

PHB coating on jute fibers and its effect on natural fiber composites performance

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Abstract

In this work, a novel treatment on plant fibers is presented and its effect on the mechanical properties and water absorption of vinyl ester matrix composites is analyzed. The treated fibers used in this study consisted in alkaline-treated jute fibers and alkaline-treated jute fibers coated with polyhydroxybutyrate (PHB). Bending tests and IZOD impact tests were performed to evaluate the mechanical performance of the composites. The samples were immersed in water (at room temperature and at 80°C) and the water sorption and flexural modulus were measured in time. Flexural strength and impact energy were measured on dry specimens and the detrimental effect of water on those properties was evaluated by testing the samples after the immersion tests. The composites manufactured with alkali-treated fibers coated with PHB showed the best performance in terms of water absorption and mechanical properties.

Keywords

Natural fiber composites, physical treatments, polyhydroxybutyrate, water absorption, mechanical properties

Introduction

Plant fibers have different contents of cellulose, hemicellulose, and lignin as main compounds, as well as other compounds such as pectins and waxes (Table 1). They consist of two cell walls arranged as concentric cylinders with a small channel in the middle called the lumen. The bulk of the fiber is essentially constituted by the layer S2 of the secondary wall cell. The main chemical constituent of the fiber cell wall is cellulose, which chains are arranged in parallel to form bundles, denoted microfibrils, which are usually bonded together with lignin, pectin, and hemicellulose. The structure of the cell wall is organized into a number of layers differing by the angle of the cellulose microfibrils to the longitudinal fiber axis. Thus, the cell wall of plant fibers is organized like a composite laminate with a number of layers with differently oriented, stiff and strong semicrystalline cellulose microfibrils embedded in a matrix of hemicellulose and lignin.¹

It is well known that the properties of composite materials depend on the properties of the reinforcement, the properties of the matrix, and the characteristics of the matrix–reinforcement interface. In the case of natural fiber-based composites, Mukherjee et al.² suggested that the properties of the interface between elementary fibers could have a significant effect on the

composite mechanical properties, because longitudinal splitting can occur in that region. In addition, mechanical properties of natural fibers depend on their crystallinity, which is affected by the orientation of the microfibrils of cellulose within each elementary fiber.²

Many researchers have tried to improve the fiber–matrix interface. Bledzki and Gassan³ made an excellent review on the most used methods for surface modification of natural fibers. They sorted the treatments as chemical or physical methods. Usually, chemical methods bring about an active surface by introducing some reactive groups, and provide the fibers with higher extensibility through partial removal of lignin and hemicelluloses,⁴ while physical methods change structural and surface properties of the fiber and thereby influence the mechanical bonding to polymers. Some physical methods are stretching, calendering, thermotreatment, production of hybrid yarns,

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Table 1. Chemical composition (%) of some vegetable fibers.

Fiber	Cellulose	Lignin	Hemicellulose	Pectin	Wax	Moisture
Jute	61.0–71.5	12.0–13.0	13.6–20.4	0.2	0.5	12.6
Flax	71.0	2.2	18.6–20.6	2.3	1.7	10.0
Hemp	70.2–74.4	3.7–5.7	17.9–22.4	0.9	0.8	10.8
Kenaf	31.0–39.0	15.0–19.0	21.5	–	–	–
Sisal	67.0–78.0	8.0–11.0	10.0–14.2	10.0	2.0	11.0

electric discharge (corona, cold plasma), and mercerization (alkali treatment). Chemical treatments considered by Bledzki and Gassan³ are coupling in materials, change of surface tension, impregnation of fibers with polymers compatible to the polymer matrix of the composite, chemical coupling, graft copolymerization, treatment with compounds which contain methanol groups, treatment with isocyanates, triazine-coupling agents, and organosilanes-coupling agents.

The effect of the alkaline treatment on natural fibers' strength is dependent on the treatment time and NaOH concentration used during the chemical treatment. Alkali treatment causes fiber fibrillation, which increases fibers' surface roughness and enhances fiber wetting with the resin and this increases the number of anchorage points, resulting in a good mechanical interlocking fiber–matrix.⁵ This effect increases fiber–matrix interfacial adhesion, having a positive impact on the composite strength. In addition, Cyras et al.⁶ suggested that the treatment with alkali leads to an increase in stiffness and strength of individual natural fibers due to the change of cellulose I into cellulose II that leads to a tighter packaging of the chains and an increase in the degree of molecular orientation. On the other hand, severe alkaline treatment can produce extensive damage in the cell walls and excessive extraction of lignin and hemicellulose, which play a cementing role in the structure of the fibers,^{7,8} having a detrimental effect on the properties of the fibers. Therefore, when the alkaline treatment is used, the strength of the composites depends on the relative effect of the mentioned mechanisms. Gomes et al.⁹ studied the effect of alkali treatment on tensile properties of curauá fiber green composites. They found that alkali-treated fiber composites increased in fracture strain twice to three times more than untreated fiber composites, without a considerable decrease in strength. Pickering et al.¹⁰ also performed an alkali treatment that was found to produce strong fibers with a low lignin content and good fiber separation. Stocchi et al.¹¹ performed an alkaline treatment superimposed to biaxial tensile stress to woven jute fabric. They achieved a significant improvement in stiffness by the composite treated with alkali

under stress for 4 h, and an improvement in strength by composites treated for 4 h and 24 h.

The effect of water and moisture absorption of natural fiber composites is a serious concern, especially for outdoors applications. Water affects the mechanical properties of the composites as it plasticizes the polymer matrix and interacts with it chemically (hydrolyze),^{12–14} and also degrades the fiber–matrix interface. In addition, it has been shown that the water absorption induce the generation of interfacial micro cracks^{15,16} that weaken the composite and debond the fiber from the matrix. When natural fibers are used in the composites, it should be taken into account that water absorption causes the fibers to soften^{17,18} and swell^{19,20} affecting the fiber strength, stiffness, and the characteristics of the fiber–matrix interface.

Bessadok et al.²¹ performed different treatments on Alfa fibers, which involved acetylation, with the help of chemicals such as styrene, acrylic acid, and maleic anhydride. They found that treatments reduced the overall water uptake of the fibers, in particular the styrene treatment. Moreover, Sreekala and Thomas²² also performed various treatments on oil palm fibers such as mercerization, latex coating, gamma irradiation, silane treatment, isocyanate treatment, acetylation, and peroxide treatment. They found that hydrophilicity of the fibers decreased upon many modifications and that the mechanical properties of the fibers decreased upon sorption and regained on desorption. Sgriccia et al.²³ found that silane-treated composites absorbed less water than alkali-treated fiber composites. Satheesh Kumar and Siddaramaiah²⁴ fabricated composites by impregnating the jute nonwoven fabric in acrylonitrile–butadiene (NBR) latex. They noticed a drastic improvement in the water resistance behavior of the composites with increase in the pickup ratio of NBR to jute.

In previous literature works,²⁵ it was found that a polyhydroxybutyrate (PHB) coating was very effective reducing the water absorption of plant (jute) fibers. PHB (a type of polyhydroxyalkanoate) is a biodegradable thermoplastic polymer with a high hydrophobic character. The aim of the present work was to study the mechanical properties and the water sorption

characteristics of composites made with PHB-coated jute fibers and a vinylester polymeric matrix. Results were compared to those obtained from untreated and alkali-treated jute fiber composites.

Experimental procedure

Materials

Commercially available bidirectional plain woven jute fabrics (Casthanal, Textile CIA, Brazil, surface density = 0.0300 g/cm²) were used as reinforcement. The matrix material was prepared from general purpose vinylester resin (Derakane Momentum 411–350 from Dow), and accelerator in a weight ratio of 1:0.05, respectively.

Fabric treatments

Washed. As a common pretreatment, jute fabrics were washed by hand with a 2% V/V distilled water and detergent solution to remove contaminants and normalize the fabrics conditions. After washing, fabrics were air dried and ironed in order to eliminate wrinkles caused by drying. These simply washed fabrics will be referred here as untreated fabrics.

Alkali treatment. Washed jute fabrics were treated with Na(OH) aqueous solution (5% w/v) for 4 h with continuous shaking at 25°C. This was done by immersing the fabrics in the solution and placing the container on a shaker machine. During the treatment, Na(OH) concentration decreases at the fibers surface, and continuous shaking helps keeping the concentration constant and equal to the desired value. After the alkaline treatment, the fabrics were washed with distilled water until all the sodium hydroxide was eliminated, that is the PH was neutral. PH was measured directly onto the fibers by means of PH indicators.

Alkali treatment + PHB coating. Alkali-treated jute fabrics were coated with PHB by wetting out the fabric with a 2% PHB (Biocycle-Brasil) in chloroform solution. PHB was dissolved by continuous stirring in chloroform heated to 60°C and this solution was poured into a reservoir containing the jute fabrics. After wetting, the fabrics were placed on a dry surface where the solvent was evaporated, leaving a continuous PHB coating on the fibers. Surface density of the coated fabrics was 0.033 g/cm², higher than that of the untreated ones, as expected. Further details of this procedure can be found in literatures.^{25,26}

Composites preparation

Treated and untreated jute fabrics were dried until constant weight in an oven at 60°C under vacuum before use. Each layer of fabric was preimpregnated with matrix material and placed in the mold by a hand layup technique, taking care to keep practically achievable tolerances on fabric alignment. Five layers were compression molded in a hydraulic press for 2 h at 90°C. A 3 mm in thickness steel spacer was used to set the panel thickness, leading to fiber volume fractions close to 0.35.

Three point bending and IZOD impact tests specimens were machined from the compression molded plaques in accordance with ASTM D790-03 and ASTM D256-04 standard recommendations, respectively. Seven samples could be obtained from each panel.

Water sorption tests

Test samples were immersed in two different aqueous environments, which were distillate water at room temperature and distillate water at 80°C. The samples were weighed periodically using an analytical scale accurate to 10⁻⁴ g and the time of each weight measure was controlled with a chronometer. Before the weight measurements, the specimens were withdrawn from the waters and wiped dry to remove the surface moisture. Therefore, the specimen weight and time were collected. In order to become independent of the weight of the specimen tested, the relative water absorption was calculated with equation (1)

$$M_r(t) = \frac{[W(t) - W_0]}{W_0} \times 100 \quad (1)$$

where $M_r(t)$ = relative water absorption of the specimen at each time, $W(t)$ = specimen weight at each time, W_0 = initial specimen weight.

The tests were interrupted after 1400 h (approximately 58 days).

Mechanical properties evaluation

Three point bending tests. Three point bending tests were performed in the Instron dynamometer 4467 at 1.4 mm/min by using a span of 52 mm. Load–displacement curves were obtained from these tests and flexural modulus and strength values were determined from these curves, according to ASTM D790-03 standard. Flexural modulus was measured on dry specimens and periodically alongside the water sorption tests in order to correlate the decrease in modulus with the composites water uptake. On the other hand, flexural strength was measured on dry specimens and on specimens that had been exposed to the water absorption

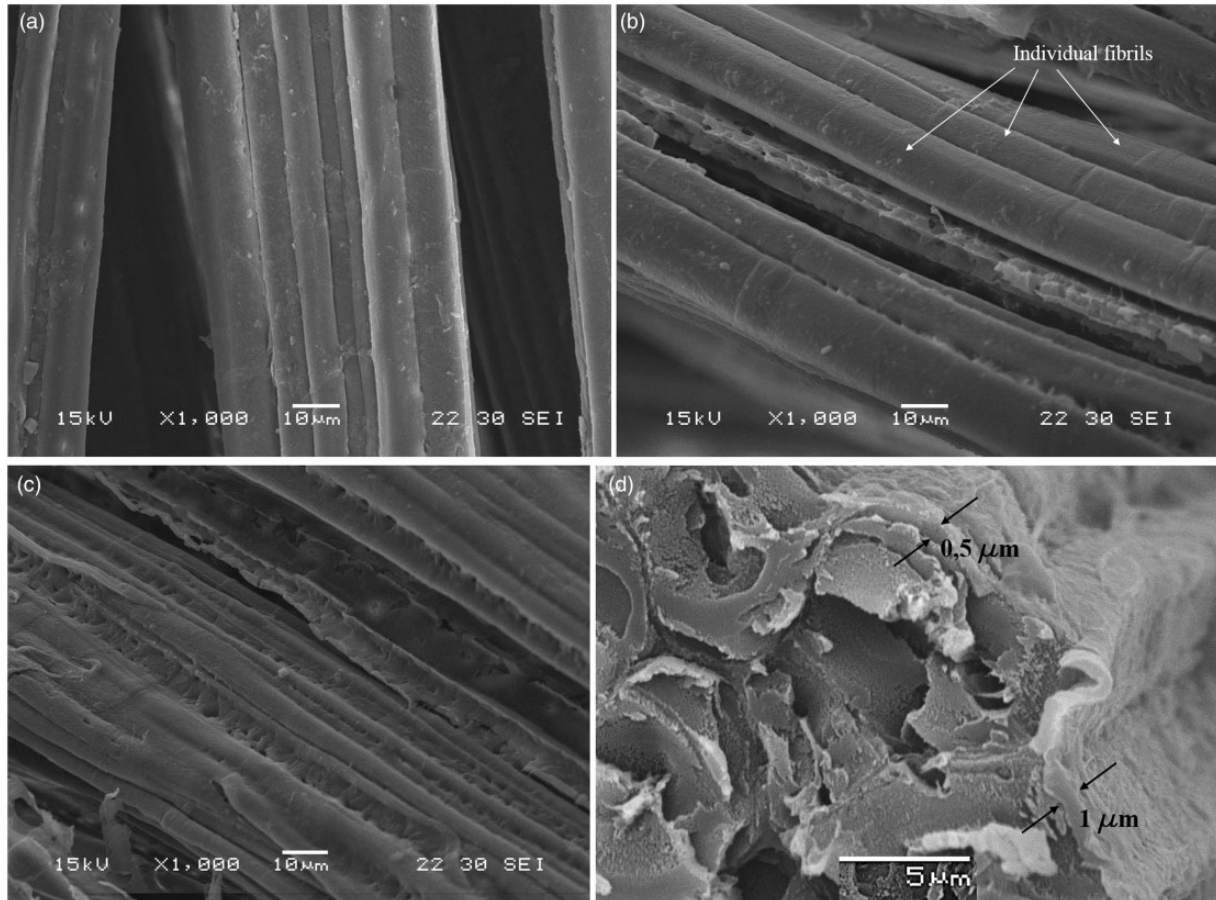


Figure 1. SEM images of jute fibers. (a) Washed fibers, (b) alkali-treated fibers, (c) alkali-treated fibers coated with PHB, and (d) PHB coating detail.

tests (1400 h). Seven samples were tested for each treatment and immersion condition.

IZOD impact tests. An instrumented impact testing machine (Ceast-Fractovis, falling weight) was used in the IZOD tests. The dart drop speed was 1.56 m/s, the hammer weight was 28.6 kg, and no dumping was used in these tests. Dry treated and untreated samples were tested, as well as samples that were immersed in the water absorption tests. Seven specimens were tested for each treatment and immersion condition. Load–displacement curves were obtained, and the impact energy was calculated as the area under the curves. Finally, the impact energy was divided by the sample transversal area to obtain the impact toughness of the laminates.

Scanning electron microscopy (SEM)

Fracture surfaces of specimens broken in IZOD tests as well as treated and untreated jute fiber yarns were analyzed by SEM (model JEOL JSM 6460 LV) after they had been coated with a thin layer of gold. SEM images

were also used to estimate void content in the composites using an image analyzing software. This software allows calculating the area of voids throughout the surface and then the fraction of voids is estimated by dividing the total voids area by the total area of the sample. This procedure was done twice for each composite (using two different images from different fracture surfaces) and the results were averaged.

Results and discussion

SEM images of treated and untreated fibers

Figure 1 shows SEM images of the fibers used as reinforcement in the composites. Alkali treatment cleaned the surface of the fibers and removed lignin and hemicellulose from the fiber causing fiber fibrillation (Figure 1(b)), as observed by other authors.^{7,9,11} The removal of the cementing materials increases the roughness of the fiber, which leaves more fiber surface to be wetted by the matrix during the manufacturing process, and gives more heterogeneity that allow mechanical adhesion with the matrix. The PHB coating over

the alkali-treated fibers was formed on the individual elementary fibers (Figure 1(c)), since alkali treatment produced fiber fibrillation. Surface roughness seems to be slightly higher than the one resulted from the alkali treatment. It should be taken into account that it was not possible to strictly control the coating thickness using such a simple treatment. The parameters that can be changed to modify the thickness are the PHB concentration in the solution and the immersion time. In this work, the fabrics were dipped in the solution and instantaneously removed, because it was observed that longer immersion times led to very thick coatings, and PBH concentration was used as recommended by Cyras et al.²⁶ The coating thickness obtained with this procedure was between 0.5 mm and 1 mm, as shown in Figure 1(d).

Water sorption tests

Akil et al.²⁷ mentioned three different mechanisms acting in the water sorption of fiber-reinforced composites: diffusion of water molecules inside the micro gaps between polymer chains, capillary transport into the gaps and flaws, within the interfaces between fibers and the matrix, and transport of micro cracks in the matrix arising from the swelling of fibers (particularly in the case of natural fiber composites). Moreover, the hydrophilic character of natural fibers increases the water absorption in the composites. Water absorption also depends on the void content in the resin, the relaxation of the resin in the presence of moisture and elevated temperature, and the binding of water molecules to the molecular structure of the resin. In this work, all the composite samples were obtained using the same resin system, and therefore the effect of fiber treatments

on the composite water absorption behavior could be studied isolated. However, since the treatments performed to the fibers could affect fiber wetting and void formation in the composites, void content of all samples was measured as explained in Scanning electron microscopy (SEM) section. Void content was almost the same in all the materials: $2.91 \pm 0.72\%$, $3.17 \pm 0.83\%$, and $2.76 \pm 0.81\%$ for untreated, alkali treated, and alkali+PHB-treated jute composites, respectively.

The water sorption tests conducted in this work showed that the composites immersed at room temperature (Figure 2(a)) followed a linear Flickean behavior, where the moisture weight gains gradually reach equilibrium after a rapid initial take off; while the samples immersed at 80°C (Figure 2(b)) suffered chemical and physical breakdown leading to the leaching out of the material from the bulk, where the weight gains follows a decrease trend after the initial take off loss of the samples. An increase in the temperature of water accelerates the absorption and degradation process and allows obtaining long-term results in lower exposure times. The accelerated results are valid, while new degradation mechanisms are not activated with temperature. In the case of vinyl ester composites, it was found that there is no change in the degradation mechanism at 80°C.²⁸

Results showed that both treatments were effective in decreasing water uptake of the composites. In the room temperature immersion tests, the composites made with alkali-treated fibers coated with PHB showed the best resistance to water absorption, followed by the alkali-treated fiber composites. Several authors have found the alkali treatment to reduce the water absorption of vegetable fibers, being the main

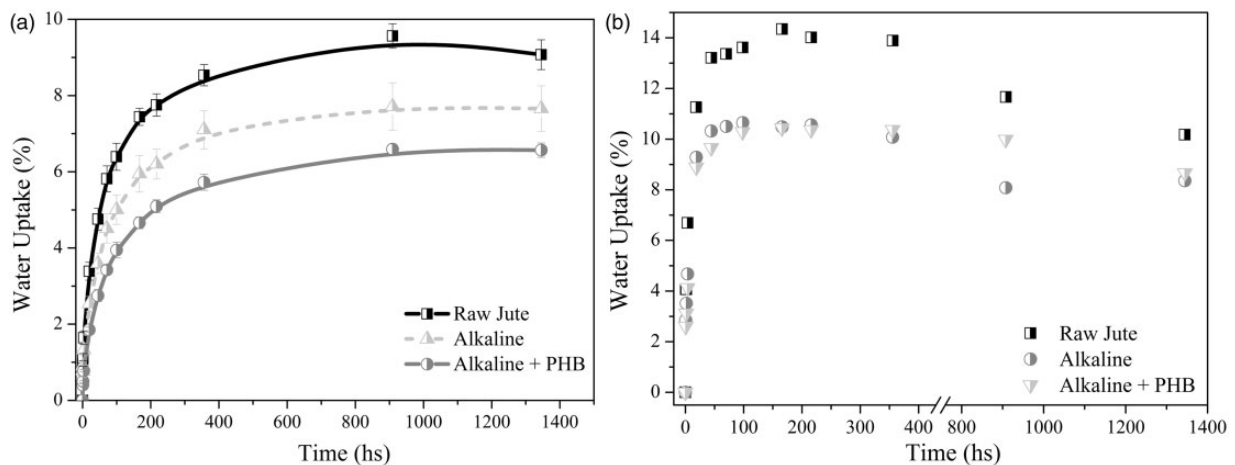


Figure 2. Weight gain (%) as a function of time for (a) specimens immersed in distillate water at room temperature and (b) specimens immersed in distillate water at 80°C.

accepted explanation for the removal of lignin and hemicellulose from fiber surface.^{29–33} Furthermore, it was also stated that the hydrophilic character of vegetable fibers changes to a more hydrophobic nature by the alkali treatment³³ as the NaOH hydroxyl groups reacts with the hydroxyl groups present in natural fiber. In addition to the mentioned benefits of the alkali treatment, the PHB coating isolated jute fibers from the water being absorbed, decreasing even more the water uptake of the composites.

At 80°C, the diffusion of water molecules inside the micro gaps between polymer chains is enhanced. Therefore, water molecules can reach natural fibers easier and the water transport along the fibers and the fiber–matrix interface is enhanced. The results of the water absorption tests at 80°C showed that the composites made with jute fibers absorbed the higher amount of water (14.35%) and lost more weight due to fiber degradation (4.17%) than the other samples. Alkali-treated fiber composites coated and uncoated with PHB showed a similar behavior, despite the coated fibers had a slightly better performance. They showed the lowest initial water uptake of the composites studied (10.65% in alkali-treated fibers and 10.44% in alkali-treated fibers coated with PHB) and they experimented less weight loss due to fiber degradation (2.28% weight loss in alkali-treated fibers and 1.77% in alkali-treated fibers coated with PHB). The degradation process of natural fibers at a given temperature takes a certain period of time. Due to the differences in the chemical structures between hemicellulose, cellulose, and lignin, they decompose at different temperatures or different times of exposure at a given temperature. Crystalline cellulose is more stable and difficult to degrade than amorphous lignin and hemicellulose^{34,35}; therefore, the composites made from alkali-treated fibers suffered less weight loss because some lignin and hemicellulose were removed during the chemical treatment with NaOH. On the other hand, composites made with raw jute fibers suffered lignin and hemicellulose degradation in a higher extent. In addition, the lowest degradation observed in alkali-treated fibers coated and uncoated with PHB could also be consequence of the lower amount of water content in those composites. What is more, many authors have reported weight loss mechanisms in vinyl ester resin, attributed to the desorption of low molecular weight groups, diffusion of residual volatile, or hydrolysis and diffusion of residues induced by cracks and leaching.^{36,37} However, all the composites used in this work were made with the same vinyl ester resin, thus they are supposed to suffer the same amount of weight loss of the matrix during the water absorption tests. A decrease in the weight of the samples was observed in the last part of the room temperature tests for the untreated jute composites, and

was evident for all the samples in the accelerated tests at 80°C. While matrix diffusion should be the same for all composites, PHB and alkali treatment can delay hydrothermal degradation at the interphase.

Composites mechanical performance

Figure 3 shows the flexural strength of the composites used in this study. The results of the tests performed on dry samples showed a slight decrease (5.8%) in strength in the composites as a consequence of the treatments done to the fibers. In all the composites (treated and untreated), the interface between the technical fiber and the matrix failed before the interface between elementary fibers did. This can be seen in Figure 4, where the technical fibers were pulled out of the matrix, without suffering internal pullout of the elementary fibers.

Flexural strength of the composites immersed in water at room temperature for 1400 h decreased 9%, 3.6%, and 5.8% when untreated, alkali-treated, and PHB-coated alkali-treated fibers were used, respectively. The better performance of the composites made with treated fibers could be caused by the less amount of water absorption and fiber softening in those cases. In addition, results obtained from the samples immersed at 80°C showed that the degradation of the matrix and fibers caused excessive damage on the composite properties, decreasing substantially their flexural strength.

Nevertheless, the difference in flexural strength for all the composites is not substantial, and fiber treatments and water absorption showed to have little effect on the strength of the composites. Therefore, it can be suggested that the composite strength is mainly dominated by the matrix strength, and that fibers have little effect on this property. The flexural strength of the matrix (unsaturated polyester resin) was 73.3 ± 1.1 MPa, which is in accordance with the reported value for this property by other authors.³⁸ Francucci et al.³⁹ theorized that the weak fiber–matrix interfacial adhesion present in the hybrid composites (plant fiber reinforcing a petrochemical based polymer) causes the load not to be transferred properly from the resin to the fibers and therefore most of the load is withstood by the resin itself. In addition, they found the properties of the hybrid composites to be lower to those of the matrix itself, which was explained stating that the empty space between the fibers and the matrix acts as flaws in the resin, and they initiate cracks at stresses lower than that of the resin failure stress. SEM pictures shown in Figure 4 indicate that the fiber–matrix interface was poor in all the materials and therefore the materials strength could have been dominated by the matrix properties itself as stated previously.

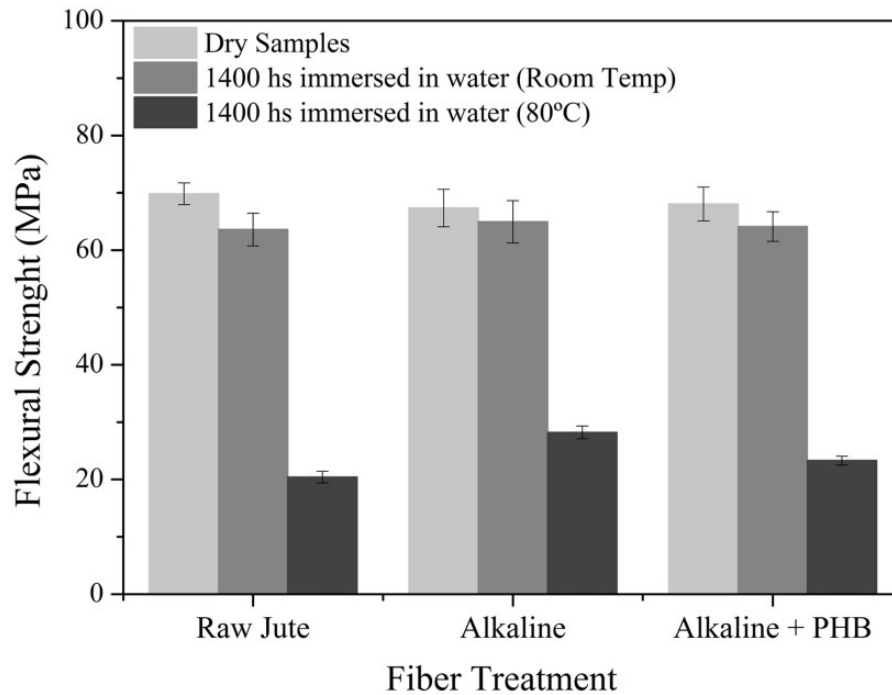


Figure 3. Flexural strength of the composites.

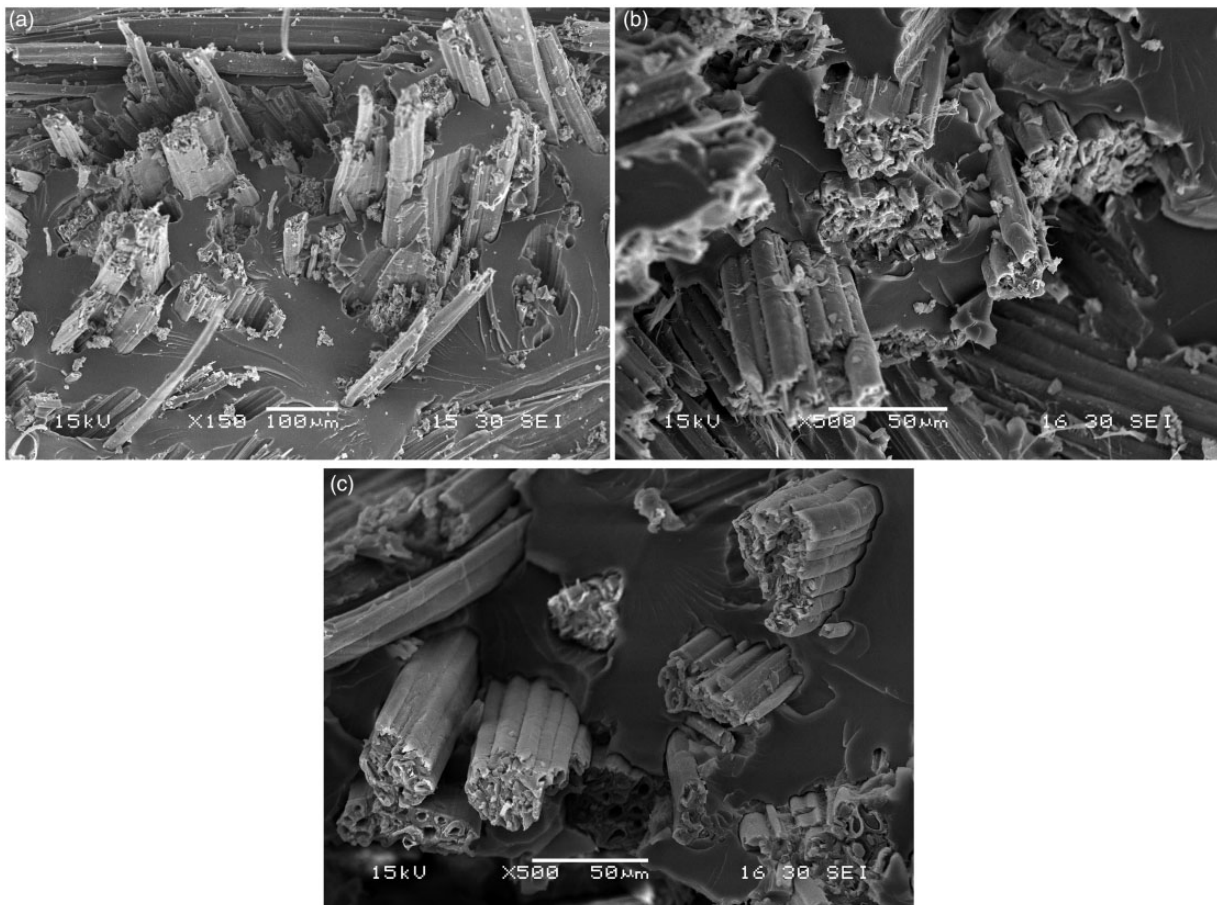


Figure 4. SEM pictures of the fracture surface of the dry composites reinforced with: (a) washed fibers, (b) alkali-treated fibers, and (c) alkali-treated fibers coated with PHB.

Table 2 shows the strain at break for all the composites and conditions. Dry samples did not show substantial differences in this property. Flexural strain for samples immersed in water at room temperature increased dramatically compared to dry samples

Table 2. Strain at break (%) for the dry composites and after 1400 h of immersion at room temperature and 80°C.

Condition/treatment	None	Alkali	Alkali + PHB
Dry	2.45 ± 0.19	2.38 ± 0.21	2.45 ± 0.22
1400 h Room temperature	3.12 ± 0.28	3.96 ± 0.31	3.84 ± 0.46
1400 h 80°C	2.10 ± 0.14	2.10 ± 0.12	1.89 ± 0.17

Note: PHB: polyhydroxybutyrate.

Table 3. Flexural modulus of the dry composites.

Treatment	None	Alkali	Alkali + PHB
Flexural modulus	4.2 ± 0.09	4.2 ± 0.08	4.6 ± 0.14

Note: PHB: polyhydroxybutyrate.

(27%, 66%, and 57% for untreated, alkali-treated, and alkali/PHB-treated composites, respectively). Same observations were made by other authors who claimed that natural fiber-reinforced composites tend to be ductile once the loss of cellulose and integrity has taken place⁴⁰ and that water molecules act as a plasticizer agent in the composite material, leading to an increase of the maximum strain for the composites after water absorption.⁴¹

The flexural modulus of the dry composites was found to be almost the same, although a 10% increase in this property could be found for the PHB-coated alkali-treated fiber composites (Table 3). The effect of water immersion at room temperature on the flexural modulus of the materials is shown in Figure 5. The relative modulus (E_r) plotted in this figure was calculated with equation (2), where E_0 is the dry flexural modulus and $E(t)$ is the flexural modulus at a certain immersion time “ t ”

$$E_r(t) = \frac{[E(t) - E_0]}{E_0} \times 100 \quad (2)$$

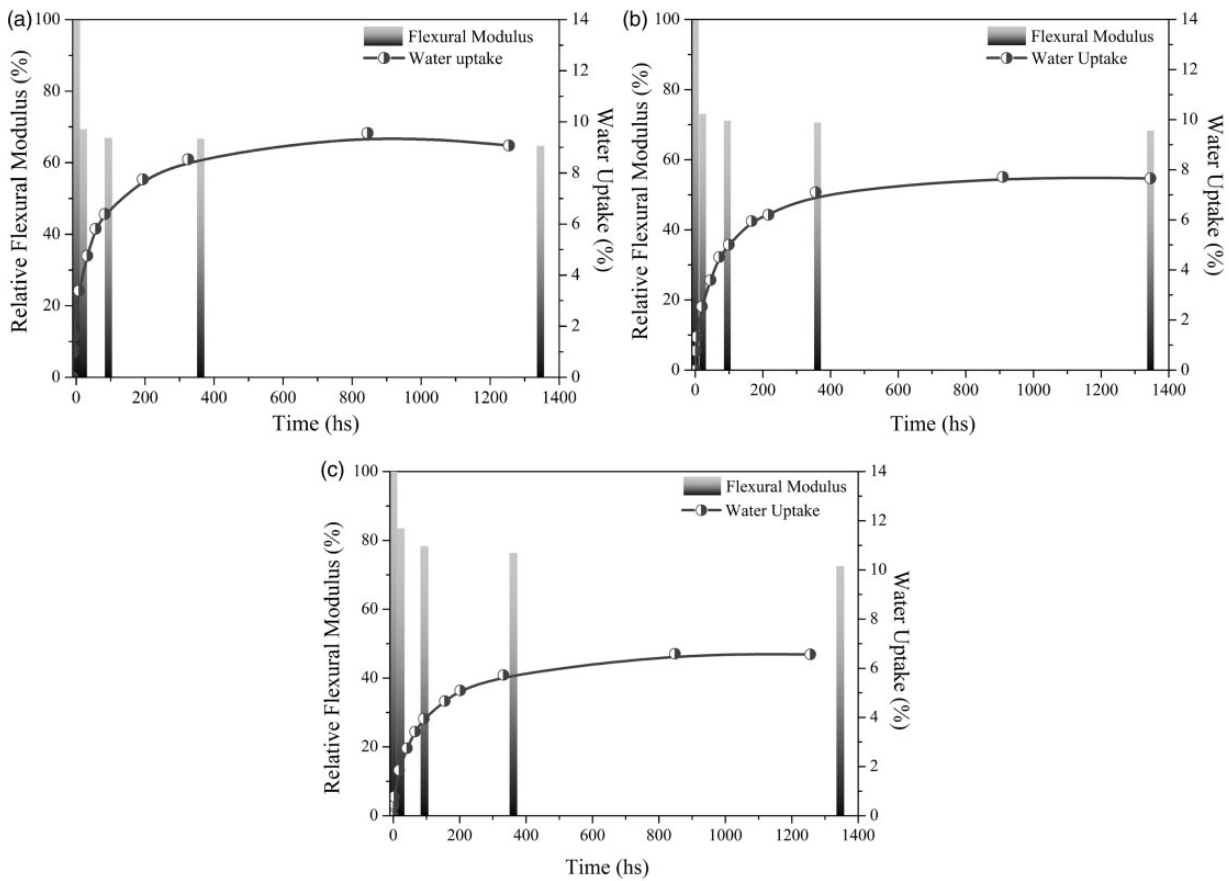


Figure 5. Evolution of the composites' flexural modulus as a function of the immersion time in water at room temperature. (a) Washed fibers, (b) alkali-treated fibers, (c) alkali-treated fibers coated with PHB.

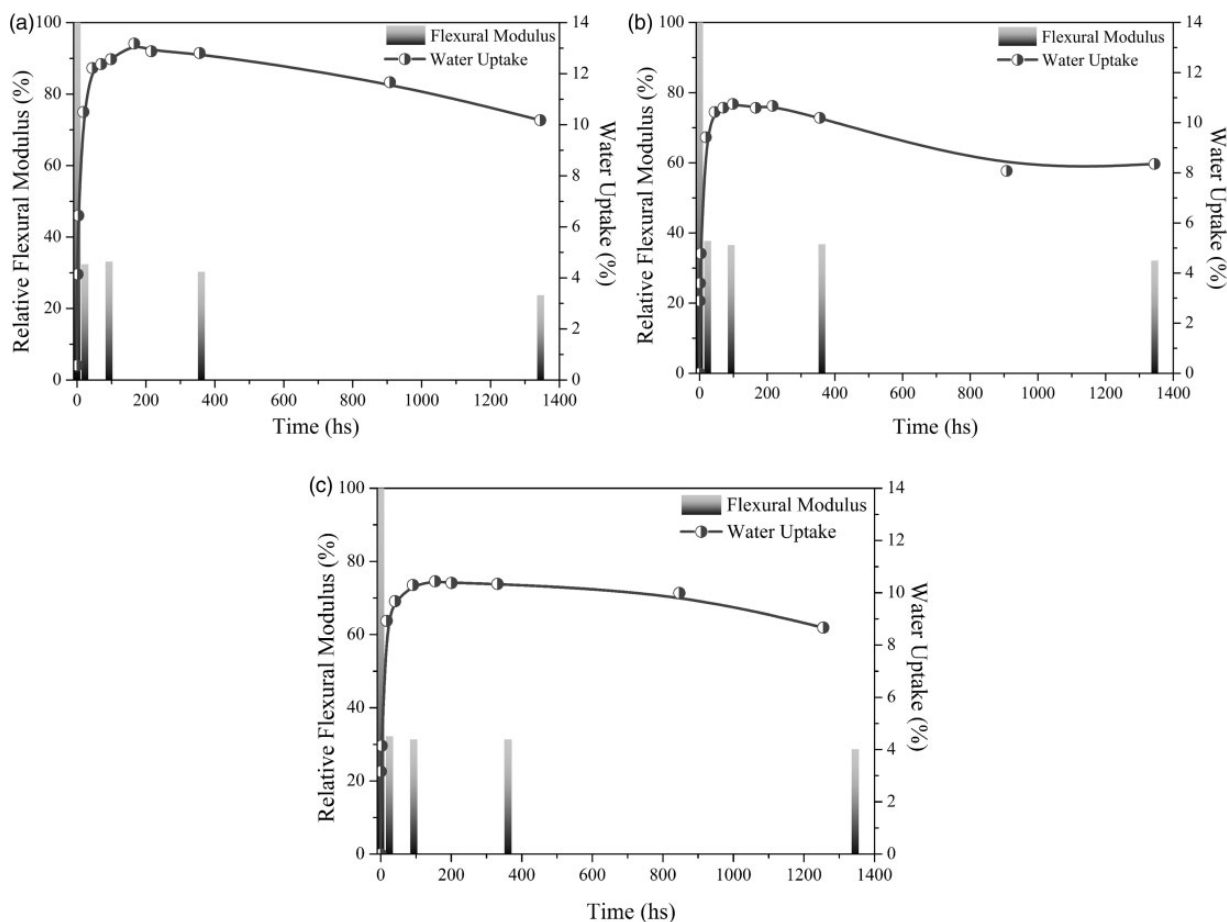


Figure 6. Evolution of the composites' flexural modulus as a function of the immersion time in water at 80°C. (a) Washed fibers, (b) alkali-treated fibers, and (c) alkali-treated fibers coated with PHB.

A very steep drop in this property was observed as the composites were immersed in water (at room temperature and at 80°C), and afterward it seemed to stabilize close to the final value (at 1400 h). The best performance was found for the PHB-coated alkali-treated fiber composites, showing a final decrease in the flexural modulus of 28%. Flexural modulus of alkali-treated fiber composites was reduced 32% and the worst behavior was observed for the untreated fiber composites, which modulus decreased 36% after the immersion in water at room temperature. These results correlate well with the water absorption results (replotted in the same figure for comparison purposes), since higher water absorption leads to a higher degree of fiber softening, reducing overall stiffness of the composite.

Composites immersed in water at 80°C suffered a severe reduction (more than 60%) in their flexural modulus as a consequence of fiber and matrix degradation. These results can be seen in Figure 6.

IZOD impact tests results are shown in Figure 7. It can be seen that the alkali-treated fiber composites

performed better than the untreated fiber composites, which can be explained by two main factors: better mechanical properties of the treated fibers and larger interfacial area caused by the fibrillation of elementary fibers. Pullout was evident in all the composites, as it can be seen in Figure 4. The pullout length was measured with an image analyzer software from the SEM images, and the average lengths were $34 \pm 12 \mu\text{m}$, $38 \pm 14 \mu\text{m}$, and $34 \pm 10 \mu\text{m}$ for untreated, alkali-treated, and PHB-coated alkali-treated fiber composites. Since these lengths are almost the same, the higher the area under friction during fiber pullout (given by fiber fibrillation due to the alkali treatment), the higher the energy consumed during the fracture of the specimen. In addition, composites reinforced with PHB-coated alkali-treated fibers showed the best performance to impact loads. In addition to the benefits of the alkali treatment mentioned previously, the deformation of the ductile PHB skin around the fibers could have consumed some amount of energy during the fracture of the specimens, causing the impact energy of

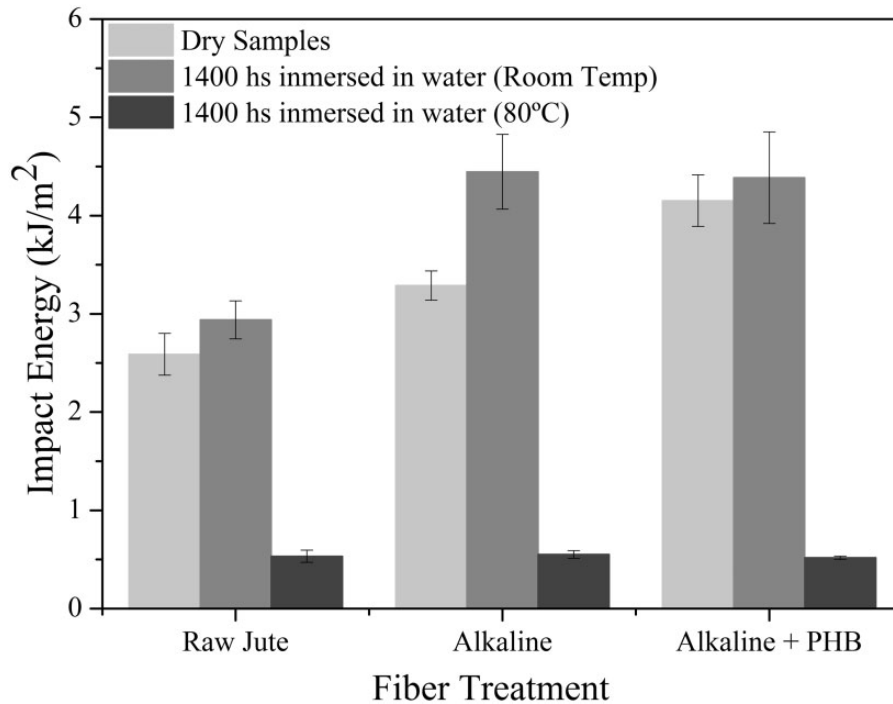


Figure 7. Impact energy of the composites.

these specimens to be the highest. Immersion of the composites in water at room temperature increased their impact strength. In general, it is known that fiber swelling due to water absorption can increase the friction between fibers and matrix, and therefore the energy that is dissipated during the pullout process. This effect is stronger in the alkali-treated fiber composites due to the higher roughness of the fiber surface, but is less notorious in the PHB-treated fiber composites due to the lower degree of fiber swelling. Softening of the matrix due plasticizing effect of the water contributes positively to the impact properties of the water-immersed composites. In the case of the samples immersed at 80°C, there is a general degradation of the matrix (the extraction of the unreacted monomers and low molecular weight portions of the network produces resin embrittlement), of the fibers and of the interphase, and the impact resistance is severely affected.

Conclusions

In this work, a novel physical treatment consisting in coating plant fibers with PHB was presented. The main objective of the treatment was to reduce the hydrophilic nature of jute fibers and therefore mitigate the negative effect of water absorption on the composites mechanical performance. Composites samples were manufactured with untreated jute fibers, alkali-treated jute fibers, and alkali-treated and PHB-coated jute fibers; and

water absorption and the mechanical properties of the materials were evaluated. Flexural strength and modulus of the dry composites remained almost unchanged after the fiber treatments. On the other hand, impact energy of dry specimens was found to be higher in PHB-coated alkali-treated fiber composites, followed by the alkali-treated fiber composites and finally the worst performance was shown by the untreated fiber composites. Water absorption of the composites made with alkali-treated fibers coated with PHB showed the best resistance to water absorption, followed by the alkali-treated fiber composites. Flexural modulus of jute fiber composites was found to be severely degraded by water absorption. The PHB coating over alkali-treated fibers showed to be the best treatment to mitigate the flexural modulus degradation, followed by the alkali treatment. On the other hand, no significant differences could be observed in the flexural strength of the treated and untreated composites after the water immersion tests. Impact energy was increased with the proposed treatments, being the PHB treatment the most effective for increasing the impact resistance. This was attributed to the deformation of the ductile PHB skin around the fibers that increases the energy during the fracture of the specimens.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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