Recycling of Jute Textile in Phenol Formaldehyde–Jute Composites

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ABSTRACT: Jute textile was recycled into composites using different percents of phenol formaldehyde (PF) resin. The effect of the resin percent, from 12 to 30%, on the flexural strength, tensile strength, water absorption, and thickness swelling of the produced composites was studied. To improve the dimensional stability of the produced composites, jute textile was acetylated or steamed. The effect of steaming and acetylation on the structure and thermal stability of jute fibers was studied using Fourier Transform Infrared (FTIR) spectroscopy and Thermogravimetric analysis (TGA), respectively. The effect of these treatments on the flexural strength, tensile strength, water absorption, and thickness swelling of the produced composites was studied. Steaming of jute textile was superior to acetylation in improving the dimensional stability. Cyclic wetting and drying test of the composites showed that steaming of the jute textile resulted in much less irreversible and reversible thickness swelling than in case of using acetylated or untreated jute textile. © 2003 Wiley Periodicals, Inc. J Appl Polym Sci 90: 3588–3593, 2003

Key words: composites; recycling; jute; dimensional stability

INTRODUCTION

Jute is an annual plant in the genus *Corchorus*. Jute has a pithy core, known as jute stick, and the bast fibers grow lengthwise around this core. Jute bast fiber is separated from the pith in a process known as retting. Retting is carried out by placing cut jute stalks in ponds for several weeks. Microbial action in the pond softens the jute fiber and weakens the bonds between the individual fibers and the pith. The fiber strands are then manually stripped from the jute stick and hung on racks to dry. Very long fiber strands can be obtained this way. If treated with various oils or conditioners to increase flexibility, the retted jute fiber strands are suitable for manufacturing into textiles. Most composites made using jute exploit the long fiber strand length.[1] Jute textiles are used as overlays over other composites, as underlay for carpet, and for making bags that are used in packaging of vegetables, flours, etc. Also, jute stick wastes have been used for making different kind of composites using different polymer matrices. For example, jute sticks were used for making particleboard using urea–formaldehyde resin as a binder[2] or unsaturated polyester resin.[3] On the other hand, jute fibers were also studied extensively for making composites due to their high strength properties. For examples, nonwoven jute fibers were impregnated with phenol formaldehyde resin and pressed into composites.[4] Jute fibers were treated with methyl methacrylate and cured using UV radiation to make composites.[5] Nonwoven jute fibers were chemically modified to improve the dimensional stability of the produced composites by cyanoethylation then jute–polyester composites with improved dimensional stability were made from the modified fibers.[6] Short jute fibers were used for making polypropylene composites.[7] Three-ply composite laminates were prepared from glass fibers and jute fibers as reinforcing agents and amine-cured epoxy resin as the matrix material.[8] Jute slivers were acetylated and jute boards were pressed under heat and pressure using acetylated jute sliver and urea formaldehyde resin.[9] Jute fibers– urethane polymer composites were also prepared.[10]

The aim of this work is to recycle jute textile into composites using PF resin and to study the mechanical properties and dimensional stability of the produced composites.

EXPERIMENTAL

Jute textile and PF resin

Jute textile having five warps by five wefts per cm^2 was cut into 20 by 10-cm pieces; PF resin used was generously supplied from Al-Mansoura Company for Resins and Particleboard in form of 50% aqueous solution.

PF–jute textile composites

Jute textile was sprayed with different level of PF resin, and 12 sheets were overlaid and pressed under

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TABLE I
Effect of Phenol Formaldehyde Resin Content on the Properties of PF–Jute Composites

% PF	MOR (MPa)	MOE (GPa)	Tensile strength (MPa)	Water absorption (for 24 hrs) (%)	Thickness swelling (for 24 hrs) (%)
12	51.3 (3.81)	5.55 (0.185)	33.07 (2.73)	54.9	34.5
20	56.89 (4.72)	4.59 (0.136)	27.56 (1.88)	45.9	23.1
30	57.27 (4.63)	4.77 (0.159)	27.21 (1.79)	23.7	12.2

Values in parentheses are the standard deviation.

a pressure of 2 MPa at 170°C for 8 min. The thickness of the produced composites was about 3 mm.

Acetylation of jute textile

Jute textile was aceylated as follows:[11] oven-dried jute textile was immersed in acetic anhydride for 15 min, removed, and put in a covered vessel inside an oven preheated at 120°C for 2 h. The acetylated textile was washed thoroughly with water and oven-dried at 100°C for about 4 h. The degree of acetylation is reported as weight percent gain (WPG) from the jute textile oven-dry weight before and after acetylation. WPG of 7.6% was obtained.

Steaming of jute textile

Jute textile was treated with tap water at 170°C for 5 min in a rotating autoclave; the heat-up time was about 60 min. The textile was then washed with water and oven-dried at 100°C for 4 h.

Fourier transform infrared analysis

Infrared spectra of untreated, acetylated, and steamed jute were obtained by using a JASCO FTIR 800 E spectrometer. The samples were measured using the KBr disc technique.

Thermogravimetric analysis

A Perkin-Elmer thermogravimetric analyzer was used to study the thermal properties of the untreated, acetylated, and steamed jute. The heating rate was set at 10°C/min over a temperature range of 50–700°C. Measurements were carried out in a nitrogen atmosphere, with a rate of flow of 50 cm^3/min.

Testing of PF–jute textile composites

Static bending [modulus of rupture (MOR) and modulus of elasticity (MOE)], tensile strength parallel to surface, and water absorption and thickness swelling tests of the produced composites were determined according to ASTM D1037-94.[12] Five specimens of each sample were tested and the results averaged.

Cyclic thickness swelling test of PF–jute textile composites[13]

PF–jute textile composites made using untreated, acetylated, and steamed jute textile were soaked in water at roam temperature. Changes in their thickness were measured after 24 hs. The percentage increase in thickness (reversible thickness swelling) was calculated based on the original oven-dry thickness. The samples were then reoven-dried and the thickness swelling (irreversible thickness swelling) was redetermined. The samples were then reimmersed in fresh water and the thickness swelling was measured. This cycle was repeated five times, and five replicates of each sample were run and the results averaged.

RESULTS AND DISSCUSION

Effect of resin content on the properties of PF– jute textile composites

Table I shows the effect of PF resin content on the properties of PF–jute composites. The attempts to use lower resin contents were failed due to the loose mat structure of the jute textile used. Increasing the resin content resulted in an increase on MOR, a decrease in tensile strength, water absorption, and thickness swelling. A slight decrease in MOE was noticed on increasing the resin. The minimum requirements for the standard hardboard according to the ANSI standards are: 31 MPa for MOR, 15 MPa for tensile strength parallel to surface, <35% for water absorption, and <25% for thickness swelling. As seen in Table I, these requirements are easily fulfilled except for the high water absorption and thickness swelling at 12 and 20% resin content. Only at 30% resin content water absorption and thickness swelling are within the limit. Using of this high resin content is not economic. It is interesting to note that the pattern of fracture during the bending and tensile tests is not abrupt failure but stepwise, as shown in Figure 1, i.e., safe mode of failure. This pattern is due to the mat structure of the jute textile used.

Acetylation and steaming of jute textile

As seen from the above results, the water absorption and thickness swelling of PF–jute textile composites

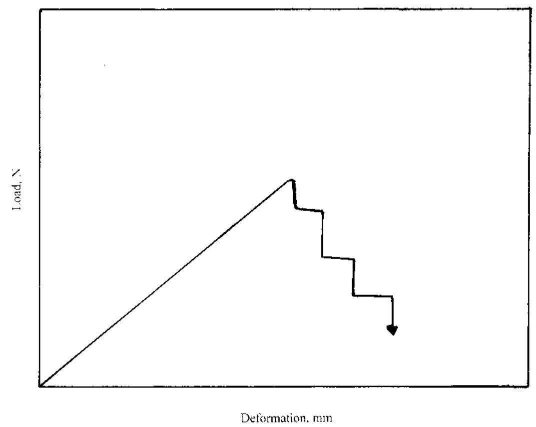

Figure 1 Schematic of the load vs. deformation curve displaying the failure mode observed for the different jute–phenol formaldehyde composites in bending and tensile tests.

were much higher than that required for the ANSI requirement of standard hardboard at the lower and commercially used resin content. Consequently, treatment of jute textile by acetylation or steaming before composites making was carried out to improve the aforementioned properties. Steaming and acetylation are known to improve the dimensional stability of lignocellulosics-based composites.[14,15] Attempts to acetylate the jute textile resulted in relatively low weight percent gain due to acetylation (WPG 7.6). Previous work on acetylation of jute slivers using a similar acetylation method[9] showed a higher WPG of 11.37. The relatively low WPG of the acetylated jute textile may be due to its woven structure.

FTIR of acetylated and steamed jute textile

Figure 2 shows the FTIR spectra of untreated, acetylated, and steamed jute textiles. Table II shows the absorption intensities of some characteristic bands; the absorption intensities were calculated as the ratio of the peak height of these bands to the peak height of the aromatic ring stretching band at 1514 cm^{-1} (internal standard band). As shown in the table, significant increase in the intensities of the C═O stretching vibration band at 1735 cm^{-1}, the CH_3 bending vibration band at 1375 cm^{-1}, and C—O stretching vibration band due to ester groups at 1240 cm^{-1} occurred in case of acetylation as a result of the introduction of O—CO—CH_3 groups into jute constituents. On the other hand, a slight decrease in the intensity of the C═O band at 1735 cm^{-1} and C—O band at 1240 cm^{-1} occurred as a result of steaming. The decrease in the intensities of these bands may be due to partial loss and hydrolysis of hemicelluloses during steaming. A previous study on steaming of wood showed decrease in the amounts of xylan, mannan, and galactan (the sugars that constitute hemicelluloses) in the wood without any apparent change in the cellulose or lignin content.[16]

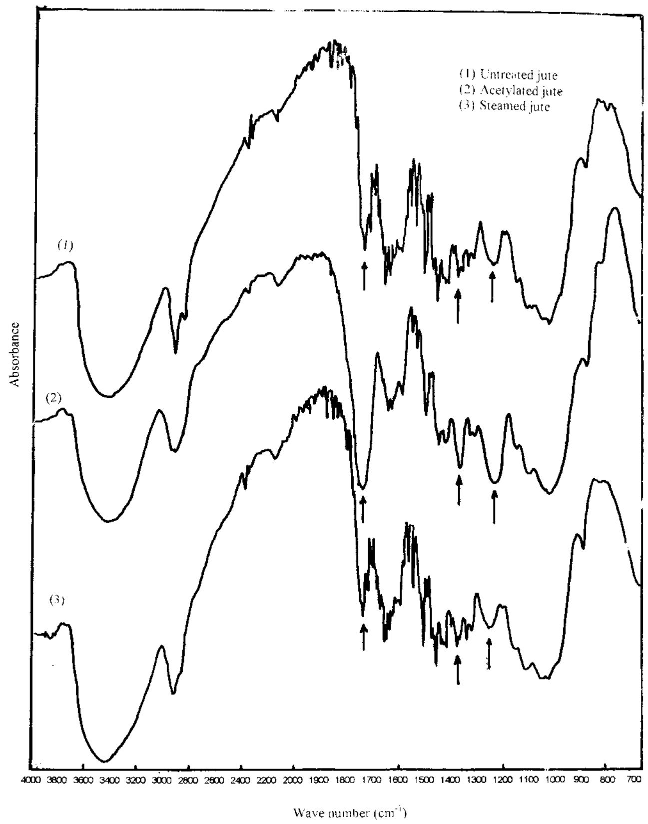

Figure 2 FTIR spectra of untreated, acetylated, and steamed jute textiles.

Thermogravimetric analysis of acetylated and steamed jute textile

Thermogravimetric analysis is a useful tool for natural polymers that are subjected to heat during their processing into final products. Figure 3 shows the thermogravimetric curves of untreated, acetylated, and steamed jute textiles. Untreated jute showed two main

TABLE II
Band Intensities of Some FTIR Bands of Untreated, Acetylated, and Steamed Jute Textiles

Band	Band Intensity[a] Untreated jute	Acetylated jute	Steamed jute
C═O band at 1735 cm^{-1}	1.16	2.67	1.09
CH_3 band at 1375 cm^{-1}	0.31	0.8	0.31
C—O of ester group band at 1250 cm^{-1}	0.42	1.0	0.28

[a] Band intensities were calculated as the ratio of the peak height of these bands to the peak height of the aromatic ring-stretching vibration band at 1514 cm^{-1}.

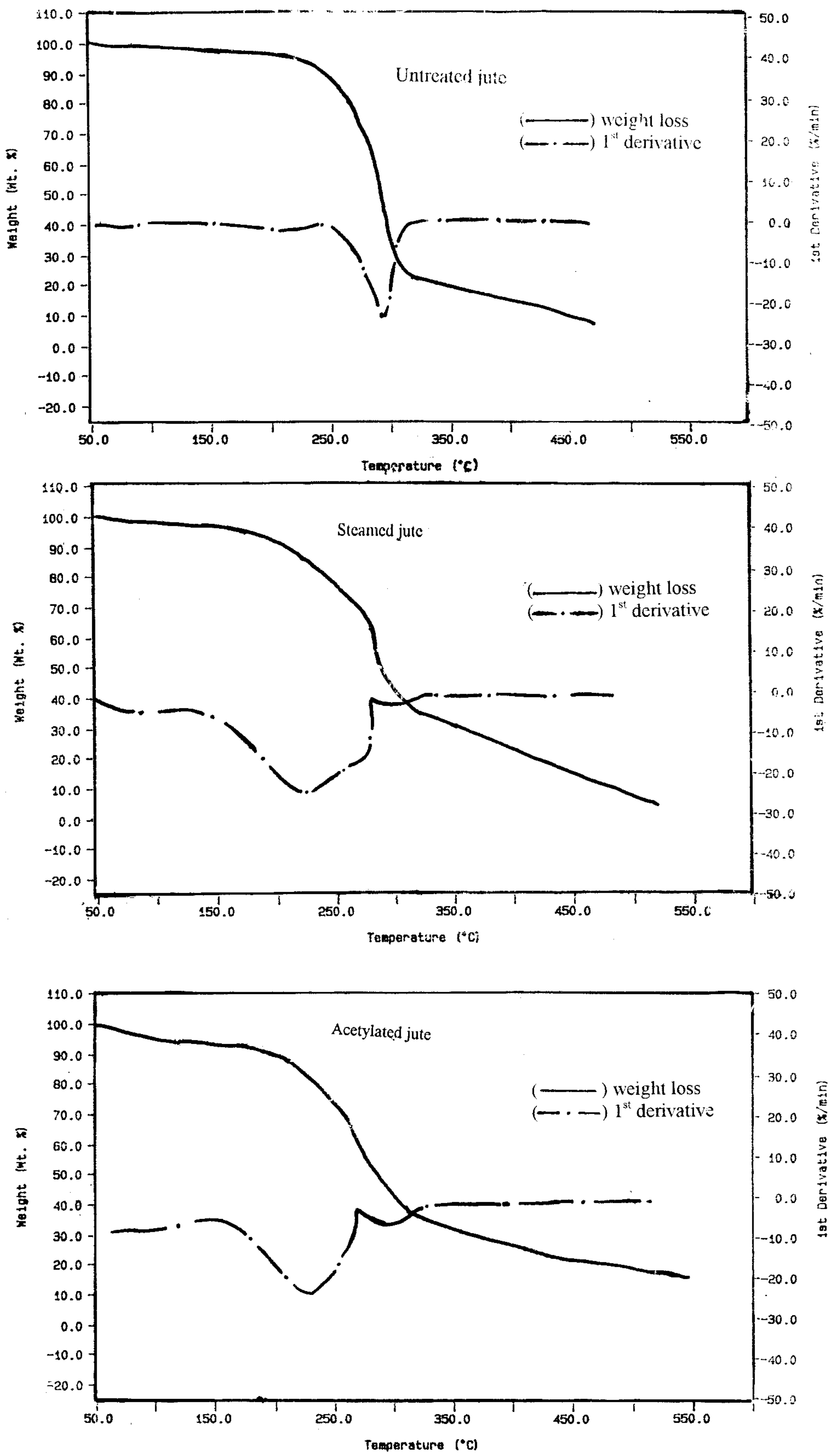

Figure 3 Thermogravimetric analysis curves of untreated, acetylated, and steamed jute.

TABLE III
Effect of Steaming and Acetylation on the Properties of Jute-Phenol Formaldehyde Composites Containing 12% Phenol Formaldehyde Resin

Treatment	MOR (MPa)	MOE (GPa)	Tensile strength (MPa)	Water absorption (for 24 h) (%)	Thickness swelling (for 24 h) (%)
Non	51.3 (3.81)	5.55 (0.185)	33.07 (2.73)	54.9	34.5
Steaming	45.78 (3.64)	3.34 (0.148)	24.07 (1.60)	29.4	11.73
Acetylation (WPG 7.6)	38.07 (3.29)	3.54 (0.108)	19.68 (1.94)	22.7	13.8

Values in parentheses are the standard deviation.

weight loss stages due to degradation of jute constituents in addition to the initial weight loss due to moisture evaporation up to about 110°C. The first degradation stage, which is due to generation of noncombustible gases such as CO_2, formic, and acetic acids,[17] started at about 200°C, which is significantly higher than the pressing temperature (190°C) used for making the PF–jute textile composites. The maximum weight loss of this stage was at 295°C, as seen from the first derivative of the TG curve. The second degradation stage, which is due to pyrolysis and generation of combustible gases,[17] started at about 330°C. On the other hand, both steamed and acetylated jute showed much lower first degradation stage onset temperature. The onset degradation temperatures of the first stage were about 178 and 163°C for acetylated and steamed jute, respectively. These temperatures are remarkably lower than the pressing temperature used for making composites. The second degradation step for both acetylated and steamed jute started at about 334°C. It is noted that the first degradation stage for both acetylated and steamed jute was split into two substages. The maximum weight loss temperatures of these two substages were at 229 and 294°C for acetylated jute, and 227 and 299°C for steamed jute.

Effect of acetylation and steaming on the properties of PF–jute textile composites

Table III shows the effect of acetylation and steaming of jute textile on the properties of PF–jute textile composites using 12% resin content. Both steaming and acetylation treatments significantly reduced water absorption and thickness swelling to values that meets the ANSI requirements of standard hardboard but acetylation greatly impaired the MOR and tensile strength of the composites to values lower than steaming treatment did. However, in both treatments, MOR and tensile strength were higher than ANSI requirements. Acetylation of jute resulted in lower water absorption of the produced composites than steaming, but the thickness swelling of the PF–acetylated jute composite was higher than that of PF–steamed jute composites. The decrease of water absorption and thickness swelling due to acetylation may be due to replacement of the hydroxyl groups by the acetyl groups. The decrease in the mechanical properties may be due to degradation of the fibers by the acetic acid byproduct during acetylation and degradation of jute during pressing as seen from the TGA of acetylated jute as well as the decrease in hydrogen bonding between jute fibers due to acetylation. Although the decrease in water absorption and thickness swelling in case of steaming may be due to partial hydrolysis and loss of hemicelluloses, which play a major role in water absorption, partial hydrolysis and loss of hemicelluloses increases the compressibility of jute fibers and, in turn, significantly reduced the buildup of internal stresses in the composites during pressing.[18] Also, the decrease in mechanical properties as a result of steaming may be due to degradation of jute during pressing, as seen from the TGA of steamed jute.

Cyclic thickness swelling of PF–jute textile composites

Dimensional stability in water, especially in the thickness direction, is an important requirement in composites made from high percentage of lignocellulosic fibers. The composites undergo normal (reversible) swelling and irreversible swelling caused by the release of residual compressive stresses imparted to the product during pressing. Figure 4 shows the thickness changes in the repeated water-soaking test. As shown, the composite

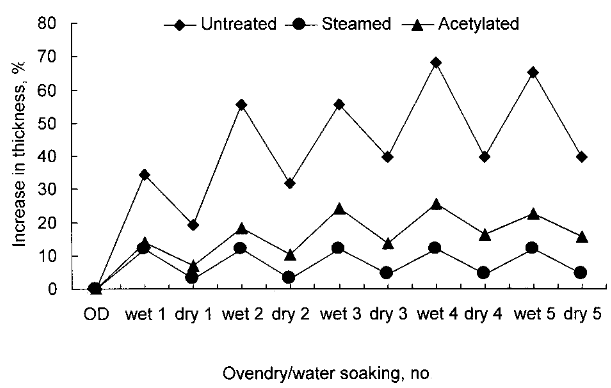

Figure 4 Effect of steaming and acetylation of jute textile on irreversible and reversible thickness swelling of PF–jute textile composites.

made from untreated jute textile had more reversible and irreversible thickness swelling than that of the composites made from acetylated and steamed jute textiles. The PF—untreated jute composite swelled irreversibly a total of about 40% in thickness during the five wetting cycles compared to about 10 and 4% for the PF–acetylated and–steamed jute composites, respectively. As mentioned above, partial hydrolysis and loss of hemicelluloses increases the compressibility of jute fibers and, in turn, significantly reduced the build up of internal stresses in the composites during pressing.

CONCLUSION

Jute textile could be recycled into PF–jute textile composites that had significantly higher MOR and tensile strength than the ANSI requirements for standard hardboard, but the jute textile should be treated to improve the high water absorption and thickness swelling. Steaming of jute textile was superior to acetylation in improving the dimensional stability of the composites with less impaired MOR and tensile strength. Due to the lower thermal stability of the steamed and acetylated jute than untreated jute, it is recommended to use a resin having curing temperature <160°C, for example, urea formaldehyde, if high mechanical properties along with high dimensional stability are required.

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