Semnan University

Mechanics of Advanced Composite Structures

Journal homepage: https://macs.semnan.ac.ir/

ISSN: 2423-7043

Research Article

Investigation of Mechanical Properties for Blend Epoxy-Polysulfide Reinforced with Woven Carbon and Glass Fiber

Waleed H. Hamza, Orhan S. Abdullah *, Ibtihal A. Mahmood

(Orhan Sabah Abdullah *)

Mechanical Engineering Department- University of Technology- Iraq- Baghdad

ARTICLE INFO

Article history:

Received:
Revised:
Accepted:

Keywords:

Epoxy;
Polysulfide;
Carbon fiber;
Glass fiber;
Stacking sequence;
Buckling Behavior.

ABSTRACT

In this work, the effect of the axial buckling load characteristics of a composite material consisting of epoxy resin (EP) and different weight percentages of polysulfide (PS) (0%, 2%, 4%, 6%, and 8%) prepared and reinforced with woven carbon and glass fibers was studied. Buckling and tensile specimens were manufactured using hand lay-up techniques according to ASTM D6641, ASTM D638, and ASTM 3039 standards. Using eight layers of fibers in three stacking sequences S1(Carbon-Carbon-Glass-Glass)x2, S2(Carbon-Glass-Carbon-Glass)x2, and S3(Carbon-Glass-Glass-Carbon)x2 and different orientation angles (0, 30, 60, and 90°), testing was performed on critical buckling load specimens by applying an axial compressive force using a testing machine. Increasing the amount of polysulfide in blends made them more flexible, but it also made the critical buckling load, tensile stress, and modulus of elasticity properties decrease compared to the pure epoxy. It was also observed that the hybrid composite material made of (EP+6% PS) reinforced with fiber improved the critical buckling load and tensile stress by (186.6%, 141%, and 219%) and (760, 698%, and 875%) when the fibers layers arranged according to (S1, S2, and S3) models, correspondingly. The experimental results obtained manifested that the best value of the critical buckling load and tensile stress at stacking sequence (CGGC)x2 was when the carbon fibers were in the direction (0–90°) and when the axial force of tension and compression was in the direction of the fibers.

1. Introduction

Composite materials are a blend of two or more types of materials with different properties. They often consist of an epoxy matrix and reinforcing materials. Composite materials have features that cannot be achieved for either of the two components alone [1]. The process of dispersing or implanting fibers within an epoxy matrix produces composite materials that are effective. The epoxy matrix provides external protection for the fibers from chemical and mechanical damage, cohesion of fibers, holding the fibers together and providing some toughness, and transfer of loads to reinforcing materials [2]. The matrix phases may be metals, ceramics, or polymers, while the fibers may be particles, filaments, or fabric [3-7].

Epoxy is a crucial polymer in technical applications. It has been extensively used in adhesives and materials for electronic packaging. Epoxy compounds are used in vehicles, aircraft, and civil engineering because of their outstanding mechanical properties. Epoxy is subject to fracturing under pressure because of its high cross-link density, which

*** Corresponding author.**
E-mail address: *20313@uotechnology.edu.iq*

Cite this article as:
Mohammadi, A. and Mahdi-Nia, M., 2025. Title of article. *Mechanics of Advanced Composite Structures*, 12(1), pp. xx-xx
https://doi.org/10.22075/MACS.2024.39315.2050

causes it to be brittle. While polysulfide resin is an elastomeric polymer, its structure includes sulfur bonds in its main chain, which improve its ductility and flexibility. Therefore, the addition of polysulfide to epoxy to prepare a blend polymer creates a new polymer with a good degree of rigidity and ability to return to the original shape under stretch and compressive loads [6-8].

The fiber-reinforced polymer composites are broadly employed in modern engineering, with glass, carbon, quartz, basalt, boron, and aramid fibers being the most commonly employed for reinforcement. Glass fibers are the preferred choice for structural applications due to their great strength and cost-effectiveness [9]. Carbon-fiber-reinforced polymers are composite materials that employ carbon fiber to improve stiffness and strength. Also, carbon-fiber-reinforced composites and laminated plate structures have become recently common in the industry of aerospace, marine, automobiles, and architectural applications [10]. In addition, they have been used in other engineering sectors because of their exceptional properties, including high strength and stiffness, low weight, and excellent fatigue resistance [11].

Hybrid composites are highly advanced materials known for their lightweight, cost-effectiveness in manufacturing, high rigidity, and excellent resistance to corrosion. They are commonly used in various industries, such as building construction, automotive manufacturing, aircraft production, and wind turbine development. Hybrid composites are made of a polymer matrix, like polyester or epoxy, strengthened with glass, carbon, and Kevlar fibers [12]. Due to the high cost and low strain at failure of carbon fibers, it is necessary to determine a balance between cost and properties of fibers when used [13]. Hybrid composites combine the benefits of individual fibers and can use the advantages of two materials simultaneously, resulting in superior physical and mechanical qualities that are highly versatile across several industries. The current study is focused on the mechanical characteristics of hybrid composites [14].

Buckling is the rapid failure of a structural element under high compressive loads, occurring when the compressive stress at the failure point is lower than the maximum compressive stress thresholds of materials. The buckling behavior is an important factor to consider while designing modern structures, including lightweight and thin composite structures. Improving the safety and stability of engineering structures is important for maintaining their dependability. Current studies are an effort to improve the mechanical performance to prevent failures under heavy loads [15]. Euler first talked about column buckling in 1744, and Walker conducted experimental research on it [16].

Many researchers have studied the effect of the amount of fiber volumetric content, stacking sequence, and fiber orientation in the composite material and its influence on the critical buckling load. Dr. Jawad Kadhim Oleiwi et al. [17] tested the critical buckling load by adding more layers of carbon and glass fibers that were mixed together. The sample was then put inside the layers of Perlon and covered with the polymethyl methacrylate resin. And, it was found that the critical buckling load rises with the increase in the number of layers of hybrid fibers, and the percentage increase was 257.22% for three layers compared to one layer. Battawi [18] discovered that with an increase in the volume content of fibers, the critical buckling load value begins to increase, and then after a certain point, when the fiber volume increases to a certain extent, the critical buckling load value begins to decrease due to the high increase in fiber volume. Because the fibers are not fully wet with the matrix, this leads to the brittleness of the content. Abdalikhwa H. Z. et al. [19] studied the effect of woven carbon and glass fibers on improving the critical buckling load, placed within layers of perlon and polymethyl methacrylate resin. The percentage increase in properties when using three layers of carbon compared to using three layers of class fiber was 12.5%, 15.5%, and 17.5% for the modulus of elasticity, tensile stress, and critical buckling load, respectively. Dhuban S. B. et al. [20] stated that the stacking sequence in hybrid composites has a significant effect on the critical buckling load. The maximum critical buckling load for hybrid composites that contain carbon fiber as one of their components is when the carbon fibers are placed on the outer surface of the hybrid composite. Bi Pin. P. B [21] investigated the critical buckling load behavior in a composite plate consisting of 10 layers of carbon fiber and epoxy with varying lengths and aspect ratios (L/w). The laboratory results demonstrated that the critical buckling stress varies with the length, increasing as the length decreases. Ahamed S. R. et al. [22] studied the properties of a hybrid composite composed of carbon fiber and aluminum mesh in polymer compared with aluminum panels of the same thickness (6 and 4 mm). The experimental results were that a 6 mm thick panel increased the buckling load by 40.4%, and a 4 mm panel reduced the weight by 40.6% compared to aluminum panels. Bozkurt Ö. Y. et al. [9] studied the effect of the orientation angles of bidirectional glass fibers (0–90°) on the critical buckling load value by implanting 12 layers of fibers inside the epoxy matrix at orientation angles (0–90°, 15–105°, 30-120°, and 45–125°). The laboratory results showed that the greatest amount of the axial critical buckling load was at the fiber orientation angle (0–90°). Azadi R. et al. [23] mentioned that, as for unidirectional fibers, the largest value of the critical buckling load is at an angle of 0 when the direction of the fibers is in the direction of the axial compressive force. Rostomyan, Y., and Azade, R. [24] studied the influence of the unidirectional carbon angles on the critical buckling load; samples were manufactured using the hand lay-up method according to ASTM D6641 and the Taguchi design method by using 16 layers with different orientations. The result was that the highest amount of the critical buckling load was at an angle of 0 when the axial compressive force was parallel to the fibers' direction, and the minimum amount was at an angle of 90° when the axial compressive force was perpendicular to the direction of the fibers.

This research aimed to evaluate the influence of polysulfide concentration up to 8% upon the mechanical prioperties of blend epoxy matrix, as well as, investigate the effect of woven carbon and glass fibers with different orientation angles (90º, 60º, 30º, 0º, 0º, 30º, 60º, and 90º) and three stacking sequences models {(C-C-G-G)x2, (C-G-C-G)x2, and (C-G-G-C)x2} on the buckling behavior of the prepared blend matrix composites.

2. Methodology and Materials

2.1. Buckling Behavior

The theoretical critical buckling load of composite materials and hybrid composite materials is calculated according to Euler's equation for long column that illustrated in equation (1), the columns classified as long columns when the slenderness ratio is greater than the column constant which calculated according to equations (2, 3 and 4) [25], for columns subjected to a longitudinal compressive load. The equivalent length is considered one of the most important variables in the critical buckling load equation, as it depends on the method of installing the column in the inspection machine (the boundary conditions of a column). Therefore, the column fixed at both ends has the least effective length compared to the rest of the columns [25]. In this study, the fixed-fixed column stabilization method was used. From both ends, the effective length of the column is equal to 0.5 of the original length of the column [25].

$$\text{cr} = \frac{\pi^2 E\, I}{L^2} \quad (1)$$

$$\text{Slenderness ratio} = \frac{Le}{\text{r}} \quad (2)$$

$$\text{r} = \sqrt{\frac{I}{A}} \quad (3)$$

$$\textit{Column constant} = \sqrt{\frac{2\pi^2\, E}{\sigma y}} \quad (4)$$

where Pcr = Critical buckling load , E = Modulus of Elasticity, I = Moment of Inertia, and L = Effective Length Factor, Le = effective length, A = the cross section area, σy = yield stress

2.2. Raw Materials

2.2.1 Epoxy (EP) and Polysulfide (PS) Resin

The epoxy used in this research is Sikadur®-52 Injection Type LP, which comprises (2) parts: Resin and hardener with a yellowish-brownish color. And, the recommended mixture is (2 g) of epoxy resin with (1 g) of hardener. Polysulfide utilized in this study was Sikadur® polysulfide PG, comprising two components: Resin and hardener with a gray hue. The optimal ratio suggested was 95 grams of polysulfide combined with 5 grams of hardener. Tables (1) and (2) show the properties of the epoxy and polysulfide resins [26, 27].

Table 1. Mechanical properties of epoxy resin [26]

Properties	Values
Tensile strength (MPa)	27 MPa
Modulus of elasticity (MPa)	1,060 MPa
Flexural strength (MPa)	50 MPa
Compressive strength (MPa)	70 MPa
Viscosity (MPa.s)	290 MPa.s
Density (Kg/liter)	1.1 Kg/liter
Pot life	60 min at 20°C, 30 min at 30°C

Table 2. Mechanical properties of polysulfide [27]

Properties	Values
Tensile strength (MPa)	8.3
Compressive strength (MPa)	20-100
Density (Kg/liter)	1.60
Young modulus (MPa)	3.7-5
Failure strain %	550
Pot life	2 hours at 25°C
Curing Time	1 week

2.2.2 Woven Carbon and glass fibers

The fibers used in the current research are bi-directional woven fibers (0–90°). The carbon fiber type T300-3K was obtained from Yixing T-carbon Fiber Material Technology Company in China, and the glass fibers utilized in this study were woven E-glass fibers (EWR 200) obtained from Focus Technology Company in China. Table (3) depicts the mechanical properties of carbon and glass fibers [28, 29]. Figures (1) and (2) reveal the carbon and glass fiber used in this research.

Table 3. The mechanical characteristics of carbon fibers [28, 29]

Properties	Carbon fiber type T300-3K	E-glass fibers (EWR 200)
Tensile Strength (MPa)	3520	3445
Tensile Modulus (GPa)	230	72
Areal Weight (g/m^2)	200	200
Density (g/m^3)	1.8	2.58

Fig. 1. Woven Carbon Fiber

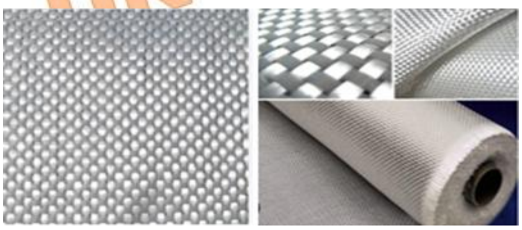


Fig. 2. Woven Glass Fiber

3. Experimental Parts

3.1. Mold Preparation

According to the ASTM standards, the two molds used in this work were prepared with dimensions of (200 × 140 × 4 mm) for tensile samples and (150 × 50 × 4.8 mm) for buckling samples, as displayed in Figure 3. The blends typically exhibit a strong adhesion, hence requiring molds constructed from materials of moderate strength and hardness, therefore, glass has been used to prepare the molds. These molds were then cleaned, and then Vaseline and Teflon paper (PVC) were applied to the internal side to prevent the sticking between the molds and the mix matrix. This will provide a consistent dispersion and a surface that is uniform.

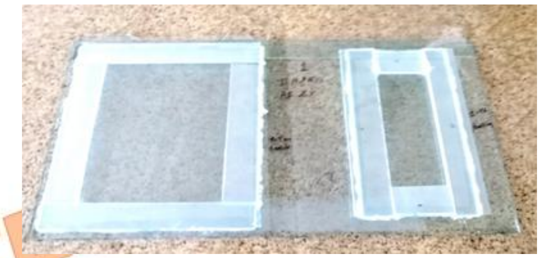


Fig. 3. The prepared molds

3.2. Sample manufacturing

The first step involved mixing the epoxy and polysulfide (2, 4, 6, 8% wt.) resins by weight percentage. In the second step, the epoxy and 6% polysulfide were mixed together without any hardeners. This was done for three hours using a magnetic stirrer of the MR Hel-Standard type (a Heldolph instrument made in Germany) until the mixture was homogenous. The components were placed in a vacuum oven (BINDER by USA) for 30 minutes at (-25 lbs.) to eliminate the bubbles. The two hardeners, epoxy and polysulfide, were mixed for five minutes together and added to the mixture of resins. Then, a magnetic stirrer mixed them for ten minutes, while the manual mixing blended the mixture for five minutes. Until the mixture becomes homogenous enough, the first amount of the blend was added to the mold and distributed evenly. The first layer of fibers was placed in the mold above the mixture, and the air between the fibers and the mixture was removed by moving it from inside to outside using a brush or roller, as well as by completely wetting the fibers. The process was iterated for each layer, and the final coat of the mixture was then applied above the last layer of fibers to ensure the perfect saturation of the fibers. According to the data sheet for epoxy and polysulfide, the prepared specimens must remain in the mold for seven days at the laboratory temperature to complete the curing process. Then, the produced mold was cured by leaving it for one hour in a drying oven at 50°C to achieve proper curing. This step is very important to complete polymerization, relieve the stresses caused by the preparation process, and complete the hardening of the samples [30]. The samples for each required test were then prepared by cutting the molds with a saw and a CNC machine according to the standard dimensions of each mechanical test. Figure 4 illustrates the stages of sample manufacturing.

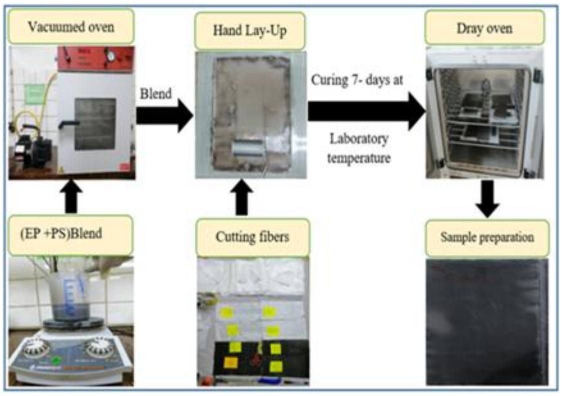


Fig. 4. Sample manufacturing

The samples required in this study were prepared via utilizing the Hand lay-up method in the following two stages, and the mechanical properties were studied for each of the two stages and for all samples, with three samples for each test:

First stage: In this stage, a blend matrix was prepared by mixing epoxy (EP) and polysulfide resin (PS) with various weight percentages (0, 2, 4, 6, and 8% wt..) of PS.

Second stage: In this stage, the optimal blend samples (EP+6%PS) was selected due to their balancing between epoxy brittleness behavior and flexural polysulfide behavior to reinforced by using (8) laminates of carbon fiber (CF) and glass fiber (GF) with different orientations (90°, 60°, 30°, 0°, 0°, 30°, 60°, and 90°) and stacking sequences. The fiber laminates are distributed in the blend matrix according to Table 4. And, the fibers distribute the stress throughout the composite structure and improve the material's structural properties by acting as crack stoppers[31].

Table 4. Distribution of Carbon and Glass Fibers in the Blend matrix (EP+6%PS)

Orientation / Model	90	60	30	0	0	30	60	90
S1	C	C	G	G	G	G	C	C
S2	C	G	C	G	G	C	G	C
S3	C	G	G	C	C	G	G	C

3.3. Experimental Tests

3.3.1.Tensile Test

The tensile test is the most commonly performed mechanical test. A uniaxial force is applied along the main axis, which increases gradually, and the tested specimen is deformed until it fractures. The tensile testing machine (computer-controlled electronic universal testing machine, 50 KN) shown in Figure 5 was used to perform the test at the lab temperature. The load was exerted at a uniform cross-head speed of 5 mm/min continuously till the failure of the specimens.

The composite specimens (blend matrix) were prepared in accordance with the ASTM D638 standard [32]. However, specimens blended with carbon (CF) and E-glass fibers (GF) were prepared in accordance with the ASTM D3039 standard, and the nominal dimensions of the specimens for the tensile test are 250 x 25 x 4 mm [33], as evinced in figures (5 – 7). The tensile stress-strain relationships, tensile modulus, and strength of composite samples were calculated directly using the computer software that comes with this machine. Three tests were performed on each type of model, and the average value was considered. The hybrid composite and composite material samples before and after the tensile test are elucidated in Figure 8.

Fig. 5. Tensile Test

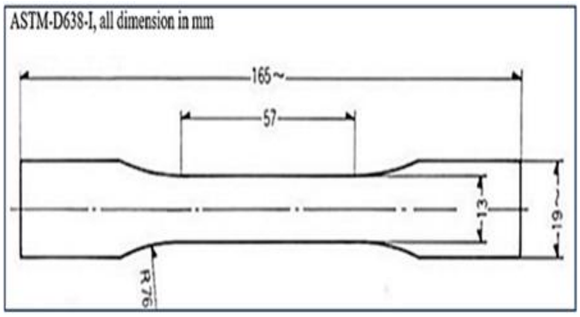


Fig. 6. ASTM D638 standard dimensions [32]

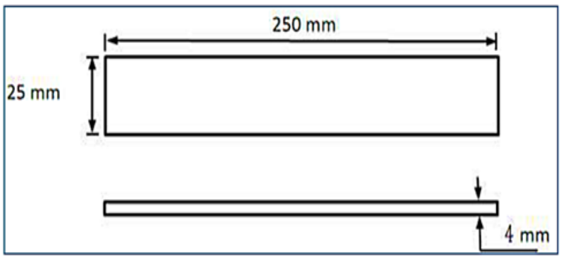
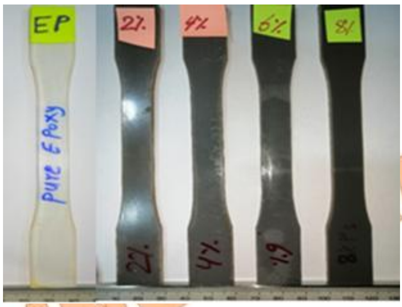
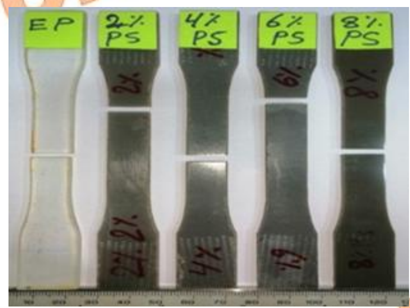


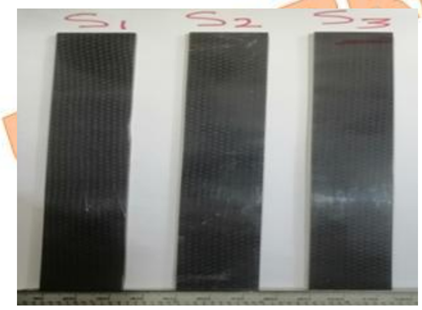
Fig. 7. ASTM D 3039 standard dimensions [33]



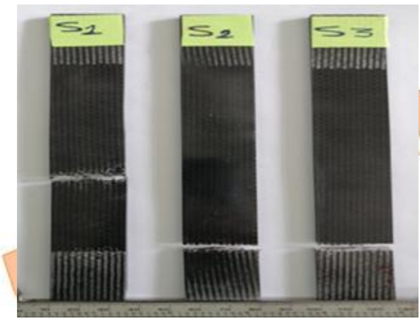
(a)



(b)



(c)



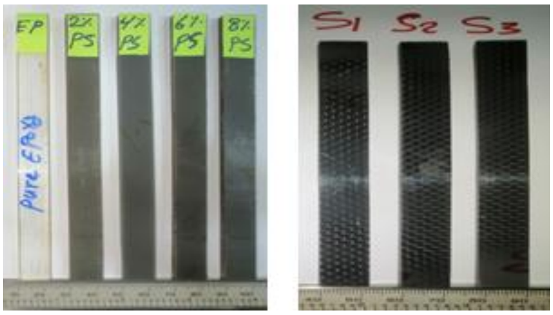
(d)

Fig. 8. (a, b) The blend matrix composite test specimens before and after tensile test, (c, d) the hybrid 6% PS composite material blend matrix with different C/G fiber orientations and stacking sequences before and after tensile test.

3.3.2. Buckling Test

The sudden failure of a structural member under high compressive loads is called buckling. This happens when the compressive stress at the failure point is less than the highest value of compressive stress that the material can handle [34]. Reducing the structural weight, while at the same time increasing the buckling capacity, enables the composite materials to exhibit high strength-to-weight and stiffness-to-weight ratios [35]. The critical buckling loads of the blended matrix-reinforced and unreinforced fibers were determined experimentally. The buckling test samples were obtained by cutting the manufactured composites using a circular diamond-blade saw. The dimensions of the samples were 140 mm length × 12 mm width × 4.8 mm thickness after being cut. At the test, the samples were fixed at a distance of 20 mm from the edges of the upper and lower testing devices for the handles of the machine. Thus, the effective length of the test samples is 100 mm [36]. The sample is subjected to a test where the lower jaw is fixed and the upper jaw is mobile. The axial compressive force is applied to the sample until it is exposed to buckling and failure. The load-displacement curve for each test sample, whether reinforced or unreinforced with fiber, is obtained directly from the computer controlling the testing machine. The buckling tests were done by applying the ASTM D6641 standard [24], with a loading rate of 5 mm/min. The buckling testing machine (a computer-controlled electronic universal testing machine, 50 KN) is shown in Figure 9. All the experiments were done at the laboratory temperature, and three samples were prepared for each test to obtain the standard deviation and mean values. The tested buckling specimens from the blend matrix with different percentages of polysulfide and blend reinforced with carbon and glass fiber are portrayed in Figures 10 (a and b).

Fig. 9. Buckling test



(a) (b)

Fig. 10. The buckling test specimens (a) unreinforced and (b) reinforced with fibers

4. Results and Discussion

4.1.Mold Preparation

Figure 11 demonstrates the experimental effects of the blend matrix, which includes epoxy and varying proportions of polysulfide. It should be noted that as the proportion of polysulfide in the mixture increases, the tensile stress decreases, but the failure strain increases. This is because the addition of polysulfide to the mixture reduces the brittleness of the epoxy.

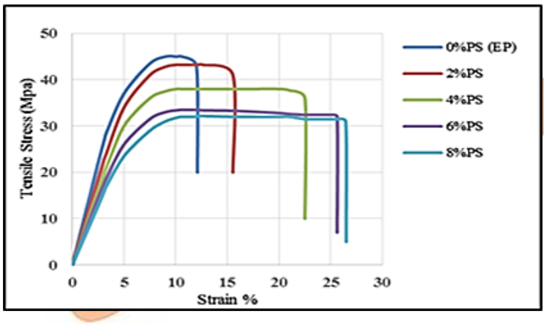


Fig. 11. Stress-strain curve for blend matrix

Figure 12 shows the decrease in the tensile stress of the blend after adding polysulfide. Also, Figure 13 exhibits the decrease in the Young's modulus value of the mixture with an increase in the weight percentages of polysulfide in the mixture compared with the pure epoxy.

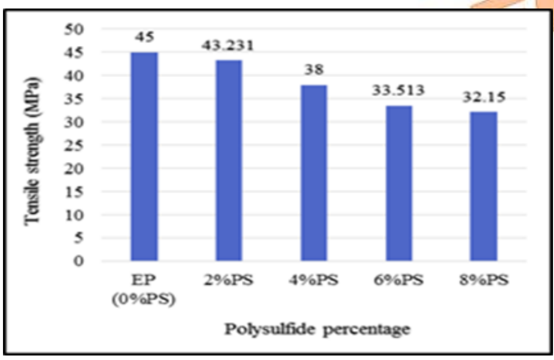


Fig. 12. The influence of Polysulfide percentage on tensile strength

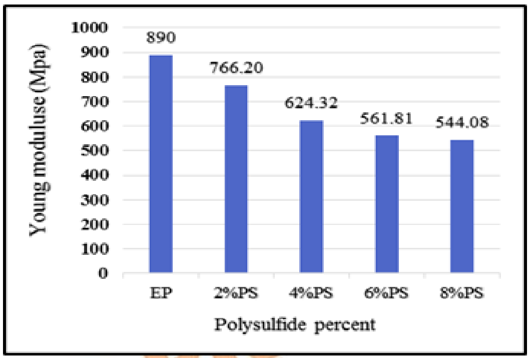
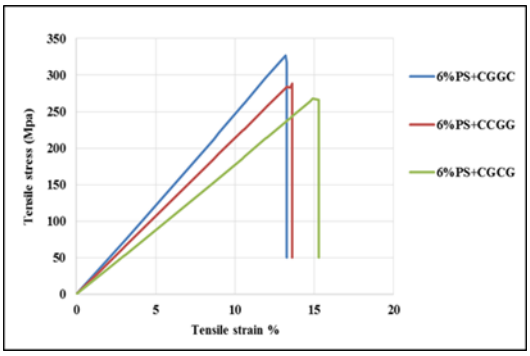
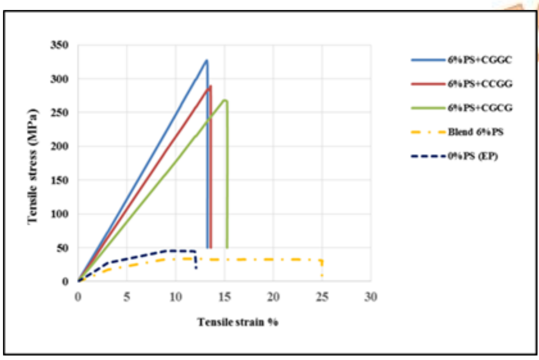


Fig. 13. The influence of Polysulfide percentage on Young modulus

The experimental results of the tensile tests for the blend consisting of epoxy and 6% polysulfide reinforced by eight layers of carbon fiber and glass fiber with different stacking sequences and orientation angles, as shown in Table No. 4, manifested that the fiber orientation had a significant influence on the tensile test outcomes. The tensile tests outcomes evinced that the bi-directional fiber orientation angle had a significant influence upon the tensile test outcomes, especially carbon fiber, because of its unique properties when used in reinforcement polymeric materials, which have high a hardness and a good resistance to tensile stress, compressive stress, fatigue stress, creep, and corrosion resistance. Figures (14 a) and (15 a) elucidate that the highest tensile stress value is 327 MPa recorded in model S3 as a result of oriented the carbon fibers layers in perpendicular direction to each other and in the direction of the axial tensile force of the testing machine, as well as, the arrangement of carbon fibers layers in model S3 surrounded the outer side of prepared composite which made it more resistabile to tensile forces due to their high tensile strength. On the other hand, models S1 and S2 showed lower tensile stress values than model S3 by 288.5 MPa and 267.5 MPa, respectively, due to the orientation of a lower number of carbon fibers in the (0^{o}-90^{o}) direction and being highly dependent on glass fiber layers to resist the axial applied load. Figure (14 b) portrays the amount of improvement in the tensile stress value when reinforced with carbon and glass fibers compared to the pure epoxy and the mixture composed of (EP+6% PS). The Young's modulus values (2.3903 GPa, 1.9697 GPa, and 2.7224 GPa) for the prepared fiber-reinforced blend composite in models S1, S2, and S3, respectively, are shown in the figure (15 b).

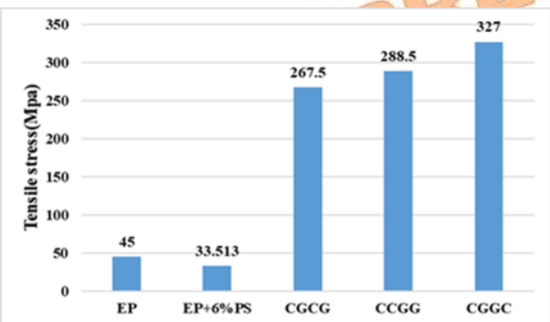


(a)

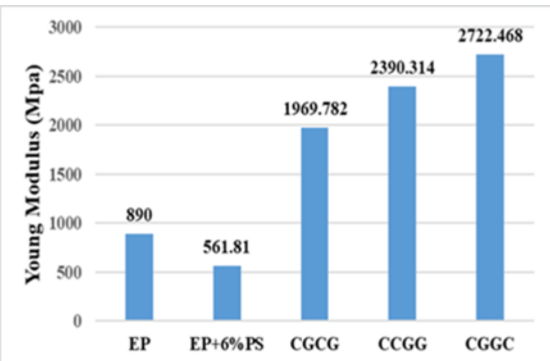


(b)

Fig 14. Stress-strain curves: (a) for the blend with carbon and glass fiber and (b) for the blend with carbon and glass fiber compared to the pure epoxy and the mixture composed of (EP+6% PS).



(a)



(b)

Fig 15. Influence of stacking sequence on (a) tensile strength and (b) Young's modulus

4.2 *Buckling test results*

The experimental outcomes of the buckling test samples indicated that the value of the axial buckling load and the critical buckling load for the test specimens prepared by applying an axial compressive load to the test specimens for the blend matrix consisting of epoxy and different weight percentages of polysulfide gradually decreased with an increase in the percentage of polysulfide. Figure (16) shows the values of the experimental and theoretical critical buckling load for the blend (2%, 4%, 6%, and 8%) and pure epoxy, where the percentage reduction in the critical buckling load value was (-13.9%, -29.88%, -37.115%, and -38.89%), respectively compared with the pure epoxy.

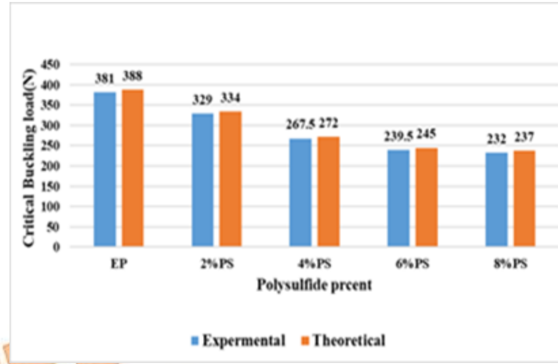
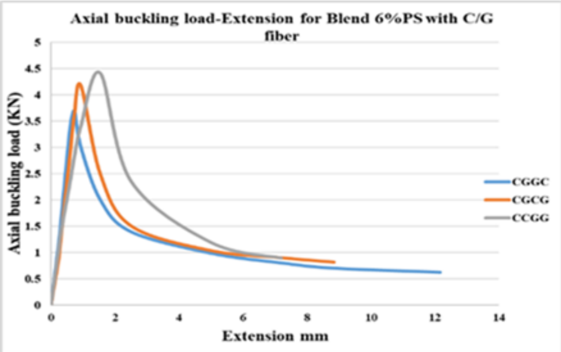
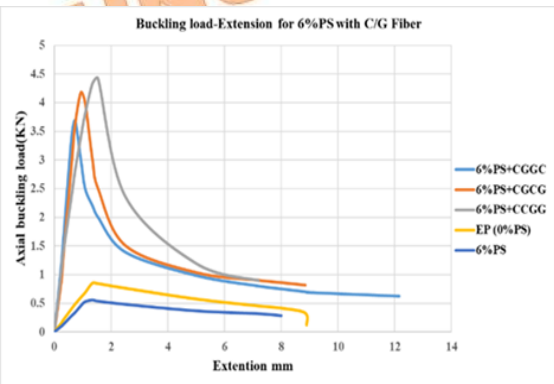


Fig 16. The experimental and theoretical critical buckling load

The experimental results obtained from the testing machine for the hybrid composite materials manufactured from (EP+6% PS) reinforced with carbon and glass fibers for the models (S1, S2, and S3) are shown in figures (17 a, b), and figure (18a) showed that the largest amount of critical buckling load was (1.2167 KN) for model S3 when the stacking sequence of the hybrid composite material is (CGGC)x2 followed by the value of (1.042533 KN) for model S1 in the stacking sequence (CCGG)x2. Also, the results revealed that the minimum amount of the critical buckling load was (0.92085 KN) for model S2 in the stacking sequence (CGCG)x2 compared with the net epoxy and blend (EP+6%PS). The experimental outcomes compared to the theoretical results are depicted in Figure 18. Additionally, it was observed that the critical buckling load for the composite materials reinforced with fibers depends greatly on the orientation angle of the fibers. The carbon fibers at an orientation angle (0–90°) in Model S3 had the greatest effect in this study on improving the critical buckling load of composite materials because of their high tolerance to the axial compressive force, with the direction of the fibers due to their super properties. Furthermore, the glass fiber, which is in the orientation (30–60°), has the ability to resist the formation and extension of cracks because it has a lower Young's modulus and a greater failure strain than carbon.



(a)



(b)

Fig.17. Axial buckling load-displacement curves showing the effects of fiber orientation angle on the axial buckling load

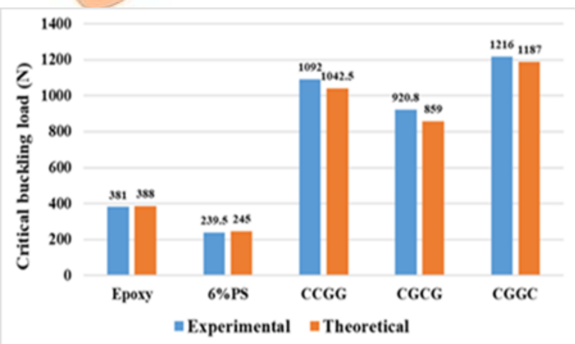


Fig.18. The critical buckling load for the hybrid composite material compared with the composite material and epoxy, depicting the experimental and theoretical results

5. Conclusions

1. The increasing in polysulfide content decreasing the tensile stress values by (3.933%, 15.55%, 25.52%, and 28.55%) and increasing the strain percentages by (8.388%, 85.95%, 111.768%, and 118.595) while decreasing the critical buckling load by (13.6%, 29.6%, 37%, and 39%) with the addition of (2%, 4%, 6%, and 8%) polysulfide respectively in comparative to pure epoxy.

2. All the values of tensile stress have been improved with the addition of eight woven carbon and glass fiber layers with different orientations and stacking sequences to blend epoxy + 6% polysulfide. This is especially true when all carbon fibers are oriented in a perpendicular direction to each other in model S3, followed by models S1 and S2, with improvement percentages of (875%, 760%, and 698%), respectively, in comparison to the blend epoxy + 6% polysulfide tensile stress value.

3. Due to presence of eight woven carbon and glass fibers layers with different orientations and stacking sequences, the critical buckling load increased by (186.6%, 141%, and 219%) in comparative to blend epoxy + 6% polysulfide critical buckling load value as a result of arrange the reinforced fibers layers according to models S1, S2, and S3 respectively.

Funding Statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of Interest

The authors have no conflicts of interest to declare.

References

[1] Madenci, E., Özkılıç, Y. O., Aksoylu, C., Asyraf, M. R. M., Syamsir, A., Supian, A. B. M., & Mamaev, N. ,2023. Buckling Analysis of CNT-Reinforced Polymer Composite Beam Using Experimental and Analytical Methods. Materials, 16(2), 614.

[2] Asyraf, M. R. M., Syamsir, A., Bathich, H., Itam, Z., Supian, A. B. M., Norhisham, S., & Rashid, M. Z. A.,2022. Effect of Fibre Layering Sequences on Flexural Creep Properties of Kenaf Fibre-reinforced Unsaturated Polyester Composite for Structural Applications. Fibers and Polymers, 23(11), 3232-3240.

[3] Madenci, E., Özkılıç, Y. O., & Gemi, L. .2020. Experimental and theoretical investigation on flexure performance of pultruded GFRP composite beams with damage analyses, Composite Structures, 242, 112162.

[4] Kadhim, F. M., Takhakh, A. M., & Abdullah, A. M. ,2019. Mechanical properties of polymer with different reinforcement material composites used to fabricate prosthetic sockets. Journal of Mechanical Engineering

Research and Developments, 42(4), 118-123.

[5] Madenci, E., & Özütok, A. ,2017. Variational approximate and mixed-finite element solution for static analysis of laminated composite plates. Solid State Phenomena, 267, 35-39.

[6] Karataş, M. A., & Gökkaya, H. 2018. A review on machinability of carbon fiber reinforced polymer (CFRP) and glass fiber reinforced polymer (GFRP) composite materials, Defence Technology, 14(4), 318-326.

[7] Madenci, E., Özkılıç, Y. O., & Gemi, L. ,2020. Buckling and free vibration analyses of pultruded GFRP laminated composites: Experimental, numerical and analytical investigations, Composite Structures, 254, 112806.

[8] KadeR, E. E., Asaad, L. M., & Abed, A. M. ,2021. Structural properties of epoxy–polysulfide copolymer reinforced with silicon carbide powder. Journal of Mechanical Engineering Research and Development cc, 44, 289-295.

[9] Bozkurt, Ö. Y., Bulut, M., Erkliğ, A., & Faydh, W. A. ,2019. Axial and lateral buckling analysis of fiber reinforced S-glass/epoxy composites containing nano-clay particles. Composites Part B: Engineering, 158, 82-91.

[10] Zhou, X., You, Q., Gao, Y., Hua, F., Fu, W., Huang, Q., & Wang, Y. ,2023. Buckling Analysis on Resin Base Laminated Plate Reinforced with Uniform and Functional Gradient Distribution of Carbon Fiber in Thermal Environment, Polymers, 15(9), 2086.

[11] Wang, C., Liu, G., An, Q., & Chen, M. ,2017. Occurrence and formation mechanism of surface cavity defects during orthogonal milling of CFRP laminates. Composites Part B: Engineering, 109, 10-22.

[12] El-Wazery, M. S. ,2021. Mode I fracture toughness of Carbon/glass hybrid composite. International Journal of Engineering, 34(11), 2418-2423.

[13] Maier, R., & Mandoc, A. C. ,2023. Investigation on layer hybridization of glass/carbon fibre woven reinforced composites subjected to low-speed impact, Journal of Composites Science, 7(2), 83.

[14] Wu, W., Wang, Q., & Li, W. ,2018. Comparison of tensile and compressive properties of carbon/glass interlayer and intralayer hybrid composites, Materials, 11(7), 1105.

[15] Bhoi, R. M., & Kalurkar, L. G. ,2014. Study of buckling behavior of beam and column. IOSR J Mech Civ Eng, 11, 36-40.

[16] Walker, A. C. ,1984. A brief review of plate buckling research. Elsevier Applied Science Publishers,, 375-398.

[17] Kadhim Oleiwi, J., & Jumaah Ahmed, S. ,2016. Tensile and buckling of prosthetic pylon made from hybrid composite materials. Engineering and Technology Journal, 34(14), 2642-2653.

[18] battawi,A.A., 2017. Factors affecting critical buckling load of reinforced beam, International Journal of Current Engineering and Technology, E-ISSN 2277 – 4106, P-ISSN 2347 – 5161, Available at http://inpressco.com/category/ijcet.

[19] Abdalikhwa, H. Z., Al-Shammari, M. A., & Hussein, E. Q. , 2021. Characterization and buckling investigation of composite materials to be used in the prosthetic pylon manufacturing. In IOP Conference Series: Materials Science and Engineering (Vol. 1094, No. 1, p. 012170), IOP Publishing.

[20] Dhuban, S. B., Karuppanan, S., Mengal, A. N., & Patil, S. S. ,2017. Effect of fiber orientation and ply stacking sequence on buckling behaviour of basalt-carbon hybrid composite laminates.

[21] Bipin, P. B., Senthikumar, K., & Deepak, K. P. ,2016. Buckling Analysis of Laminated Carbon Fiber Composite Beam using Ansys. International Journal of Engineering Research and Technology, 5(7), 399-404.

[22] Ahamed, S. R., Luqman, S. M., Purushotham, G., Dsouza, V., & Farzana, S. ,2018. Comparison of buckling strength between metallic and composite panel. Materials Today: Proceedings, 5(1), A1-A10.

[23] Azadi, R., & Rostamiyan, Y. ,2015. Experimental and analytical study of buckling strength of new quaternary hybrid nanocomposite using Taguchi method for optimization. Construction and Building Materials, 88, 212-224.

[24] Rostamiyan, Y., & Azadi, R. ,2016. The buckling strength of the new hybrid nanocomposite laminates using combination of layered and particulate nano fillers, Advances in Mechanical Engineering, 8(9), and 1687814016668706.

[25] Mhlongo, S. M. M. ,2019. Buckling analysis of nano-composite laminate using finite element analysis (Doctoral dissertation).

[26] Product Data sheet, Sika® - 52 LP, Manufactured in Bahrain by Sika Golf B.S.C(c), Bidg .325 ,Sitra Area 501,Kingdom of Bahrain , http://www.sika.com .bh .

[27] Product Data Sheet, Sika® Polysulphide PG, July 2018, July 2018, Version 03.02 020515070000000036, Product by UNITED ARAB EMIRATES, http://www. gcc.sika.com.

[28]TECHNICAL DATA SHEET, Yixing T-carbon Fiber Material Technology Co.ltd No-35 Chuangye Road, Heqiao Town,Yixing City ,Jiangsu Province, PR China.

[29] Product Data Sheet, Focus Technology Co., Ltd. https://utekcomposites.en.made-in china.com/product/souJDNZCGFrM/China-High-Strength-EWR200-Fiberglass-Woven-Roving.html.

[30] Kader, E. E., Abed, A. M., & Al-Shammari, M. A. ,2020. Al_2O_3 Reinforcement Effect on Structural Properties of Epoxy Polysulfide Copolymer. Journal of Mechanical Engineering Research and Developments, 43(4), 320-328.

[31] Li, F., Liu, Y., Qu, C. B., Xiao, H. M., Hua, Y., Sui, G. X., & Fu, S. Y. ,2015. Enhanced mechanical properties of short carbon fiber reinforced polyethersulfone composites by graphene oxide coating. Polymer, 59, 155-165.