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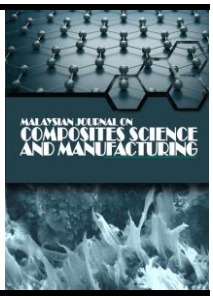

Fabrication and Analysis of Physico-Mechanical Characteristics of Chemically Treated Bhendi Fiber Reinforced Thermoplastic Composites: Effect of UV Radiation

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ABSTRACT

Unidirectional polypropylene (PP) composites reinforced with bhendi fibers (BFs) were produced after BFs were subjected to UV light at different intensities. Mechanical parameters such as tensile strength, tensile modulus, and impact strength of irradiated BF/PP composites significantly improved compared to non-irradiated counterparts. To enhance their properties, different amounts of 2-hydroxyethyl methacrylate (HEMA) in methanol were applied to the surfaces of irradiated BFs, and UV light was subsequently used to cure them. Tensile strength, tensile modulus, and impact strength values rose by 32%, 20%, and 37%, respectively, after the optimized grafting and mechanical properties. Alkali solutions were applied to BFs for 30 minutes at varying temperatures and concentrations to alter their surfaces. Then, using the same UV light, BFs were photocured after being grafted with an optimal HEMA solution. Of all the composite samples treated with 10% HEMA, the alkali + 10% HEMA-treated composites exhibited superior mechanical performance. SEM studies exhibited that the optimized alkali with 10% HEMA treated composite had better dispersion than the 10% HEMA treated composite. Water absorption was significantly lower in the treated than in the untreated sample. According to weather studies, the treated specimens may have less loss tensile characteristics than the untreated specimens.

1. Introduction

Composites are engineered materials made of two or more constituent materials that, on a macroscopic level, remain separate and distinct within the finished construction but have distinctly differing physical or chemical properties. People have been making plant fiber composites since the

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beginning of time. Tools, clothing, shelters, and weapons were also made from these composite materials. In modern civil construction, the automotive and marine sectors, the military, and the production of space or aircraft, composite materials are used for everything from furniture to packing to assembly boards to paneling to fencing. Composites are a valuable family of materials that can be utilized in a variety of industries for applications that require high quality but are also inexpensive.

In recent years, there has been a rise in environmental consciousness, which has piqued industrial interest in using natural fibers as a reinforcing component in polymer composites [1-4]. Natural fibers supply a renewable resource that may be recycled without causing ecological damage. They also have low costs, low densities, suitable definite strengths, strong thermal insulation features, and materials that serve equipment and lessen velum. The most significant chemical component of natural fibers is cellulose, especially for producing composites [5]. Plastic composites made of cellulose-based fibers have been employed for both structural and non-structural purposes. The bottlenecks most frequently associated with the fiber were poor fiber matrix adhesion, incompatibility with particular polymer matrixes, and moisture absorption by the fiber [6, 7]. A pretreatment or surface modification of the fiber surface must be added during processing to increase fiber-matrix adhesion. Various techniques have been devised to fix the surface of the fibers, including chemical and photochemical processes [8, 9]. Chemicals can activate the hydroxyl group in cellulose to cause the polymer to take on the desired properties. Many coupling agents are frequently applied to encourage contacts and connections between fibers and matrix. The strength of the fiber and interfacial adhesion affect the mechanical characteristics of composites.

Due to poor interfacial adhesion induced by the presence of tissues and gums on the surface of the natural fiber, the composite's strength is diminished. However, prior studies have demonstrated that it is impossible to create a completely clean surface. By hand layup and compression molding techniques, Singleton et al. [10] and Bairado et al. [11] produced composite laminate utilizing flax and recycled high-density polyethylene. The expected behavior of the tensile and impact properties was assessed. The characteristics of composite materials under low-velocity impacts have been researched by Richardson and Wisheart [12]. The impact parameters of the composite have been reviewed, and post-impact performance is measured in terms of residual strength. The improvement in strength and stiffness was examined while varying the fiber volume fraction.

Strength increased by 30% when fiber with acetate groups was used instead of natural fibers. Alkali treatment enhances mechanical properties. Lignin, hemicellulose, and pectin are removed from hydrophilic materials during the alkali treatment process to change the condition of hydrophobic materials. As a result of severe hemicellulose degradation, which separates the fibers from one another and turns them into fine powder, the fibers may lose their strength to serve as cement [12, 13]. Radiation is a particularly effective technique for graft initiation. Polymer materials for UV radiation treatment have the advantages of reduced space requirements, no solvent emissions, and rapid processing. There have been reports of several processes that improve the usage of certain elite solutions under UV radiation. These processes are related to natural fibres' physical and mechanical features [14]. Previous research has shown that treated natural fiber significantly increased the mechanical properties of natural fiber-reinforced composites [15, 16].

Bhendi fiber (BFs), scientifically known as Abelmoschus esculentus, one of the natural fibers, is a monocotyledon herbaceous plant in the Malvaceae family that is primarily found in Bangladesh and other tropical parts of the world. Malvaceae, a family of vegetables whose products are widely used in the food industry. Among many other names, it is also called Bamia, Bhendi in Bangladesh, and Bhindi elsewhere (India). Other names for it include Gumbo in the United States, Guibeiro in Portuguese, Lady's finger in England, Guino-gombo in Spain, and many more [17-20]. Due to its simplicity of cultivation, drought resistance, consistent output, and capacity to adapt to varying

moisture levels, it is highly well-liked in Bangladesh [21]. It is usually used as a fresh, green, nonfibrous fruit, making it a great crop. Fiber can be obtained from the extrinsic layers of the stem. It comprises some water-soluble materials related to jute, flax, pineapple leaf fibers, etc., as well as 60–70% -cellulose, 15-20% hemicellulose, 5–10% lignin, and 3-5% pectin [22]. Both oil (15–19%) and protein (30%) are present in bhendi seeds. Fiber currently has limited commercial value because it is a byproduct of plant burning. Recent studies on the thermal and mechanical properties of polymer-matrix composites reveal that a variety of candidates could be used as reinforcement [23]. However, moisturizers like mucilage have been the main application of bhendi fibers in materials. Bhendi fiber mucilage could be a source of polysaccharides that can be used, for example, in conjunction with polyacrylonitrile and the appropriate kind of chemical grafting to generate biodegradable polymers. Utilizing these fibers in composites is undoubtedly something that will be considered.

Thermoplastic resin PP was selected for this investigation because it has many exceptional qualities, including transparency, superior surface strength, high impact strength, high thermal distortion temperature, and dimensional stability. PP is also excellent for filling, strengthening, and mixing. One of the possible ways to make natural synthetic polymer composites is by mixing PP with fibrous natural fibers. In the current study, unidirectional bhendi fiber-PP composites were developed and their physicomechanical properties evaluated. Bhendi fibers were treated with HEMA under UV radiation before and after being treated with sodium hydroxide to enhance the composites' mechanical properties.

2. Experimental

2.1 Ingredients

The thermoplastic polymer matrix PP, which forms as pellets with a specific gravity of 0.91-0.92 and a melting temperature of 160-170°C, was purchased from MTBE (Malaysia) Sdn. Bhd. In the Manikganj District of Bangladesh, a bhendi fiber plant was bought. Plants were harvested when they were five months old and around two meters tall. The plant was collected and submerged to test for bacterial deterioration. Water retting was employed to take the fiber out of the stacks for around 15 days. The fibers were then repeatedly washed with distilled water. They were air-dried and stored in spick-and-span containers. HEMA was provided by E. Merck in Darmstadt, Germany, together with methanol (MeOH), a swelling agent, and irgacure-500, a photoinitiator, from Ciba-Geigy in Switzerland. Irgacure-500 is a mixture of 1-hydroxycyclohexyl phenyl ketone (structure I) and benzophenone (structure II) that was procured from Ciba-Geigy (Switzerland) according to Scheme 1 (a).

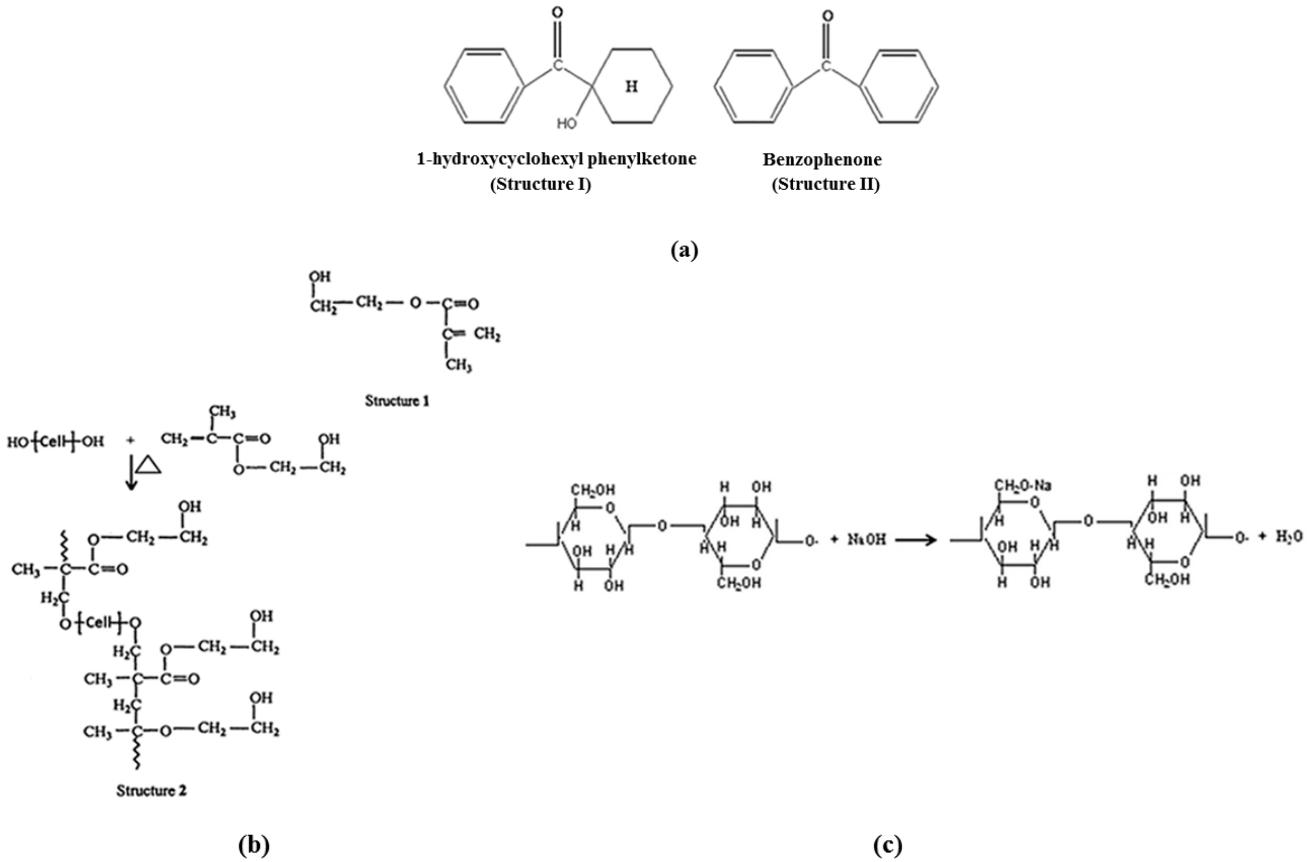
2.2 Methods

2.2.1 Treatments for fiber surfaces

After being cleaned and dried, BFs were exposed to UV light with the following specifications: 2 kW power output, 254–313 nm wavelength, 50 amp current, and a range of intensities (10–60 UV-pass) (UV curing equipment; IST technique, Germany). A mercury lamp inside a conductive belt serves as the UV light source. Once the conductor hits the lamp, it is regarded to have passed. The conductor moves at a pace of 4 m/min and a carrier separation of 1 m. The number of UV passes was estimated after the composite samples were exposed to UV light.

Natural fibers are subjected to an alkaline process known as mercerization. For mercerization, use a 5-25% NaOH in water solution. BFs were immersed in mercerized solution at 15–60°C for 30 minutes. Then, mercerized fibers were carefully washed several times in water to check for any traces

of NaOH. The final washing was carried out using 2% acetic acid to remove the last traces of NaOH. The fibers were then dried in an air dryer for 24 hours after being cleaned and dried. Table 1 lists the formulated compositions from a group of formulations that were organized.



Scheme. 1. (a) The structure of 1-hydroxycyclohexylphenyl ketone and benzophenone; (b) The mechanism of the reaction between cellulose and HEMA; and (c) The hypothesis that cellulose and alkali react to form water molecules

Table 1
Composition of several formulations based on 2-hydroxyethyl methacrylate (HEMA)

Materials	Formulations (w/w %)			
	H_1	H_2	H_3	H_4
HEMA	5	10	15	20
Methanol	93	88	83	78
Photoinitiator	2	2	2	2

The exposed BFs were then covered with this mixture and cured using UV light (10–60 UV passes) of various intensities. The curing samples were removed, and benzene was heated for 48 hours to determine the extent of grafting. The following formula (Eq. 1) was used to estimate the grafting percentage:

$$\text{Grafting (\%)} = [(W1-W2)/W1] \times 100 \quad (1)$$

where W1 and W2 are weighed both before and after the removal of heated benzene. Mercerized fibers (15% NaOH) were dipped in various mixtures for better comparison, and they were then let to stand for 5 minutes.

2.2.2 Making of Composite Specimens

The PP sheet (0.25-0.30 mm thickness) was made from PP pellets in a hot press machine at 170°C with 8 MPa of pressure for 5 minutes. The BFs were positioned lengthwise on the PP sheet using manual rotation. In stages resembling PL-BFL-PL..., PP sheet layers (PL) were created by stacking BF layers (BFL), with two layers of PP sheet making up the outer layers. A hot press at 180°C with an 8 MPa pressure was used to create composite samples, which were then cooled in a second press with the aid of two steel plates.

2.3 Characterizations

Using a Shimadzu UTM (Model AG-1, Japan) with electrical weight cells of 6 kN, the composite sample's tensile characteristics were measured per ASTM-D 638-03 standards. Tensile testing was completed with a gauge length of 20 mm and a crosshead speed of 10 mm/min. An impact machine (model, Toyo Seiki Co., Japan) was used to test the Izod impact strength following ASTM-D 256 specifications. The sample's measurements were 63.5 × 12.7 × 3 mm3. All trials were conducted at a temperature of 23°C ± 2°C and a relative humidity of 50 ± 5%. The values reported are the mean of five measurements.

The SEM micrographs of untreated and treated composite materials were analyzed using a Zeiss Evo 50 scanning electron microscope. To evenly distribute the electric charge throughout the test, the specimens' fracture edges were coated with a tiny layer of gold and inserted in an aluminum spit.

The amount of water the untreated and treated composite samples absorbed was compared by placing the sample in a glass beaker filled with water at 23°C. The sample was taken out of the water, drained, and weighed following a continuous time break.

The Accelerated Weathering Tester (Model Q-U-V, Q-Panel Company, USA) carried out the composite sampling. Test specimens included untreated, 10% HEMA-treated, and alkali-treated with 10% HEMA-treated samples. The treatment varied between 60 ± 2°C (sunshine) and 40 ± 2°C (condensation) during a period of 600 hours, with periods of 4 hours of sunlight and 2 hours of condensation. Due to weather testing, the specimens were dried in an oven for half an hour, and their tensile characteristics were measured.

3. Results

3.1 Morphological Analysis

Figure 1 shows the SEM graphs for the fracture surfaces of composites that have not been treated (a), treated with 10% HEMA (b) and treated with alkali and 10% HEMA (c), respectively. BF/PP composites (Figure 1a) appear to be separated from the PP matrix and have a significant pull-out, in contrast to previous treatment composites. It was found that the interfacial structure of this composite could not effectively transfer stresses. This result was consistent with the low tensile strength values stated in Table 2. SEM observation shows that alkaline with HEMA treatment and HEMA treatment composites interact with fibers and matrix differently. Better bonding has been observed between alkali + 10% HEMA treatment composite and 10% HEMA treatment composite. Despite the fact that fiber pull-out was apparent in both cases (alkali + 10% HEMA treatment), a significant amount of matrix residue was found in the fiber. In the instance of the HEMA treatment, the fiber was made available in pull-out packages and spread randomly by the matrix. Thus, the composite of HEMA treatments shows more pull-out. The alkali + 10% HEMA treatment composites were found to be surrounded by a PP matrix, demonstrating a tight connection between the fibers

and the matrix (Figure 1, c). The multicellular matrix's cementing components were partly reduced in this instance, enhancing the prominence of the isolate cells. After NaOH treatment, some hemicellulose and lignin were removed from the fiber cell walls. The mechanical characteristics of the composite can be enhanced by reducing hemicellulose.

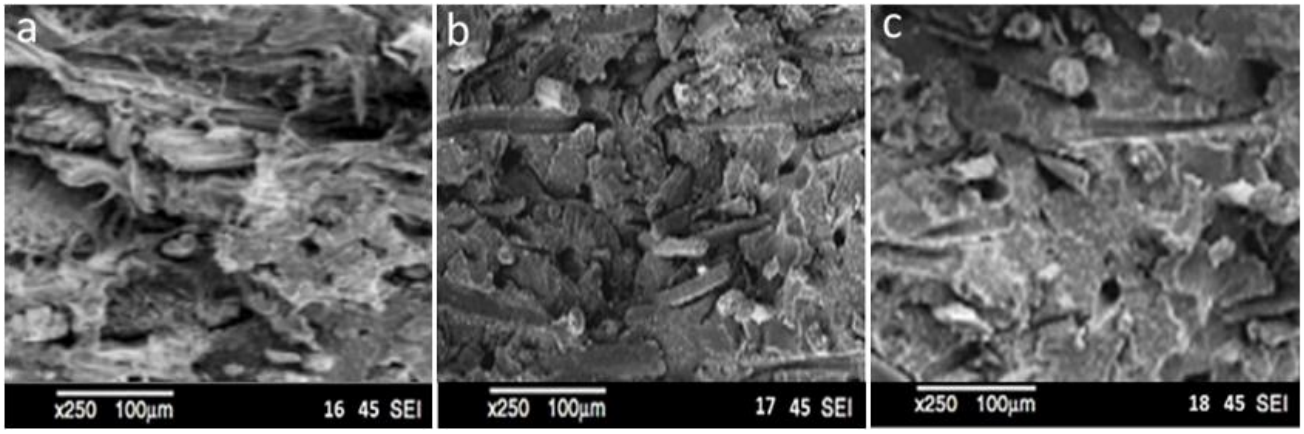


Fig. 1. SEM pictures of the fracture surfaces of composites that had been (a) untreated (UC), (b) treated with 10% HEMA (HC), and (c) treated with alkali and 10% HEMA (AHC)

3.2 Effect of UV Radiation on the Tensile Properties of Composites

After being cleaned and dried, BFs were exposed to varying amounts of UV radiation (10–60 UV passes), and then composites were produced. The effects of UV radiation on the mechanical properties of the exposed BF/PP composites were measured and displayed in Table 2. We found that the tensile properties of BFs significantly enhanced after exposure to UV radiation. The UV pass is expanded in the fiber, which enhances the specimens' tensile strength (TS), tensile modulus (TM), and impact strength (IS). The TS (43.5 MPa), TM (0.99 GPa), and IS (14.3 kJ/m^2) with the highest values were found after 30 UV passes of radiation. These numbers were greater than those of the untreated composite by 22%, 14%, and 31%, respectively. This might be brought about by an increase in the specimen's tensile characteristics after UV exposure, which might subsequently lead to intercross-links among the neighbouring cellulose particles, raising the tensile strength of the natural fiber.

Table 2
The mechanical properties of exposed BF/PP composites against various UV passes

Materials	No. of UV passes	Properties		
		TS (MPa)	TM (GPa)	IS (kJ/m^2)
Irradiated BF/PP composites	0	35.6 ± 0.8	0.87 ± 0.05	10.9 ± 0.6
	10	39.4 ± 0.7	0.89 ± 0.07	12.1 ± 0.5
	20	41.8 ± 0.8	0.93 ± 0.04	12.9 ± 0.5
	30	43.5 ± 0.6	0.99 ± 0.06	14.3 ± 0.6
	40	42.1 ± 0.5	0.98 ± 0.05	12.9 ± 0.5
	50	40.1 ± 0.6	0.96 ± 0.07	12.5 ± 0.7
	60	39.3 ± 0.7	0.93 ± 0.06	11.7 ± 0.5

UV pretreatment marginally increased the tensile properties, which later decreased due to two opposing processes occurring simultaneously under UV radiation: photodegradation and photo-crosslinking [24]. The fusion reaction stabilizes the free radicals in the lower passes and causes photo- or inter-crosslinking in the adjacent cellulose particles. Using a longer UV pass, the main chain can be

disrupted, reducing the polymer fragment. As a result, the tensile properties deteriorate with increasing UV passes.

3.3 Effect of HEMA on the Mechanical Properties of Composites

After exposure to UV light at various intensities (10–60 UV pass) for 30 UV passes, the exposed BF was submerged in MeOH for 10 minutes at various HEMA concentrations (5%-20%) to cure it. The number of UV passes as a function of HEMA concentration and the grafting outcomes are contrasted in Figure 2(a). Grafting quantities are used to assess the amount of cross-linking between fibrous monomers, and we observed that grafting increases with UV pass achieves its maximum value at a specific UV pass, and then gradually decreases with UV pass.

The bulk of the grafting samples were almost always treated with 10% HEMA during the 40th UV pass. 15% HEMA solution had the highest grafting value (5.6%), followed by 10% HEMA solution. The amount of BFs being grafted with HEMA decreased at concentrations over 10% because grafting through a double bond with a photoinitiator of the monomer drove them into the network polymer structure to promote quick free-radical propagation. It is possible to explain the decrease in grafting with an increase in HEMA by supposing that at higher HEMA concentrations, a radical-radical recombination process may predominate and lead to the production of more homopolymers as opposed to the monomer + BFs cellulose backbone reaction. For a 5% HEMA solution, the minimum grafting value (3.1%) was attained during the 40th UV pass. All subsequent trials were conducted under this idealized circumstance.

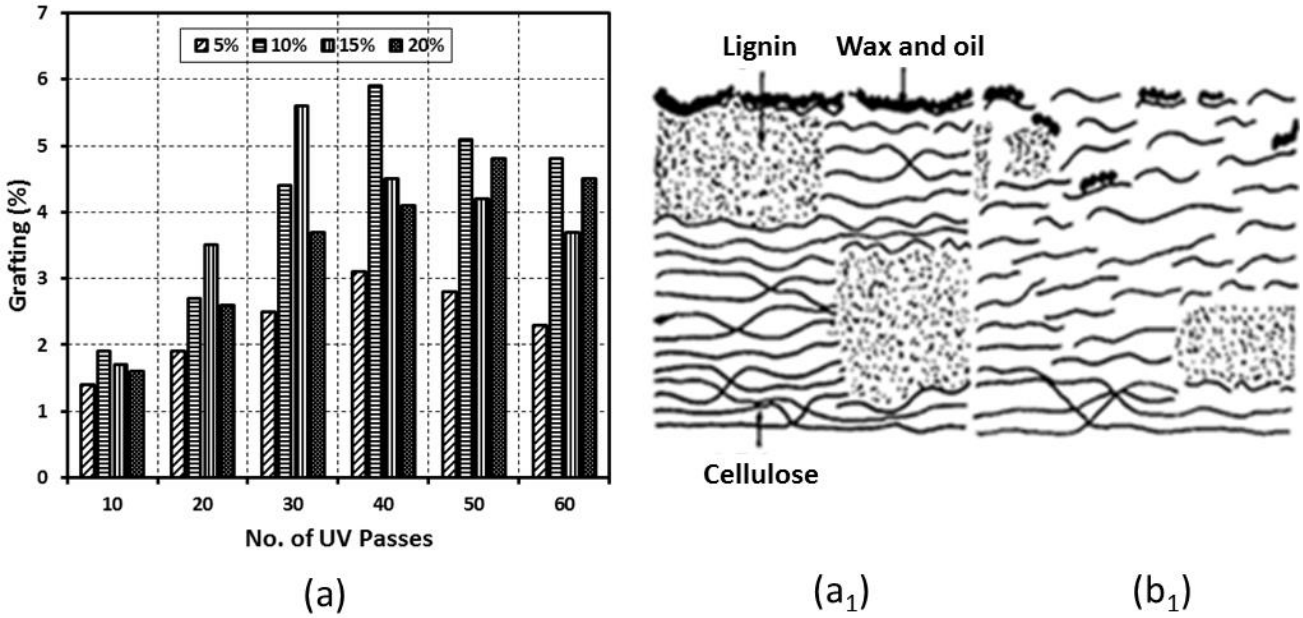


Fig. 2. (a) Grafting (%) of HEMA in BF against the intensity of radiation related to HEMA concentration; (b) Typical structure of (a1) untreated and (b1) alkalized cellulosic fiber

The mechanical characteristics of a 10% HEMA-exposed BF/PP composite have been evaluated and are shown in Table 3. Up to a certain point, the mechanical features grew with rising UV radiation, and then they shrank with increasing UV pass. The highest TS (46.9 MPa), TM (1.04 GPa), and IS (14.9 kJ/m2) over the untreated composite were determined to be 32%, 20%, and 37%, respectively. When the photoinitiator is subjected to UV radiation, free radicals are produced. This free radical strengthens the link between the fibre and matrix by starting a free radical reaction between the

fibers' monomer and -OH groups. HEMA's vinyl group of acrylate moiety reacts with the -OH group of cellulose spine via graft-copolymerization (Scheme 1, b). This will reduce the hydrophilic nature of BF, which is attributed to superior mechanical features.

Table 3
Mechanical properties of exposed-BF/PP composites 10% HEMA treated against different UV passes

Materials	No. of UV passes	Properties		
		TS (MPa)	TM (GPa)	IS (kJ/m^2)
UC	0	35.6 ± 0.8	0.87 ± 0.05	10.9 ± 0.6
HC	10	39.1 ± 0.5	0.92 ± 0.07	11.7 ± 0.5
	20	42.2 ± 0.6	0.96 ± 0.06	13.1 ± 0.6
	30	44.1 ± 0.7	0.97 ± 0.07	13.9 ± 0.7
	40	46.9 ± 0.5	1.04 ± 0.08	14.9 ± 0.5
	50	45.6 ± 0.8	1.01 ± 0.07	13.7 ± 0.6
	60	42.9 ± 0.6	0.97 ± 0.05	12.9 ± 0.7

3.4 Effects of Alkali (NaOH) Treatment on Composite Features

By removing lignin, waxy substances, and oils from the fiber cell wall's exterior surface, alkaline treatment advances the bonding between the fiber and matrix (Figure 2b, a1). It offers the fibers an acceptable topography and allows them to express themselves (Figure 2b, b1). The alkaline treatment increases the discrepancy between the amount of cellulose released on the fiber surface in good mechanical interlocking and the amount of cellulose exposed to the surface. Eq. 2 shows the NaOH reaction with cellulose.

$$\text{Cell-OH} + \text{NaOH} \rightarrow \text{Cell} - \text{O}^{-}\text{Na}^{+} + \text{H2O} + [\text{surface impurities}] \quad (2)$$

The following responses result from alkaline treatment (Scheme 1, c). Interestingly, the molecular structure of native cellulose I depolymerizes when it is formed by alkaline short-length crystals (Figure 2b, b1). Due to this, BFs exhibited long-lasting effects on mechanical behavior, particularly in the case of alkali treatment [25].

Varying alkali concentrations (5–25%) and varying temperatures (10–40°C) were used to split the washed-dried BFs. Before HEMA treatment, the weight loss percentage was calculated and shown in Figure 3(a). After increasing the temperature to a particular number and after reaching its maximum value, the percentage of weight loss caused by alkaline treatment is reduced. When using a 15% alkaline solution and a temperature of 20°C, the greatest weight loss (10.7%) was achieved. BFs were thoroughly cleaned, dried, and then treated with a 15% alkali solution at 20°C. After that, 10% HEMA was grafted onto the fibers, and 40th UV passes of UV radiation were used to cure them. Table 4 displays grafting values (Gr), TS, TM, and IS. The results showed that the alkaline treatment composite had more grafting (Gr) and mechanical properties than the 10% HEMA treatment composite, with the Gr being about 15%, 13.1%, 25%, and 26% higher in the alkaline treatment composite.

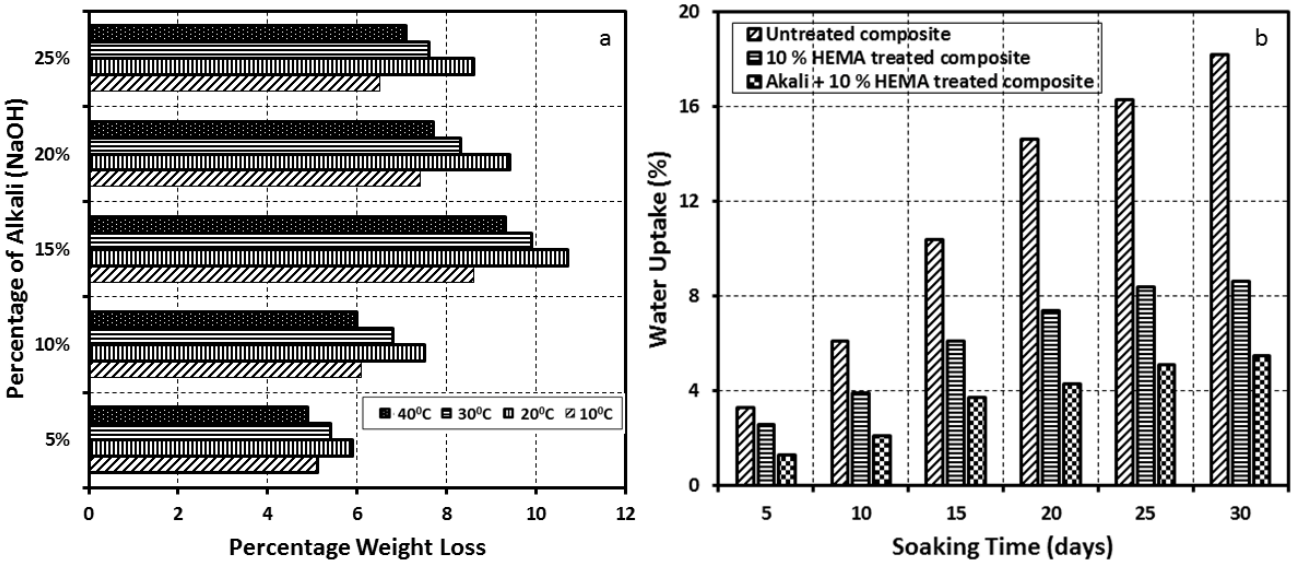


Fig. 3. (a) The influence of alkaline treatment on BF weight loss at various alkali (NaOH) concentrations as a function of solution temperature; (b) The quality of water uptake of untreated and treated composite as compared to the amount of time spent soaking in water

Table 4
Polymer grafting (%) and mechanical properties of alkali + 10% HEMA-treated exposed-BF/PP composites against different UV passes

Materials	No. of UV passes	Properties			
		Grafting (%)	TS (MPa)	TM (GPa)	IS (kJ/m^2)
UC	0	-	35.6 ± 0.8	0.87 ± 0.05	10.9 ± 0.6
AHC	10	3.3	41.3 ± 0.6	0.95 ± 0.06	12.8 ± 0.5
	20	4.2	44.2 ± 0.5	0.98 ± 0.07	16.1 ± 0.7
	30	5.5	48.9 ± 0.7	1.12 ± 0.08	17.2 ± 0.8
	40	6.8	53.1 ± 0.5	1.30 ± 0.07	18.8 ± 0.6
	50	5.5	52.1 ± 0.4	1.27 ± 0.08	17.9 ± 0.5
	60	5.1	51.8 ± 0.6	1.25 ± 0.06	16.7 ± 0.6

UC: Untreated composite; AHC: alkali + 10% HEMA treated exposed BF/PP composite

3.5 Water Absorption

The outcomes of a 30-day examination into the water absorption of BF/PP composite samples (20 × 10 × 2.5 mm3) at 25°C in a glass beaker are shown in Figure 3(b). After 25 days of soaking, the treated samples absorb water, and the values then stay essentially constant. Untreated specimens, however, continued to consume water throughout the observation. Untreated samples (UC) adopted high water content (18.2%), whereas alkaline + 10% HEMA treatment samples (AHC) adopted low water content (5.5%). Because HEMA interacts with the cellulose's -OH group and lowers the hydrophilic characteristic of BF, the treated specimens absorb less water. It should be observed that the HC sample demonstrates excellent water resistance. It complies with the TS, TM, IS, and Gr standards.

3.6 Effects of Weather

Untreated and treated samples were tested to simulate severe weather conditions and 600 hours of condensation in the periodic cycle. The samples' TS and TM were calculated periodically. The TS and TM of the specimens decreased due to the weather, as seen in Figures 4(a) and 4(b). Most observations showed that the loss of TS for untreated specimens was approximately 31%, compared to 16% and 13% for the treatment composites of 10% HEMA (HC) and alkali + 10% HEMA (AHC). The TM loss in the untreated sample was around 26.4%, whereas it was approximately 14.2% and 9.8% in the HC and AHC samples, respectively. When exposed to severe weather for 600 hours, treated specimens were found to retain their tensile features, but untreated specimens lost their tensile properties (TS and TM). The alkali + 10% HEMA treatment specimen displays improved weather absorption and stability compared to other specimens.

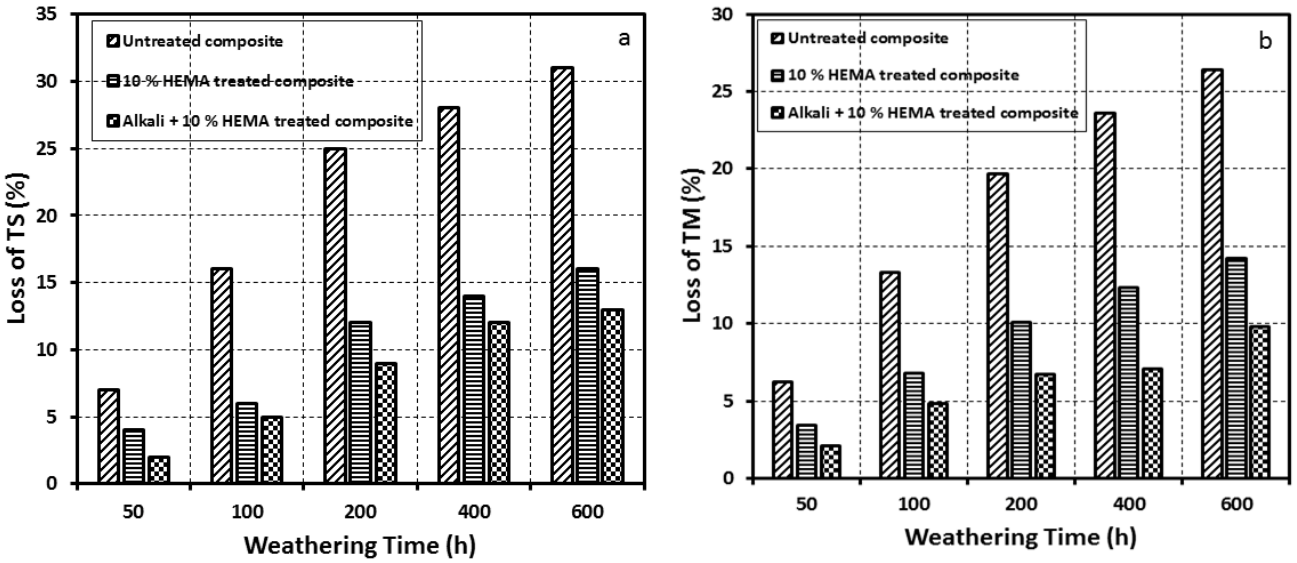


Fig. 4. (a) Tensile strength loss of untreated and treated BF/PP composites as a result of weather simulation; (b) Tensile modulus loss of untreated and treated BF/PP composites as a result of weather simulation

3.7 Use of Composite Material

The world's attention was drawn to environmental consciousness because natural fibers were used as reinforcement in the polymer matrix. In many situations, natural fiber-reinforced polymer composites have shown to be an effective substitute for synthetic fiber-reinforced polymer composites [26]. Despite the large number of natural fiber composite products being produced and sold, relatively few of these materials have been developed, and most of their technologies are still in the research and development stages. Natural fiber composites are utilized in automobiles for instrument panels, door panels, seat shells, armrests, headrests, and parcel shelves. Applications for natural fiber composites can be found in the automotive, aerospace, marine, sporting goods, and electronic industries. The studies above show that bhendi fibers have strong tensile properties when wet, making them a possible environmentally friendly replacement for traditional materials in automotive applications.

4. Conclusions

From those mentioned above, we can conclude the following:

a) In this article, BF/PP composites were fabricated by compression molding. The mechanical characteristics of the BF/PP composite, such as tensile strength, tensile modulus, and impact strength, perform better after 30 UV passes than those of untreated samples.
b) After being photocured under UV radiation (10–60 UV passes) at various intensities, irradiated BFs were treated with HEMA solutions (5–20%). Following HEMA treatment, a notable improvement in the tensile characteristics was found.
c) Alkali (NaOH) solutions in various concentrations and temperatures were applied for 30 minutes to modify the surfaces of BFs. After that, BFs were grafted with optimized HEMA solution and photocured using the same UV radiation. The grafting of alkali + 10% HEMA-treated composites showed better mechanical properties than 10% HEMA-treated composite sample.
d) Studies using scanning electron microscopy (SEM) showed that the optimized alkali with 10% HEMA-treated composite had better dispersion than the 10% HEMA-treated composite.
e) Water uptake in treated samples was significantly lower than in untreated ones. Weather investigations have demonstrated that the loss tensile properties of treated specimens may be inferior to those of untreated specimens, depending on the period of their weathering.

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