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Thermal and Tensile Mechanical Behavior of Polystyrene Graft Acetic Anhydride-Treated Pulque Fibers

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In the present study, pulque (*Agave cantala*) fibers treated with acetic anhydride were grafted with styrene monomer by free radical graft copolymerization techniques. The grafted fibers were then characterized by Fourier transform infrared spectroscopy (FTIR), scanning electron microscope (SEM), thermogravimetric analysis (TGA), and tensile mechanical tests. Untreated raw pulque fibers were also taken as control for comparison. FTIR analysis confirmed the grafting of styrene monomer onto pulque fibers. It was also found that polystyrene graft acetic anhydride-treated pulque fibers displayed higher thermal resistance, improved tensile properties, and lower moisture content as compared to untreated raw pulque fibers.

Keywords: acetylation, graft copolymerization, pulque fiber, styrene, tensile properties, thermal resistance

用聚苯乙烯接枝乙酸酐-处理后龙舌兰纤维的热性能和拉伸力学性能在目前的研究中，用乙酸酐接枝苯乙烯单体进行自由基接枝共聚技术处理龙舌兰纤维（肯太拉麻）。用傅里叶变换红外光谱（FTIR）、扫描电子显微镜（SEM）、热重分析（TGA），对接枝纤维进行表征测试和拉伸试验。未经处理的原龙舌兰纤维也作为对照比较。红外光谱分析证实了苯乙烯单体接枝到龙舌兰纤维。同时还发现，比未经处理的原龙舌兰纤维，聚苯乙烯接枝乙酸酐处理的龙舌兰纤维显示更高的耐热性，改进的拉伸性能，和较低的水分含量。

关键词：乙酰化、接枝共聚、龙舌兰纤维、苯乙烯、拉伸性能、耐热性

INTRODUCTION

Bio-degradability, availability, and physico-mechanical properties of natural fibers or ligno-cellulosic fibers ensured its manifold applications in different sectors. Nowadays, an important application of natural fibers is as reinforcing filler in polymer composites. Bio-degradability, renewability, availability, and low cost of natural fibers (e.g., sisal, jute, flax, hemp, kenaf, etc.) made it potential reinforcing filler as replacement to synthetic fibers (e.g., glass fiber) in polymer composites. Natural fibers are available and can be obtained from different parts of plants such

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as stem (e.g., jute, hemp, kenaf, etc.), fruit (e.g., cotton, coir, oil palm fruit, etc.), and leaf (sisal, pulque, pineapple, etc.). Although natural fibers possess many advantages such as renewability, availability, low cost, light weight (density, about 40% lower than glass fibers) (George et al. 2001), high toughness, comparable specific strength properties, reduction in tool wear, CO₂ neutrality, etc. (Mohanty et al. 2000) and also incorporation of natural fibers into polymer matrices can offer a possibility to design new composite materials with reduced environmental impact, but the main drawbacks for the application of natural fibers are the strong hydrophilic nature of their surface, which causes poor adhesion and non-homogenous dispersion in most non-polar matrices resulting poor properties of final materials. In addition, since they are grown naturally, the properties of the fibers can vary greatly from plant to plant.

Possibility and scope of different physical and chemical modifications of natural fibers may impart in improvement of properties of cellulosic materials used in different sectors and also may open up opportunity for future industrial applications. Several fiber surface treatments such as alkaline, silane, acetylation, benzylation, graft copolymerization, maleated coupling agent, peroxide, permanganate, isocyanate, stearic acid treatment, etc. (Xue Li and Panigrahi 2007) have been studied to improve the adhesion between ligno-cellulosic fibers and polymer matrices. Among various chemical treatments, acetylation and graft copolymerization are very important chemical treatments of cellulosic fibers. Chemical modification with acetic anhydride substitutes the hydroxyl groups of the cell wall of cellulosic fibers with acetyl groups, reducing the hydroxyl groups of cellulose so that they become hydrophobic (Callum et al. 1998). Paul et al. studied the electrical properties of short-sisal-fiber-reinforced low-density polyethylene composites by acetylation of sisal fiber. They reported that the dielectric constant values of the composites were decreased as a result of acetylation that decreases the hydrophilic nature of natural fiber (Paul et al. 1997). Nair et al. treated the sisal fibers by acetic anhydride and found that acetylation of the fibers improved the fiber-matrix adhesion in PS/sisal composites, which are thermally more stable than unreinforced PS and sisal fiber (Nair et al. 2001).

Properties of natural fibers can also be modified by graft copolymerization with vinyl monomers under selective and controlled conditions (Ghosh et al. 1989; Singha and Rana 2012). Graft copolymerization promises to be potentially effective means of altering the fiber surfaces. Some of the important changes in properties that have been brought about by grafting to ligno-cellulosic fibers are improved, such as dye-ability, thermal stability, tensile properties, stereo-regularity, water repellency, bactericidal properties, resistance to acids, alkalies, etc. Graft copolymerization of acrylonitrile (AN) on sisal fibers was studied by Mishra et al. using a combination of NaIO₄ and CuSO₄ as initiator in an aqueous medium at temperatures between 50°C and 70°C. They found that grafting of chemically modified fibers with 5% AN brought a higher increase in tensile strength and Young's modulus of fibers than that of untreated sisal fibers (Mishra et al. 2001). Kalia et al. studied the graft copolymerization of sisal fibers by methyl acrylate monomer. They reported that graft copolymerization enhanced the thermal stability and crystallization of sisal fibers (Kalia et al. 2011). Chand et al. modified the surface of sisal fibers with various polymers (PE, PS, PP, PVA, polyester, etc.). Maximum tensile strength for PS-coated sisal fiber was reported by them (Chand and Joshi 2010).

In the present work, pulque fibers treated with acetic anhydride were grafted with styrene monomer by free radical graft copolymerization techniques. Pulque plant is similar as sisal plant and pulque fibers are obtained from the leaves of pulque plants. Pulque fibers can be considered as an important fiber after jute and cotton—which are available and widely used—in Bangladesh. The chemical modifications of jute fibers (Gassan and Bledzki 1997; Mondal and Haque 2007; Park et al. 2006; Samanta et al. 2008) have been reported by many researchers. Whereas, a very little study have been carried out on pulque fibers (Maniruzzaman et al. 2006; Sultan et al. 2013). Generally, pulque plants are not cultivated in Bangladesh. These plants grow here and there without any care. This plant is familiar to villagers as Forkoria tree. Villagers use these plants for making fence at their field and use pulque fibers for making rope. In our previous work, we studied the compositions

and properties of pulque fibers (Maniruzzaman et al. 2006). In the present work, we treated pulque fibers by acetic anhydride—which can increase the hydrophobic nature of fibers—and then we graft copolymerized styrene monomer onto acetic anhydride-treated pulque fibers by free radical initiator potassium persulfate (KPS) induced by Fe(II).

In the present paper, we focused the attention on the morphology, thermal behavior, and mechanical performance of pulque fibers, analyzing the effectiveness of chemical treatments, namely, acetic anhydride treatment and graft copolymerization of styrene monomer onto pulque fibers. It is expected that both the advantageous properties of acetic anhydride treatment, i.e., improved hydrophobic nature of acetic anhydride treated fibers—which may facilitate graft copolymerization reaction between pulque fibers and styrene monomer (hydrophobic in nature) by reducing surface potential—and PS grafting (improved thermal and mechanical properties of PS grafted fibers) will be achieved after chemical modifications of pulque fibers.

MATERIALS AND METHODS

Materials

Pulque (*Agave cantala*) fibers were collected from Islamic University, Kushtia, Bangladesh. Styrene monomer (purity > 99%), sodium carbonate (Na_2CO_3) (purity > 99.5%), sodium chlorite (NaClO_2) (purity > 80%), sodium meta-bi-sulfate ($\text{Na}_2\text{S}_2\text{O}_5$) (purity > 99.9%), sulfuric acid (H_2SO_4) (purity > 98%), acetic acid (CH_3COOH) (purity, 100%), acetic anhydride, sodium acetate (CH_3COONa) (purity > 98%), potassium per sulfate ($\text{K}_2\text{S}_2\text{O}_8$) (purity > 98%) were purchased from BDH (England). All chemicals were analytical grade and used as such without further purification.

Isolation and Scouring of Pulque Fibers

Figure 1(a) shows a photograph of pulque plant. From the leaves of this plant fibers were obtained. The leaves collected from plants were put under dirty water for 15 days. When the leaves were



FIGURE 1 Photographs of pulque: (a) plant with leaves, (b) RF, (c) BF, and (d) AF.

rotten, the fibers were taken out from the leaves and washed thoroughly with water several times and dried in air without exposure sunlight. Pulque fibers were washed with surface active agents to remove impurities such as dirty materials and gummy substances from the surfaces of pulque fibers. It was carried out by the use of surface active agents, such as soda and detergents. Pulque fibers were coursed in a solution containing 6.5 g of soap flake and 3.5 g of soda per liter at 70°C–75°C for 30 min in a large beaker. The ratio of the fibers to solution was 1:50. The fibers were thoroughly washed with distilled water and dried in the open air and finally stored in a desecrator. This raw pulque fiber (Figure 1(b)) is represented as RF in the present paper.

Bleaching of Pulque Fibers

Bleaching of pulque fibers was carried out following the procedure reported by Mondal and Haque for bleaching of jute fibers (Mondal and Haque 2007). Sodium chlorite (NaClO_2) solution of strength 7.5 g/L was prepared and its pH was adjusted to 4 by adding 0.2 M acetic acid (CH_3COOH) solution from a burette and pH change was observed directly with a pH meter. A pH 4 solution was prepared by adding 0.2 M acetic acid to 0.2 M sodium acetate (CH_3COONa) solution. Bleaching was conducted at temperature 85°C–90°C for 90 min maintaining the fiber–liquor ratio 1:50. Prior to start bleaching, 1 mL buffer solution of acetic acid and sodium acetate of pH 4 was added for every 10 mL of the liquor to maintain the constant pH throughout the process. After the completion of bleaching, the fibers were washed well with distilled water and immersed in 0.2% sodium meta-bi-sulfide solution for 15 min. Then the fibers were washed with distilled water and dried in open air and then stored in desiccators. Bleached pulque fiber (Figure 1(c)) is represented as BF in the present paper.

Acetylation of Pulque Fibers

10 g of dried fibers were immersed in distilled water for 15 min and then the fibers were pressed out on a Buchner funnel. The wetted fibers were transferred to a stopper bottle and covered with 150 mL of glacial acetic acid. After being shaken occasionally for 1 h, the fibers were pressed out as before. Dewatering of fibers was done twice in the same manner. 20 g of fibers adhered acetic acid were taken in a stopper bottle containing 180 mL of 10% acetic anhydride and 1 mL of concentrated H_2SO_4 at 25°C. The mixture was shaken vigorously for 1 min and then 50 mL of acetic anhydride was added and shaken again vigorously for another 1 min and 50 mL of acetic anhydride was added and shaken again. The resultant mixture was held for 5 min at 25°C. The fibers were then washed with distilled water. Finally, the fibers were dried at 60°C and stored in desiccators. Acetic anhydride-treated pulque fiber (Figure 1(d)) is represented as AF in the present paper. A reaction scheme for pulque fiber with acetic anhydride is shown in Figure 2.

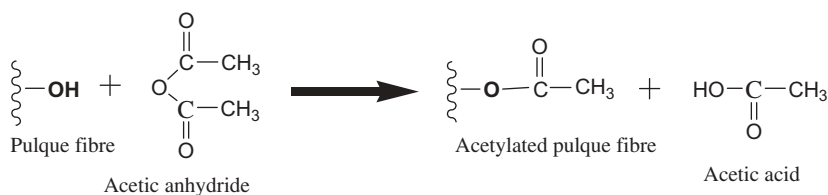


FIGURE 2 Reaction scheme for pulque fiber with acetic anhydride.

Grafting of Styrene Monomer onto Acetylated Pulque Fibers

Graft copolymerization of styrene monomer onto acetylated pulque fiber was carried out in aqueous medium using potassium per sulfate as initiator induced by Fe(II). 1 g of fibers (acetylated) was immersed in 10 mL of monomer (5 wt.%) solution of a 200 mL beaker. Then 5 mL (0.001 wt.%) of catalyst ($\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$) solution and 25 mL of distilled water were added, respectively. After that the beaker was taken in a water bath for heating the mixture. When the temperature was raised at 80°C then 10 mL of 0.005 wt.% potassium per sulfate ($\text{K}_2\text{S}_2\text{O}_8$) initiator was added to the mixture. The mixture covering with a watch glass was kept at 80°C for 2 h and 45 min. The grafted fibers were washed with distilled water three times and once with acetone. Finally, the fibers were dried and stored in desiccators. Grafting of styrene monomer onto fibers was confirmed by Fourier transform infrared spectroscopy (FTIR) analysis. Styrene grafted pulque fiber is represented as SAF in the present paper.

Testing Methods

The raw and modified pulque fibers were analyzed by FTIR spectroscopy using an FTIR 8400s Shimadzu spectrometer. At first the sample fibers were dried at 105°C for 24 h and then powdered in a mortar. The powdered sample of fibers (1 mg) was mixed with KBr (200 mg) and ground. The thorough mixing and grinding were accomplished in a mortar by a pestle. The powdered mixture was then compressed in a metal holder under a pressure of 8–10 tones to produce a film. The film was then placed in the path of the infrared beam for analysis. The samples were scanned in the frequency range $500\text{--}4000\text{ cm}^{-1}$ at a resolution of 4 cm^{-1} .

Thermogravimetric analysis (TGA) and differential thermal analysis (DTA) of fiber samples were carried out in a TG/DTA 6300 (Seiko Instruments Inc., EXSTAR 6000). The samples (4–10 mg) were heated from 30°C to 600°C at heating rate of $20^\circ\text{C}/\text{min}$ under nitrogen, after equilibrating at 50°C . The change of weight percent and its derivative (DTG) was recorded as a function of temperature. This instrument has been design to simultaneously perform thermogravimetric and differential thermal analytic measurement on inorganic materials like ceramics and metals, as well as on high polymer organic materials. The thermocouple (platinum-platinum rhodium 13%) for DTA measurement was incorporated at the end of each of the balance beam ceramic tubes, and the temperature difference between the holder on the sample side and the holder on the reference side was detected. This signal was amplified and the temperature difference signal was used to measure the thermal change of the sample.

Surfaces of raw and modified pulque fibers were examined by using the scanning electron microscope S-3400N operating with an acceleration voltage of 1500 volt. Before analysis all fiber samples were coated with a layer of gold. Scanning electron microscope (SEM) was used to observe the microstructure and the surface morphology of treated and untreated fibers.

The tensile mechanical tests of raw and modified pulque fibers were carried out using a Hounsfield UTS 10KN (H10KS) at a cross-head speed of 0.8 mm/min. Single fibers were extracted from untreated and treated bunches of pulque fibers to carry out tensile tests. Single fiber was bonded to a rectangular hole of 10 mm length. Twenty single-fiber specimens for each item, i.e., raw, bleached, acetylated, and grafted pulque fibers were prepared. The gage length for each specimen was 10 mm. The diameter of each specimen was measured using an optical microscope. Tensile strength, elastic modulus, and elongation at break were determined by this test.

RESULTS AND DISCUSSION

FTIR Analysis

Figure 3 represents the FTIR spectra of (a) raw, (b) bleached, (c) acetic anhydride-treated, and (d) styrene grafted acetic anhydride-treated pulque fibers that contain mainly cellulose (72 wt.%), hemicelluloses (11 wt.%), and lignin (6 wt.%) (Maniruzzaman et al. 2006). The peaks appeared in the region of $3900\text{--}3000\text{ cm}^{-1}$ (e.g., the peak at 3384 cm^{-1} in the spectra of raw fiber) and $1216\text{--}921\text{ cm}^{-1}$ in the spectrum of each fiber sample are due to the characteristic band spectrum of OH (primary and secondary) groups of cellulose and C-O-C stretching vibrations of pyranose ring skeletal together with β -glycosidic linkages, respectively (Łojewska et al. 2005). The peaks in the region of $2820\text{--}3050\text{ cm}^{-1}$ are assigned to the C-H stretching vibration from the CH and CH_2 groups of cellulose and hemicelluloses (Alvarez and Vasquez 2006). The peaks present at 1735 cm^{-1} —corresponds to the CO group—in the spectra of each fiber are due to the presence of carboxylic acid in lignin or ester group in hemicelluloses (Liu et al. 2004) and at 1641 cm^{-1} in the spectrum of raw fiber are due to OH bending of adsorbed water in fiber (Juan et al. 2008).

The FTIR spectra of treated fibers are very similar to the spectrum of raw fiber, only showing differences in the region of $1800\text{--}1400\text{ cm}^{-1}$ particularly for acetic anhydride-treated fiber and styrene grafted acetic anhydride-treated fiber. If the FTIR spectrum of acetic anhydride-treated fiber is deeply scanned, then it can be seen that there are two peaks—due to the presence of CO group—in the region of $1800\text{--}1700\text{ cm}^{-1}$, one at about 1734 cm^{-1} and another appeared as shoulder at about 1718 cm^{-1} that can be attributed to the acetylating of fibers. Similar characteristics were also reported by Chand et al. for sisal fiber treated with acetic anhydride (Chand et al. 1989).

In the FTIR spectrum of styrene grafted fiber (Figure 3(d)), it is seen that a small sharp peak at about 1510 cm^{-1} is appeared. This is due to the stretching mode of $\text{C}=\text{C}$ of aromatic ring present in styrene, which confirms the addition of styrene monomer onto fiber surface. Here, it should be noted that ligno-cellulosic fiber displays different peaks in the region of $1600\text{--}1400\text{ cm}^{-1}$ due to $\text{C}=\text{C}$ aromatic skeletal vibration of lignin (Rosa et al. 2010).

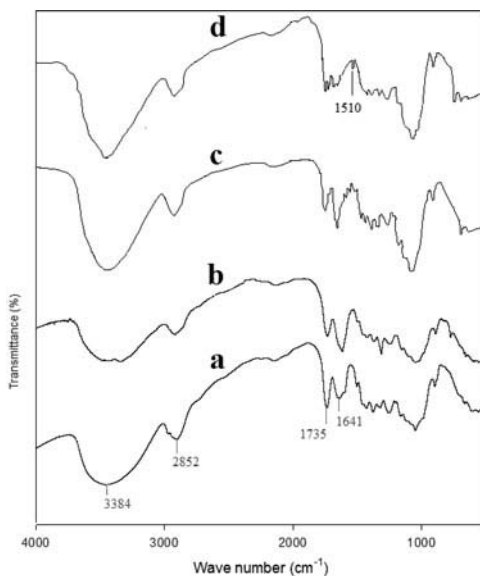


FIGURE 3 FTIR spectra of (a) RF, (b) BF, (c) AF, and (d) SAF.

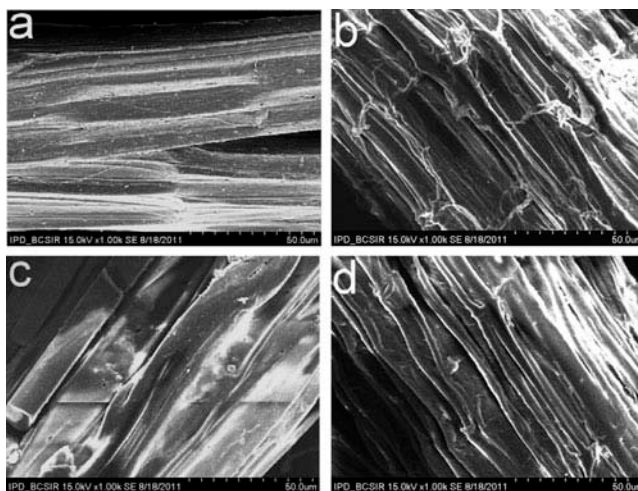


FIGURE 4 Scanning electron micrographs of (a) RF, (b) BF, (c) AF, and (d) SAF.

Morphological Analysis

Figure 4 shows the scanning electron micrographs of (a) raw, (b) bleached, (c) acetic anhydride-treated, and (d) polystyrene graft acetic anhydride-treated pulque fibers, respectively. The surface of raw fiber is smoother than that of treated fibers, i.e., the surfaces of treated fibers are very rough or different as compared to surfaces of raw fiber. The multi-cellular nature of fibers filament is not visible in the case of raw fiber. Whereas, the surfaces of bleached fiber (Figure 4(b)) show large roughness with the multi-cellular nature of fibers filament that can be ascribed to the partial removal of lignin from fiber surface and also degradation effects of bleaching onto fibers. However, in the case of AF and SAF, the multi-cellular nature of fibers filament is more clearly appeared. This may be due to partly removal of hemicelluloses from the surface and the intercellular space of pulque fibers during acetic anhydride treatment.

Thermal Analysis

Figures 5 and 6 represent the TG and DTG curves, respectively, of raw, acetic anhydride-treated, and polystyrene graft anhydride-treated pulque fibers. Percentage of weight loss at different temperatures during TGA experiments is also reported in Table 1. In the case of raw pulque fiber, the first weight loss between 40°C and 100°C corresponds to the removal of moisture and volatile mater. Raw pulque fibers were degraded through two main stages: (i) in between 220°C and 330°C showing maximum degradation rate at about 308.9°C (Figure 6), due to thermal depolymerization of hemicelluloses and (ii) in between 330°C and 400°C showing maximum degradation rate at about 363.1°C (Figure 6), due to the cleavage of glucosidic linkages of cellulose (Yang et al. 2007). Another stage of weight loss between 450°C and 500°C was also observed that may be attributed to the further breakage of the decomposition product of stage (ii) leading to the formation of tar through levoglucosan (Nair et al. 2001). Similar degradation behavior for other natural fibers, e.g., Okra (De Rosa et al. 2010), Kenaf (Jonoobi et al. 2009), Sisal (Nair et al. 2001) was reported by several researchers.

In Figure 5, it is also seen that up to 250°C (Table 1) both acetic anhydride-treated pulque fibers and polystyrene graft anhydride-treated pulque fibers exhibited lower percentage of weight loss than that of raw pulque fibers. Although acetic anhydride-treated fibers exhibited lower percentage

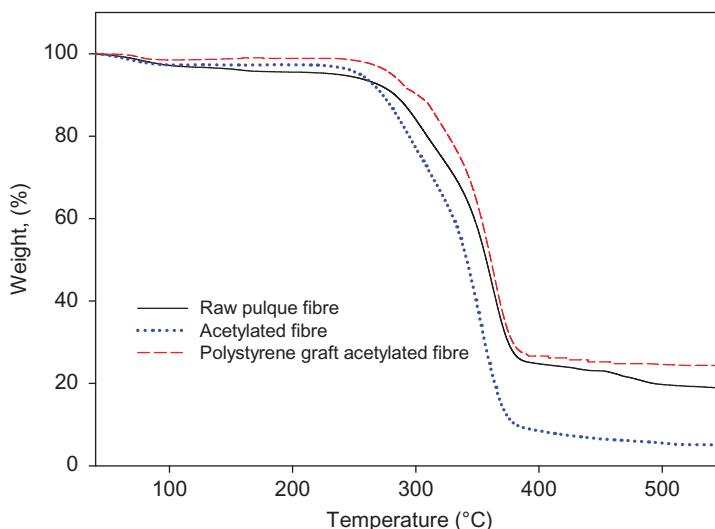


FIGURE 5 TG curves of RF, AF, and SAF.

of weight loss up to 250°C, but above 250°C it displayed higher percentage of weight loss than that of raw fibers indicating enhancement in thermal degradation of pulque fibers. On the other hand, polystyrene graft anhydride-treated pulque fibers displayed lower weight loss percentage in all over the temperature range (40°C–600°C) than that of raw and acetic anhydride-treated pulque fibers. This analysis suggests that polystyrene graft anhydride-treated pulque fibers are thermally more resistant than that of raw and acetic anhydride-treated pulque fibers. This improvement in thermal resistance of polystyrene graft anhydride-treated pulque fibers is probably due to the grafting of polystyrene onto pulque fiber surface, which impart in thermal resistance. It has been reported that for neat polystyrene, decomposition starts at higher temperature (288°C) (Nair et al. 2001) than that of ligno-cellulosic fibers (for pulque fibers at 220°C). In Table 1, it can also be noticed that at 100°C both acetic anhydride-treated pulque fibers and polystyrene graft anhydride-treated pulque fibers exhibited lower percentage of weight loss than that of raw pulque fibers that indicates the moisture repellence of treated fibers.

Tensile Properties

Tensile strength value and elongation at break percentage of raw, bleached, acetic anhydride, and polystyrene graft acetic anhydride-treated pulque fibers are reported in Table 2. Since large variations in tensile properties (higher value of standard deviation) of pulque fibers (both of treated and untreated) were observed during mechanical tests, therefore to have an idea about the tensile properties of pulque fibers minimum and maximum values together with average values of tensile strength of each fiber sample are also reported in Table 2. This large variation in tensile properties of pulque fibers probably due to the variation in pulque plant age. Chand et al. studied the effect of plant age on the mechanical properties of sisal fibers. They observed a large variation in tensile strength of sisal fiber with plant age (Chand and Hashmi 1993).

However, comparing tensile strength among RF and BF, it is clear from Table 2 that bleaching of pulque fibers produces a decrease of tensile strength of pulque fibers. This decrease of tensile strength can be associated with the removal of lignin—which acts as a cementing material in ligno-cellulosic fibers—by bleaching operation. In the case of AF, tensile strength was also decreased.

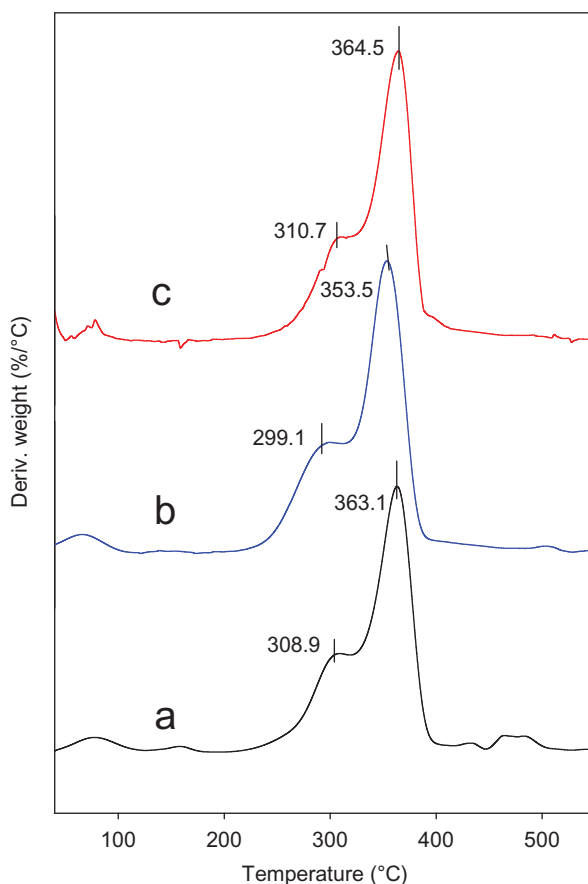


FIGURE 6 DTG curves of (a) RF, (b) AF, and (c) SAF.

TABLE 1
Percentage weight loss at different temperatures of RF, AF, and SAF

Temperature (°C)	Weight loss (%)		
	RF	AF	SAF
40	0.0	0.0	0.0
100	2.83	2.72	1.50
250	5.68	4.36	1.61
450	76.96	93.63	74.77
550	81.16	94.99	75.65

Although AF displayed lower values of tensile strength than that of RF, but it is seen in Table 2, the polystyrene graft acetic anhydride-treated pulque fiber (SAF) exhibited higher values of tensile strength than that of raw fiber (RF). However, an increase in the stiffness of AF and SAF (Table 2) was found probably due to the higher hydrophobic nature of AF and SAF than that of RF. The higher values of tensile strength and lower values of elongation at break percentage (higher stiffness) of SAF than that of raw pulque fibers are probably due to lower moisture content of SAF than that of RF

TABLE 2
Tensile strength and strain% of (a) RF, (b) BF, (c) AF, and (d) SAF

Sample	Tensile strength (MPa)			Elongation at break (%)
	Minimum	Maximum	Average	
RF	37.39	243.30	122.72 ± 80.40	28.64 ± 6.52
BF	20.89	255.20	102.62 ± 90.62	27.08 ± 5.61
AF	35.86	239.00	114.14 ± 80.99	26.59 ± 8.36
SAF	57.00	289.00	123.84 ± 97.77	24.70 ± 12.58

supported by thermogravimetric analysis (Table 1). The SAF exhibited also higher values of elastic modulus (minimum—0.49 GPa and maximum 3.41 GPa) than that of RF (minimum—0.30 GPa and maximum—0.96 GPa).

Weibull Modulus

An appreciable scattering of tensile strength was observed in the tensile test results. The statistical distribution of tensile strengths of fiber is generally described by means of the Weibull equation (Naito 2013; Weibull 1951). The two-parameter Weibull distribution is given by Eq. (1)

$$P_F = 1 - \exp \left[-L \left(\frac{\sigma_f}{\sigma_o} \right)^{m_f} \right], \quad (1)$$

where P_F is the cumulative probability of failure of a fiber of length L at applied tensile strength σ_f , m_f is the Weibull modulus (Weibull shape parameter) of the fiber, and σ_o is a Weibull scale parameter (characteristic stress). The cumulative probability of failure, P_F , under a particular stress is given by

$$P_F = \frac{i}{n + 1}, \quad (2)$$

where i is the number of fibers that have broken at or below a stress level and n is the total number of fibers tested. Rearrangement of Eq. (1) gives the following:

$$\ln \left(\ln \left[\frac{1}{1 - P_F} \right] \right) = m_f \ln(\sigma_f) - m_f \ln \left(\sigma_o L^{-\frac{1}{m_f}} \right). \quad (3)$$

Hence, the Weibull modulus, m_f can be obtained by linear regression from a Weibull plot of Eq. (3).

Figure 7 represents the Weibull plots based on Eq. (3) for (a) RF, (b) BF, and (c) SAF fibers' breaking strength at 10 mm gauge length. In all cases, the R^2 coefficient is from 0.9003 to 0.9630, which indicates a good degree of linearity. In other words, the linear regression of the fiber strength at 10 mm gauge lengths shows a good approximation to experimental data. Similar Weibull plots were also reported by Xia et al. for jute fibers breaking strength (Xia et al. 2009).

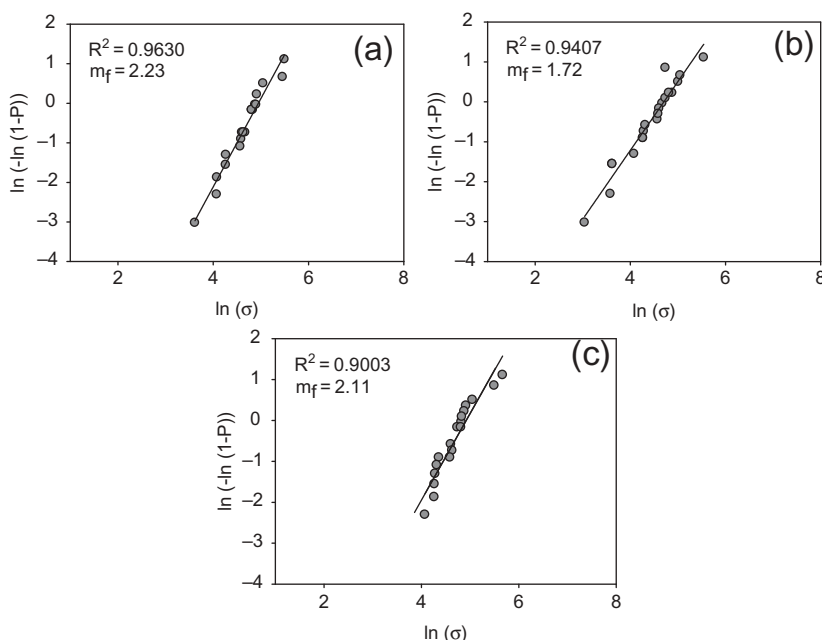


FIGURE 7 The Weibull plots of (a) RF, (b) BF, and (c) SAF fibers breaking strength at 10 mm gauge length.

CONCLUSION

Pulque fibers treated with acetic anhydride was graft copolymerized with styrene monomer by free radical graft copolymerization techniques. Grafting of styrene onto pulque fibers was confirmed by FTIR analysis. SEM analysis pointed out the rough surfaces of treated fibers as compared to untreated fibers surfaces. Higher thermal resistance and improved tensile properties were also found for polystyrene graft acetic anhydride-treated pulque fibers as compared to untreated raw pulque fibers. SAF also displayed lower moisture (indicated by TGA) content as compared to untreated raw pulque fibers. It can be expected that if SAF is used as reinforcing agent in polymer matrix composites, then SAF may be well dispersed in polymer matrix and the resulting polymer matrix composites may have higher thermal resistance and improved tensile properties than that of untreated raw pulque fibers.

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