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Abstract

Changes occurring in jute and coir fiber composites with 2–8% concentration of a NaOH treatment for 24 h were investigated, respectively, for void content, microscopy images, mechanical properties and water absorption. The jute and coir fibers were vacuum dried before molding composite specimens. Mechanical properties indicated good adhesion between natural fibers and PP. Jute fibers, when alkali-treated with 2% concentration for 24 h, showed best improvement in tensile strength by 40% and modulus by 9%, respectively, while coir fibers, when alkali-treated with 6% concentration for 24 h, showed best improvement in tensile strengths by 62% and modulus by 17%, respectively. With 2% concentration of alkali-treatments, the elongation of jute and coir composites reached 8% and 13.5%, respectively. Moisture absorption for jute and coir composites are 50% and 60% lower than untreated fiber composites, respectively.

Keywords

Jute fiber, coir fiber, mechanical properties, NaOH treatment

1. Introduction

The advantages of natural fibers are low cost, low density, acceptable specific strength, good thermal insulation properties, reduced tool wear, reduced dermal and respiratory irritation; they provide a renewable resource and recycling is possible without effecting environmental damage. Furthermore, they are frequently biodegradable [1, 2].

However, in their natural state, these natural fibers exhibit a high hydrophilic property as they are composed of lingo-cellulose, which contains strongly polarized hydroxyl groups. Therefore, such fibers are inherently incompatible with hydrophobic polymer matrix materials and especially produce poor interfacial adhesion between the hydrophilic natural fibers and conventional resin matrix [1, 3].

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Jute consists of 71% cellulose, 13% hemi-cellulose, 11% lignin, 2.3% water soluble, 0.5% fats and waxes and 0.2% pectin [4, 5].

Coir is classified as a seed or fruit fiber because it is taken from the outer husk of coconut. Virgin coir fibers are about 40% cellulose, 40% lignin, 18% hemi-cellulose, and 2% pectin [4, 5].

Processing removes most of the pectin and hemi-cellulose, and lignin giving jute and coir a high tensile strength and making it useful in production of reinforced composites [4].

Alkali treatment is one of the processes to increase mechanical properties. The process removes chemicals from the crude fiber as lignin, hemi-cellulose and pectin to change the state of the materials from hydrophilic to hydrophobic. The large loss of hemi-cellulose makes the fibers lose their cementing capacity and they consequently separate out from each other, making them finer [5, 6].

2. Experimental

2.1. Materials

2.1.1. Polypropylene Fibers

PP fiber was supplied by Honam petrochemical Corp. Specific weight ~ 0.95 g/cm^3, diameter = 20–200 μm, melting point = 170°C and molecular weight >10 000 g/mol.

2.1.2. Natural Fibers

Jute and coir crude fibers were from the western area of Vietnam. Coir fiber density = 1.25 g/cm^3, thickness = 50–350 μm, and 200 mm in length. Jute fiber density = 1.15 g/cm^3, thickness = 10–20 μm and 200 mm in length.

2.2. Processing

2.2.1. Fiber Treatments

Jute and coir fibers were alkali treated for 24 h with 2%, 4%, 6% and 8% concentrations of NaOH, respectively. The fibers were then washed with distilled water several times to remove any traces of NaOH on the fiber, neutralized with dilute acetic acid, and again washed with distilled water. Final pH measurement was 7.

2.2.2. Preparation of Composite Specimens

PP fiber layers were stacked up with natural fiber layers alternately, such as PP-J-PP-J... or PP-C-PP-C.... Outer layers were composed of two layers of PP. The stacks were vacuum dried at 75°C for 48 h and molded in a hot press to form the mechanical test specimen for 7 min at 195°C and 3 kgf/mm^2 pressure.

2.3. Voids Contents

The void contents of composite may significantly affect some of its mechanical properties (ASTM D-2734). Higher void contents usually mean lower fatigue resistance, greater susceptibility to water penetration and weathering, and increased variation or scatter in strength properties. The void content is desirable for estimation of quality of composites:

$$V = 100(T_\mathrm{d} - M_\mathrm{d})T_\mathrm{d}, \tag{1}$$

where V = void content (vol%), T_d = theoretical composite density, and M_d = measured composite density (ASTM-D792).

2.4. Mechanical Properties

Tensile strength, tensile modulus and elongation were tested according to ASTM-D638 Type-I.

An Instron 5882 machine was used for the mechanical properties tests. For each mechanical test, a minimum of 10 specimens were tested.

2.5. Water Absorption of Composites

Specimens of $76.2 \times 25.5 \times 3.2\ \mathrm{mm}^3$ were immersed in the distilled water at room temperature (ASTM-D570). Immersed specimens were removed from the bath and wiped before weighing. Weight change measurements were made in quadruplicate using a micro-balance. Percent weight change during water sorption was determined by

$$M(\%) = (M_t - M_0)/M_0 \times 100, \tag{2}$$

where M_0 is the mass of the dried specimen and M_t is the mass of the specimen as a function of immersed time.

2.6. Fick's Law and Diffusion Coefficient

Equation (3) is normally referred to as Fick's second law:

$$J = -D\frac{\partial^2 C}{\partial x^2}, \tag{3}$$

where J is the rate of transfer per unit area of section, C is the concentration of diffusion substance, x is the space coordinate measured normal to the section, and D is the diffusion coefficient.

Its solution for a plane sheet with uniform initial distribution and equal initial surface concentrations under non-steady-state can be expressed by:

$$\frac{M_t}{M_\infty} = 1 - \sum_{n=0}^{\infty} \frac{8}{(2n+1)^2\pi^2} \exp\left[\left(-D(2n+1)^2\pi^{2t}/(w^2)\right)\right], \tag{4}$$

where t is the immersion time and M_∞ is the mass of the specimen in equilibrium with water, M_1 denotes the corresponding quantity after infinite time, and w denotes the thickness of sheet.

The solution for Fick's law at short times then reduces to the following equation for the initial stage of diffusion:

$$M_t = \frac{2M_\infty\sqrt{D}}{\sqrt{\pi}}\frac{\sqrt{t}}{l}. \tag{5}$$

Thus, the average diffusion coefficient can be calculated as follows:

$$D = \frac{\pi}{4} M_{\infty}^{-2} \ell^2 \theta^2, \tag{6}$$

where θ is the slope of M_t and $\sqrt{t}$ plot.

3. Results and Discussion

3.1. Microscopy Images

Figures 1, 2, 3 and 4 show surface morphologies of the jute and coir fibers examined by SEM before and after treatments.

Figures 1 and 3 shows the multi-cellular nature of jute and coir fibers, the smooth surface of the raw jute and coir is clearly visible. The surface featuring 24-h alkali-treated fibers is shown in Figs 2 and 4 for jute and coir composites, respectively.

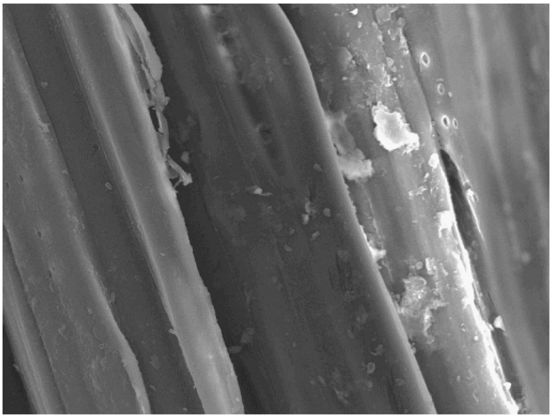

Figure 1. Jute/PP composites, untreated.

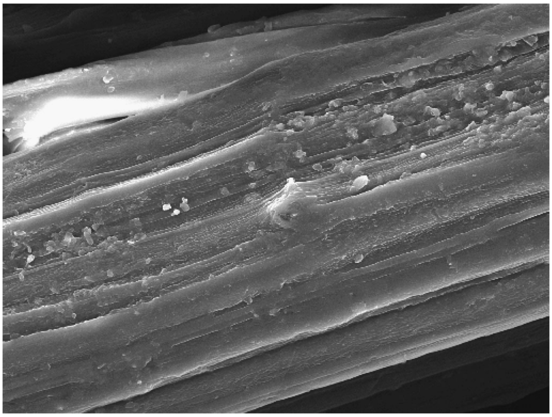

Figure 2. Jute/PP composites with 2% NaOH treated.

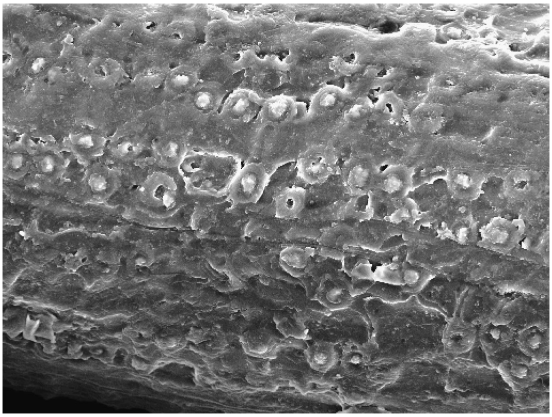

Figure 3. Coir/PP composites, untreated.

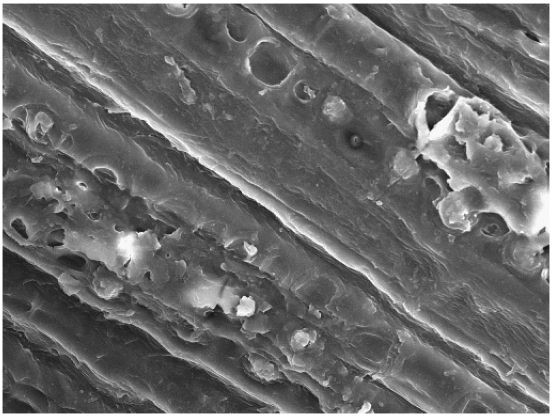

Figure 4. Coir/PP composites with 6% NaOH treated.

Here, the cementing material from the multi-cellular matrix was removed to some extent and the individual cells became more prominent.

After NaOH treatment, the hemi-cellulose and a part of the lignin were removed from the cell walls of the fiber. The hemi-cellulose has lower molecular weight than cellulose.

The reduced hemi-cellulose contents in the fibers may lead to the improvement of the composites' mechanical properties.

3.2. Void Contents

Table 1 shows void contents of jute/PP and coir/PP composites, respectively. With untreated fibers, the average void contents for jute and coir composites were 4.54% and 4.39%, respectively. After NaOH treatments, the void contents of jute composites were from 1.41–1.46% and that of coir composites were approximately 1.46–1.65%. A good composite should have less than 1% voids.

Table 1.
Void content in jute and coir/PP composites

NaOH treatment (%) of composites	Jute/PP composites (50 wt% fiber)		Coir/PP composites (50 wt% fiber)	
	Void content	Density (g/cm^3)	Void content	Density (g/cm^3)
Untreated	4.54	0.9699	4.39	1.0070
2%	1.41	1.0032	1.60	1.0398
4%	1.45	1.0028	1.65	1.0394
6%	1.44	1.0029	1.44	1.0416
8%	1.46	1.0027	1.46	1.0413

The lowest voids content with 2% NaOH treated for jute fiber and 6% NaOH treated for coir fiber may be the explanation for the highest tensile strength. In contrast, the highest voids content in crude jute and coir fibers will show the lowest mechanical properties.

3.3. Mechanical Properties

3.3.1. Tensile Strengths

Figures 5 and 6 shows the tensile strengths of jute/PP and coir/PP composites with 50 wt% fibers, respectively.

The average tensile strength of untreated jute composites is 71 MPa, while average tensile strength of 2% NaOH treated is 100 MPa. This indicates an improvement of about 40% compared with untreated jute fiber.

For coir/PP composites, the average tensile strength is 22 MPa with 6% NaOH treatment, and that of untreated is 13 MPa. So, after the NaOH treatment, the tensile strength was increased by about 62%.

Tensile strength of jute composites was decreased in 4, 6 and 8% NaOH treated compared with 2% NaOH treated since the higher concentration of NaOH treatments provided stiffer and more brittle composites in accordance with the increase in the crystallinity of the fibers [4, 14].

Coir composites have the highest tensile strength with 6% NaOH treatment compared with 2, 4 and 8% NaOH treatment. This indicates that the hemi-cellulose and lignin content in coir was higher than that of jute fiber, and with 8% NaOH treated coir fiber become more brittle; so tensile strength and other properties, such as modulus (Fig. 8) and elongation at break (Fig. 10), will be decreased.

The increases in tensile strength due to the NaOH treatment are shown in Figs 5 and 6, respectively. Treated fibers may have improved the compatibility with the matrix.

3.3.2. Tensile Modulus

Figures 7 and 8 show the tensile modulus of jute/PP and coir/PP composites, respectively.

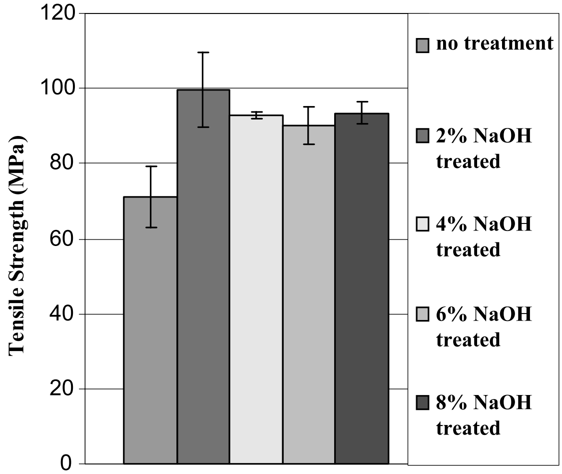

Figure 5. Tensile strength of jute/PP composites.

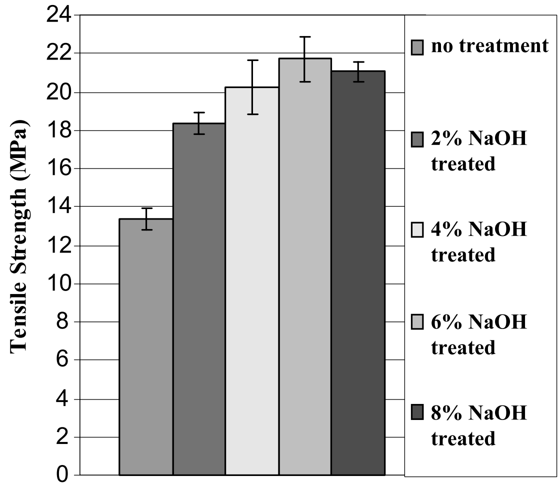

Figure 6. Tensile strength of coir/PP composites.

The average tensile modulus of untreated jute composites is 4.2 GPa, while the average tensile modulus of 2% NaOH treated is 4.7 GPa — an improvement of about 8% compared with untreated jute fiber.

For coir/PP composites, the average tensile modulus is 0.55 GPa with 2% NaOH treatment, and untreated they have a value of 0.47 GPa. After the NaOH treatment, the tensile modulus was therefore increased by about 14%.

3.3.3. Elongations

Figures 9 and 10 show the elongation of jute/PP and coir/PP composites, respectively. For jute/PP composites, the average elongations at break of 2% NaOH treated and untreated are approximately 8% and 6%, respectively.

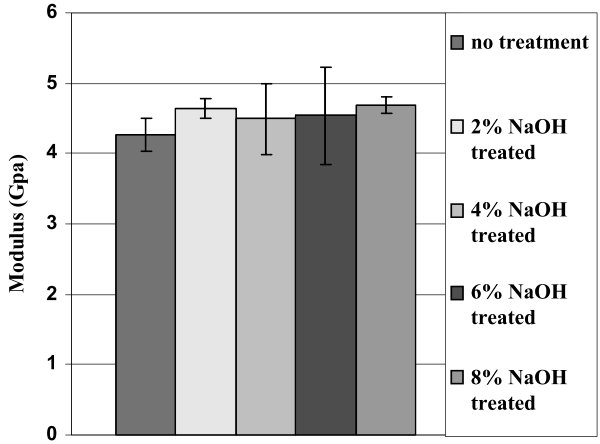

Figure 7. Tensile modulus of jute/PP composites.

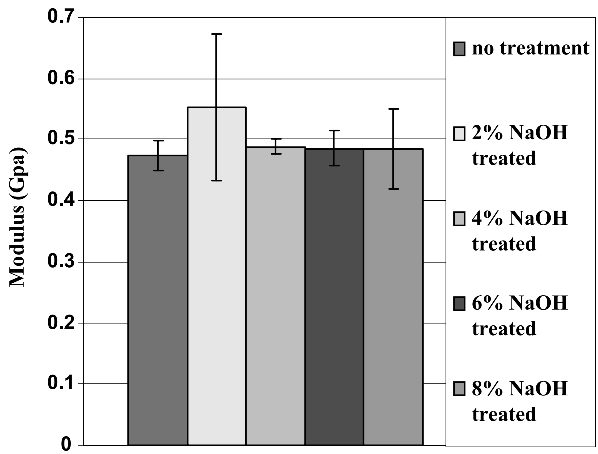

Figure 8. Tensile modulus of coir/PP composites.

For coir/PP composites, the average elongations at break of 6% NaOH treated and untreated are 14% and 5%, respectively.

The mechanical property improvements for jute/PP and coir/PP composites may be due to the enhancement in the compatibility between the fibers and PP.

3.4. Water Absorptions

The water absorption of jute/PP and coir/PP composites, respectively, for samples equilibrated in water as a function of the immersion time is shown in Figs 11 and 12. The value of the slope of water absorption (θ) and diffusion coefficient (D) is shown in Table 2. The weight gain is lower for 6% and 8% NaOH treated fiber composite than for the 2% and 4% NaOH treated jute fiber composites. For coir/PP composites, the weight gain is lowest with 8% NaOH treated, after that are 6%, 4% and

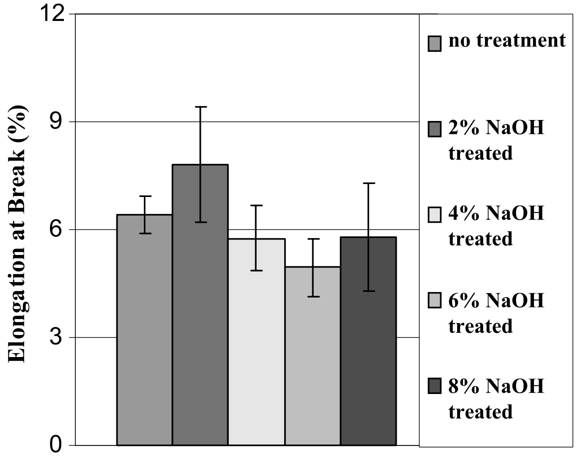

Figure 9. Elongation at break of jute/PP composites.

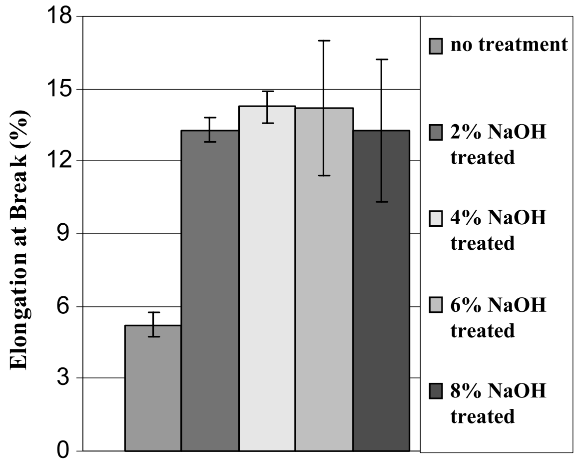

Figure 10. Elongation at break of coir/PP composites.

2% NaOH treated, respectively. The computed diffusion coefficients, reported in Table 2, were highest for the untreated jute and coir fibers composites and lowest for 8% NaOH treated.

For 6% and 8% NaOH treated jute/PP composites, the maximum water absorption is about 5% for 36 h immersion at room temperature. For untreated fibers, the water absorption is 10%.

For 6% and 8% NaOH treated coir/PP composites, the water absorption values are 5 and 3.8%, respectively. For untreated fibers, the water absorption is 12.4%.

Flame retardant properties of natural fiber/PP composites could be reduced down by almost 50% with addition of magnesium hydroxide to PP [16].

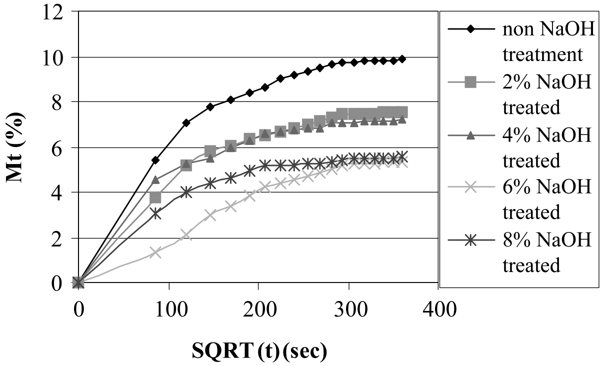

Figure 11. Water absorption on jute/PP composites.

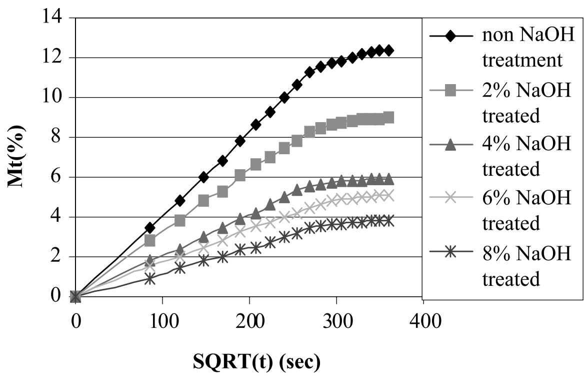

Figure 12. Water absorption on coir/PP composites.

Table 2.
Values of slope of water absorption curve (θ) and diffusion coefficient (D) for jute and coir/PP composites with 50 wt% fiber content

NaOH treatments (%)	Jute composites		Coir composites	
	θ (%/s$^{0.5}$)	D (cm^2/s × 10^5)	θ (%/s$^{0.5}$)	D (cm^2/s × 10^5)
No NaOH treatment	0.0545	7.55 ± 0.05	0.0421	4.51 ± 0.01
2% NaOH treated	0.0408	4.23 ± 0.04	0.0305	2.36 ± 0.06
4% NaOH treated	0.0390	3.87 ± 0.01	0.0207	1.09 ± 0.01
6% NaOH treated	0.0305	2.36 ± 0.06	0.0165	0.69 ± 0.02
8% NaOH treated	0.0308	2.41 ± 0.03	0.0127	0.41 ± 0.002

4. Conclusions

(a) The lowest void contents and highest tensile strengths for jute and coir composites were obtained from 2% and 6% NaOH treatments, respectively.

(b) The visual inspection and mechanical test results indicate that the jute and coir were quite evenly adhesive within the PP matrix. This may be due to the enhancement of compatibility of the fibers within a matrix.

(c) For 50 wt% jute fiber-containing composites, the tensile strength was 100.0 MPa with 2% NaOH treatment and 71.0 MPa with untreated composite. The tensile modulus was 4.7 GPa for 2% NaOH treated and that of untreated composite was 4.2 GPa. Elongation at break after 2% NaOH treatment and for untreated composite was 8.0% and 6%, respectively.

(d) For 50 wt% coir-containing composites, the tensile strength was 22.0 MPa with 6% NaOH treatment and untreated was 13 MPa. The tensile modulus was 0.55 GPa with 6% NaOH treatment and untreated was 0.47 GPa. Elongation at break of 6% NaOH treatment and untreated was 14% and 5%, respectively.

(e) For 36 h water absorption of jute/PP composites for 6% and 8% NaOH treatments was 5%, and that of coir/PP composites was 3.8% with 8% NaOH treatment.

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