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The Behavior of Banyan (B)/Banana (Ba) Fibers Reinforced Hybrid Composites Influenced by Chemical Treatment on Tensile, Bending and Water Absorption Behavior: An Experimental and FEA Investigation

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Abstract: Natural fiber-based composites are highly prioritized in present industries due to their properties and benefits over synthetic fibers. Due to their biodegradable nature, banyan and banana fibers were used for the present work. This paper deals with an experimental and FEA investigation of the tensile and bending behavior of banyan (B) and banana (Ba)-reinforced composites with different volume fractions, such as 25B/25Ba, 30B/20Ba, and 35B/15Ba, with a 50% weight fraction of epoxy resin and different fiber orientations. The hybrid composites treated with a 5% NaOH solution have better results as compared to untreated hybrid composites, with a volume fraction of 30% banyan fibers and 20% banana fiber (30B/20Ba), giving greater tensile and flexural properties for both treated and untreated fiber composites when compared to other volume fraction composites at 0/0/0/0 orientation. The maximum tensile and bending strength was found in the 30B/20Ba volume fractions to be 63.37 MPa and 67.07 MPa, respectively. For treated fiber composites, water absorption increases with an increase in the duration of immersion in composites up to 144 h.

Keywords: fiber's orientation; chemical treatment; mechanical properties; water absorption; hybrid composites

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1. Introduction

The fibers extracted from natural plants or trees and animals are called natural fibers. These kinds of fibers are used in daily life commodities such as threads, wicks, ropes, etc., due to of their highly flexible nature. Natural fibers have several benefits, such as easy availability, lower production costs, and low specific weight, and because of their biodegradable properties, they are environmentally friendly and highly preferable for insulating and thermal properties. The use of natural fibers in aerospace, automobile, construction, and many other industries is drastically increasing [1]. Due to the implications of hybrid-reinforced (synthetic/natural fiber) and appropriate fiber volume fraction, orientation and fabrication methods improve the thermal, mechanical, and physical properties with the combination of both synthetic and natural fibers [2]. Natural fiber composites have some limitations, such as swelling, moisture absorption, poor resistance towards fire, and also chemical reactions between fibers and matrix materials that lead to crack formation in both matrix and fibers. To overcome such drawbacks, techniques such as alkaline, maleic anhydride grafting and permanganate and chemical treatments are being used. These techniques also enhance the mechanical, thermal, and physical properties [3]. Bran, a hybrid natural fiber composite (bidirectional woven banyan fibers and neem fibers), was used as a filler for fabrications using the hand layup process to analyze thermal properties like heat deflection, temperature, thermal conductivity, flame retardance, and the coefficient of thermal expansion. With the usage of dual natural fibers, thermal properties have greatly improved [4]. Field hockey equipment is made of synthetic fibers. Over 90% of field hockey equipment produced in the world comes from Pakistan and Sialkot. Researchers replaced synthetic fibers with natural fibers like banana and other natural fibers for durability, safety, and efficiency. It is worth noting that with hybrid composites, the load-bearing capacity of hockey products has shown positive results [5]. Different processes involved in the extraction of banyan fibers such as selecting proper aerial roots, soaking, bleaching, and softening fibers were carried out. The fibers were treated with different chemical agents like sodium carbonate, sodium hydroxide, urea, and enzymes to observe physical properties and were then compared with other natural fibers. Sodium carbonate-treated fibers have high yielding capacity during extraction. Sodium hydroxide gives the best results in terms of properties compared to other chemicals, while banyan fibers have moisture-regaining capacity and retention compared to other fibers [6]. Alkali-treated cotton and areca fibers, when treated without alkali, have higher water absorption capacity compared to banana and pineapple leaves [7]. With combined banyan woven and neem fiber hybrid composites, the tensile, compressive, and flexural strength are much higher. Equal-weight fractions of neem and banyan fibers yield the greatest hardness and water absorption [8]. An experiment on the effect of stacking a series of hemp and sisal with green epoxy on physical, water absorption, and mechanical properties showed that the hybrid provides better mechanical properties than the non-hybrid material; however, the smallest resistance in terms of water absorption was observed [9]. Aerial roots of banyan underwent different mechanical tests by treating them with alkali chemicals, and a great improvement in the results was observed [10]. According to studies, ijuk fibers prepared via multistage treatments (alkalization, oxidation, and hydrolysis) both in method A and method B reveal that the level of crystallinity increases due to the annihilation of amorphous and hydrophilic parts in the fibers. Method A can raise the crystallinity of polypropylene composite to 31%, while method B rises to 28%, which is more effective compared to untreated ijuk fibers. Apart from the percentage of crystallinity, the time needed to crystallize when combined with polypropylene also speeds up, and in method A and method B, crystallinity accelerates, being 0.44 and 1.2 s faster [11].

From the literature, significant points can be perceived. Firstly, the mechanical properties of natural fiber composites can be enhanced by using hybridization. Secondly, numerical and theoretical analysis can be carried out by considering proper inputs through finite elements analysis and micromechanics, furthering the effect of chemical treatments on the natural fibers and the mechanical properties. Though many researchers put effort and attention into hybrid composites with different orientations and different stacking sequences using different natural fiber combinations, no work has been carried out regarding banyan/banana fibers, where the different orientations of natural fibers (banyan or banana) play a substantial role in a constant stacking sequence. This work consists of four layers of hybrid composite fabrication with different angles of arrangement to determine the best orientation as well as the hybridization effect of banyan and banana fibers. The work also focused on investigating the mechanical properties (tensile strength, bending strength, and water absorption) when chemically treating the fibers for different orientations and weight fractions of the fibers. One of the objectives of this work is to replace suitable aero and automobile parts with hybridized banyan and banana fibers. The best way in which the environment could be conserved is by using nontoxic and renewable materials.

2. Materials and Methods

2.1. Materials

To carry out the current research work, raw banyan (B) and banana (Ba) fibers were procured from M/s. Vruksha Composites, Tenali, India, as shown in Figure 1a. The hardener (HY951) and epoxy resin (LY556) were procured from Herenba Instruments and Engineers, Chennai, India, as shown in Figure 1b. Normal glass was used for the preparation as a mold material.

(a) (b)

Figure 1. (**a**) raw banyan (B) and banana (Ba) fibers. (**b**) The hardener (HY951) and epoxy resin (LY556).

2.2. Preparation of Reinforcement and Matrix Material

The fibers are available in a bundle form. The hand-sitting process was used to choose the fibers, carefully rejecting or removing unnecessary materials like small pellets, stems, and foreign materials. Once the unwanted materials were removed from the fibers, followed by cutting, as shown in Figure 2a, the water treatment was carried out, and the fibers were dipped in the water and dried until the water content was eliminated from the fibers [12–17]. After the water treatment, the fibers possessed a smooth surface and reduced adhesive properties. To overcome these effects, the fibers underwent chemical treatment by using a 5% NaOH solution and later using distilled water. The fibers were cleaned, followed by drying in an oven [18–22]. The treated fibers are shown in Figure 2b.

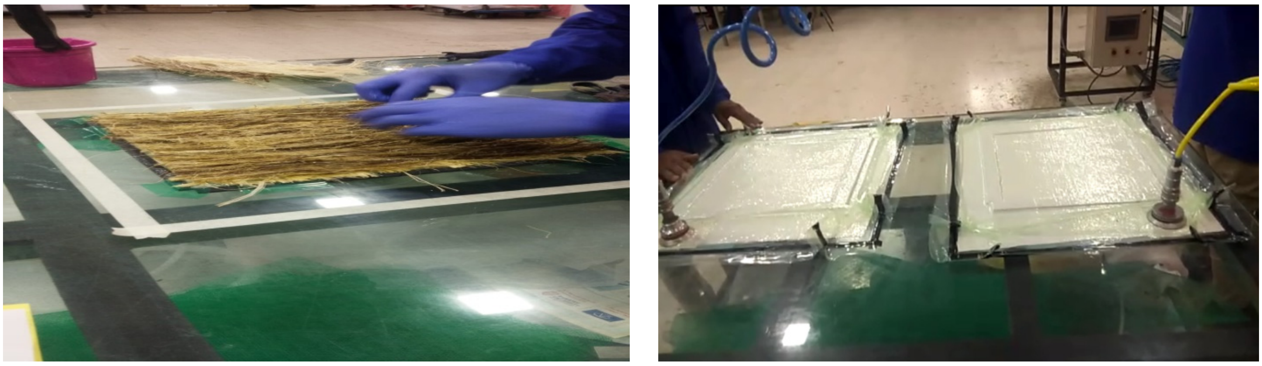
(a) (b)

Figure 2. (**a**) Cutting of banyan and banana fibers. (**b**) The treated fibers of banyan and banana.

A suitable proportion of resin and hardener mixed at a ratio of 10:1 was put in a plastic container and stirred for 5 min; the mixture was allowed to settle to obtain a clear solution. Once the solution had settled, it was taken for specimen preparation.

2.3. Composite Sample Preparations

In the current work, banyan (B) and banana (Ba) fiber hybrid composites were fabricated in addition to epoxy resin. The hand layup process was chosen to fabricate the composite specimens. They were stagnated properly without twisting and were gap-free in the mold, with the selected weight fraction of the fibers and epoxy as shown in Figure 3a. The fibers were placed in different orientations (0/0/0/0, 0/30/−30/0, 0/30/−45/0, 0/−30/45/0, 0/45/−30/0, 0/−45/30/0 and 0/45/−45/0), and a vacuum bag process was used to uniformly distribute the resin and remove excess resin from the mold, as shown in Figure 3b. Three different weight fractions of composites were fabricated by maintaining the constant weight of epoxy at 50% and varying the weight fraction of the fibers as follows: 25% banyan and 25% banana (25B/25Ba), 30% banyan and 20% banana (30B/20Ba), and 35% banyan and 15% banana (35B/15Ba) same shown in the Table 1. Different orientations of fibersand the schematic representation of ply in composites are shown in Figure 4. In each case, three specimens with and without chemical treatment were fabricated because there were experimental errors such as the direction of crosshead alignment and specimen alignment, mounting of the extensometer (displacement sensor), environmental effects on achieving the speed of the test, etc.



(**a**) (**b**)

Figure 3. (**a**) the fibers are stagnating. (**b**) Vacuum bag process.

Table 1. The weight fraction of composite samples.

% of Banyan (B)/ % Banana (Ba)	Total Matrix (%)	Banyan (B) (%)	Banana (Ba) (%)	Total Reinforcement (%)
25B/25Ba	50	25	25	50
30B/20Ba	50	30	20	50
35B/15Ba	50	35	15	50

The composites were prepared by using the hand layup process technique. Proper care was taken to avoid bubble formation in the composites. In this study, a 300 × 300 mm mold was used to fabricate the composite laminate. After the curing was complete, and the composite laminate with the dimensions of 300 × 300 × 3 mm is shown in Figure 5a. The composite laminates were cut according to ASTM standard dimensions by use of a CNC cutting machine for tensile, bending, and water absorption. The sample specimen size for the tensile test is given in Figure 5b,c.

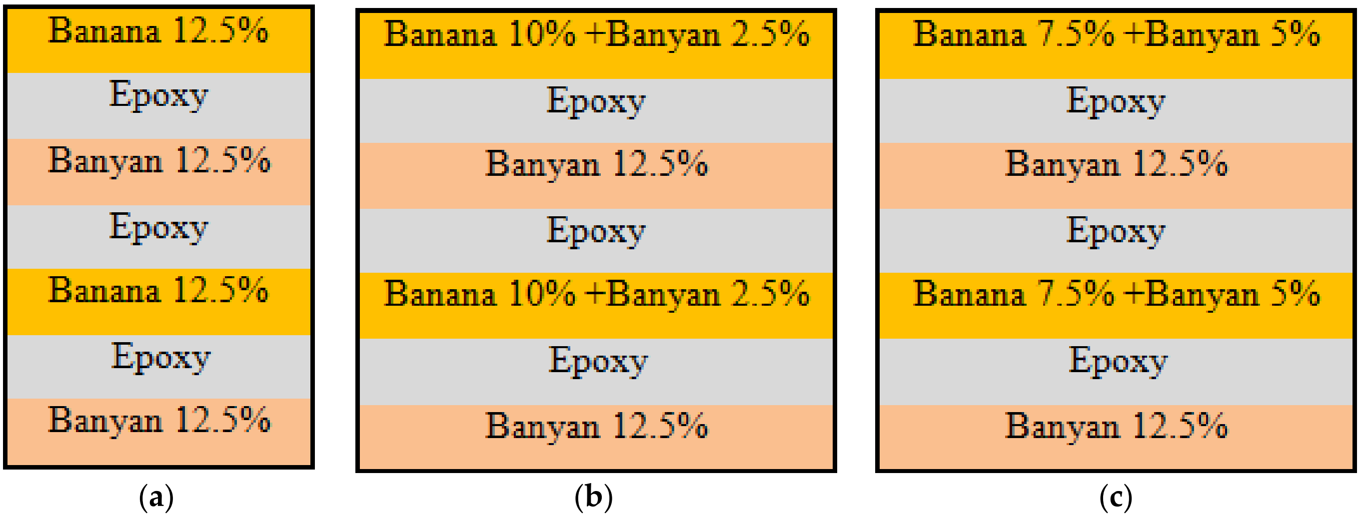


Figure 4. Schematic layout of the ply sequence for banyan (B) and banana (Ba) fiber epoxy hybrid composites. (**a**) 25B/25Ba, (**b**) 30B/20Ba and (**c**) 35B/15Ba.

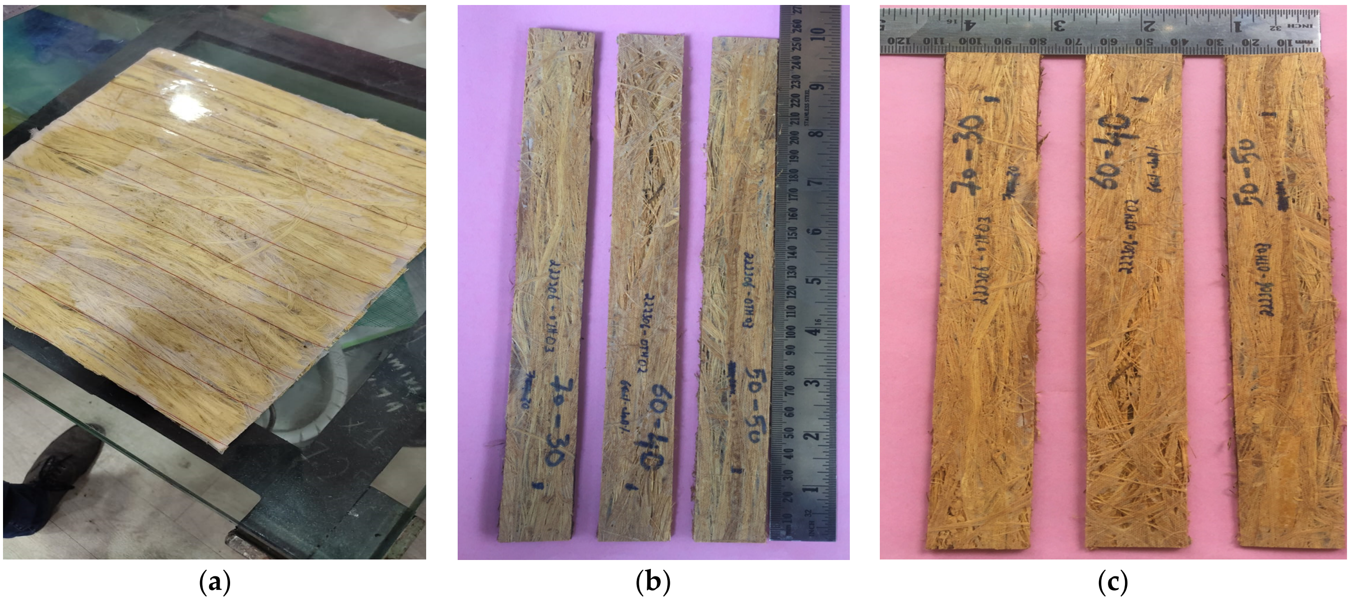


Figure 5. (**a**) Laminate composite, (**b**) Tensile test composite specimens 30 and (**c**) Bending test specimens.

2.4. Characterization Methods

2.4.1. Tensile Test

A servo-hydraulic-type Nano Plug-n′-Play Series Universal testing machine by BISS, shown in Figure 6a, was used to measure the tensile modulus and strength of the composite specimens. The test was carried out at a crosshead speed of 2 mm/min and 0.10 mm/min strain rate for all the specimens. The specimens were tested according to ASTM D3039 [12–16]. For each weight fraction variation, three specimens were tested, and the average values were taken.

(a) (b)

Figure 6. (**a**) A servo-hydraulic-type Nano Plug-n′-Play Series Universal testing machine. (**b**) Three-point bend fixture.

2.4.2. Flexural Test

A servo-hydraulic-type Nano Plug-n′-Play Series Universal testing machine by BISS, shown in Figure 6a, was used to measure the flexural modulus and strength of the composite specimens. We chose the 3-point bending test and a 3-point bend fixture, as shown in Figure 5b, because the applied load at the center in 3-point bending is distributed uniformly over the 4-point bending test. The test was carried out at a crosshead speed of 2 mm/min and 0.10 mm/min strain rate for all the specimens. The specimens were tested according to ASTM D790 [17–23]. In each variation weight fraction, three specimens were tested, and the average values were taken.

2.4.3. Water Absorption Test

The effects of water absorption on the hybrid composite specimens were analyzed according to ASTM D570 [22]. The dimensions for the specimens were 76.2 × 25.4 × 3 mm [24]. The experimentation of the test begins with placing the specimens in an oven at 60 degrees C for 24 h so that the moisture and any water particles will be removed. The specimens were weighed (Wi) immediately after being removed from the oven and were immersed in distilled water for 24 h. After 24 h, the specimens were taken out of the water bath and wiped using a smooth cloth. Later, the specimens were periodically weighed for mass gain (Wo) every 24 h (24, 48, 72, 96,120, and so on) until the water absorption of the specimens attained saturation level [25]. The percentage of water absorbed by the specimens at different time durations was calculated by using the following equation:

$$Wa\ (\%) = ((Wo - Wi)/Wi) \times 100$$

where Wa is water absorption, Wi is the weight of the composite before immersion, and Wo is the weight of the composite after immersion.

2.4.4. Finite Element Analysis

In this work, ANSYS 2020 R2 software is engaged to determine the tensile strength and bending strength of a hybrid composite. The material properties of fibers and epoxy resin are obtained from the supplier, which are measured before supply, and these are given in Table 2. By the use of the hybrid mixture rule, the longitudinal modulus E1 and Poisson's ratio in longitudinal v12 and v13 are predicted. The transverse modulus E2 and shear modulus G12, G13, and G23 were predicted by using the modified Halpin–Tsai equation.

Table 2. Material properties.

Materials	Young's Modulus (GPa)	Poisson's Ratio	Density (g/cm^3)
Banyan (B) fibers	1.5	0.24	1.92
Banana (Ba) fibers	3.5	0.28	1.35
Epoxy resin	2.8	0.35	1.19

3. Results and Discussions

3.1. Effect of Fibers on Tensile Properties

The tensile strength and tensile modulus of the banyan (B) and banana (Ba) hybrid composite were measured for both treated and untreated conditions. It is noticed that an increase in banyan (B) fibers in a composite from an equal weight fraction (25B/25Ba) to a weight fraction of (30B/20Ba) increased with tensile strength, max load, and tensile modulus. A slight decrease in tensile properties from weight fraction (30B/20Ba) to weight fraction (35B/15Ba) was also observed. For better results, at least three measurements for each orientation were performed, and the mean value as well as the standard deviation were calculated for these results [26]. The results of different volume proportions of fibers and different orientations for both untreated and treated fibers are listed in Tables 3 and 4.

Table 3. Tensile test results of composites for fibers without chemical treatment.

Weight Fraction →		25B/25Ba			30B/20Ba			35B/15Ba	
Orientations ↓	Tensile Strength (MPa)	Tensile Modulus (GPa)	Max Load (kN)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Max Load (kN)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Max Load (kN)
0/0/0/0	18.32 ± 0.15	1.16 ± 0.02	1.59 ± 0.01	49.16 ± 1.66	4.19 ± 0.13	5.86 ± 0.28	43.86 ± 1.20	3.88 ± 0.07	4.18 ± 0.07
0/30/−30/0	17.32 ± 0.14	1.09 ± 0.02	1.51 ± 0.01	44.76 ± 2.08	3.81 ± 0.12	5.33 ± 0.25	40.32 ± 1.11	3.56 ± 0.07	3.84 ± 0.06
0/30/−45/0	17.64 ± 0.20	1.11 ± 0.02	1.53 ± 0.01	46.02 ± 1.55	3.92 ± 0.12	5.48 ± 0.26	41.21 ± 1.13	3.64 ± 0.07	3.93 ± 0.06
0/−30/45/0	17.64 ± 0.14	1.11 ± 0.02	1.53 ± 0.01	46.02 ± 2.23	3.92 ± 0.12	5.48 ± 0.26	41.21 ± 1.13	3.64 ± 0.07	3.93 ± 0.06
0/45/−30/0	16.89 ± 0.13	1.07 ± 0.02	1.47 ± 0.01	43.71 ± 1.47	3.72 ± 0.12	5.21 ± 0.25	38.89 ± 1.50	3.44 ± 0.06	3.71 ± 0.06
0/−45/30/0	16.89 ± 0.18	1.07 ± 0.02	1.47 ± 0.01	43.71 ± 2.00	3.72 ± 0.12	5.21 ± 0.25	38.89 ± 1.10	3.44 ± 0.06	3.71 ± 0.06
0/45/−45/0	16.08 ± 0.25	1.01 ± 0.01	1.40 ± 0.01	43.98 ± 1.48	3.75 ± 0.12	5.24 ± 0.25	38.99 ± 1.80	3.45 ± 0.06	3.72 ± 0.06

Table 4. Tensile test results of composites for fibers with chemical treatment.

Weight Fraction →		25B/25Ba			30B/20Ba			35B/15Ba	
Orientations ↓	Tensile Strength (MPa)	Tensile Modulus (GPa)	Max Load (kN)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Max Load (kN)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Max Load (kN)
0/0/0/0	23.61 ± 0.51	1.49 ± 0.05	2.06 ± 0.03	63.37 ± 3.02	5.40 ± 0.8	7.55 ± 0.43	56.53 ± 2.22	5.00 ± 0.16	5.39 ± 0.07
0/30/−30/0	22.24 ± 0.48	1.40 ± 0.03	1.94 ± 0.04	58.73 ± 2.80	5.01 ± 0.26	7.00 ± 0.40	51.19 ± 2.01	4.53 ± 0.13	4.88 ± 0.06
0/30/−45/0	22.65 ± 0.49	1.43 ± 0.05	1.97 ± 0.03	60.38 ± 2.88	5.15 ± 0.21	7.20 ± 0.41	52.30 ± 2.06	4.62 ± 0.14	4.99 ± 0.10
0/−30/45/0	22.65 ± 0.49	1.43 ± 0.06	1.97 ± 0.02	60.38 ± 2.88	5.15 ± 0.19	7.20 ± 0.41	52.30 ± 2.06	4.62 ± 0.14	4.99 ± 0.06
0/45/−30/0	21.69 ± 0.48	1.43 ± 0.03	1.97 ± 0.08	57.35 ± 2.84	5.10 ± 0.19	7.13 ± 0.26	49.35 ± 2.09	4.61 ± 0.15	4.97 ± 0.08
0/−45/30/0	21.69 ± 0.9	1.43 ± 0.04	1.97 ± 0.03	57.35 ± 2.85	5.10 ± 0.26	7.13 ± 0.22	49.35 ± 2.05	4.61 ± 0.13	4.97 ± 0.10
0/45/−45/0	20.65 ± 0.45	1.30 ± 0.03	1.80 ± 0.02	57.70 ± 2.75	4.92 ± 0.25	6.88 ± 0.39	49.48 ± 1.95	4.37 ± 0.16	4.72 ± 0.06

A weight fraction of 30% banyan (B) fiber and 20% banana (Ba) fiber (30B/20Ba) and an 0/0/0/0 orientation yielded a maximum tensile strength of 49.166 MPa, a maximum tensile modulus of 5.864 GPa and maximum load of 4.193 kN for untreated fiber composites 0/0/0/0 orientation specimens give better results for tensile strength and tensile modulus when compared to other orientations, as shown in Figure 7. It is also observed that the tensile strength will vary or reduce with changing orientations from 0° to 45° on positive and negative sides. Decreased tensile strength and tensile modulus were observed in 45°

orientation specimens both with and without fiber-treated specimens. The same effect was observed for the load-carrying capacity of specimens, wherein the treated specimens will have higher load-carrying capability compared to the untreated specimens, as shown in Figure 8. One of the major objectives of this work is to focus on the change in the properties between chemically treated and untreated fiber composites. From the experimental results, it can be observed that the chemically treated fiber tensile composites have higher tensile properties (tensile strength, tensile modulus, and maximum tensile load carrying capacity) compared to the untreated fiber tensile composites. An increase of 28 to 31% was noticed in tensile properties from untreated to treated fiber composites. This is due to better interaction and chemical bonding between the fiber and matrix, which is a result of the removal of surface impurities and the partial removal of amorphous hemicellulose and lignin and increase in crystallinity. From 0/0/0/0 orientation of various orientations, the results of the tensile properties (tensile strength, maximum load carrying capacity, and tensile modulus) were 96.26% to 87.74% in untreated fiber composites and 95.92% to 87.45% in the treated fiber composites.

3.2. Effect of Fibers on Flexural Properties

The flexural strengths and flexural modulus of the banyan (B) and banana (Ba) hybrid composite are measured for both fibers treated and untreated conditions. It is noticed that an increase in banyan fibers in a composite from an equal weight fraction (25B/25Ba) to a weight fraction of (30B/20Ba) increased with bending strength, max load, and bending modulus. A decrease in flexural properties when decreasing banyan (B) fiber content from a weight fraction of (30B/20Ba) to a weight fraction of (35B/15Ba) was also observed. For better results, at least three measurements for each orientation were performed, and the mean value, as well as the standard deviation, were calculated for these results [26]; the results of different volume proportions of fibers and different orientations for both untreated and treated fibers are listed in Tables 5 and 6.

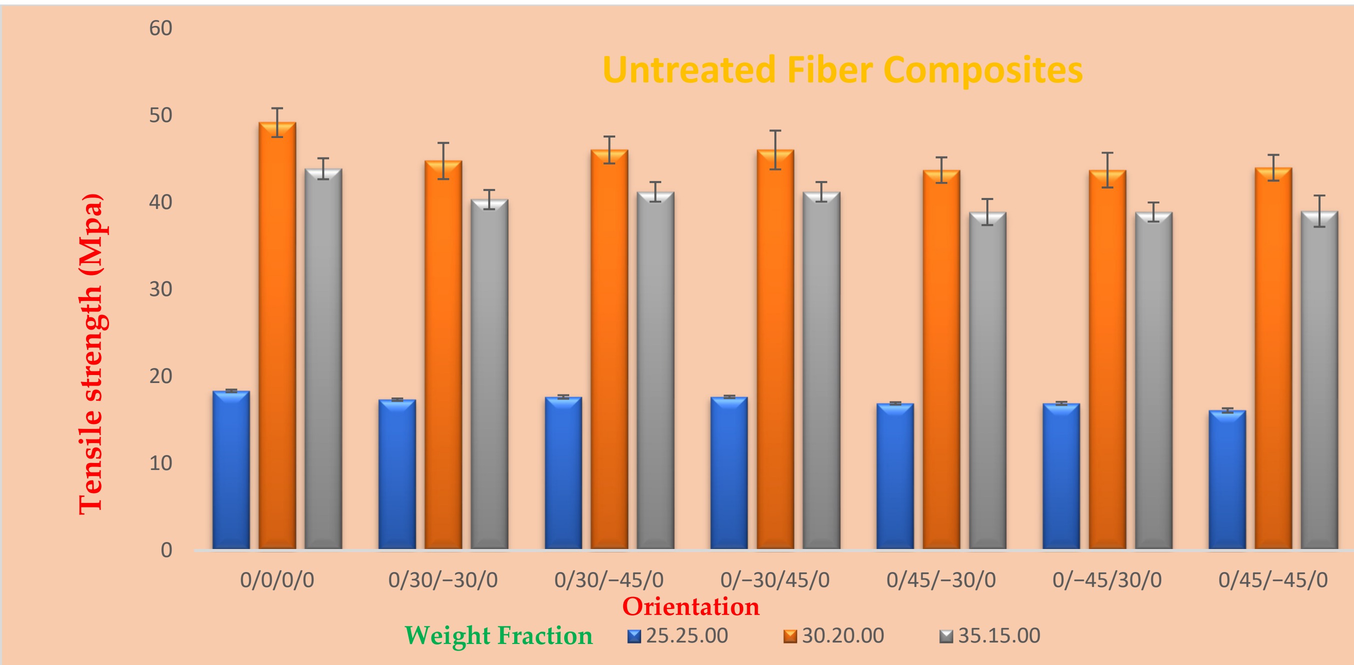


Figure 7. Tensile strength variation of natural fiber reinforced without treatment composite for different volume fractions and different orientations.

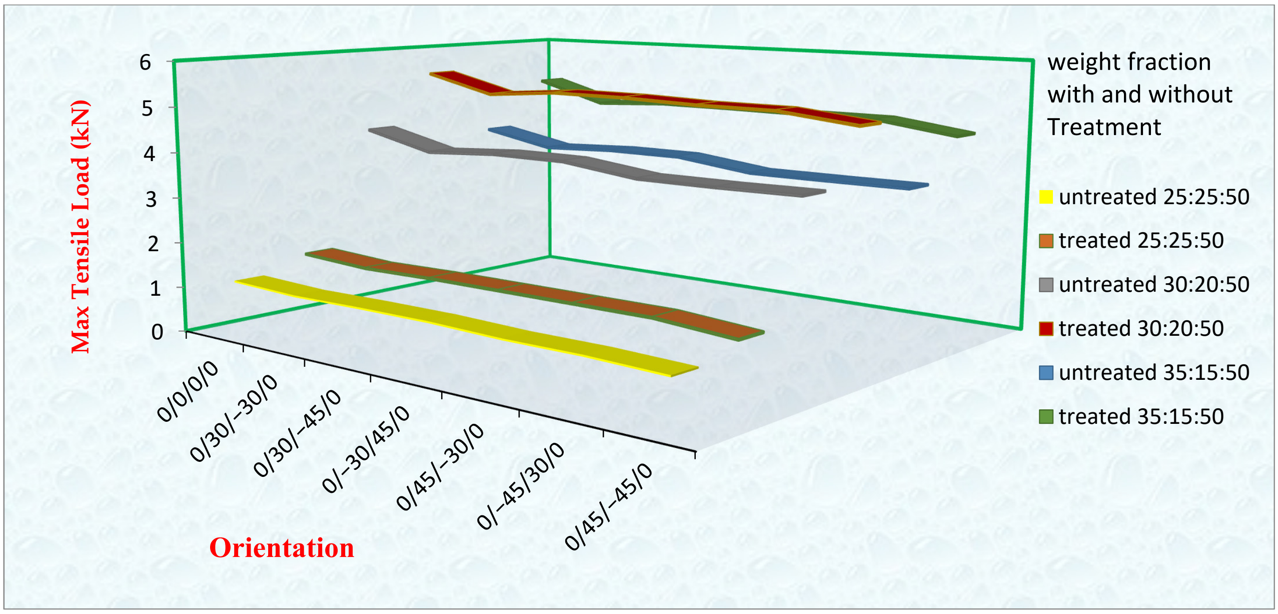


Figure 8. Tensile load carrying capacity of natural fiber reinforced with and without treatment composite for different volume fractions and different orientations.

Table 5. Bending test results of composites for fibers without chemical treatment.

Weight Fraction →	25B/25Ba			30B/20Ba			35B/15Ba		
Orientations ↓	**Bending Strength (MPa)**	**Bending Modulus (GPa)**	**Max Load (kN)**	**Bending Strength (MPa)**	**Bending Modulus (GPa)**	**Max Load (kN)**	**Bending Strength (MPa)**	**Bending Modulus (GPa)**	**Max Load (kN)**
0/0/0/0	39.46 ± 1.34	0.05 ± 0.04	1.37 ± 0.001	54.58 ± 0.41	0.13 ± 0.05	3.95 ± 0.003	36.42 ± 0.14	0.04 ± 0.19	2.86 ± 0.002
0/30/−30/0	38.04 ± 1.29	0.05 ± 0.04	1.32 ± 0.001	52.08 ± 2.08	0.12 ± 0.13	3.77 ± 0.003	34.66 ± 0.13	0.04 ± 0.42	2.72 ± 0.002
0/30/−45/0	37.77 ± 0.20	0.05 ± 0.04	1.31 ± 0.001	51.61 ± 0.39	0.12 ± 0.18	3.73 ± 0.003	34.34 ± 0.13	0.04 ± 0.38	2.70 ± 0.002
0/−30/45/0	37.77 ± 1.28	0.05 ± 0.04	1.31 ± 0.001	51.61 ± 2.23	0.12 ± 0.13	3.73 ± 0.003	34.34 ± 0.13	0.04 ± 0.34	2.70 ± 0.002
0/45/−30/0	37.73 ± 014	0.05 ± 0.04	1.31 ± 0.001	51.59 ± 0.39	0.12 ± 0.15	3.73 ± 0.003	34.32 ± 1.50	0.04 ± 0.41	2.70 ± 0.002
0/−45/30/0	37.73 ± 0.18	0.05 ± 0.04	1.31 ± 0.001	51.59 ± 2.00	0.12 ± 0.13	3.73 ± 0.003	34.32 ± 1.10	0.04 ± 0.43	0.70 ± 0.002
0/45/−45/0	37.49 ± 0.25	0.05 ± 0.04	1.30 ± 0.001	51.21 ± 0.39	0.12 ± 0.18	3.71 ± 0.003	34.26 ± 1.80	0.04 ± 0.57	2.69 ± 0.002

Table 6. Bending test results of composites for fibers with chemical treatment.

Weight Fraction →	25B/25Ba			30B/20Ba			35B/15Ba		
Orientations ↓	**Bending Strength (MPa)**	**Bending Modulus (GPa)**	**Max Load (kN)**	**Bending Strength (MPa)**	**Bending Modulus (GPa)**	**Max Load (kN)**	**Bending Strength (MPa)**	**Bending Modulus (GPa)**	**Max Load (kN)**
0/0/0/0	49.83 ± 1.19	0.07 ±0.04	1.77 ± 0.002	67.07 ± 0.81	0.16 ± 0.09	5.09 ± 0.002	45.11 ± 1.02	0.05 ± 0.06	3.69 ± 0.016
0/30/−30/0	46.45 ± 1.11	0.06 ± 0.05	1.56 ± 0.016	64.98 ± 0.79	0.16 ± 0.12	4.99 ± 0.022	41.74 ± 0.95	0.05 ± 0.21	3.40 ± 0.013
0/30/−45/0	46.90 ± 1.15	0.06 ± 0.10	1.63 ± 0.008	64.82 ± 0.79	0.16 ± 1.36	4.97 ± 0.021	41.59 ± 0.94	0.05 ± 0.20	3.38 ± 0.022
0/−30/45/0	46.90 ± 1.12	0.06 ± 0.08	1.57 ± 0.012	64.82 ± 0.78	0.16 ± 0.13	4.97 ± 0.058	41.53 ± 1.06	0.05 ± 0.10	3.38 ± 0.031
0/45/−30/0	46.11 ± 1.14	0.06 ± 0.08	1.61 ± 0.008	66.01 ± 0.77	0.16 ± 0.14	4.89 ± 0.003	40.95 ± 0.98	0.05 ± 0.16	3.53 ± 0.003
0/−45/30/0	46.34 ± 1.12	0.06 ± 0.18	1.57 ± 0.007	66.29 ± 0.80	0.16 ± 0.09	5.04 ± 0.011	40.91 ± 1.10	0.05 ± 0.12	3.43 ± 0.014
0/45/−45/0	45.85 ± 1.13	0.06 ± 0.09	1.59 ± 0.003	66.06 ± 0.81	0.16 ± 0.10	5.07 ± 0.024	41.31 ± 0.94	0.05 ± 0.22	3.3±0.018

A weight fraction of 30% banyan (B) fiber and 20% banana (Ba) fiber (30B/20Ba) yielded a maximum bending strength of 52.581 MPa, a maximum bending modulus of 0.131 GPa, and maximum load of 3.95 kN for untreated fiber composites. The 0/0/0/0 orientation specimens yielded better results in terms of bending strength and bending modulus compared to other orientations, as shown in Figure 9. It is also observed that the bending strength will vary or reduce with changing orientations from 0° to 45° on positive and negative sides. Decreased bending strength and bending modulus were observed in the 45° orientation specimens both with and without fiber-treated specimens. The same effect was observed for the load-carrying capacity of specimens and treated specimens will have higher load-carrying capability compared to those without treated specimens, as shown in Figure 10. The work is focused on the change in properties between chemically treated and untreated fiber composites. From the experimental results, it is observed that the chemically treated fiber composites have higher flexural properties compared to untreated fiber composites and also noticed that 27 to 31% increase in flexural properties from untreated to treated fiber composites. From the 0/0/0/0 orientation of other orientations, the bending properties (bending strength, maximum load carrying capacity, and bending modulus) are observed with 96.38% to 93.45% in untreated fiber composites and 99.63% to 87.14% in treated fiber composites.

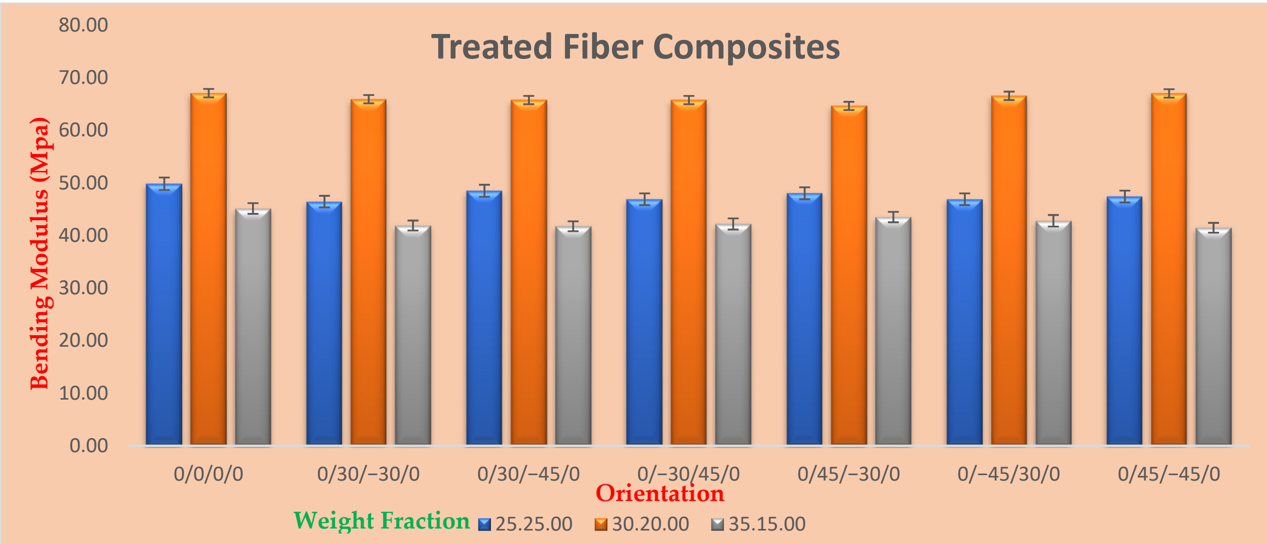


Figure 9. Flexural strength variation of natural fiber reinforced with treatment composite for different volume fractions and different orientations.

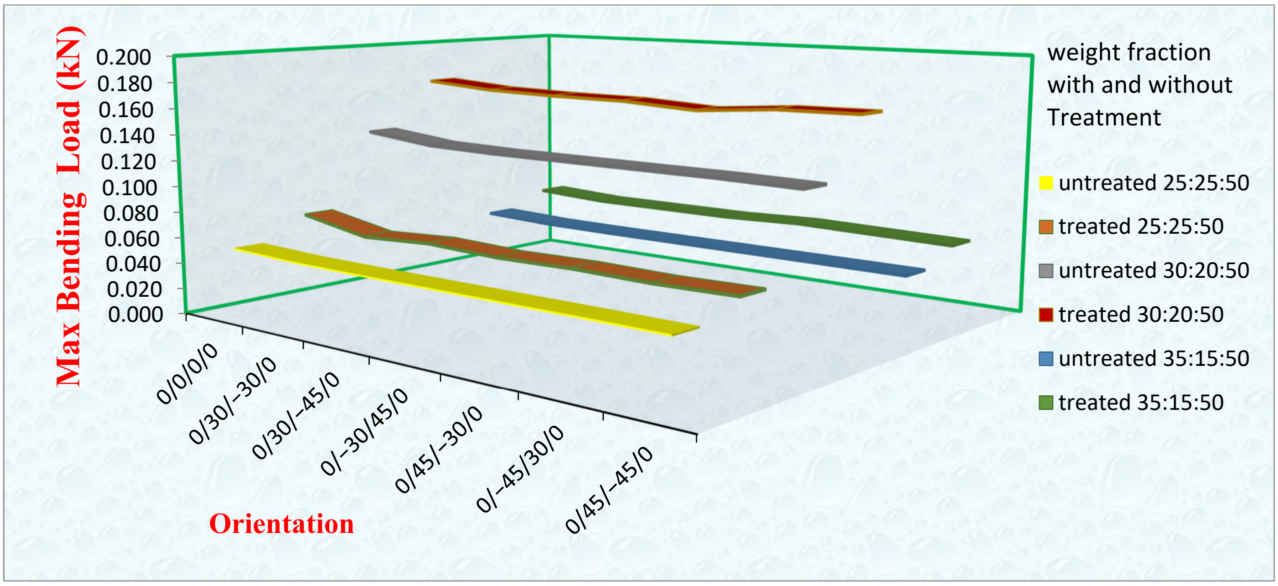


Figure 10. Bending load carrying capacity of natural fiber reinforced with and without treatment composites for different volume fractions and different orientations.

3.3. The Effect of Water Absorption

Water absorption is a very important property in understanding composite materials. Figure 11 shows the water absorbed by the treated and untreated composite specimens in terms of percentage for different weight fractions of fibers and the duration of immersion. The water absorption takes place from 9 to 22% in both treated and untreated fiber composites with different durations; water absorption remains saturated after 144 h.

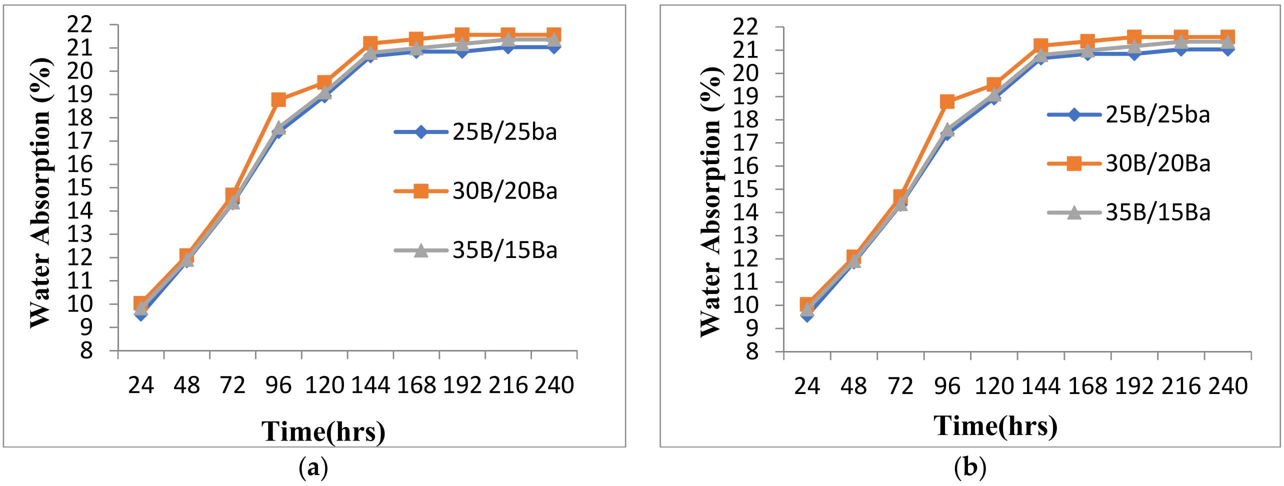


Figure 11. Water absorption curves (**a**) untreated banyan and banana fiber-reinforced composites and (**b**) treated banyan and banana fiber-reinforced composites.

The water absorption capacity with an equal proportion of fibers (25B/25Ba) in the composites is less compared to other weight proportions (30B/20Ba and 35B/15Ba). With the increase in banyan (B) fibers in the composite, a small increase in water absorption capacity can be observed. The composites with treated fibers have comparatively less water absorption capacity of about 2% compared to the untreated fibers composites with the same volume fraction and same duration of immersion; this is because of the chemical bonding and interaction between fibers and matrix, removing impurities on the surfaces of the fibers and increases crystallinity.

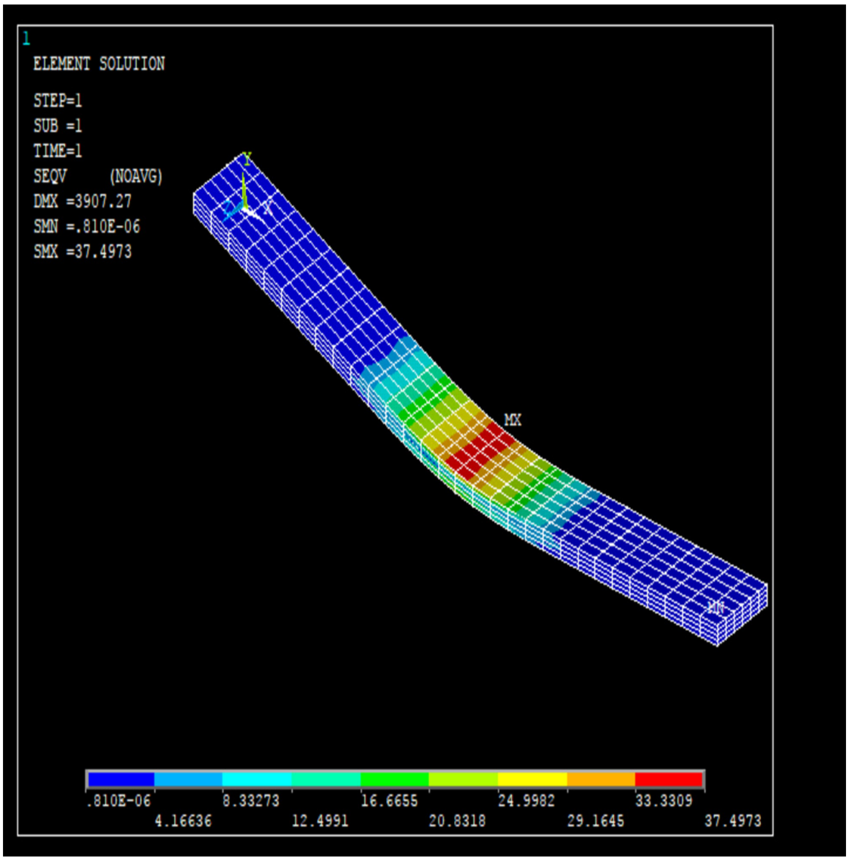
3.4. Simulation Results

Simulated stress distribution tests for the tensile and bending strength of banyan (B) and banana (Ba) hybrid treated and untreated at different volume fractions were performed. Table 7 summarizes the comparison of the experimental (as in Tables 3–6) and simulated results. The FEA results are higher compared to the experimental results because it assumes that the fibers are perfectly aligned, the presence of a perfect bond between fibers and matrix, the fibers are uniform in diameter, and that the fibers are non-porous. It is observed that the maximum percentage of the difference between the experimental and simulated results was found to be 7.36%.

In the FEA, one of the important factors are von Mises stresses, and the concentration areas of maximum and minimum stress indicated with red and blue. The plots of the elemental solutions for tensile and bending strengths showing simulated stress distributions for banyan (B) and banana (Ba) hybrid treated and untreated composites are shown in Figure 12. As the results indicate, tensile strengths and flexural strengths increased in treated fiber composites.

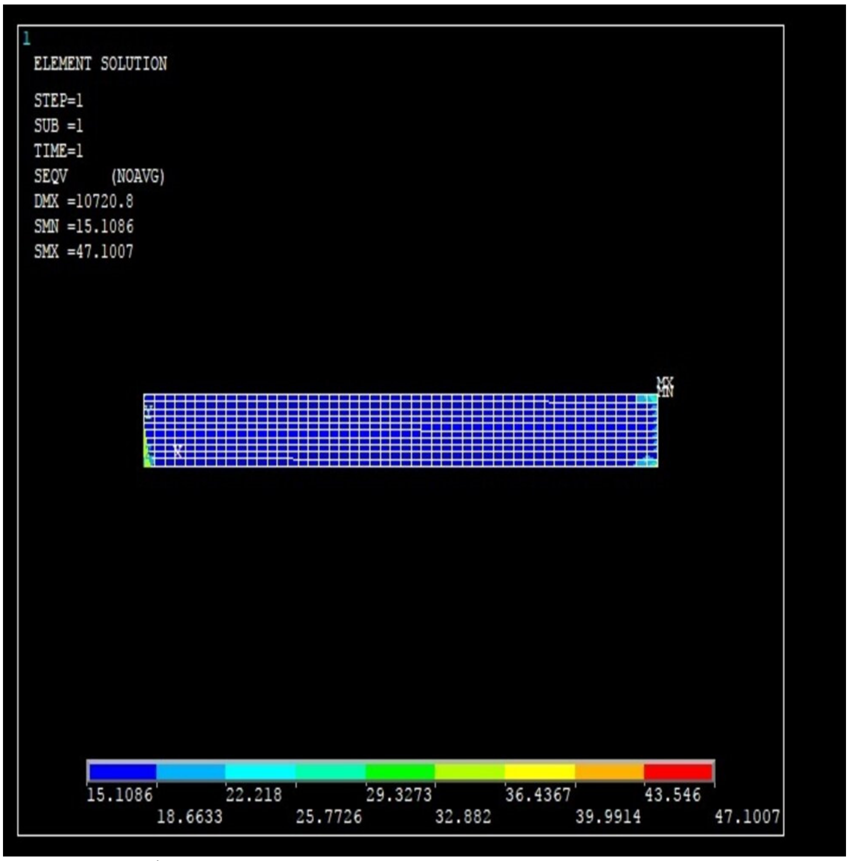
Table 7. Comparison of experimental and FEA results.

Mechanical Properties	Orientations	Untreated			FEA Untreated			Treated			FEA Treated		
		25B/25Ba	30B/20Ba	35B/15Ba	25B/25Ba	30B/20Ba	35B/15Ba	25B/25Ba	30B/20Ba	35B/15Ba	25B/25Ba	30B/20Ba	35B/15Ba
Tensile strength (MPa)	0/0/0/0	18.32	49.16	43.86	19.16	50.92	45.19	23.61	63.37	56.53	24.97	65.38	58.13
	0/30/−30/0	17.32	44.76	40.32	18.13	47.10	42.17	22.24	58.73	51.19	23.17	62.69	54.40
	0/30/−45/0	17.64	46.02	41.21	18.42	48.03	43.10	22.65	60.38	52.30	23.54	63.93	55.60
	0/−30/45/0	17.64	46.02	41.21	18.42	48.03	43.100	22.65	60.38	52.30	23.54	63.93	55.60
	0/45/−30/0	16.89	43.71	38.89	17.46	45.84	41.15	21.69	57.35	49.35	22.31	61.01	53.08
	0/−45/30/0	16.89	43.71	38.89	17.46	45.84	41.15	21.69	57.35	49.35	22.31	61.01	53.08
	0/45/−45/0	16.08	43.98	38.99	17.26	45.11	40.40	20.65	57.70	49.48	22.06	60.04	52.12
Bending strength (MPa)	0/0/0/0	39.46	54.58	36.42	39.46	54.58	36.42	49.83	67.07	45.11	50.85	68.89	46.75
	0/30/−30/0	38.04	52.08	34.66	38.04	52.08	34.66	46.45	64.98	41.74	48.62	68.32	44.71
	0/30/−45/0	37.77	51.61	34.34	37.77	51.61	34.34	46.90	64.82	41.59	48.27	68.69	44.30
	0/−30/45/0	37.77	51.61	34.34	37.77	51.61	34.34	46.90	64.82	41.53	48.27	68.69	44.30
	0/45/−30/0	37.73	51.59	34.32	37.73	51.59	34.32	46.11	66.01	40.95	48.22	68.67	44.27
	0/−45/30/0	37.7	51.59	34.32	37.73	51.59	34.32	46.34	66.29	40.91	48.22	68.67	44.27
	0/45/−45/0	37.49	51.21	34.26	37.49	51.21	34.26	45.85	66.06	41.31	47.91	68.16	44.20

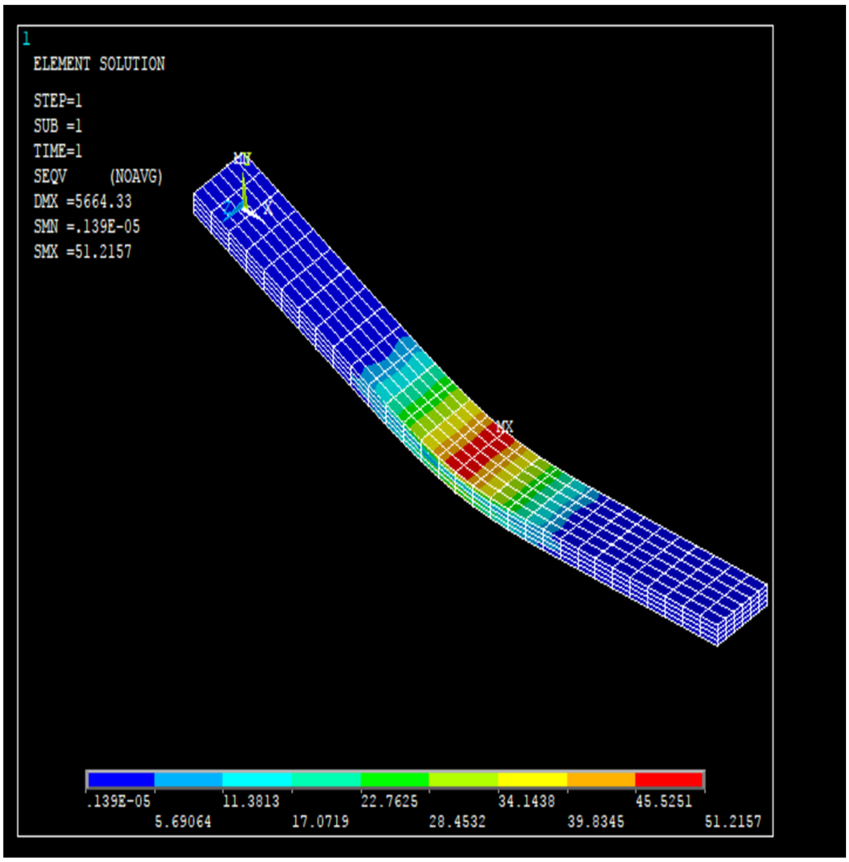


(**a**) simulated bending test results for 25B/25Ba composite with 0/45/−45/0 orientation

Figure 12. *Cont.*

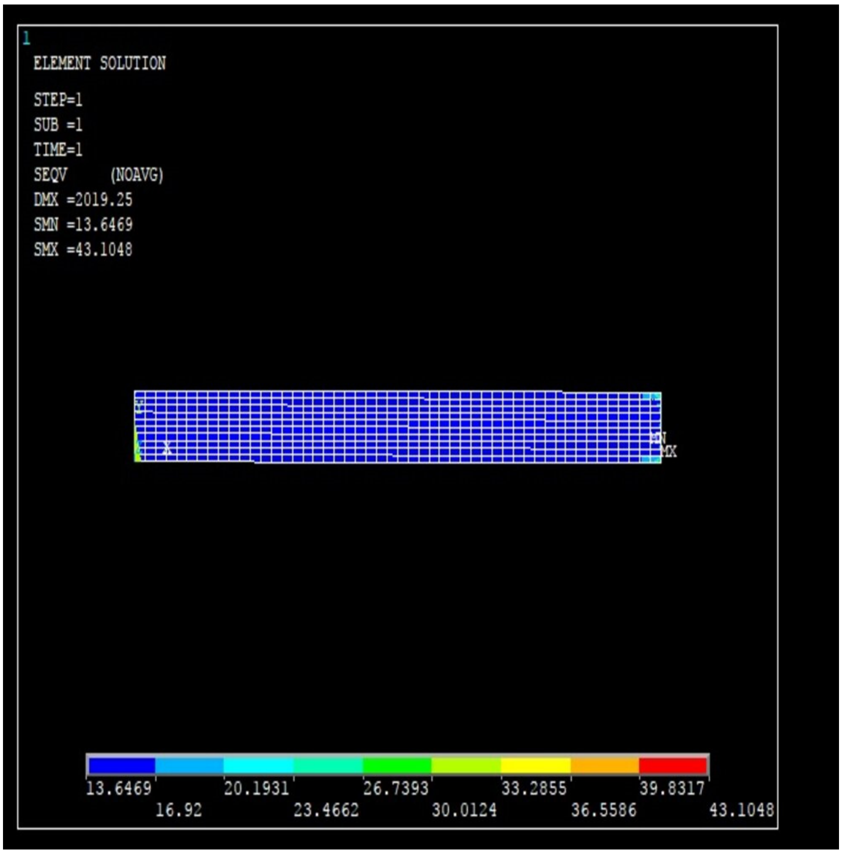


(**b**) simulated tensile test results for 30B/20Ba composite with 0/30/−30/0 orientation

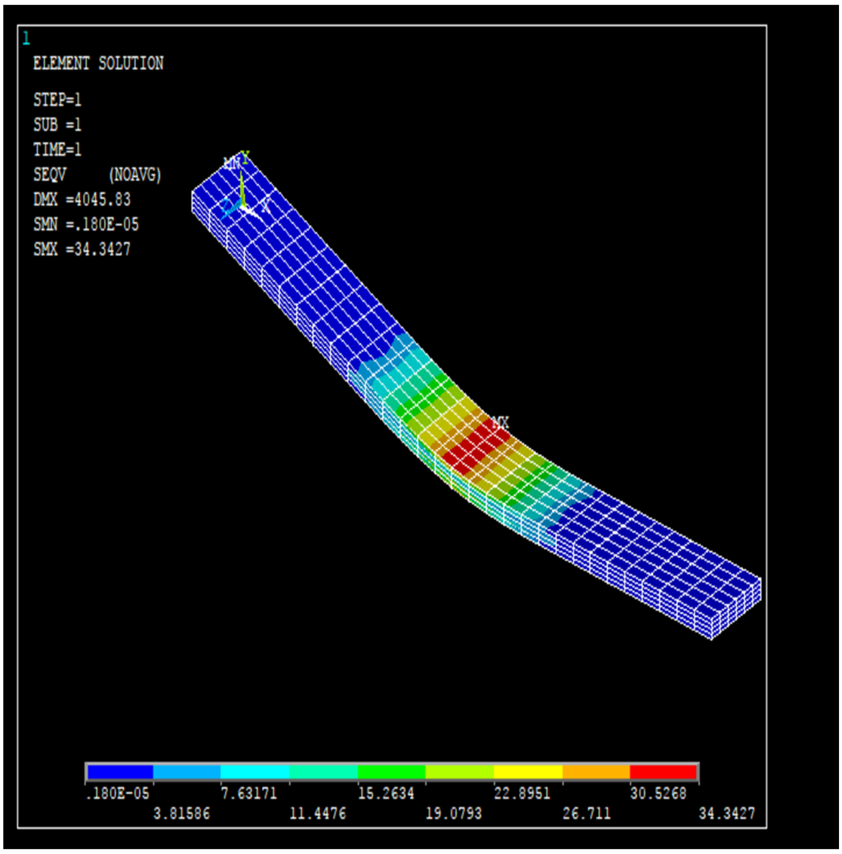


(**c**) simulated bending test results for 30B/20Ba composite with 0/45/−45/0 orientation

Figure 12. *Cont.*



(**d**) simulated tensile test results for 35B/15Ba composite with 0/−30/45/0 orientation



(**e**) simulated bending test results for 35B/15Ba composite with 0/−30/45/0 orientation

Figure 12. Simulated tensile and flexural stress distribution with different volume fractions and different orientations.

4. Conclusions

This work discussed a study of the tensile, bending, and water absorption behavior of chemically treated and untreated banyan (B) and banana (Ba) hybrid composites with different volume fractions and different orientations. The following key observations were carried out in the study:

(i) The major study is focused on the comparison of treated and untreated natural fiber composite properties, and the results clearly show that the chemically treated fiber composites were enhanced in tensile and bending strengths with a range of 26.9% to 31.2%.
(ii) Chemical treatment of fibers will improve the tensile and flexural strength in banyan (B) and banana (Ba) hybrid composites and can give higher values of 63.37 MPa and 67.07 MPa, respectively, in 0/0/0/0-orientation composites.
(iii) A volume fraction of 30% banyan fibers and 20% banana fibers (30B/20Ba) yielded higher tensile and flexural properties for both treated and untreated fibers with 0/0/0/0-orientation composites compared to other volume fraction and orientation composites.
(iv) Both FEA and experimental results showed a similar trend in maximum stress (strength) in composites, but FEA results are proven to be fair up to 7.36% higher than the experimental results, and the stress concentration region was due to applied load according to simulation parameters.
(v) With the increase in duration of immersion of composites in water, there will be an increase in water absorption for up to 144 h in both treated and untreated composites. However, the treated fiber composites have less water absorption compared to untreated fiber composites.

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References

1. Shyam, S.; Kaul, S.; Kalsara, N.; Babu, T.N. Mechanical behaviour and microscopic analysis of epoxy and E-glass reinforced banyan fibre composites with the application of artificial neural network and deep neural network for the automatic prediction of orientation. *J. Compos. Mater.* **2021**, *55*, 213–234. [CrossRef]
2. Bichang'a, D.; Aramide, F.; Oladele, I.; Alabi, O. A Review on the Parameters Affecting the Mechanical, Physical, and Thermal Properties of Natural/Synthetic Fibre Hybrid Reinforced Polymer Composites. *Adv. Mater. Sci. Eng.* **2022**, *2022*, 7024099. [CrossRef]
3. Aravindh, M.; Sathish, S.; Raj, R.R.; Karthick, A.; Mohanavel, V.; Patil, P.P.; Muhibbullah, M.; Osman, S.M. A Review on the Effect of Various Chemical Treatments on the Mechanical Properties of Renewable Fiber-Reinforced Composites. *Adv. Mater. Sci. Eng.* **2022**, *2022*, 2009691. [CrossRef]
4. Raja, T.; Mohanavel, V.; Sathish, T.; Djearamane, S.; Velmurugan, P.; Karthick, A.; Nasif, O.; Alfarraj, S.; Wong, L.S.; Sureshkumar, S.; et al. Thermal and Flame Retardant Behavior of Neem and Banyan Fibers When Reinforced with a Bran Particulate Epoxy Hybrid Composite. *Polymers* **2021**, *13*, 3859. [CrossRef]
5. Al Rashid, A.; Khalid, M.Y.; Imran, R.; Ali, U.; Koc, M. Utilization of Banana Fiber-Reinforced Hybrid Composites in the Sports Industry. *Materials* **2020**, *13*, 3167. [CrossRef]
6. Rana, P.; Chopra, S. Extraction and Characterization of Inherently Antimicrobial Fibres from Aerial Roots of Banyan Tree. *J. Nat. Fibers* **2022**, *19*, 6196–6213. [CrossRef]
7. Begum, H.A.; Tanni, T.R.; Shahid, A. Analysis of Water Absorption of Different Natural Fibers. *J. Text. Sci. Technol.* **2021**, *7*, 152–160. [CrossRef]
8. Raja, T.; Anand, P.; Karthik, K.; Udaya Prakash, J. Mechanical properties and moisture behaviour of neem/banyan fibres reinforced with polymer matrix hybrid composite. *Adv. Mater. Process. Technol.* **2021**, *7*, 1–12.

9. Thiagamani, S.M.K.; Krishnasamy, S.; Muthukumar, C.; Tengsuthiwat, J.; Nagarajan, R.; Siengchin, S.; Ismail, S.O. Investigation into mechanical, absorption and swelling behaviour of hemp/sisal fibre reinforced bioepoxy hybrid composites: Effects of stacking sequences. *Int. J. Biol. Macromol.* **2019**, *140*, 637–646. [CrossRef]
10. Ganapathy, T.; Sathiskumar, R.; Senthamaraikannan, P.; Saravanakumar, S.; Khan, A. Characterization of raw and alkali treated new natural cellulosic fibres extracted from the aerial roots of banyan tree. *Int. J. Biol. Macromol.* **2019**, *138*, 573–581. [CrossRef]
11. Prabowo, I.; Pratama, J.N.; Chalid, M. The effect of modified ijuk fibers to crystallinity of polypropylene composite. *IOP Conf. Series Mater. Sci. Eng.* **2016**, *223*, 012020. [CrossRef]
12. Supian, A.; Jawaid, M.; Rashid, B.; Fouad, H.; Saba, N.; Dhakal, H.N.; Khiari, R. Mechanical and physical performance of date palm/bamboo fibre reinforced epoxy hybrid composites. *J. Mater. Res. Technol.* **2021**, *15*, 1330–1341. [CrossRef]
13. Sujon, A.S.; Habib, M.A.; Abedin, M.Z. Experimental investigation of the mechanical and water absorption properties on fiber stacking sequence and orientation of jute/carbon epoxy hybrid composites. *J. Mater. Res. Technol.* **2020**, *9*, 10970–10981. [CrossRef]
14. Arshad, M.N.; Mohit, H.; Sanjay, M.R.; Siengchin, S.; Khan, A.; Alotaibi, M.M.; Asiri, A.M.; Rub, M.A. Effect of coir fiber and TiC nanoparticles on basalt fiber reinforced epoxy hybrid composites: Physico–mechanical characteristics. *Cellulose* **2021**, *28*, 3451–3471. [CrossRef]
15. Jawaid, M.; Thariq, M.; Saba, N. (Eds.) *Failure Analysis in Biocomposites, Fibre-Reinforced Composites and Hybrid Composite*, 1st ed.; Woodhead Publishing: Duxford, UK, 2019; pp. 133–153.
16. Kumar, V.J.B.; Raj, J.B.; Karuppasamy, R.; Thanigaivelan, R. Influence of Chemical Treatment and Moisture Absorption on Tensile Behavior of Neem/banana Fibers Reinforced Hybrid Composites: An Experimental Investigation. *J. Nat. Fibers* **2022**, *19*, 3051–3062. [CrossRef]
17. Ganapathy, T.; Sathiskumar, R.; Sanjay, M.R.; Senthamaraikannan, P.; Saravanakumar, S.S.; Parameswaranpillai, J.; Siengchin, S. Effect of Graphene Powder on Banyan Aerial Root Fibers Reinforced Epoxy Composites. *J. Nat. Fibers* **2021**, *18*, 1029–1036. [CrossRef]
18. Raj, M.K.A.; Muthusamy, S.; Panchal, H.; Ibrahim, A.M.M.; Alsoufi, M.S.; Elsheikh, A.H. Investigation of mechanical properties of dual-fiber reinforcement in polymer composite. *J. Mater. Res. Technol.* **2022**, *18*, 3908–3915.
19. Dhanunjayarao, B.; Sanivada, U.K.; Naidu, N.S.; Fangueiro, R. Effect of graphite particulate on mechanical characterization of hybrid polymer composites. *J. Ind. Text.* **2022**, *51*, 2594S–2615S. [CrossRef]
20. Vinod, A.; Vijay, R.; Singaravelu, D.L.; Khan, A.; Sanjay; Siengchin, S.; Verpoort, F.; Alamry, K.A.; Asiri, A.M. Effect of alkali treatment on performance characterization of *Ziziphus mauritiana fiber* and its epoxy composites. *J. Ind. Text.* **2022**, *51*, 2444S–2466S. [CrossRef]
21. Raja, T.; Vinayagam, M.; Thanakodi, S.; Seikh, A.H.; Siddique, M.H.; Subbiah, R.; Gebrekidan, A.M. Mechanical Properties of Banyan Fiber-Reinforced Sawdust Nanofiller Particulate Hybrid Polymer Composite. *J. Nanomater.* **2022**, *2022*, 9475468. [CrossRef]
22. Ganesamoorthy, R.; Reddy, R.M.; Raja, T.; Panda, P.K.; Dhoria, S.H.; Nasif, O.; Alfarraj, S.; Manikandan, V.; Jenish, I. Studies on Mechanical Properties of Kevlar/Napier Grass Fibers Reinforced with Polymer Matrix Hybrid Composite. *Adv. Mater. Sci. Eng.* **2021**, *2021*, 6907631. [CrossRef]
23. Izwan, S.M.; Sapuan, S.; Zuhri, M.; Mohamed, A. Effects of Benzoyl Treatment on NaOH Treated Sugar Palm Fiber: Tensile, Thermal, and Morphological Properties. *J. Mater. Res. Technol.* **2020**, *9*, 5805–5814. [CrossRef]
24. Devnani, G.; Mittal, V.; Sinha, S. Mathematical modelling of water absorption behavior of bagasse fiber reinforced epoxy composite material. *Mater. Today Proc.* **2018**, *5*, 16912–16918. [CrossRef]
25. Sanjeevi, S.; Shanmugam, V.; Kumar, S.; Ganesan, V.; Sas, G.; Johnson, D.J.; Shanmugam, M.; Ayyanar, A.; Naresh, K.; Neisiany, R.E.; et al. Effects of water absorption on the mechanical properties of hybrid natural fiber/phenol formaldehyde composites. *Sci. Rep.* **2021**, *11*, 13385. [CrossRef]
26. Kryszak, B.; Biernat, M.; Tymowicz-Grzyb, P.; Junka, A.; Brożyna, M.; Worek, M.; Dzienny, P.; Antończak, A.; Szustakiewicz, K. The effect of extrusion and injection molding on physical, chemical, and biological properties of PLLA/HAp whiskers composites. *Polymer* **2023**, *287*, 126428. [CrossRef]