14% and 27%, respectively.

3. Impact strength increased by 49.75% at 800 N, and flexural properties also improved, with the maximum flexural stress and modulus increasing by 263.3% and 76%, respectively.

4. At the pretension load level of 1200 N, a decrease in all mechanical properties was observed compared to 800 N, indicating internal damage to the fibers and matrix that reduces the performance of the composite.

Limitations

1. Reinforcing the epoxy with a single layer of woven glass fibers.

2. Applying pretension load to the fibers at different levels (0, 400, 800, and 1200 N).

3. Prepare sample and conduct mechanical tests, including tensile, flexural, impact.

RECOMMENDATIONS

Expand the study to include other fiber types, such as carbon fibers or Kevlar fibers, under equi-biaxial pre-tensioning load conditions.

Study the effect of different pretension load levels to determine the optimum level more accurately.

Investigate the fatigue behavior and vibration response of preloaded composites.

6. REFERENCES

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