

# Effect of Maleic Anhydride Grafted Polypropylene on the Mechanical and Morphological Properties of Chemically Modified Short-Pineapple-Leaf-Fiber-Reinforced Polypropylene Composites

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**ABSTRACT:** With the rising cost of petroleum-based fibers, the utilization of plant fibers in the manufacture of polymer–matrix composites is gaining importance worldwide. The scope of this study was to examine the perspective of the use of pineapple leaf fibers (PALFs) as reinforcements for polypropylene (PP). These fibers are environmentally friendly, low-cost byproducts of pineapple cultivation and are readily available in the northeastern region of India. Here, both untreated and treated pineapple fibers were used. Maleic anhydride grafted polypropylene (MA-g-PP) was used as a compatibilizing agent. The polymer matrix of PP was used to prepare composite specimens with different volume fractions (5–20%) of fibers by the addition of 5% of MA-g-PP. These specimens were tested for their mechanical properties, and additional

assessments were made via observations by scanning electron microscopy, thermogravimetric analysis, and IR spectroscopy. Increase in the impact behavior, flexural properties, and tensile moduli of the composites were noticed, and these were more appreciable in the treated fibers mixed with MA-g-PP. PALF in 10 vol % in PP mixed with MA-g-PP was the optimum and recommended composition, where the flexural properties were the maximum. The impact strength and the tensile modulus were also considerably high. © 2007 Wiley Periodicals, Inc. *J Appl Polym Sci* 107: 1507–1516, 2008

**Key words:** compatibility; composites; esterification; morphology; poly(propylene) (PP)

## INTRODUCTION

Some of the world's most important agricultural fibers are classified as bast fibers, including jute, flax, kenaf, sunnhemp, and hemp. However, leaf fibers from banana and pineapple are of particular importance in some regions. Certain cultivars of pineapple (*Ananas comosus* L.) are also grown especially for fiber production; the fruits are removed to produce optimum yields. The leaves generate a strong, white, silky fiber, which is used to produce the sheer fabric. In India, Manipur has a good production of pineapple. The fibers are taken out of the mature leaves. About 1 m in height, the short, stocky pineapple plant belongs to the family Bromelia. Although most Bromeliads grow on trees, the pineapple is a ground fruit.

Natural fibers are lignocellulosic materials in which cellulose microfibrils are embedded in an amorphous matrix of lignin and hemicellulose. The mechanical

properties of these fibers are dependent on the cellulose content in the fiber, the degree of polymerization of the cellulose, and the microfibrillar angle. Fibers with high cellulose content, a higher degree of polymerization, and a lower microfibrillar angle exhibit a higher tensile strength and modulus.<sup>1</sup>

Pineapple leaf fibers (PALFs) were selected as reinforcement materials for polypropylene (PP) for the following reasons. First, because of their very high cellulose content of 70–82% and high degree of crystallinity, PALF has a very good tensile strength (400–1600 MPa).<sup>2</sup> Second, because pineapple can be cultivated throughout northeastern India, it is available in abundance. Third, natural fibers from hemp, banana, henequen, jute, and so on have already been reported by various authors. Studies of PALF as a reinforcement to low-density polyethylene (LDPE), phenol formaldehyde, and PP have also been reported. However, little work has focused on the effects on the mechanical properties of chemically modified PALF reinforced PP composites with maleic anhydride grafted polypropylene (MA-g-PP) as the compatibilizer, which was examined in this study. The mechanical properties of PALF-reinforced PP composites were investigated by Sapuan et al.<sup>3</sup>

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TABLE I  
Physical, Chemical, and Mechanical Properties of PALF

Natural fiber	Diameter ( $\mu\text{m}$ )	Density ( $\text{kg}/\text{m}^3$ )	Cell length/diameter ratio	Volume resistivity at 100 V ( $\Omega \text{ cm}$ ) $\times 10^5$ at 65% relative humidity	Cellulose (%)	Lignin (%)	Microfibriller angle ( $^\circ$ )	Initial modulus (GPa)	Ultimate tensile strength (MPa)	Elongation
Pineapple leaf	20–80	1440	450	0.71–0.84	81	12	8–14	34.5–82.5	413–1627	0.8–1

They prepared composite laminates by sandwiching one layer of fiber between two layers of PP film and reported an increase in the value of the tensile and flexural properties. The influence of short pineapple fiber on the viscoelastic properties of LDPE was studied by George et al.<sup>4</sup> They found an increase in the value of the storage modulus in longitudinally oriented fiber composites. Mangal et al.<sup>5</sup> studied the thermal properties of PALF-reinforced phenol formaldehyde composites and reported a decrease in the values of thermal conductivity and thermal diffusivity with increase in fiber content. Thomas et al.<sup>6</sup> reported the effect of the water environment on the sorption characteristics and mechanical properties of LDPE composites reinforced with PALF by immersion in distilled water. All of the treated composites showed lower water uptakes than the unmodified composites. Table I shows the typical properties of PALF.<sup>1</sup>

The main drawback of natural fiber–thermoplastic composite systems is the poor bonding between the natural fiber and the plastic due to their dissimilar chemical nature. All natural fibers are hydrophilic in nature, which lowers their compatibility with the hydrophobic PP matrix. During processing of composites with thermoplastic matrices, their moisture contents can lead to poor processability and porous products. Moreover, the tendency to form aggregates during processing because of the poor dispersion of the fiber in the matrix and the low resistance to moisture greatly reduces the potential of natural fiber to be used as reinforcements for polymers.

The mechanical properties of natural fiber composites depend on the level of adhesion between the fiber and the matrix material. The fiber–matrix interface has to be sufficiently strong for the composite to obtain reinforcement from the fibers. Hence, to achieve good mechanical properties, the fiber–matrix compatibility must be optimized by certain techniques.

In this study, new natural fiber–polymer composites were fabricated by surface treatments on the fiber. Dewaxing was followed by alkali treatment, which was stated to improve the binding capability of the fiber with the PP matrix in the presence of the compatibilizer. MA-g-PP was prepared for

potential compatibility between the fiber surfaces and the polymer, which was caused by the esterification of the anhydride groups of MA-g-PP with the hydroxyl groups of the natural fiber.<sup>7</sup> The mechanical properties of the composites prepared from treated fibers were compared to those from untreated fibers, and morphological observations were made by scanning electron microscopy (SEM). Thermogravimetric analysis (TGA) was performed to check the thermal stability of the fibers and composites.

## EXPERIMENTAL

### Materials

The pineapple fibers were obtained from the Mushroom Growers Welfare Society (Agartala, Tripura, India). PP (injection grade, Repol, H110MA) was obtained from Reliance Industries, Ltd. (Jamnagar, Gujarat, India). Ethanol, benzene, sodium hydroxide, methanol, hydrochloric acid, and isopropyl alcohol were obtained from Merck (India), Ltd. (Mumbai, India). Xylene was obtained from Central Drug House (P), Ltd. (New Delhi, India). Maleic anhydride (MA) and benzoyl peroxide were obtained from G.S. Chemical Testing Lab and Allied Industries (Mumbai, India).

### Surface modifications

Various methods have been adopted by different researchers to modify the surface of fibers. Dewaxing followed by alkali treatment was reported by Mohanty et al.<sup>7</sup> The pineapple fibers were dewaxed with a 1 : 1 mixture of ethanol and benzene at 60°C for 36 h in a hot-air oven and were then washed with distilled water and dried at 60°C in a hot-air oven for 24 h.<sup>6</sup> The fibers thus obtained were known as defatted fibers. The defatted fibers were then treated with 2N NaOH for a period of 60 h at a temperature of 23°C in a climatic chamber. This was followed by washing with cold distilled water and then with acidified water (diluted HCl acid) until the fibers showed no alkalinity reaction and again with

distilled water. Then, the fibers were dried again in a hot-air oven at 60°C for 24 h.<sup>6</sup>

### Resin modification

PP was grafted to MA by a grafting process. The process adopted here was reported by John et al.<sup>8</sup> For this, 50 g of PP was dissolved in 500 mL of xylene at 100°C. When PP was completely dissolved, 4 g of MA was added by dissolution into isopropyl alcohol at a minimum quantity and 0.4 g of benzoyl peroxide in the previous solution with continued stirring. The solution was then heated to 100°C for 7 h. The grafted PP was then precipitated in methanol. The product thus obtained was known as MA-g-PP. It was a whitish powderlike material. This MA-g-PP was used as the compatibilizing agent in the blending of the fiber and the resin.

### Chopping of pineapple fibers

The fibers, after being separated into strands, were chopped into lengths of 4 mm with scissors. Fiber diameters taken in this study were in the range 25–60  $\mu$ , as measured by a Dial thickness gauge.

### SEM

The surface topographies of the raw and chemically modified fibers, unmodified PP, and MA-g-PP were scanned with the aid of a variable-pressure digital scanning electron microscope (model LEO 1430VP) (Cambridge, UK). The substances were mounted on special stubs and given a coating of gold by the sputter coater, which rendered them conductive to be studied under the scanning electron microscope. Coatings were applied at a thickness of about 20 nm, which was too thin to interfere with the dimensions of the surface features.

### Spectral and thermal analysis

PALF fibers were pulverized and compressed in KBr to form pellets. Again, virgin PP pellets and MA-g-PP were separately pulverized and compressed to form pellets. The Fourier transform infrared (FTIR) spectra of those fiber samples prepared from raw and alkali-treated PALF and those from PP and MA-g-PP were recorded in a PerkinElmer FTIR spectrometer (Shelton, CT). TGA was carried out with a Mettler Toledo TGA instrument (Schwerzenbach, Switzerland) for the raw and the alkali-treated fibers and for virgin PP and the composites with 10% loading of treated and untreated fibers to compare the thermal stabilities.

### Biocomposite fabrication

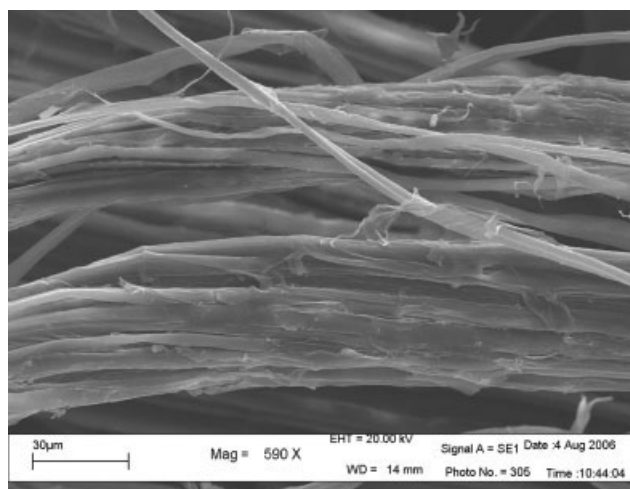
The required amount of PALF and PP to be mixed for each volume fraction of the fibers were calculated

before composite fabrication. For this, the density of the PALF was first determined according to ASTM D 729. Then, the fiber and the polymer for different volume fractions, namely, 5, 10, 15, and 20%, were weighed out with an allowance for flash in the sheet mold of the compression-molding press.

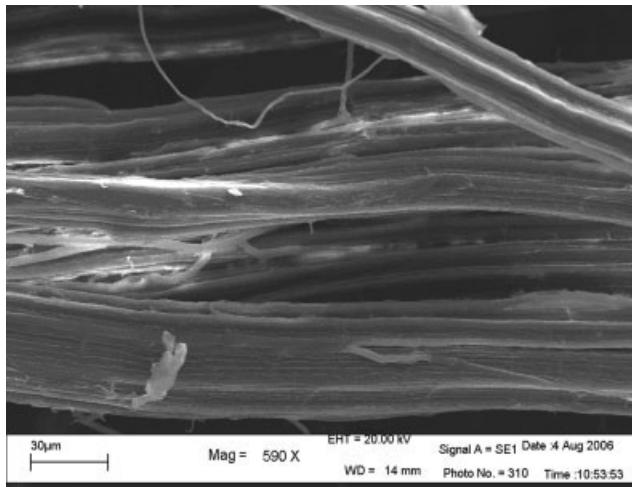
The melt mixing of the chopped PALF and PP were carried out in a two-roll open mill heated with rows of cartridge heaters. The temperature of the front and the back rollers were maintained at 140 and 160°C, respectively. For the untreated fibers, no compatibilizing agent was used, whereas MA-g-PP was incorporated at a 5% level into PP for the treated fibers. After the uniform mixing of the fibers and the polymer matrix, we scraped out the resultant fiber–polymer matrix mix from the roller without allowing it to harden and immediately pressed it into a 115  $\times$  115  $\times$  3.5 mm sheet mold in a compression molding press by applying a load of 25 tons for 1 min. The material was kept at a contact temperature of 120°C for 5 min. After sufficient time was given for the cooling of the composite sheet, it was taken out, and the edges were trimmed. Two polyester sheets were put above and beneath the mold plates to better facilitate the surface finish of the molded composite sheets.

### Physicomechanical property evaluation

The weights of the final composite sheets were measured with an electronic balance. The densities of the composite sheets of different compositions were evaluated according to ASTM D 729. The tensile and three-point flexural properties were evaluated with a universal testing machine (model H 100K-S), supplied by Hounsfield Equipments (Salfords, Redhill Surrey, England) according to ASTM D 638 (Type IV) and IS 13360 (Part 5/Sec7) : 1996,



**Figure 1** SEM micrograph of the untreated fiber surface.



**Figure 2** SEM micrograph of the dewaxed fiber surface.

respectively. Tensile tests were performed at a load range of 10 kN and at a speed of 1 mm/min. For the flexural properties evaluation, the load range and speed were set at 500 N and 1 mm/min, respectively.

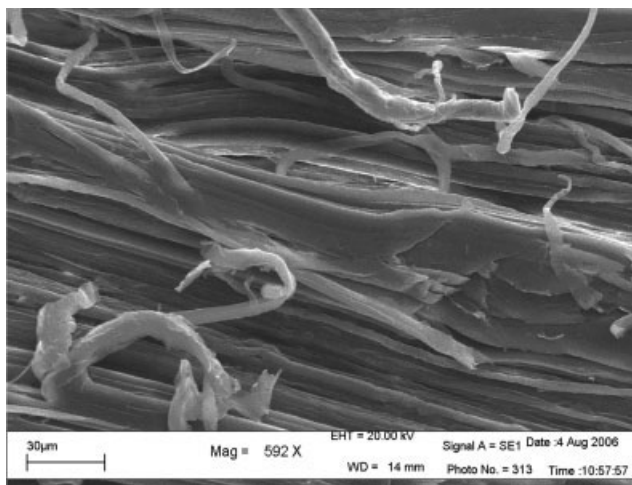
The notched Izod impact was determined with a junior impactor tester supplied by CEAST (Pianezza, Italy) following ASTM D 256. Five specimens from each composition were tested for each property evaluation.

The fiber–polymer interface of both the treated and untreated fiber composites and the fractured surfaces of the impact test specimens of different compositions of both treated and untreated fiber composites were observed under SEM.

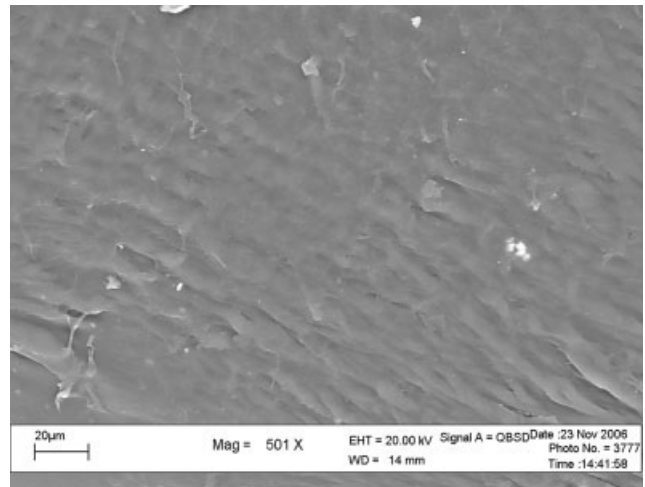
## RESULTS AND DISCUSSION

### Characterizations of the fiber and the resin

The fibers after dewaxing were much clearer in appearance. The color of the alkali-treated fibers was

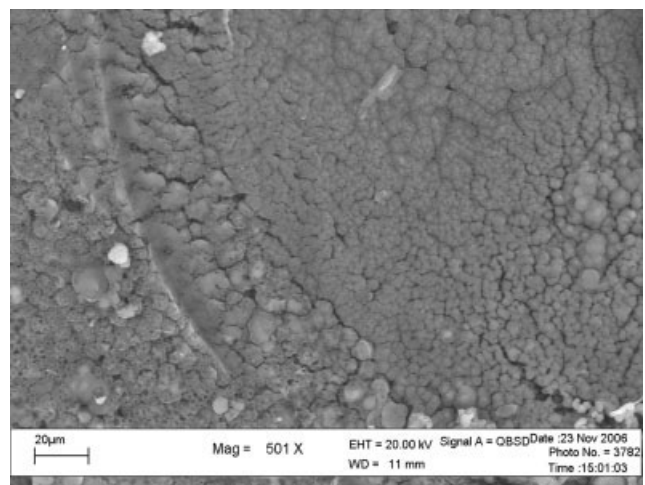


**Figure 3** SEM micrograph of the alkali-treated fiber surface.



**Figure 4** SEM micrograph of PP.

visibly clear white due to the removal of natural and artificial impurities. This was further proven by the weight loss of the fiber after each treatment process. The SEM micrographs of raw, dewaxed, and alkali-treated fibers are shown in Figures 1, 2, and 3, respectively. A fibrillated smooth surface was visible in the untreated fibers. The raw surface of the fiber consisted of a waxy coating called *cuticle* of aliphatic origin and nonpolar in nature, which rendered it incompatible with the polymer matrix. This suggests that the surface of the fiber should be modified by either coating (including multiple coatings) with materials which have compatibility with the matrix or leaching out of the cuticle layer so as to increase compatibility between the fiber and matrix.<sup>7</sup> A swelling of the fibers could be seen on dewaxing, whereas fibers treated with alkali became much thinner, and surface roughness was obvious. This led to increased adhesion between the fiber and the matrix by the enhancement of fiber wetting and impregna-



**Figure 5** SEM micrograph of MA-g-PP.

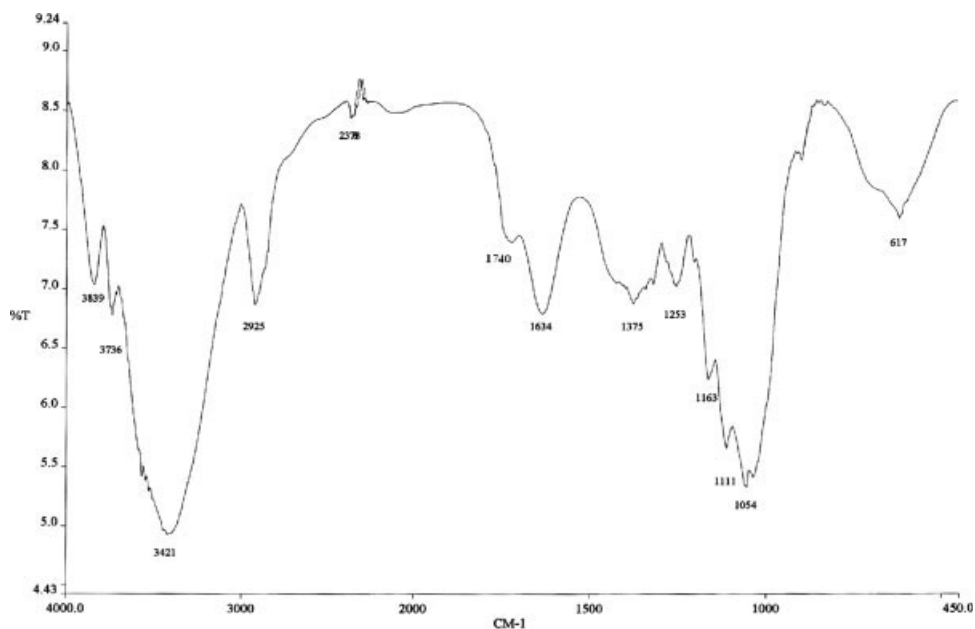


Figure 6 FTIR spectrum of raw PALF [transmittance percentage (%*T*) versus wave number].

tion in the presence of the compatibilizer as there was an increase in the effective surface area of contact.

SEM micrographs of virgin PP and MA-g-PP are shown in Figures 4 and 5, respectively. A considerable amount of the grafted polymer was seen as a deposit on the respective polymer backbone.

The FTIR spectra of the untreated and alkali-treated fibers are shown in Figures 6 and 7, respectively. There was an absorption in the untreated fiber at about  $1740\text{ cm}^{-1}$ , which vanished in the

NaOH-treated fibers.<sup>1</sup> By the action of alkali, a substantial portion of uronic acid, a constituent of hemicellulose xylan, was removed, which resulted in the disappearance of the peak at about  $1740\text{ cm}^{-1}$ . The hemicellulose contained groups that absorbed in the carbonyl region.<sup>1</sup> They were soluble in aqueous alkaline solutions.

The FTIR spectra of PP and MA-g-PP are shown in Figures 8 and 9, respectively. MA-g-PP showed an absorption peak at about  $1717\text{ cm}^{-1}$ , which was not

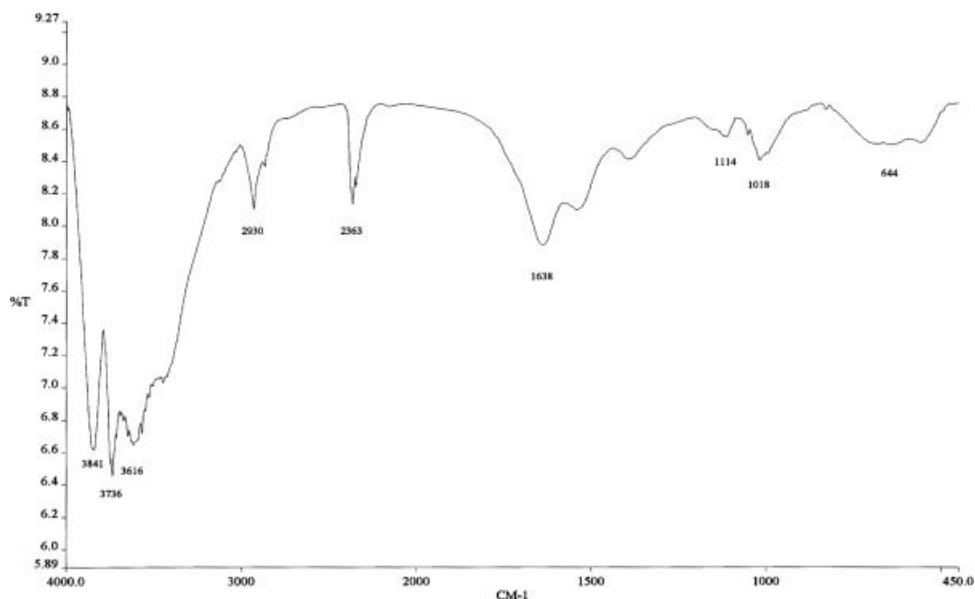


Figure 7 FTIR spectrum of alkali-treated PALF (%*T* versus wave number).

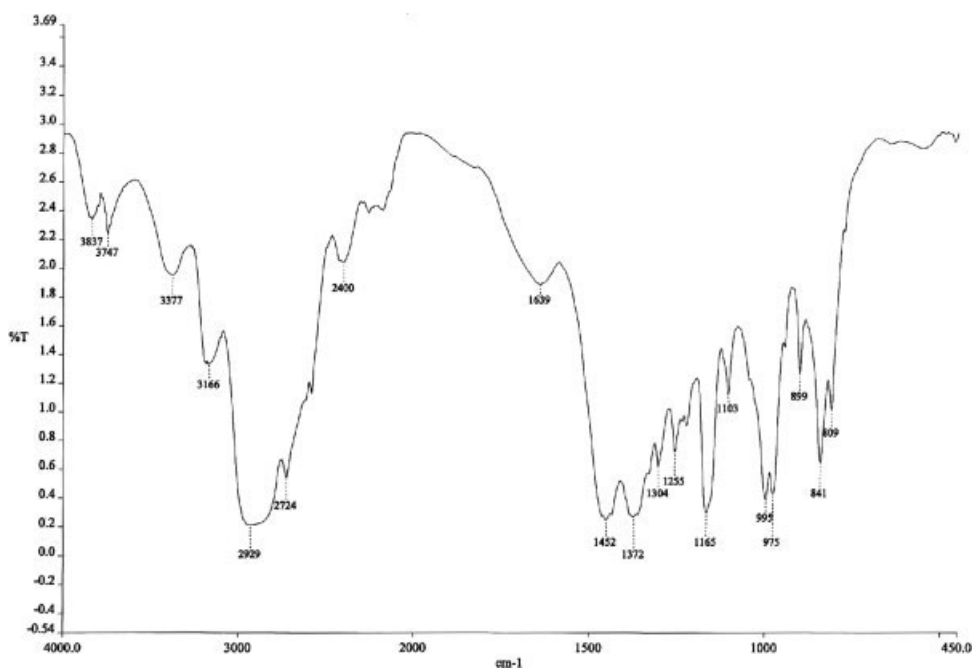


Figure 8 FTIR spectrum of PP (%T versus wave number).

found in the case of virgin PP. This peak is a characteristic of carbonyl group that is present in anhydride.

Figure 10 shows the TGA of the raw and the alkali-treated fiber. TGA of the pure PP and composites with untreated and treated fibers (10%) is shown in Figure 11. The maximum decomposition temperatures for the pure PP and composites with

untreated and treated fibers were 451, 458, and 460°C, respectively. There was a marginal improvement in thermal behavior of the fibers after alkali treatment, as evident in the figure. A change in the degradation pattern of the composite was noticed after fiber incorporation, and a slight improvement was also observed in the thermal stability of the composite after alkali treatment.

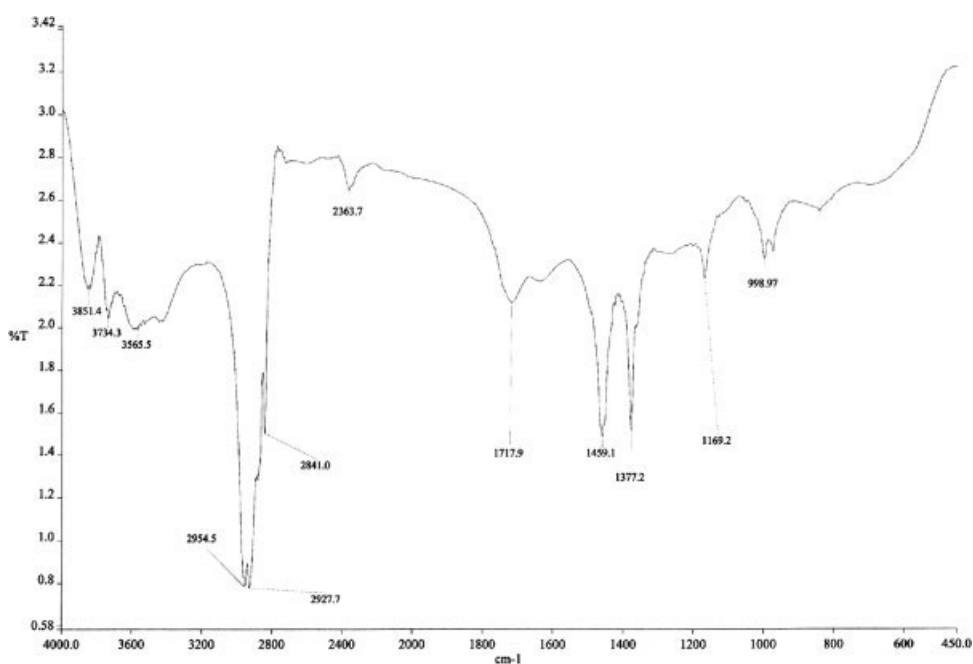
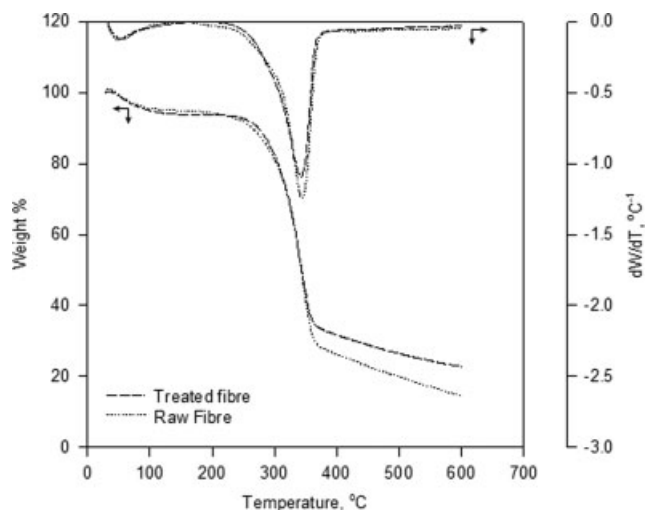


Figure 9 FTIR spectrum of MA-g-PP (%T versus wave number).



**Figure 10** TGA of raw and alkali-treated fiber.  $dW/dT$ : differential weight loss with differential change in temperature.

#### Effect of surface modifications and compatibilizer on the physicomachanical properties of the composites

The impact strengths of the untreated fiber composites were more than that of the neat resin, and the strength further increased with increasing volume fraction of the fiber. Table II gives the values of impact strength with the standard deviation for each composition. The increase was more appreciable in the case of alkali-treated fibers mixed with the MA-g-PP compatibilizer. This was attributed to the fact that alkali treatment improved the adhesion between the fiber surface and the polymer, whereas the compatibilizer bound the two surfaces chemically. Furthermore, fibers reduced the crack propagation rate by forcing a crack around the fiber and bridging the

**TABLE II**  
Impact Strength of the PALF-PP Composites

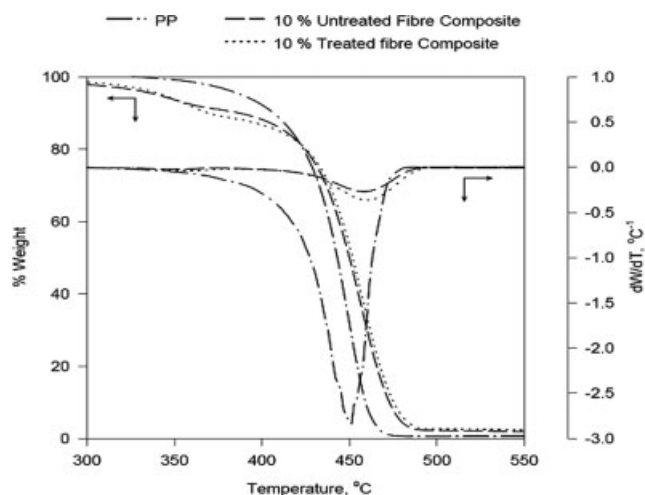
Fiber (vol %)	Raw fiber + PP (J/m)	Treated fiber + PP (J/m)	Treated fiber + PP + MA-g-PP (J/m)
0	$27.00 \pm 0.1581$	$27.00 \pm 0.3581$	$27.00 \pm 0.1581$
5	$32.35 \pm 0.6088$	$6.17 \pm 0.2548$	$42.50 \pm 0.9444$
10	$35.33 \pm 0.5777$	$9.318 \pm 0.3211$	$51.35 \pm 1.4760$
15	$41.50 \pm 0.8637$	$13.289 \pm 0.7011$	$62.50 \pm 0.8591$
20	$50.00 \pm 0.4037$	—	$74.36 \pm 0.7664$
30	$108.1 \pm 0.4971$	—	—
40	$100.0 \pm 0.5399$	—	—

crack through fiber pullout, which led to an increase in the impact strength.<sup>9</sup>

Thus, there were increases of up to 85.2 and 175.4% in the values of impact strength in the untreated and treated fibers, respectively, with 20% loading of fibers. For 30% loading of fibers (untreated), the impact strength value was excessively high ( $108.1 \text{ J/m}^2$ ), and it showed a subsequent decrease in its value ( $100.0 \text{ J/m}^2$ ) for 40% loading of fibers. This indicated that the impact strengths of the composites for both untreated and treated fibers monotonically increased up to a fiber loading of about 30% and then decreased with the further addition of fiber.

The flexural properties (flexural strength and modulus) of the PP-PALF composites are tabulated with their corresponding standard deviations in Table III. For the chemically treated fiber, with increasing fiber volume fraction, the values increased and attained a maximum value at a fiber volume fraction of 10% and again started decreasing. The decrease in flexural properties at higher volume fractions of fiber loadings may have been due to the increase in fiber-fiber interactions, the fibers not being perfectly aligned with matrix, and poor dispersion of fibers in the matrix. Moreover, higher void content (which might have been due to the presence of moisture in trace amounts) and low interfacial strength resulted in a lower efficiency of load transfer with increasing fiber loading. MA-g-PP acted as a compatibilizer; hence, its treatment showed an increase in flexural properties in all of the respective treated fiber composites compared to the untreated ones. This increase was due to the esterification of fiber.

The tensile strength and modulus values, along with standard deviations, for different fiber volumes are shown in Table IV. The tensile moduli were quite lower compared to the flexural counterparts, which also supports the literature. There was not any significant increase in the tensile strength values compared to that of the virgin resin even after treatment of the fibers, although the tensile strength values for the treated fiber composites were greater than those of the untreated fiber composites. How-



**Figure 11** TGA of virgin PP and the composites with 10% treated and untreated fibers.  $dW/dT$ : differential weight loss with differential change in temperature.

**TABLE III**  
Flexural Properties of the PALF-PP Composites

Fiber (vol %)	Raw fiber + PP		Treated fiber + PP		Treated fiber + PP + MA-g-PP	
	Flexural strength (MPa)	Flexural modulus (MPa)	Flexural strength (MPa)	Flexural modulus (MPa)	Flexural strength (MPa)	Flexural modulus (MPa)
0	38.00 ± 0.3036	1650 ± 2.549	38.00 ± 0.3036	1650 ± 2.549	38.00 ± 0.3036	1650 ± 2.549
5	38.93 ± 0.1999	1673 ± 2.000	22.33 ± 0.5011	1142 ± 3.1250	48.81 ± 0.3403	1888 ± 4.062
10	41.62 ± 0.3922	1760 ± 3.162	11.88 ± 0.6289	1210 ± 2.341	57.80 ± 0.5505	2300 ± 7.382
15	39.95 ± 0.2197	1703 ± 2.915	11.82 ± 0.4033	901 ± 2.156	43.96 ± 0.4845	2027 ± 3.873
20	38.10 ± 0.2286	1651 ± 2.236	—	—	41.63 ± 0.3717	1818 ± 3.807

ever, the tensile strength of a single alkali-treated fiber increased with respect to the untreated one. This trend is also supported by the literature.<sup>10–12</sup> According to Hancox,<sup>13</sup> if stresses are applied in the principal fiber direction, the modulus and the strength are excellent. In other directions, transverse to the fibers or in shear, the properties are essentially those of the interface or resin matrix and are much lower. Thus, the observed behavior in this case was possibly due to the random orientation of the fibers in the matrix. The presence of voids in the composite was another factor contributing to the lower value. This was confirmed by the fiber pullout, as shown in the SEM micrographs (Fig. 12). Moreover, at certain points, fibers were found as aggregates, which formed stress concentration points, thus initiating failure at those points.

PP/alkali-treated PALF composites without MA-g-PP compatibilizer were also tested to study the mechanical properties of the composite. The properties did not show any improvement with respect to virgin PP; rather, they decreased after alkali treatment. The values of the properties (for 5, 10, and 15 vol % of fiber) are reported in Tables II, III, and IV, respectively. From the data, we observed that impact strength decreased by approximately 51–77% compared to that of virgin PP, whereas the flexural strength and modulus values decreased by 41–69% and 27–45%, respectively, and the tensile strength and modulus values decreased by 40–72% and 6–8%, respectively. This decrease in properties after alkali treatment was attributed to the fact that the rougher surface morphology due to the removal of the lignin (the binding material in the fiber) and cuticle layer

during alkali treatment did not lead to any improvement in the mechanical properties of the composites<sup>14</sup> but rather got in the way of binding between the fibers and matrix, whereas the compatibilizer effectively bound the two surfaces chemically and helped in the transfer of stresses from the fibers to the matrix.

#### Morphology of the interface

The fiber-polymer interface was studied with SEM (Figs. 13 and 14). As evident from the micrographs, poor dispersion was noticed for the untreated fiber (Fig. 14) composite because the fibers were bunched together as they tended to agglomerate. The dispersion was marginally better and relatively more uniform in the treated fiber composites (Fig. 13) in the presence of a compatibilizer than in the untreated ones (Fig. 14). However, more uniform dispersion of the treated fibers might have yielded a further improvement in the mechanical properties of the composite.

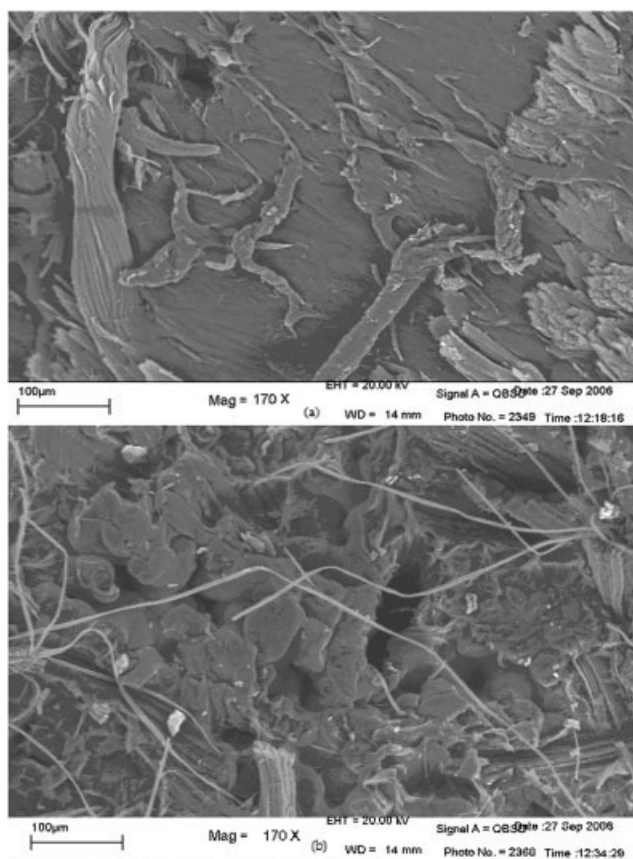
#### Morphology of the fractured surface

The fractured surfaces of the impact specimens were observed under the scanning electron microscope. As shown in Figure 12, poor dispersion was noticed in the untreated fiber composite, as the fibers were bunched together as they tended to agglomerate, and many holes were left after the fibers were pulled out from the matrix when stress was applied.<sup>3</sup> Fracture characteristics are also evident in these micrographs. However, the presence of a compatibilizer

**TABLE IV**  
Tensile Properties of the PALF-PP Composites

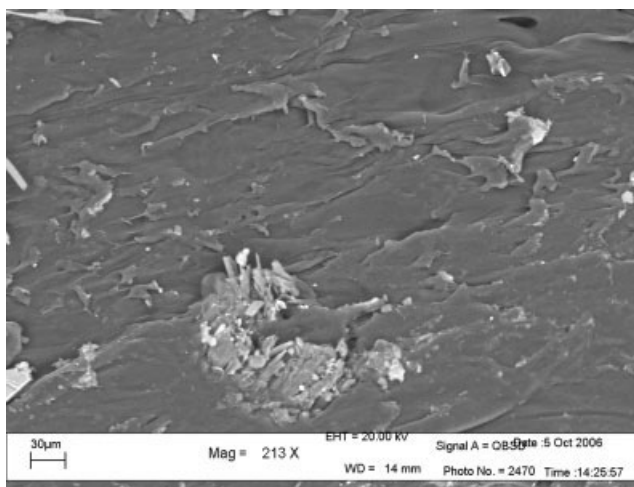
Fiber (vol %)	Raw fiber + PP		Treated fiber + PP		Treated fiber + PP + MA-g-PP	
	Tensile strength (MPa)	Tensile modulus (MPa)	Tensile strength (MPa)	Tensile modulus (MPa)	Tensile strength (MPa)	Tensile modulus (MPa)
0	24.50 ± 0.2145	560 ± 4.472	24.50 ± 0.2145	560 ± 4.472	24.50 ± 0.2145	560 ± 4.472
5	24.96 ± 0.1029	652 ± 3.162	6.91 ± 0.3241	527 ± 4.195	26.76 ± 0.3102	699 ± 2.000
10	26.95 ± 0.2621	690 ± 4.000	14.70 ± 0.2436	513 ± 4.125	31.06 ± 0.4551	707 ± 1.581
15	29.92 ± 0.2197	695 ± 3.240	8.47 ± 0.4625	521 ± 5.624	33.54 ± 0.4845	722 ± 2.549
20	31.54 ± 0.2286	707 ± 1.581	—	—	34.96 ± 0.3717	738 ± 2.000



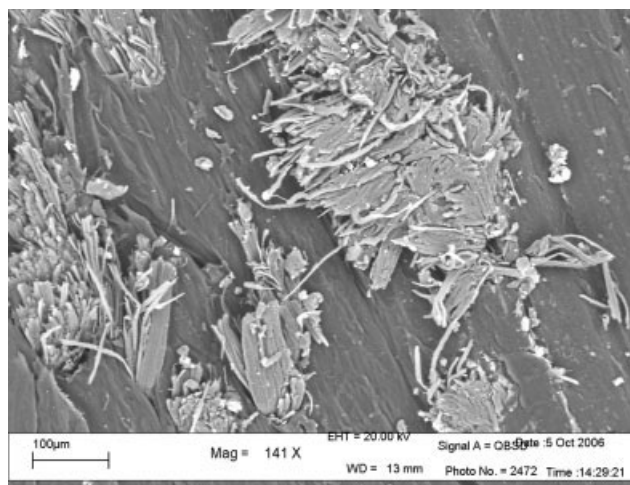


**Figure 12** SEM micrograph of the fractured surfaces of impact specimen of composites for (a) untreated fibers and (b) treated fibers, each for 10% fiber loading.

effectively improved the adhesion and the fiber dispersion in the treated fiber composites, which resulted in limited fiber pullouts and holes, as if the fibers were not coming out of the matrix and the fracture surfaces were much more uniform than in the untreated ones.



**Figure 13** SEM micrograph of the treated pineapple fiber-PP interface.



**Figure 14** SEM micrograph of untreated pineapple fiber-PP interface.

## CONCLUSIONS

The mechanical properties of short-PALF-reinforced composites were investigated in this study. Here, the combined effect of alkali treatment of the defatted fibers and the addition of MA-g-PP as the compatibilizer improved the interfacial properties by strengthening fiber-polymer interaction by enhancing fiber wetting and impregnation and, at the same time, by chemically binding the two surfaces. The impact properties improved enormously. Flexural strength and modulus increased up to 10% loading of the fibers. There was also a marginal increase in the values of tensile modulus with increasing fiber volume fraction. Fiber-reinforced polymeric composites are anisotropic, heterogeneous materials with significant properties in one or two directions, which do not deform plastically. PALF in 10 vol % in the PP matrix with MA-g-PP is the optimum and recommended composition, where the flexural modulus and flexural strength were the maximum. The impact strength and the tensile modulus were also considerably high. However, complete removal of the moisture from the fiber and more uniform dispersion would have yielded further improvements in the mechanical properties of the PALF-reinforced PP composite in the presence of compatibilizer.

There is a large scope for research in the field of natural fiber composites. Here, an effort has been made to observe the effects of chemical modification on the mechanical properties of the composites. In forthcoming communications, other aspects, thermal properties, electrical properties, and biodegradability of the natural fiber will be the focus as the area of research. There can be a lot of improvements in the properties of the composites by the optimization of the fiber length, orientation, treatment procedure, and appropriate selection of coupling agents to opti-

mize the interfacial properties, which should lead to desired specific properties and to replace glass-fiber composites.

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