Enhancement of fiber-matrix interface of recycled cotton fibers reinforced epoxy composite for improved mechanical properties

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Abstract

The aim of this study is to enhance the fiber-matrix interface of cotton waste reinforced composite panels by a specific chemical treatment. For this purpose, cotton fibers are treated in sodium hydroxide (NaOH) solution with three different concentrations (0.5 M, 1 M, and 1.5 M) and three different soaking times combinations (1 h, 3 h, and 5 h). Mechanical evaluation of treated and untreated reinforcements and composite panels are characterized using tensile test whereas the chemistries of fiber reinforcements are investigated using Fourier-transform infrared spectroscopy analysis and the fiber-matrix interactions are morphologically examined using scanning electron microscopy. Results indicate a remarkable enhancement in mechanical properties of composites via improving the interfacial adhesion and compatibility between fiber and matrix with a significant increase of Young modulus up to 270% for reinforcements and to 70% for composite materials compared to untreated materials.

Introduction

Natural fibers gain a great interest recently as a replacement to man-made fiber in fiber-reinforced composites. They are now fast evolving as a potential alternative to inorganic fibers as they offer several advantages like biodegradability, reduced energy consumption, low cost, low density, and competitive specific mechanical properties. These properties make natural fibers a potential replacement of glass or carbon fibers in textile reinforced composites (Karmarkar et al 2007, Li et al 2007, Malkapuram et al 2009, Bodur et al 2016). Moreover, natural fibers possess better sound absorbing properties compared to man-made fibers, owing to their porous structure, unlike synthetic fibers (Wei Dong and Yan 2012). In this context, there is an increasing demand from automotive companies to natural fiber reinforced composites owing to their sound-absorbing properties (Malkapuram et al 2009). However, these advantages come on the expense of poor compatibility and interfacial adhesion between natural fibers and polymers due to the hydrophilic nature of the fibers resulting from the large quantities of the hydroxyl group in the cellulose (Alvarez et al 2003, Belgacem and Gandini 2005). The chemical compositions of some natural fibers are listed in table 1.

In fact, the physical and mechanical characteristics of composites are highly affected by interfaces (Zhou et al 1995, Alvarez et al 2003). Poor interface leads to poor mechanical characteristics of composites. Hence, a better cohesion between fibers and matrix can be accomplished by a good wetting of the fiber by the matrix during composite production and by chemical interaction between the two parts. To overcome these drawbacks, surface modification of natural fibers can be utilized to ensure better cohesion between these two phases.
Many chemical treatments have been investigated namely, alkaline, silane, acetylation, benzoylation, acrylation, maleated coupling agents, permanganate, peroxide, isocyanate, etc as recently reviewed by Li et al (2007).

Among these various treatments, alkaline treatment (mercerization) is one of the most used techniques in natural fiber reinforced thermoset or thermoplastic composites. Furthermore, it is considered as the cheapest and simplest method compared to other chemical treatment methods (Hashim et al 2012).

The addition of alkaline aqueous solution to natural fibers increases the surface roughness by breaking down the fiber bundles into small fibrils and the elimination of a certain amount of lignin, wax, and oil from fibers which increases the effective surface available for contact with the matrix polymer resulting in better mechanical interlocking and the amount of cellulose exposed on the fiber surface (Bisanda 2000, Mohanty et al 2001, Aydin et al 2011). This treatment allows a swelling phenomenon in cellulosic fiber leading to a retraction and an increase in the diameter of the fiber. The natural crystalline structure of the cellulose relaxes (John and Anandiwiwa 2008) and the percentage of crystallinity index increases due to the removal of the cementing materials, which leads to better packing of the cellulose chains. Fiber modification during this chemical treatment follows the chemical reaction (1) where the hydroxyl (OH) group is removed from the structure, then reacts with water molecule and a new group is created between the remaining molecules (fiber–O–Na) (John and Anandiwiwa 2008, Bodur et al 2016).

\[
\text{Fiber} - \text{OH} + \text{NaOH} \rightarrow \text{Fiber} - \text{OH} - \text{Na} + \text{H}_2\text{O}
\]

Several papers have discussed the effect of alkalization on different natural fiber reinforced composites (Nama et al 2011), Vignesh (2018), Ganapathy et al (2019), Li et al (2019), Mittal and Chaudhary (2019), Nagarajan et al (2019), Salim et al (2019), Vinod et al (2019)). This low-cost method improves the mechanical performances of composites by approximately 40%–50% compared to untreated materials (Bodur et al 2016).

In one of the studies, Bodur et al (2016) manufactured waste cotton fabric reinforced low-density polyethylene composites using the extrusion method. In an anterior step, cotton reinforcements were treated with alkaline solution using different concentrations and soaking times. Mechanical tests showed that chemical treatment increases the tensile strength and Young modulus of the composite samples. The maximum values were detected at 1 M concentration and soaking time of 5 h (35% increment of tensile strength and 40% increment of the Young modulus compared to untreated composite). However, mechanical properties tend to decrease with increasing soaking time and concentration (Bodur et al 2016).

In another work of Weyenberg et al flax fibers were dipped in a NaOH solution of different concentrations (1, 2 or 3%) for 20 min at room temperature. Results showed that alkaline treatment (concentration of 1%) improved the tensile behavior (both tensile strength and modulus) of flax fiber reinforced epoxy composite by 30% (Van de Weyenberga et al 2003).

Jacob et al studied the effect of alkalization on sisal/oil palm hybrid fiber reinforced natural rubber composites. Fibers were treated for 1 h with NaOH solutions of varying concentrations (0.5, 1, 2, 4 and 10%) at room temperature. Results concluded that a maximum tensile strength could be obtained using a concentration of 4% (Jacoba et al 2004).

In a study of Bisanda (2000), sisal fibers were treated in a 0.5 M solution of NaOH for 24 h and 72 h. The fiber treatment improved its wetting ability, therefore reduced the porosity of the composite leading to enhanced compressive strength and water resistance.

### Table 1. Chemical compositions of some plant fibers (Ansell and Mwaikambo 2009).

| Plant fibre | Cellulose (%) | Hemicellulose (%) | Lignin (%) | Pectin (%) |
|-------------|---------------|-------------------|------------|------------|
| Cotton⁴    | 82-96         | 2-6.4             | 0-5        | <1-7       |
| Kapok⁵      | 13            | -                 | -          | -          |
| Flax⁶       | 60-81         | 14-20.6           | 2.2-5      | 1-4        |
| Hemp⁷       | 70-92         | 18-22             | 3-5        | 1          |
| Jute⁸       | 51-84         | 12-20             | 5-13       | 0.2        |
| Kenaf⁹      | 44-87         | 22                | 15-19      | 2          |
| Ramie¹⁰     | 68-76         | 13-15             | 0.6-1      | 2          |
| Banana¹¹    | 60-65         | 6-19              | 5-12       | 3-5        |
| Pineapple¹² | 90-82         | 16-19             | 5-12       | 2-3        |
| Sisal¹³     | 43-78         | 10-24             | 4-12       | 0.8-2      |
| Coir¹⁴      | 43-46         | 0.25              | 45-46      | 3-4        |
| Oil palm EFB ¹⁵ | 43-63     | 28-33             | 17-19      | 1          |

¹Seed, ⁵bast, ⁶leaf and ⁷fruit fibers.
In a study of Mohanty et al. (2000), jute fabrics were treated with 5% NaOH solution for 30 min at 30 °C and then used as reinforcement materials to polyester amide matrix. As a result, the tensile strength of the composite material has increased by more than 40% compared to untreated composite.

In this work, cotton waste fibers are utilized as a reinforcement to the epoxy resin, as they have the advantage of being eco-friendly and cost-efficient. Since there is a poor adhesion between natural fibers and epoxy matrices, alkaline treatment is applied to improve the mechanical performance of the composites. Before composite production, discarded cotton fibers are immersed in NaOH solution with three different concentration and soaking time combinations, and then carded and needle-punched to form nonwoven mats. Treated and untreated nonwoven mats are reinforced to the epoxy resin by using vacuum infusion technique. Both nonwoven fabrics and the composite panels’ physical, mechanical and morphological properties are evaluated regarding the fiber-matrix adhesion characteristics.

**Experimental study**

**Materials**

In this study, 100% cotton waste supplied by SITEX (Tunisia), is used as a reinforcement material. These wastes are shredded into fibers and then transformed into nonwoven mats by carding and needle punching process.

As a matrix system, epoxy resin (F-RES 11564) and its hardener (F-HARD 13486) are supplied by Fibermak (Turkey). The mixing ratio of resin and hardener is 100/34 by weight. The properties of the resin system are listed in table 2.

**Methods**

**Alkaline treatment**

Cotton waste fibers are immersed in 0.5 M, 1 M or 1.5 M NaOH solutions and stirred regularly to obtain a homogeneous solution at room temperature (20 °C ± 2 °C). Immersion duration is varied from 1 h to 5 h. After being soaked, fibers are filtrated and washed with distilled water several times until reaching neutral pH value, and then dried in an oven at 70 °C for 1 h. Finally, chemically treated and untreated fibers are carded and needle-punched to transform them into nonwoven mats for further processes. Images of fibers and nonwoven mats are presented in figure 1.

**Composite panels manufacturing**

The panel manufacturing is performed using a vacuum-assisted resin transfer molding method (VARTM). In this process, a vacuum pump is used to eliminate the air gaps and ensure the resin distribution into the fabric. The process starts with the preparation of the production table by applying the releasing agent, then placing the nonwoven mat covered with peel-ply fabric and the perforated film, the system is then enclosed with a vacuum.

| Table 2. Properties of the resin system. |
|-----------------------------------------|
| Density of epoxy at 20 °C (g cm⁻³)       | 1.1–1.2 |
| Density of hardener at 20 °C (g cm⁻³)    | 0.94–0.95 |
| Tensile strength (MPa)                   | 70–75 |
| Young modulus E (MPa)                    | 2850–3000 |

![Figure 1. Images of (a) recycled cotton fibers, (b) cotton nonwoven fabric and (c) cotton/epoxy composite.](image-url)
bag fixed with adhesive silicone tape. Once the air is removed from the reinforcement material, the epoxy resin pre-mixed with its hardener is introduced to the system through an inlet pipe under the vacuum pressure. Finally, when the resin is fully infused through the reinforcement, the excess resin goes through the outlet pipe. The composite panels are left for 48 h for curing and the fabrication is realized at room temperature (20 °C ± 2 °C). The dimensions of the nonwoven fabric and so the composite plates are chosen as 40 × 50 cm. Image of the manufactured composite is presented in figure 2, while the image of the composite material is shown in figure 1 (c).

**Physical analysis**
An optical microscope (ZEISS, Primostar) is used to measure the diameter of cotton fibers before and after the NaOH treatment. The thicknesses of nonwoven fabrics are measured by thickness gauge apparatus (James H. Heal) whereas the thicknesses of the composite panels are measured by a caliper. The areal densities of reinforcements and composites are calculated. Fiber weight ratios are also calculated by weighing the reinforcement materials before and after composite manufacturing, deducing the uptake of the resin.

**Fourier-transform infrared spectroscopy (FTIR) of nonwoven fabrics**
The chemistries of fiber reinforcements are evaluated using a FTIR spectroscopy (Perkin Elmer) in order to notice the differences between untreated and NaOH treated fibers. All data are recorded in the spectral range of 450–4000 cm⁻¹. The equipment has a ZnSe crystal which supplies the FTIR spectra directly from the sample. The samples were placed on to the ZnSe crystal and pressure was applied on them to attain a good contact with the incident IR beam and inhibit the IR incident radiation loss.

**Mechanical analysis**

*Mechanical characterization of nonwoven fabrics*
Mechanical characterization of nonwoven fabrics is conducted according to ISO 9073-3 standard with dimensions of 50 × 200 mm, using Titan² Tensile Tester with a load cell of 3 kN, and a cross-head speed of 50 mm min⁻¹. Tests are performed at 0° and 90° directions according to nonwoven production directions. Five samples are tested for each direction. Results are given as the average value of five samples.

*Mechanical characterization of composite panels*
The tensile test is performed using a Shimadzu AG-IS test machine with a load cell of 10 kN and a cross-head speed of 4 mm min⁻¹ according to ASTM D638-10 standard. Tests are conducted in two directions 0° and 90°. Five dog-bone shaped specimens are tested for each direction. Results are given as the average value of five samples.

**Morphological analysis**
Scanning electron microscope (SEM) is used to analyze the fiber morphology before and after NaOH treatment and to examine the fracture surface of the composites and the fiber-matrix interactions. The specimens are observed using a Tescan Vega3 instrument operated at 15 kV with magnification rates of 1000x and 3000x.
Untreated 1.7 ± 0.1
0.5 M 1 H 1.7 ± 0.2
0.5 M 3 H 1.5 ± 0.2
0.5 M 5 H 1.7 ± 0.2
1 M 1 H 1.2 ± 0.1
1 M 3 H 1.6 ± 0.1
1 M 5 H 1.5 ± 0.1
1.5 M 1 H 1.5 ± 0.1
1.5 M 3 H 2.1 ± 0.1
1.5 M 5 H 1.9 ± 0.1

Areal densities of reinforcements (g m⁻²)

Untreated 124.0 ± 0.20
0.5 M 1 H 170.3 ± 0.20
0.5 M 3 H 117.0 ± 0.10
0.5 M 5 H 150.3 ± 0.20
1 M 1 H 126.7 ± 0.10
1 M 3 H 136.7 ± 0.03
1 M 5 H 135.3 ± 0.10
1.5 M 1 H 136.3 ± 0.10
1.5 M 3 H 162.0 ± 0.04
1.5 M 5 H 170.3 ± 0.10

Thicknesses of composites (mm)

Untreated 1.0 ± 0.02
0.5 M 1 H 1.2 ± 0.08
0.5 M 3 H 0.8 ± 0.06
0.5 M 5 H 0.8 ± 0.04
1 M 1 H 0.9 ± 0.07
1 M 3 H 1.0 ± 0.04
1 M 5 H 1.1 ± 0.03
1.5 M 1 H 0.7 ± 0.03
1.5 M 3 H 1.3 ± 0.04
1.5 M 5 H 1.2 ± 0.06

Areal densities of composites (g m⁻²)

Untreated 880 ± 61
0.5 M 1 H 1360 ± 105
0.5 M 3 H 865 ± 50
0.5 M 5 H 850 ± 57
1 M 1 H 787 ± 121
1 M 3 H 1085 ± 28
1 M 5 H 1090 ± 77
1.5 M 1 H 620 ± 23
1.5 M 3 H 1345 ± 125
1.5 M 5 H 1720 ± 182

Fiber weight ratios (%)

Untreated 14
0.5 M 1 H 13
0.5 M 3 H 14
0.5 M 5 H 18
1 M 1 H 16
1 M 3 H 13
1 M 5 H 12
1.5 M 1 H 22
1.5 M 3 H 12
1.5 M 5 H 10

Table 3. Reinforcements and composite panels' characteristics.

Results and discussion

Physical analysis
The thicknesses, areal densities, and the fiber weight ratios of both reinforcements and composites are presented in table 3. The variation in the thicknesses of nonwoven fabrics can explain the variations in thicknesses, areal densities and thus fiber weight ratios of composites. The more consistent results are achieved for densities of the composites show that these variations are compensated with the resin uptake during production. The untreated cotton fibers’ average diameter is 15 ± 0.4 μm with a length of 3 to 45 mm. The fiber diameters of alkaline treated samples are presented in figure 3 and microscopic images of the fibers before and after treatment are presented in figure 4.

According to the results, diameters of cotton fibers increase slightly with increasing concentration of the NaOH solution and the soaking time. The swelling ratio varies between 6% (in the case of 0.5 M and 1 h) and 28% (in the case of 1.5 M and 5 h). This dimensional change is expected, as reported in literature, the cellulose fibers shrink in length and their cross-sectional area getting larger while immersing in alkaline solution. The type of modification depends on the concentration of the solution and the temperature. In fact, when exposed to alkaline solution, cotton fibers length is decreased by approximately 13% and their diameter increase by 20%. Thus, the cross-section becomes more circular (Wertz et al 2010).

Fourier-transform infrared spectroscopy (FTIR) analysis of nonwoven fabrics
As stated in table 1, cotton fibers are composed of 82%–96% cellulose, 2%–6.4% hemicellulose and 0%–5% lignin (Ansell and Mwaikambo 2009). Intramolecular and intermolecular hydrogen bonds cause the cellulose molecules in cotton fiber to take the form of microfibrils, resulting in a crystalline structure with a highly 3-dimensional bond structure. The other components alike lignin and hemicellulose are responsible for the amorphous structure of cotton fiber. It is possible to characterize cellulose and hemicellulose by a variety of spectroscopic techniques including ultraviolet visible, infrared and nuclear magnetic resonance. In this study,
one of these methods, FTIR analysis, is used to observe the presence of cellulose and hemicellulose in waste cotton fibers.

Figure 5 presents the FTIR spectra of untreated and alkali-treated cotton waste reinforcement with different concentrations with the wavenumber range from 4000 to 400 cm$^{-1}$. All spectra show similar characteristics regarding typical bands of pure cellulose. Cellulose has higher C=O and OH infrared (IR) absorbance level, while hemicellulose has higher infrared (IR) absorbance level of C=O. Each glucose unit with three hydroxyl groups and the long cellulose chain leads to high values for C–O and OH IR absorbance (Sabiha-Hanim and Aziatul-Akma 2016).

When more thoroughly analyzed the FTIR spectra it is seen that the band at 3320 cm$^{-1}$ is related to the O–H stretching vibrations in the cellulose structure (Masamichi 1957). The increment of this band in treated samples indicates an increase of OH group concentration (Yasar and Icel. 2016). The absence of a peak at 1750 cm$^{-1}$ in all treated samples is noticed, which represents C=O stretching, characteristic of the carboxyl and acetyl groups of hemicellulose (Portella et al 2016). This can be explained by the elimination of acetyl groups in hemicelluloses in alkali-treated samples (Yasar and Icel 2016). The absence of this peak in the untreated samples is probably due to the previous treatments of the fibers, in fact, cotton fibers used in this study are industrial wastes, not raw materials.

Also, a broad peak at 2900 cm$^{-1}$ is observed which is a region for C–H stretching present in cellulose and hemicellulose (Satyanarayana, Guimarães and Wypych 2007). The peak at 1625 cm$^{-1}$ is reduced in alkali treated cotton fibers in comparison to untreated fibers. This peak represents the C=O bonds on hemicellulose indicating an evidence of hemicellulose removal by the NaOH treatment (Sgriccia et al 2008). On the other hand, observing a band resulting from O–H bending from water molecules shifting to high frequency (1625 cm$^{-1}$) with increasing intensity may also support the rearrangement of hydrogen bonding (Proniewicz et al 2001). The absorption band at 1430 cm$^{-1}$ is attributed to CH$_3$ deformation (asymmetric) in lignin (Sinha and Rout 2009). The absorption bands at 1360 and 1311 cm$^{-1}$ are associated with bending vibrations of the C–H and C–O groups, respectively, of the aromatic rings in cellulose polysaccharides (Portella et al 2016). Intense peak
vibrations observed at 1030 cm$^{-1}$ are related to the (CO) and (OH) stretching vibrations of the polysaccharide in cellulose (Portella et al. 2016). The band detected at 890 cm$^{-1}$ is related to the aromatic C–H out of plane vibration in lignin. The changes in band intensities are due to the lignin degradation of the treated samples (Yasar and Icel. 2016).

Mechanical Analysis

Mechanical characterization of nonwoven fabrics

The tensile strength and Young modulus values of treated and untreated fabrics regarding concentration and soaking time are presented in figures 6 and 7, respectively.

In 0° direction, both tensile strength and Young modulus values of the samples are higher in comparison to those of 90° direction. This can be explained by the anisotropic behavior of the fabrics resulted from carding and needle punching processes that privilege the fiber orientation in 0° direction.

In both directions, the mechanical properties of all samples show an increment by the treatment of 1 M NaOH solution. However, with the ascending soaking time, the mechanical properties tend to decrease. In 0° direction, the tensile strength value of 1 M NaOH treated specimen with 1 h soaking time is 0.11 MPa which is three times higher than the tensile strength of untreated nonwoven specimens (0.037 MPa) (figure 6(a)). Similarly, the Young modulus of the same specimen is 0.74 MPa which is two times the Young modulus of the untreated nonwoven specimen (0.39 MPa) in 0° direction (figure 7(a)). However, reaching important values of NaOH and long soaking time have a reverse impact on the fibers by damaging their structure and decreasing their mechanical characteristics. For a concentration of 1.5 M with a soaking time of 5 h, the tensile strength and the Young modulus of nonwoven decrease by around 45% and 26% respectively compared to the maximum values observed for the modification parameters of 1 M and 1 h.
Mechanical characterization of composite panels

The tensile strength and Young modulus of the composite structures are presented in figures 8 and 9, respectively.

According to the test results, all samples have higher tensile strength and Young modulus values in 0° direction compared to 90° direction. The results are consistent with nonwoven fabric test results presented in figures 6 and 7.

Moreover, results show that alkaline treatment has a positive effect on the mechanical properties of composites, as expected. The maximum tensile strength is observed for 1.5 M concentration with 3 h soaking time where it reaches around 53 MPa for 0° and 30 MPa for 90° directions presented in figure 8. Since the molarity of NaOH is lower for 0.5 M samples in comparison to other two concentrations (1 M and 1.5 M), the tensile strength of the composites is not affected from the increment of the soaking time (3 h to 5 h) like 1 M and 1.5 M samples.

Young modulus values tend to increase with the increasing concentration of NaOH solution and reach maximum values of 5120 MPa for 0° and 4240 MPa for 90° directions for 1.5 M NaOH treatment with 1 h soaking time which is respectively 70% and 45% higher than those of untreated samples (3012 MPa and 2920 MPa).

Samples with 0.5 M NaOH concentration treatment also show a 10% and 43% improvement in Young’s modulus with increasing treatment time from 1 h to 3 h. The decrease in Young’s modulus value of 0.5 M sample exposed to NaOH for 3 to 5 h is not as much as that of 1 M and 1.5 M samples due to low NaOH concentration.

On the other hand, prolonged wetting of cotton fibers, especially at high solution concentration, significantly reduces Young’s modulus. For example, with a soaking time of 5 h at a concentration of 1.5 M, Young’s modulus decreases by 17% (0°) and 18% (90°) compared to the untreated sample.

Similar results are stated by Ansel et al. The alkaline treatment affects the cotton fiber’s structure by removing certain amounts of wax, lignin, and oil covering the fibers that are acting as a barrier towards the matrix and

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Figure 8. Tensile strength values for composites in (a) 0° direction (b) 90° direction.

Figure 9. Young modulus values for composites in (a) 0° direction (b) 90° direction.
increasing the surface roughness resulting in a better fiber-matrix interface. However, a further alkalization process exceeding optimum concentration and soaking time can have an opposite effect by damaging the cotton fiber and weakening its characteristic (Mwaikambo and Ansell 2002).

Morphological analysis
The morphologies of cotton fibers before and after NaOH treatment can be seen in figure 10(a) and 11(a). The SEM images illustrated in figures 10(b) and 11(b) refer to untreated and treated fiber-matrix interfaces.

Based on the visual inspections it can be seen that untreated samples show general ribbon like structure of cotton fiber twisting along its length (figure 10(a)), while the NaOH treated sample exhibits a swelling effect resulting in circular cross-section and cylindrical longitudinal section (figure 11(a)). The SEM images of treated and untreated cotton fibers support the fiber diameter measurements and the swelling ratios given in figure 3.
On the other hand, untreated cotton fibers are pulled out and hardly coated by epoxy resin which demonstrates a poor adhesion between fibers and matrix (figure 10(b)). Contrarily, the treated cotton fiber seems to be more coated with resin and the fiber is fractured proving that it is strained up to its breaking point (Hou et al 2014). Moreover, it is clear to notice that NaOH treatment improves the fiber-matrix interface by reducing the air gaps between cotton fiber and epoxy resin (figure 11(b)). The increment of surface roughness of the cotton fiber by NaOH treatment leads to stronger adhesion between fibers and epoxy resin which results in higher tensile strength and Young modulus values as given in figures 8 and 9.

**Conclusion**

In this work, the effect of alkaline treatment on the mechanical characteristics of cotton waste fibers and their epoxy composites are studied. The reclaimed fibers are firstly immersed in a NaOH aqueous solution and then transformed into nonwoven mats using carding and needle punching processes. Three different concentrations (0.5 M, 1 M and 1.5 M) and three different soaking times (1 h, 3 h, and 5 h) are used. The mechanical characterization of composite samples shows that the maximum tensile strength is observed for 1.5 M concentration with 3 h soaking time where it reaches around 53 MPa for 0° and 30 MPa for 90° directions. While the Young modulus values reach maximum of 5120 MPa and 4240 MPa for 0° and 90° directions respectively for a concentration of 1.5 M with 1 h soaking time. In addition, fiber-matrix interactions are also observed by SEM analysis and the images represent that alkaline treatment improves the interface by reducing the air gaps between cotton fibers and epoxy resin.

Although composites are produced using discarded cotton fibers which have lower mechanical characteristics compared to virgin fibers, produced panels show promising properties owing to the chemical modification that enhances the adhesion between fibers and matrix. The produced composite panels can be used in applications where lightness and good mechanical performances are requested such as automotive and building industries.

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