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Effect of Natural Cellulosic Fiber Surface Modifications on the Mechanical Feature Reinforced Polymer Composites

Haydar U. Zaman*

Assist. Prof., Department of Physics, National University of Bangladesh and Institute of Radiation and Polymer Technology, Bangladesh Atomic Energy Commission, P.O. Box-3787, Savar, Dhaka, Bangladesh

E-mail: haydarzaman07@gmail.com

RESEARCH ARTICLE

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Abstract

The current era's remedies to global warming revolve around replacing fossil fuels with more ecologically friendly biodegradable materials in order to slow down the rate at which they are being depleted. Calotropis gigantea fruit bunch (CGFB) fiber is one kind of substitute material that this work envisage using in place of plastics in the construction of composite materials, as supported by the study literature. CGFB fiber was chosen for this project because it is extensively accessible in Bangladesh and has less value to vegetation. The CGFB fiber undergoes three different chemical pretreatments: sodium hydroxide (alkali treatment), hydrogen peroxide (peroxide treatment) and benzoyl chloride (benzoylation). Composites are made from chemically treated fibers, and the mechanical characteristics of these materials are investigated. Benzoylated composite offers better tensile, compressive, and impact strengths than any other composite. Compared to the untreated and benzoylated versions, it has been demonstrated that the benzoylation increased the composites' tensile strength by 98.3%, compressive strength by 61.4%, and impact strength by 97.7%. Compared to other composites, the one treated with hydrogen peroxide had the highest flexural strength. Following a hydrogen peroxide treatment, the flexural strength rose by 44.5%. Despite having a little lower flexural strength than the benzoylated composite, the composite's elongation capacity was enhanced throughout tension, flexure, and compression tests after being treated with hydrogen peroxide. When considering

overall performance, benzoyl chloride seems to be the most efficient chemical treatment. There were not many flaws visible in the benzoylated composite's surface morphology.

Keywords: Calotropis gigantea, fruit bunch, alkali, peroxide, benzoylation, and mechanical properties.

Introduction

Instead of using synthetic fibers to reinforce composites, natural fibers are being used for the study's purposes. Instead of fibers and matrix, environmentally friendly and biodegradable components are used [1-3]. In addition to boat hulls, swimming pools, race car bodies, shower stalls, bathtubs, storage containers, imitation granite, and cultured marble worktops and basins, composite materials are frequently employed in the construction of buildings, bridges, and other constructions. The usage of composite materials in automotive applications is also growing [4, 5]. Fillers are used to reduce polymerization shrinkage and raise the restoration's hardness, abrasion resistance, tensile strength, and elastic modulus. Fillers are usually composed of silica, quartz, or fine glass. Interior components like door panels, dashboard elements, parcel compartments, seat cushions, backrests, cable linings, etc. frequently use natural fiber-reinforced composite materials [6]. There aren't many outside uses because mechanical strength is so highly valued. Natural fiber composites are not only inexpensive, lightweight, robust, and non-abrasive; they also have good mechanical properties, degrade naturally, and pose no environmental risks [7]. A natural fiber-reinforced composite's length and composition largely dictate its mechanical and physical properties; current trends suggest that more work is being done on defining natural fibers. Jute, flax, and technical hemp are a few natural fibers that have superior thermal, acoustic, and mechanical insulation qualities. Natural lingo-cellulosic fibers are a superior option for reinforcement in polymer composites than synthetic fibers since they are not only more readily available in large quantities but also more economical, biodegradable, and environmentally benign. The cellulose fibers were extracted from a variety of plant parts, such as leaves [8], stems [9], bark [10], roots [11], pods [12], blossom pedals [13], fruits [14], fruit bunches [15], straw [16], and nutshells [17]. They can be utilized as a natural reinforcement or filler material in polymer composites to produce parts for the packaging, automotive, and construction industries [18].

Low reactivity, strong moisture absorption capabilities, and compatibility with polymeric matrix were the typical characteristics of hydrophilic lignocellulose fibers. The adhesive force between the reinforcement and the matrix is a key component in boosting the mechanical strengths. To increase the adhesive force, a number of steps have lately been taken. One approach is to improve the reinforcement's surface qualities by applying chemical treatments. That can be overcome by a variety of chemical procedures, such as acetylation, silane, alkalization, and saltwater [19]. Treatments can activate the hydroxyl groups found in naturally existing cellulosic fiber while also removing impurities and non-cellulosic components from the fiber surface [11]. Even though there are many chemical treatments accessible, many experiments have been carried out using sodium hydroxide as an alkali to treat the natural reinforcements. These investigations showed that natural fibers treated with alkali greatly improved their ability to adhere to the matrix on the surface, raising the mechanical properties of the fibers [5, 20, 21]. The reinforcement is affected differently by each chemical, which modifies the mechanical

properties of the reinforcement. Acetic anhydride treatment is one way to improve the fiber-matrix adhesion property of a composite material. This will enhance the tensile and thermal properties of the composites [22]. Another kind of chemical treatment that improves the tensile strength of composites is silane treatment applied to natural fiber [3, 23, 24].

Composites can be made by using various plant parts as reinforcement. Many of the features of natural fibers have not yet been employed as reinforcement for composite materials, despite recent investigations into their properties. The natural fiber of choice is Calotropis gigantea fiber (CGF), which has qualities like sufficient buoyancy, hydrophobic-oleophilic properties, a high oil absorption capacity, and an oil-water separation efficiency that make it an ideal component in the oil separation process to separate oil from water. *Asclepiadaceae* is a family that includes CGF, which is found in Bangladesh, China, India, and other countries. This fiber has exceptional biocompatibility and is non-toxic [25]. CGF is mostly utilized in the textile industry as a raw material because of its inherent biodegradability. But up until now, not much research has been done on CGF-reinforced composites [26]. CGF plants can grow up to five meters tall and produce clusters of waxy flowers. It also has milky stalks that are further emphasized by fibers, as well as oval-shaped, pale green leaves. The fibers that are taken from the stems of the CG plant are used to make composites. The extract CG bark fiber contains 73.8% cellulose, 20.5% hemicellulose, 2.7% lignin, and 1.18% waxy components [27].

The fibers of the calotropis plant were isolated from its bark and stem bast, described in [28], and employed in numerous applications [29, 30]. Many chemical treatments have been devised recently, and most of them have been beneficial in improving the reinforcing element's surface quality. A limited number of natural fibers have been the subject of chemical treatment studies; however, the fiber of the calotropis gigantea fruit bunch (CGFB) has not been the subject of any research. Thus, the goal of this work is to investigate the effects of three different chemical treatments-benzoyl chloride (benzoylation), hydrogen peroxide (peroxide treatment), and sodium hydroxide (alkali treatment)-applied to the fibers of the calotropis gigantea fruit bunch on the mechanical strengths of the composite.

Experimental

Materials

Fibers from the CGFB family, which belongs to the *Apocynaceae* family, are native to Bangladesh, China, India, Malaysia, Indonesia, Cambodia, and other countries. This plant can grow up to five meters tall with a cluster of waxy blossoms. The calotropis gigantea plant's fruits were collected from surrounding Bangladeshi sources. Fibers from bunches of Calotropis gigantea fruit were used in this experiment. The matrix material maintains the fibers together while providing protection from the environment, strengthens the transverse characteristics of the laminate, and evenly distributes loads across the fibers. It also functions well with reinforcing fiber and production procedures. Epoxy, a sophisticated cross-linked polymer that meets all the criteria for a matrix material and has a long, rigid network of molecules structured in three dimensions, was the matrix material employed in this investigation. Industrial epoxy resin (LY556) and hardener (HY951) were purchased for the current investigation from M/s Javanthee Enterprises, Chennai. The parameters of the used cured epoxy resin are listed in Table 1.

Table 1. Features of cured epoxy resin.

Description	Viscosity (LY556)	Density (LY556)	Flash point (LY556)	Tensile strength	Flexural strength	Impact Strength
Unit	mPa.s	kg/m^3	^oC	MPa	MPa	kJ/m^2
Value	10000-12000	1150-1200	>200	25-30	70-75	18-20

Fiber Extraction

First, the calotropis gigantea fruits were sun-dried for seven days. We hammered some more to separate the fibers and seeds from the Calotropis gigantea fruit bunches (CGFB). The CGFB fibers were washed in water and then distilled water after extraction. The cleansed CGFB fibers were left in the sun for three days to lower their moisture content and shield them from biological attacks [31]. Figures 1a–b and c show the CGFB fiber extraction process and the Calotropis gigantea plant.

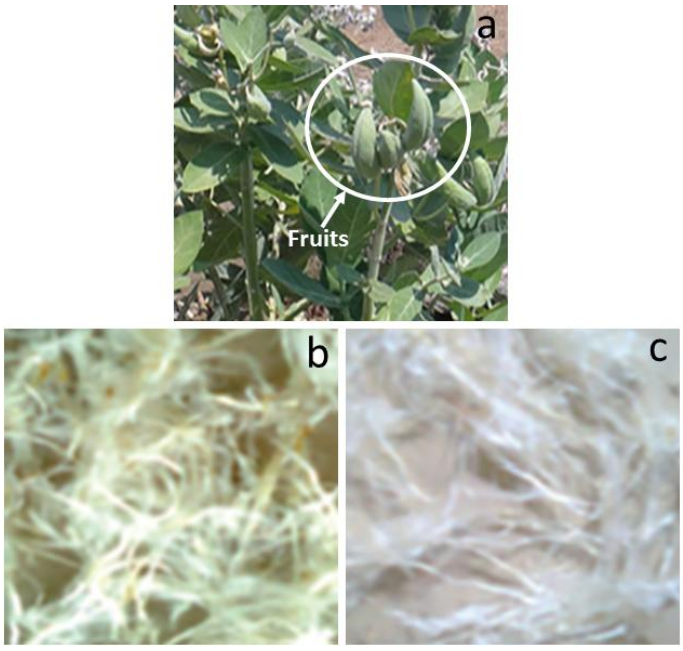

Figure 1. A bunch of fruits from a calotropis gigantea plant (a); untreated CGFB fiber (b); and treated CGFB fiber (c).

Analyzing Physical Features

The density was measured with a pycnometer using a standard liquid toluene that was known to be 866 kg/m^3. The CGFB fibers were collected raw and processed, and they were kept apart in

desiccators with silica gel for around four days to eliminate any moisture content [32]. To perform the density test, the fibers were cut into 5 mm lengths and kept in a pycnometer. The densities of treated and untreated CGFB fibers were calculated using the following formula.

$$\rho_{CGFB} = \frac{(m_2 - m_1)}{(m_3 - m_1)\,(m_4 - m_2)} \times \rho_{toluene} \qquad \text{in kg/m}^3 \tag{1}$$

The mass of the pycnometer in kg is indicated by m_1 in this example, the mass of the pycnometer filled with CGFB fibers is indicated by m_2, the mass of the pycnometer filled with toluene is indicated by m_3, and the mass of the pycnometer filled with both CGFB fibers and toluene is indicated by m_4.

Chemical Methods

The raw CGFB fibers are obtained from a local source in Bangladesh and then thoroughly cleaned in water to remove any residual impurities. The composite made with this fiber is known as untreated fiber composite (UFC). It is made up of lignin, pectin, cellulose, and hemicellulose, among other materials. These unwanted cellulose components can be removed by chemical pretreatments, which strengthens the fibers. The untreated fiber is thoroughly cleaned in distilled water before being treated with a 5% sodium hydroxide solution for around three hours. Equation 2 demonstrates that during this treatment, water, "O," and "Na" ions are produced by the reaction between the natural fiber's hydroxide and the alkali's hydroxide. The hydrogen bonds inside the structure have been removed by this treatment. The excess salt and oxide particles in the fiber are removed by giving it a thorough washing in water. The fiber is then allowed to dry at room temperature for about eight hours. The fiber is divided into three portions, the first of which is dried in a furnace at 50°C for around two hours. This fiber, also known as the sodium hydroxide treated fiber, is utilized as reinforcement in a composite material called sodium hydroxide treated composite (SHC).

$$\mathrm{CGFB - OH + NaOH \rightarrow CGFB - O^{-}Na^{+} + H_2O} \tag{2}$$

CGFB has been heated in a furnace and treated chemically. The second part of the fiber is treated with a 10% hydrogen

$$\mathrm{HO - HO \rightarrow 2HO'} \tag{3}$$

peroxide (H_2O_2) solution for around three hours. Peroxide is one kind of functional group that has O–O and assumes the form of ROOR. High temperatures are sometimes necessary for peroxide decomposition. Initially known as HOOH, hydrogen peroxide changes into HO' and HO'. It then reacts chemically with the "H" group of the CGFB fiber. The chemical interactions between CGFB and hydrogen peroxide are depicted in equations 3 and 4. After receiving one more water wash, the fiber is cooked at 50°C for around two hours in a furnace. This fiber is known as hydrogen peroxide treated fiber, and the composite made of it is called hydrogen peroxide treated composite (HPC).

$$\mathrm{HO' + CGFB - H \rightarrow HOH + CGFB'} \tag{4}$$

The third part of the fiber is immersed in a 10% sodium hydroxide and benzoyl chloride solution for around thirty minutes. The reaction between CGFB and benzoyl chloride is depicted in

Equation 5. One of the components of benzoyl chloride's molecule is C_6H_5C = O (benzoyl). After this process, the fiber is cleansed with water once again and heated to 50°C in a furnace for around two hours. This fiber is called benzoyl chloride treated fiber (BCC), and the composite made from it is called benzoyl chloride treated composite.

$$\mathrm{CGFB-O'Na^{+}+C_6H_5C=OCl\rightarrow CGFB-C_6H_5C=O_2+NaCl'} \quad (5)$$

Chemical Analysis

Standard procedures were used to measure the cellulose, hemicellulose, lignin, moisture, wax, and ash content of natural cellulosic fibers through experimentation. The method of Kurshner and Hoffer was employed to calculate the cellulose content. First, distilled water was used to remove the required amount of CGFB fibers, which had been measured once more. To eliminate any leftover moisture, the cleaned fibers were dried in a hot air vacuum oven at 80°C. From the dried CGFB, fibers were taken out for further chemical examination. The fiber samples were split up and then submerged in a 1:4 V/V ethanol and nitric acid solution. After reaching a boil, the mixture was allowed to sit for an hour. In a hot air vacuum oven, the CGFB fiber samples were dried to a constant weight at a constant temperature of 60°C. After filtration, the insoluble residue was continuously retrench using the previously described method in order to extract the insoluble fractions associated to disintegrate cellulose [33]. The hemicellulose content of CGFB fibers was determined using the NFT 120-008. In compliance with the APPITA P11s-78 standard, the lignin content of CGFB fibers was ascertained using the Klason method. The CGFB fiber samples underwent a 16-hour hydrolysis process in 67% sulfuric acid at 20°C. Subsequently, the samples underwent dilution in 2N acid, and the hydrolysis process was extended for a duration of 5 hours. The lignin content was calculated by applying the subsequent formula for the weight measurement:

$$\text{Insoluble Lignin} = \frac{\text{Weight of lignin}}{\text{Weight of the fiber}} \times 100 \quad (6)$$

The wax content was examined using the Conrad procedure [34]. The ash content was estimated using ASTM E 1755-61 standard. After being weighed with a weighing machine, the CGFB fiber samples were baked for four hours at 104°C to dry them out. The moisture content was calculated using the formula below [17].

$$\%\text{ of moisture content} = \frac{\text{CGFB fiber weight before drying} - \text{CGFB fiber weight after drying}}{\text{CGFB fiber weight before drying}} \times 100 \quad (7)$$

Composites Manufacturing

The fibers were removed, cleansed with ordinary utility water, and then left to air dry for 48 hours. The fibers are split into microscopic fibers that are 5 mm long and are used as reinforcements in a random arrangement. Three composites were made from fibers that had been benzoylated, peroxide-treated, and alkali-treated, each sized 300 × 300 × 5 mm^3. Utilizing a compression molding process, composites have been produced with a 25% by weight CGFB and a 75% by weight epoxy matrix. To guarantee effective polymerization, cobalt octoate is used as an accelerator and methyl ethyl ketone peroxide as a catalyst during the composite preparation

process. The mechanical testing, which includes the following tests: tension, compression, flexural, and impact, complies with ASTM D638, D3410, D790, and D256 standards. To be tested for tension, the test sample is sliced into the shape of a dog bone and inserted between the fixed and movable jaws of a universal testing device made by the Instron brand. In a similar manner, the test sample is placed on the table of the universal testing machine for the compression test, and a compressive load is given by the movable cross head. An extendometer was used to measure the strain during loading. Flexural testing is done using three point bending testing. A bending load is applied to the middle of the beam once the sample has been placed over the supports at both ends. Impact tests have been carried out using a pendulum impact testing apparatus. The test sample was placed into the apparatus with a 45° notch cut out of it in order to conduct this test. The amount of energy absorbed during impact loading is quantified. During mechanical testing, three samples of each composite are inspected; the composite's strength is calculated by average the three results.

Investigations into Morphology

Scanning electron micrographs of the treated and untreated composite materials were analyzed using a Zeiss Evo 50 scanning electron microscope. A thin layer of gold was applied to the fracture edges of the specimens before they were placed in an Al spit to distribute the electric charge throughout the test.

Results and discussion

Physical Evaluation

Applications for polymer composites reinforced with natural cellulosic fibers can be found in packaging, building, automotive, aerospace, and household goods. The density of the fiber-reinforced composites is determined by the fiber density and fiber content in the matrix, which can vary based on the nature and purpose of the component. The fiber density is crucial to producing lightweight components for a range of applications [18]. Densities of 455, 465, 475, and 483 kg/m^3 were found in the CGFB fibers that were left untreated, treated with alkali, treated with peroxide, and treated with benzoylation. Comparisons of the density values with various natural fibers are shown in Table 2. It was observed that the CGFB fiber density was greater than the *Phoenix pusilla* leaf fiber density [35] (Table 2). According to the density data, CGFB fibers are better suitable for producing polymer composite materials that are lightweight and eco-friendly. According to the density data, CGFB fibers are better suitable for producing polymer composite materials that are lightweight and eco-friendly.

Table 2. Compare the density and chemical composition of the fibers from the calotropis gigantea fruit bunch to other natural fibers.

Fiber details	Density (kg/m^3)	Cellulose (wt%)	Hemicelluloses (wt%)	Lignin (wt%)	Wax (wt%	Moisture Content (wt%)	Ash (wt%)	Reference
A_1	455	63.86	8.55	12.88	1.95	8.01	3.17	Current work
A_2	465	68.58	5.36	10.68	1.14	7.12	4.92	
A_3	475	71.35	4.54	9.23	1.12	6.89	5.11	

A_4	483	75.69	3.12	7.36	1.09	5.13	5.88	
A_5	-	73.1	9.41	12.04	0.57	8.21	4.06	[36]
A_6	-	79.13	3.02	7.41	0.25	6.42	3.10	
A_7	211	59.46	18.56	8.28	0.33	8.45	4.56	[35]
A_8	323	72.16	2.32	5.14	0.18	3.4	4.65	

A_1: Untreated CGFB; A_2: 5% Alkali treated CGFB; A_3: 10% H2O2 treated CGFB; A_4: benzoyl chloride treated CGFB; A_5: Raw Acacia planifrons bark fibers; A_6: Treated Acacia planifrons bark fiber; A_7: Raw Phoenix pusilla leaves; A_8: Treated Phoenix pusilla leaves

Chemical Analysis

The results of the chemical composition analysis on raw and treated fibers individually are shown in Table 2. The results of comparisons with various natural cellulosic fibers under both treated and raw conditions are also displayed in Table 2. The findings demonstrated that compared to raw fiber, processed CGFB fibers had more cellulose. Simultaneously, there was a significant drop in the other amorphous fractions present in the treated fiber, including hemicellulose, lignin, and wax content. Hemicellulose content decreased in the treated fibers. The enhanced mechanical bonding strength between the cellulosic fibers and the polymer matrix was attributed to the reduced wax content in the treated fibers. Another improvement in the strength of the bond between the fiber and the resin was the decrease in moisture content observed in the treated CGFB fibers. The alkali-treated CGFB fibers showed a rise in ash content (from 3.13 to 4.86%), which indicated the removal of amorphous components including hemicelluloses and lignin [32].

Mechanical Attributes

Tensile Strength

The outcome of the tensile strength is shown in Figure 2. The least tensile strength of the fiber composite is the untreated one. Tensile strength increases by 20.1% after the alkali treatment and by an additional 20% after the peroxide treatment, reaching a higher value. The comparison shows that the HPC samples had a tensile strength that is 51.6% higher than the sodium hydroxide treated composite (SHC) samples. The highest tensile strength value of 35.55 MPa was observed in BCC; in comparison to hydrogen peroxide treated composite (HPC), there was an 8.9% gain in tensile strength. When comparing benzoyl chloride treated composites (BCC) to untreated fiber composites (UFC), tensile strength can increase by as much as 98.3%. Equation 2 illustrates the result of the reaction between CGFB and benzoyl compound, which eliminates unwanted celluloses, and the separation of sodium chloride. In general, the unwanted cellulosic components are removed from the fiber surface by breaking the hydrogen connections within the atomic network. The outcome is an increase in the surface roughness of the fiber [37]. An increase in surface roughness strengthens the connection between the resin and the fiber. The greater the bonding strength, the greater the tensile load capacity of composite materials. This study unequivocally shows that the tensile strength has increased significantly with all chemical treatments [38, 39].

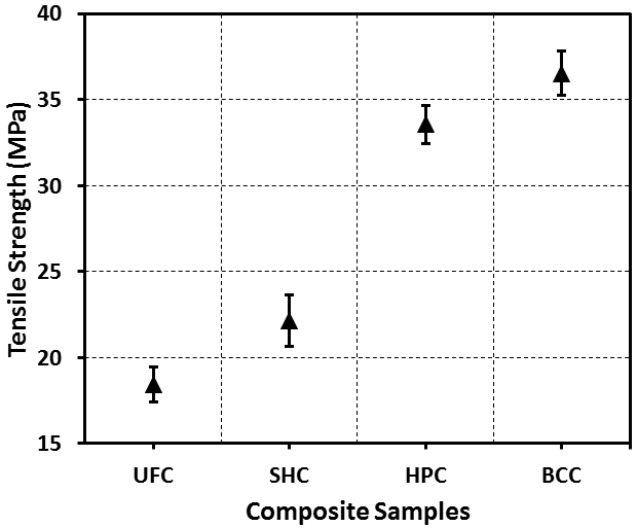

Figure 2. Plot of tensile strength.

The tensile stress-strain curve is shown in Figure 3. It has been observed that stress increases linearly with strain up to a 2% strain. In the high strain area, the composites act like a pure plastic material. This is as a result of the matrix deforming at the high strain area, which causes microcracks to form. When microcracks appear, the tensile strength before breaking is reduced because they deteriorate the bond between the matrix and fiber [40]. The sample UFC exhibits the least strain, at 6%, whilst the sample HPC displays the most strain, at 8%. This illustrates how the natural fiber's ability to lengthen before breaking is improved by chemical treatment. Sample BCC has been shown to have the highest tensile strength among the chemically treated samples; however, it is not able to achieve the maximum strain of 7%. On the other hand, although the sample HPC's strength is not as great as the sample BCC's, it can still reach its maximum potential. The best method for achieving the maximum tensile extension and a little greater tensile strength is hydrogen peroxide treatment [41].

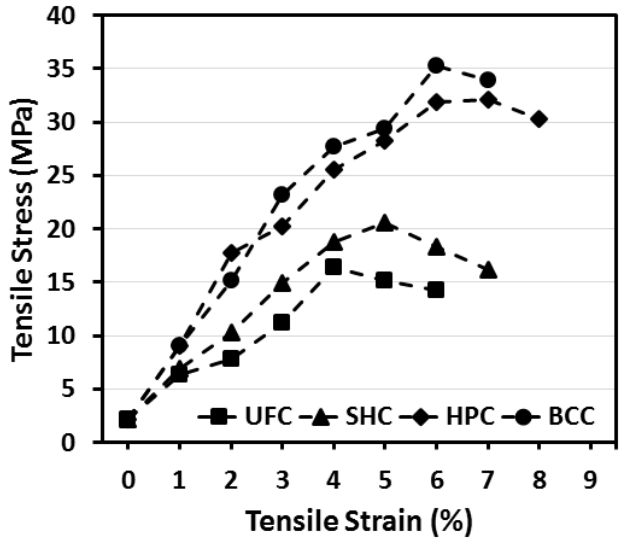

Figure 3. Plot of tensile stress-strain.

Flexural Strength

Flexural strength is a measurement of a material's capacity for bending. The plot of flexural strength is shown in Figure 4. The flexural strengths of samples UFC and HPC are 38.7 MPa for the lowest and 55.9 MPa for the highest, respectively. When tested side by side, sample SHC's flexural strength is 12.3% more than sample UFC's. When samples SHC and HPC are evaluated for flexural strength, sample HPC shows an increase of 28.7%. This happens because benzoyl chloride is more reactive than hydrogen peroxide, which causes the exterior skin of the CGFB fiber to get partially dissolved and reduce the fiber's diameter. This thinnish CGFB fiber cannot withstand bending loads even at high tensile stresses. Consequently, at less stress than the sample HPC, the sample BCC degrades less. After the sample was treated with hydrogen peroxide, its flexural strength rose by 44.5% compared to the untreated sample. During the hydrogen peroxide treatment, water (H_2O) is produced by the reaction between the hydrogen (H) in the CGFB fiber and the hydroxide (OH), as shown in equation 4. This enhances the CGFB's interaction with the matrix and breaks the hydrogen connection in the chemical network. This proves that treating with hydrogen peroxide is the most effective way to obtain the maximum flexural strength.

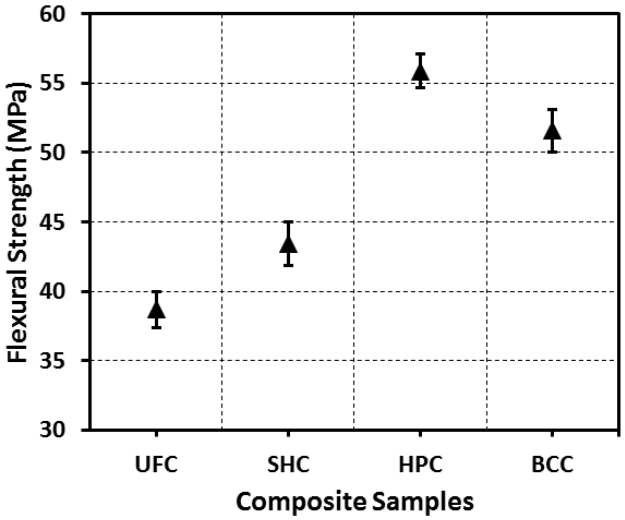

Figure 4. Plot of flexural strength.

The flexural strain-strain curve is shown in Figure 5. Flexural stress rises steadily with the elevation of flexural strain up to the breaking point, at which point it gradually falls. At low strain levels, the flexural strength appears to have increased linearly, and at high strain levels, it

appears to have increased non-linearly. This is the tendency seen in all the composites. It has been discovered that the strain increases linearly with the chemical treatment sequence before breaking. Minimum and maximum stresses of 5% and 7%, respectively, have been observed for the composites UFC and BCC. Composite HPC show highest strain and the greatest flexural strength under tensile and flexural stress. This proves that hydrogen peroxide is the most effective therapy when considering the tensile and flexural extension.

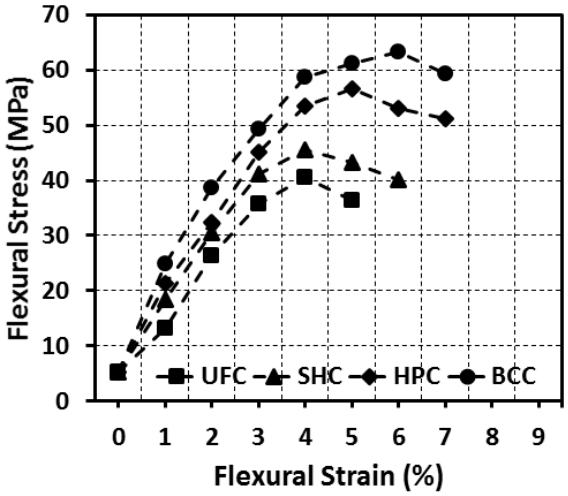

Figure 5. Plot of flexural stress-strain.

Compression Strength

The compressive strength of the composite samples is shown in Figure 6. The compressive strength of the composites UFC and BCC was measured to be 32.43 MPa at the lowest point and 52.35 MPa at the highest. Compressive strength increases linearly with a modification in the chemical treatment sequence. There seems to be a 9.9% increase in compressive strength following sodium hydroxide treatment when compared to the composite UFC. Comparably, after being treated with hydrogen peroxide, the composite SHC's compressive strength increased by 15.8%, whereas the composite HPC's improved by 26.8% after being treated with benzoyl chloride. Additionally, this research clearly shows how the chemical treatments successfully boost the compressive strength of the natural fiber, raising the strength of the composite. It is found that benzoyl chloride treatment is a more suitable method for enhancing the compressive strength of the composites. Similar results on CG fiber reinforced composites were reported by the researchers, who concluded that chemical treatment enhances all mechanical properties of the composite [42].

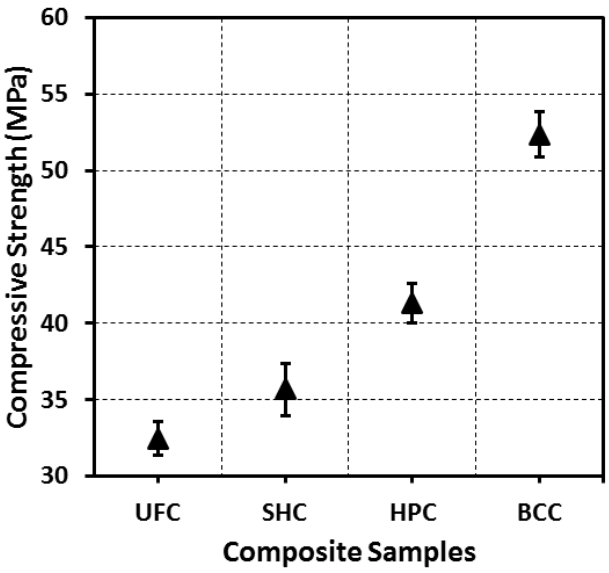

Figure 6. Plot of compressive strength.

The compressive stress-strain curve is shown in Figure 7. Under compressive pressure, it has been noted that all composites display non-linear overall behavior. On the stress-strain curve, three zones can be identified: the low strain region, the medium strain region, and the high strain zone. In the low strain zone, the stress increases linearly with respect to strain. Up until a point that is closer to the final stress level, there seems to be a non-linear increase in stress in the medium strain zone. Comparing the compressive stress-strain plot to the tensile and flexural stress-strain curves, the rise in stress in the medium strain zone seems to be moderate. The tension in the high strain zone reduces as the strain does. Fiber buckling is the reason for the composite's failure in this area, when the composite material displays ductile behavior. The compressive stress-strain curve appears to have a significant reduction in stress after the ultimate point, in contrast to the tensile and flexural stress-strain curves. All composites show this consistent behavior. Whereas composite HPC showed a maximum strain of 9%, composite UFC showed a minimum strain of 7%. This suggests that if you want to achieve a longer elongation before breaking, peroxide is a preferable choice.

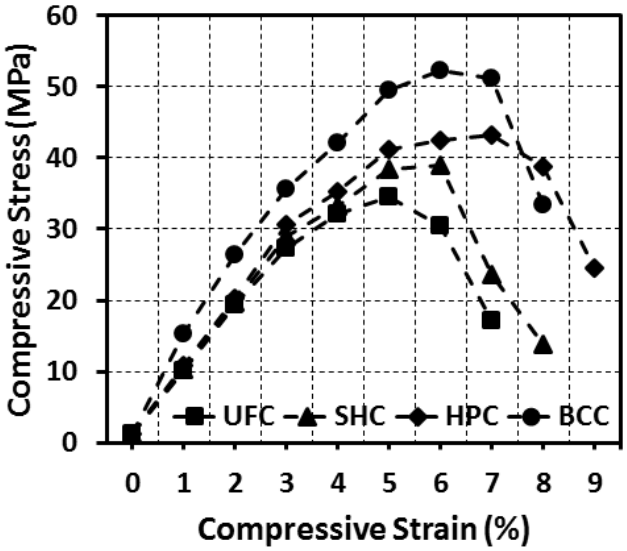

Figure 7. Plot of compressive stress-strain.

Impact Strength

The impact strength of a material indicates its ability to withstand fracture when subjected to high speed stress. The impact property is mostly determined by the interfacial bonding between the matrix and reinforcement properties. Due to the debonding of the fiber and matrix, there will be a failure that results in both a matrix fracture and a fiber fracture. Nonetheless, impact strength is also impacted by fiber pullout. The force required to remove the fiber from the matrix determines a sizable amount of the impact strength. The curve of impact energy is shown in Figure 8. The minimum impact strength of the sample UFC is 2.13 J, whereas the maximum impact energy of the composite BCC is 4.2 J. The impact energy increases with the chemical treatment sequence, much like compressive and tensile behavior does. The alkali treatment has been seen to increase the impact energy of the composites UFC and SHC by 37%. The impact energy of the composites SHC and HPC was found to be raised by 31.8% by the hydrogen peroxide treatment, while the strength of the composites HPC and BCC was found to be increased by 9.4% by benzoylation. Benzoylation is discovered to be able to boost the impact strength by as much as 97.7% when comparing the UFC and BCC composites. This analysis indicates that the impact strength of the composite has increased due to benzoylation strengthening the bond between the fiber and matrix. The reasoning is the same as that which was discussed in the tensile strength analysis.

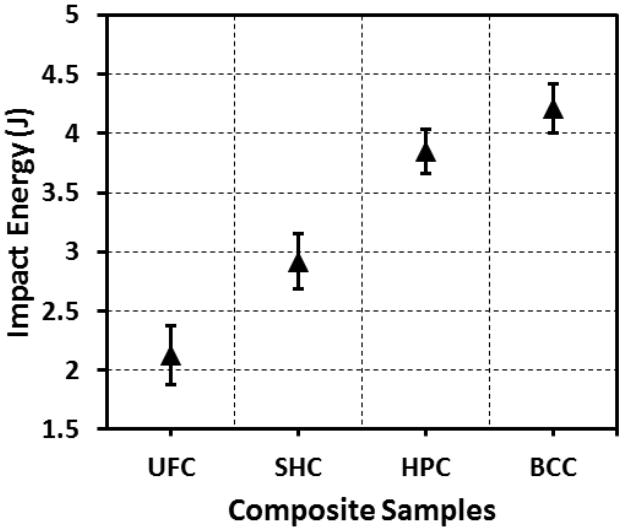

Figure 8. Plot of **i**mpact energy.

Morphological Studies

To qualitatively evaluate the connection between the fiber and matrix and to see the micro-level defects present in the composite, a microstructural analysis was carried out. Under a scanning electron microscope, the tensile fractured composites are seen in Figure 9. In the microstructural imaging of the UFC, fiber pullouts, matrix cracks, and matrix voids are some of the most prevalent defects that are seen. These micro-defects resulted from improper adhesion between the fiber and matrix. The composite is significantly impacted by these faults and fails earlier than treated composites. SHC can also have flaws like fiber pullouts and matrix cracks. SHC does have some flaws, although they are not as bad as those in UFC. In the HPC, a few fiber pullouts are apparent, but there are no matrix cavities or fractures. This indicates that the application of hydrogen peroxide treatment has increased the interfacial bonding between the fiber and matrix, bringing the properties up to par with the UFC and SHC. The BCC shows no signs of matrix deterioration or fiber withdrawal. Unlike other composites, there is no sign that the fibers have broken away from the matrix to a longer length. This indicates that the process of benzoylation enhanced the fibers' capacity to form a bond with the matrix, hence optimizing the mechanical strengths of the composite. Comparing treated and untreated composites, it has been found that treated composites do not produce matrix cavities. This shows that chemical treatment not only permits proper bonding but also allows the resin to properly wrap the fibers throughout the composite's production. This contributes to the decrease of matrix voids, as demonstrated in treated composites. Unlike with a hand-layup composite, none of the composites had microholes in the matrix. This indicates that compression molding is one of the more effective techniques for producing composite in the form of plates and slabs.

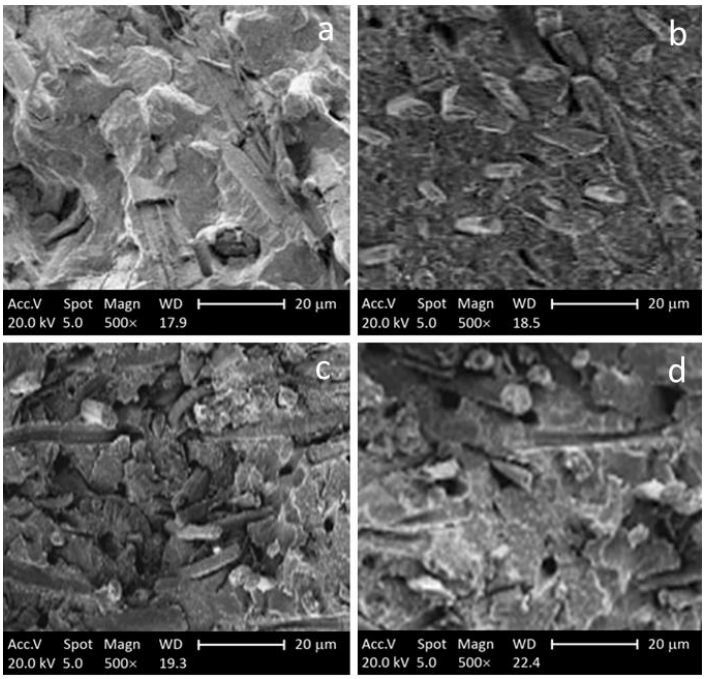

Figure 9. SEM pictures of the fracture surfaces of (a) untreated fiber composite (UFC), (b) sodium hydroxide treated composite (SHC), (c) hydrogen peroxide treated composite (HPC), and (d) benzoyl chloride treated composite (BCC).

Conclusions

New composites have been made using three different chemicals, and their mechanical characteristics have been investigated. Benzoylated composite offers better compressive, tensile, and impact strengths than any other composite. Comparing the untreated and benzoylated composites, it was found that the benzoylation enhanced the tensile strength by 98.3%, the compressive strength by 61.4%, and the impact strength by 97.7%. Compared to other composites, the one treated with hydrogen peroxide had the highest flexural strength. Following a hydrogen peroxide treatment, the flexural strength rose by 44.5%. The hydrogen peroxide treated composite showed a little lower flexural strength than the benzoylated composite in tension, flexure, and compression tests, but it boosted its elongation capacity. When considering overall performance, benzoyl chloride seems to be the most efficient chemical treatment. This has been verified by morphological analysis of the produced composites.

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