*Fibers and Polymers* 2010, Vol.11, No.8, 1181-1186 DOI 10.1007/s12221-010-1181-7

# A Study of the Mechanical Properties of Natural Fibre Reinforced Composites

**J. A. M. Ferreira, C. Capela[1], and J. D. Costa***

*CEMUC, Mechanical Engineering Department, University of Coimbra,*
*Polo II da Univ. de Coimbra, Pinhal de Marrocos, 3030-788, Coimbra, Portugal*
*[1]CDRsp, Mechanical Engineering Department, Polytechnic Institute of Leiria,*
*Morro do Lena - Alto Vieiro, 2400-901 Leiria, Portugal*
(Received December 11, 2009; Revised March 16, 2010; Accepted March 19, 2010)

**Abstract:** This paper presents the results of a current research of the tensile properties: ultimate strength and stiffness modulus in composites using natural reinforcements. Hemp short fibres and pine sawdust were randomly distributed in polypropylene matrices to produce composite plates with 5 mm thickness by injection moulding technique. The specimens were cut from these plates with bone dog shape or plane bars, and tested in tensile and four points bending, respectively. Stiffness modulus and ultimate stresses were obtained for different weight fraction content of reinforcement and discussed taking in account the failure modes. Four series of pine sawdust reinforced specimens were immersed in water in periods up to 20 days. Periodically, the specimens were removed from the water recipient and immediately tested. The damage effect of water immersion time was discussed based in the tensile results and in the water absorption curves.

**Keywords:** Polymer composites, Vegetable fibres, Mechanical properties

## Introduction

The use of panels made of natural fibre-reinforced composites are increasing in the automobile industry [1] and as building materials since they come from renewable materials and are easily recycled and reasonably strong and light. Compared with traditional synthetic fibres, the natural fibres present other advantages such as: lower cost, abrasiveness and density, and are biodegradable [2]. However, they present important disadvantages such as: thermal and mechanical degradation during processing, which can render them unable for certain applications and the incompatibility between the hydrophilic natural fibres and the hydrophobic thermoplastic matrix that makes it necessary to use coupling agents to improve the adhesion fibre/matrix [3,4]. The commonly manufacture process of natural fibre-reinforced thermoplastic composites are injection moulding and extrusion which are expensive and tend to degrade the fibres. A novel method to produce sisal fibre mats was developed by Jayaraman [5], which also obtain the best possible mechanical properties for sisal reinforced polypropylene composites, achieved when fibre length was greater than 10 mm and the fibre mass fraction in the range 15-35 %.

Fibre-matrix interface is the result of the chemical bond between the fibre surface and the matrix and plays a key role on mechanical properties since it transfers the load between the matrix and the reinforcement fibre. Surface fibre treatments to improve mechanical properties are abundantly reported in literature, particularly the alkaline solution [6] and coupling agents such as silanes and maleic anhydride grafted polypropylene which was the most efficient for cellulose fibres in polypropylene composites [7].

Many studies of the parameters affecting the mechanical properties are reported in literature [5-12] but, in spite of certain aspects of their behaviour such as their viscoelastic, viscoplastic or time-dependent due to creep and fatigue loadings [3] are still poorly understood. In many cases experimental data of the mechanical properties show inconsistent values, particularly when tested under different processing conditions in consequence of the irregular characteristics of the natural fibres and by its hydrophilic nature associated with hydrophobic nature of many thermoplastics.

Although the use of natural fibre composites is continually increasing, their high level of moisture absorption, poor wettability by non-polar plastics and insufficient adhesion between untreated fibres and the polymer matrix can lead to debonding with the time. Degradation of the mechanical behaviour of these materials can be due to the exposure to environmental conditions such as humidity, sunlight or micro organisms. Water absorption can reduce the mechanical properties and promote dimensional instability [13]. Moisture penetration in composites can be conducted by three different mechanisms: capillarity transport into gaps and flaws at the interfaces between the fibres and the polymer, the transport by micro cracks in the matrix and the main process that consists in the diffusion of water molecules inside the micro gaps between polymer chains. In many cases, diffusion is a Fickian process in which the rate of diffusion is much less than that of the polymer segment mobility rapidly reaching the equilibrium inside the polymer that is maintained regardless of the amount of time. Espert *et al.* [14] conclude that water absorption of natural fibres/polypropylene composites follows a Fickian diffusion process and that the

*Corresponding author: josé.domingos@dem.uc.pt

kinetic parameters are influenced by the fibre content, the type of matrix and, mainly, by the temperature.

In this paper, tensile and bending properties of hemp short fibres and pine sawdust with polypropylene matrix are assessed and discussed. The effects of fibre weight fraction, fibre type and water absorption are studied. Natural fibres and particularly hemp fibres are being widely tested and increased used in panels namely in automotive industry consequence of its easy of recycling. Also pine sawdust microparticle filler can be considered as a green material. The objective of the paper is to compare the mechanical performance of these two natural reinforcements.

## Materials Processing and Testing

Stiffness modulus and ultimate strength were obtained from tensile and four points bending tests in polypropylene matrix reinforced with hemp short fibres or pine sawdust. The matrix material was a polypropylene copolymer high flow, CP0408L, supplied by Aclo Compounders Inc., Canada. Hemp fibres were cut from randomly oriented nonwoven reinforcement provided by J B Plant Fibres Enterprises Ltd. The sawdust was obtained directly by milling pine, resulting in particles of tens of microns in diameter.

The hemp fibres were subjected to the follow alkaline treatment: washing with distilled water and dried in an oven for 24 h at 60 ºC; immersion during 24 h in one methanol-benzene mixture (1:1) to dewaxed the fibres followed by the immersion during 30 min, at room temperature, into a bath NaOH at a concentration of 18 wt% followed by washing of the fibres in distilled water; neutralization with a solution of 2 wt% sulphuric acid; washing again with distilled water and finally drying at ambient temperature during 48 h. The hydroxide solutions are used to modify the crystalline domains of cellulose. By treating the polysaccharide with NaOH the mercerization of cellulose occurs. It has been observed that the 18 % NaOH concentration is the ideal to get the right crystallinity and mercerization.

Afterwards, the fibres and resin were placed in alternated layers and pre-processed at 240 ºC (above melting temperature) for one hour. Then, fibres were cut from long fibres with an average length of 4 mm and subjected to a homogenisation process.

The sawdust fibre was solely pre-washed in tap water followed by washing with distilled water and dried in an oven for 24 h at 60 ºC. The two main dimensions in transverse section of hemp fibres and sawdust fibre were measured in the transversal sections of the specimens using a scanning microscopy and a magnification of 80-100X. The average major dimension ($\mu$m), maximum measured dimension ($\mu$m) and standard deviation of major dimension ($\mu$m) were: 12, 47, and 10.5, respectively, for sawdust pine and 36, 74, and 24, for hemp fibre. For pine sawdust some particularly big particles were found which seems indicate that the joining between little particles had occurred.

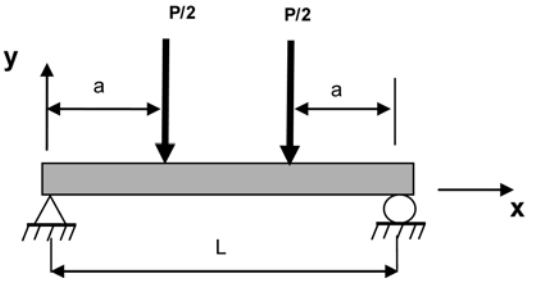


**Figure 1.** Schematic apparatus of four points bending tests.

After the preparation of the mixture matrix/fibre with an intended weight fraction, the composites were manufactured by using an industrial injection moulding DEMAG machine with a clamping force of 100 tones. The temperature was 225 ºC in the process zone and 70 ºC in the entrance zone. The mould was specially prepared to directly obtain the specimens with the geometry appropriate to the type of test. For tensile they were used specimens of dog bone type with total length 150 mm, length and width in the proof zone of 60 and 10 mm, respectively and 4 mm thickness. For the four points bending tests, the samples were square bars with 125 mm length and cross section $12 \times 4$ mm$^2$. Figure 1 presents the loading scheme of the four points bending tests. All specimens were done with 5 mm thickness. In the paper the test series are identified by the following code: fibre (H-hemp fibre, PS-pine sawdust reinforcement): loading mode (4PB-four points bending, T-tension): weight fraction in percentage.

The specimens were observed in scanning microscopy in order to see the aspect of the composites reinforcements. In both materials the homogeneous of fibre distribution is relatively fair showing a large range of particle size. Pine fibres tend, in some cases, to join in particle agglomerates promoting a poor adhesion in fibre/matrix interface.

In order to study the humidity effect on the degradation of the properties of the materials some series of pine sawdust reinforced composites were immersed in a tank with water at the controlled temperature of 25 º during periods up to 20 days. These specimens were withdrawn from the water and tested immediately.

The mechanical tests were performed by using an Instron universal testing machine, equipped with computer controller and recorder system according to ASTM D638 and ASTM D790-98, for tensile and flexural properties, respectively, with a loading rate of 1 mm/minute. The load versus displacement curves were obtained directly and the stresses were calculated by using the relationships for tension bars and linear bending beams.

The displacement analysis of the four points bending tests was made using over position method applied to elastic beams, by the equation (1):

$$\delta = \frac{Pa^2}{12EI}[3(L-4a)] \quad (1)$$

Where, δ is the bending displacement, $P$ is the load, $E$ is the Young modulus, $I$ the transverse section inertia momentum, $L$ and a are the dimensions reported in Figure 1.

In tension, the strain was obtained by the length elongation divided by the initial reference length and the stiffness modulus by linear regression in the linear region of the stress versus strain plots, while in four points bending, the stiffness modulus was calculated by linear regression of the plots $E$ against the bending displacement δ (where $E$ is given as per equation (1)).

## Results and Discussion

Figure 2(a) and (b) shows typical curves obtained in tension and in flexural tests in terms of stress versus strain and stress against displacement, respectively. These figures show a low influence of fibre content on the stiffness modulus in tension while in bending a major effect was observed. For both loading modes a non linear behaviour occurs and important effect of reinforcement content on the ultimate stress was observed.

For each test condition four tests were carried out to calculate average values and standard deviation of stiffness modulus and ultimate strength. Stiffness modulus was calculated by regression in the linear region of the stress versus strain plots and the ultimate strength is the maximum value of the stress.

Figure 3(a) and (b) show the average values and the standard deviation of the stiffness modulus against the weight fraction for the pine sawdust and hemp fibres, respectively. The analysis of these results, confirm the

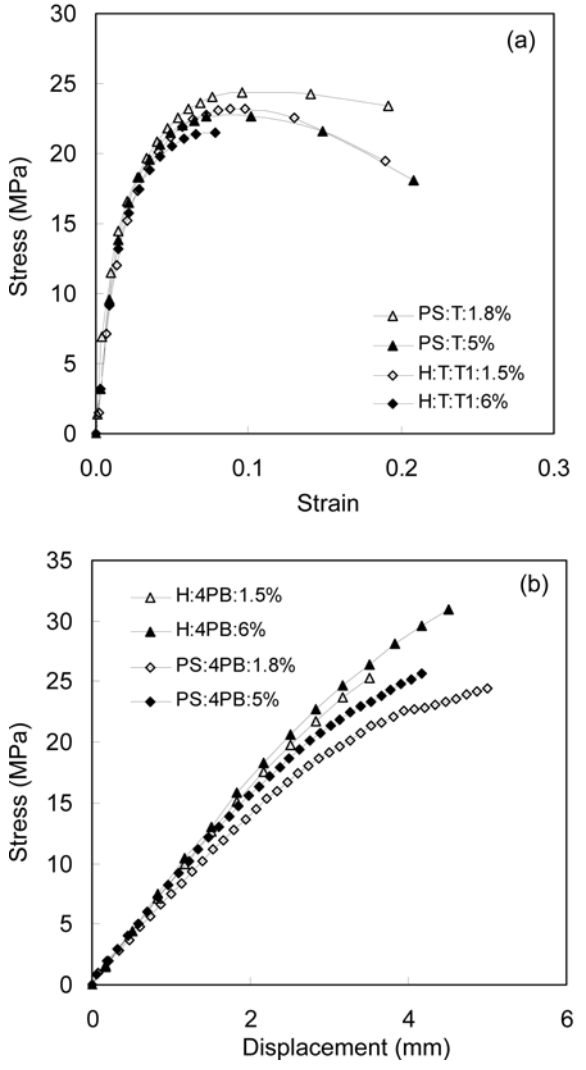


**Figure 2.** Typical plots; (a) stress-strain curves in tension tests and (b) stress-displacement curves in bending tests.

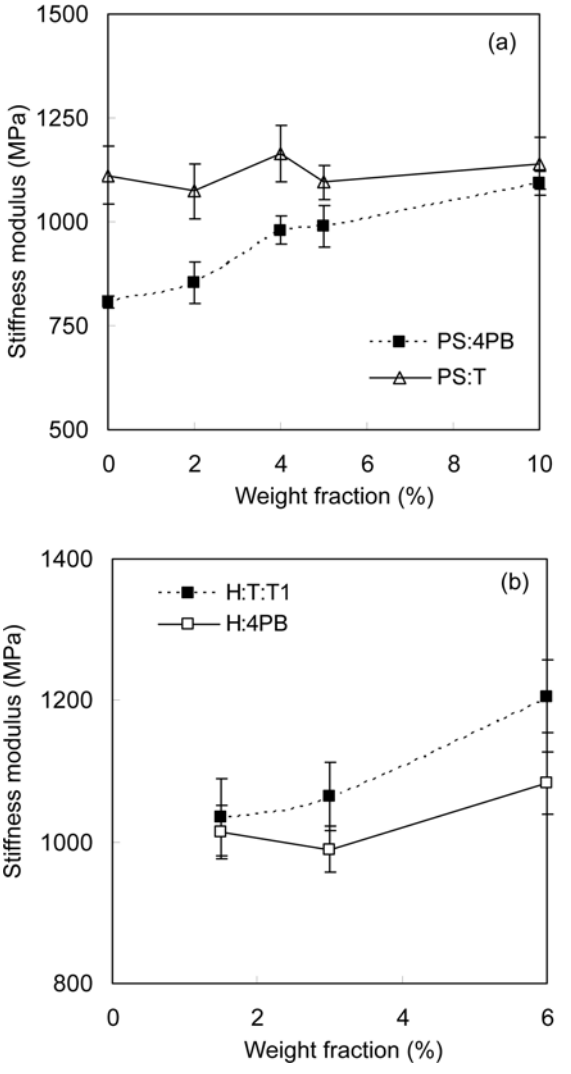


**Figure 3.** Stiffness modulus against the weight fraction; (a) pine sawdust fibres and (b) hemp fibres.

previously stated namely: for the specimens tested (with relatively low weight fraction) the stiffness of the composite is mainly dominated by the matrix properties. In spite for 4PB tests in pine sawdust reinforcement a significant increasing on the stiffness modulus with the increase of fibre content was observed while for tensile the effect of fibre content was negligible. For hemp reinforced composites a increasing of the stiffness modulus fibre volume fraction was obtained, as would be expected by applying for example the mixtures rule.

Figure 4(a) and (b) show, the average values and the standard deviation of the ultimate strength (defined as the stress at maximum load) against the weight fraction, for the pine sawdust and hemp fibres, respectively. The ultimate strength obtained for both fibre types presents values relatively close, once the tested composites were low

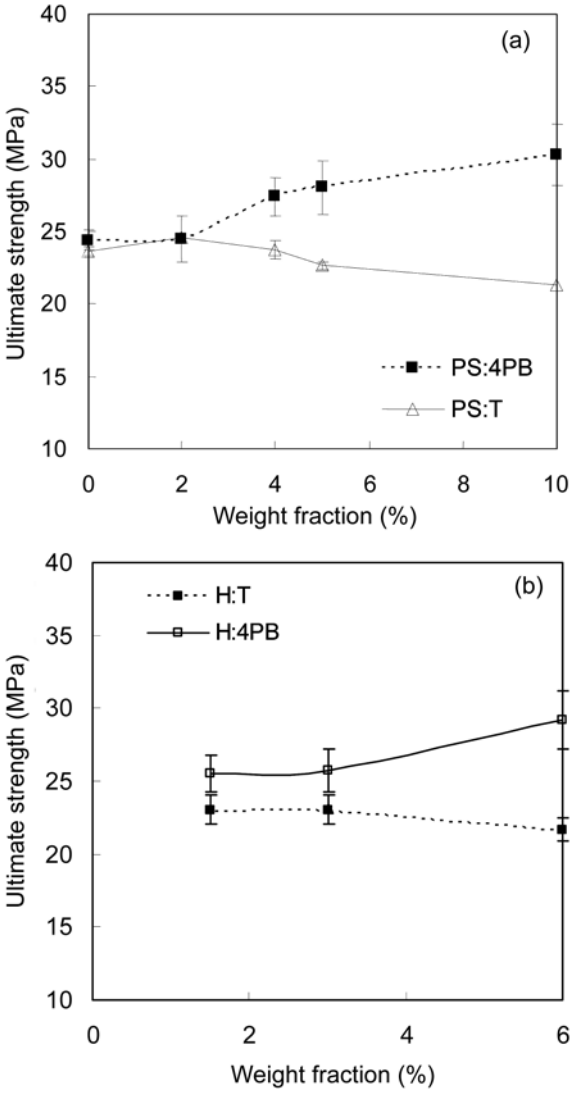


**Figure 4.** Ultimate strength against the weight fraction; (a) pine sawdust fibres ans (b) hemp fibres.

reinforcement contents and then the strength is dominated by matrix properties, but the effect of fibre content is different for tension or bending loads. The strength in tension tends to decrease with the increasing of the fibre content in opposite with fibre content effect in bending. This effect is contrary to the observed with conventional glass or carbon fibres, but it is usual in natural fibres. This mechanical behaviour was also observed by Jayaraman [5] in tensile tests for low sisal fibre content composites. In short fibre composites, mechanical properties, particularly tensile strength at low fibre content, decreases with the fibre weight increasing which has been explained with dilution of the matrix and introduction of flaws at the fibre ends where high stress concentrations occur, causing the debond between fibre and matrix. For higher fibre content, the matrix is sufficiently restrained and the stress is more evenly distributed becoming more effective the reinforcement effect.

By other side the ultimate strength in tension is lower than in bending. The lower strength in tension can be caused by a higher sensibility to non homogeneous distribution and tendency to fibre joining in agglomerates as was also observed in some specimens with sawdust fibres. This must be indicated as the need to improve manufacture techniques to avoid the fibre joining. The scanning electronic microscopy also shows some bad interface adhesion being one of the factors contributing for the poor performance of these composites.

To better understand the environmental effects the water absorption was obtained using a technique based on the weight control. The samples were previously dried in an oven at 110 ºC during two hours and afterwards cooled in air, weighted (dry weight) and immersed in water during 24 hours. Next, they were removed from the water, following the surface water was cleaned and afterwards weighted periodically at 30 second of intervals. The moisture losing was defined as

$$M(t) = \frac{\text{Wet weight} - \text{Current weight of moist material}}{\text{Wet weight}} \times 100\ \% \quad (2)$$

Figure 5(a) and (b) presents the moisture losing versus the time for specimens reinforced with pine sawdust and hemp fibres, respectively. These results show for both reinforcements that the moisture content tends to a quick stabilization. The figure shows also that the water diffusion process is governed by the Fick's Law and increases with the fibre content.

Figure 6(a) and (b) show, respectively, the stiffness modulus and the ultimate strength, against the number of days of specimen immersion in water for the pine sawdust fibre composites tested in tension. In spite of the quick water absorption and saturation as shown in Figure 5 the water degradation effect on the mechanical properties was not observed probably because, for low fibre content, the stiffness and strength are mainly controlled by the matrix

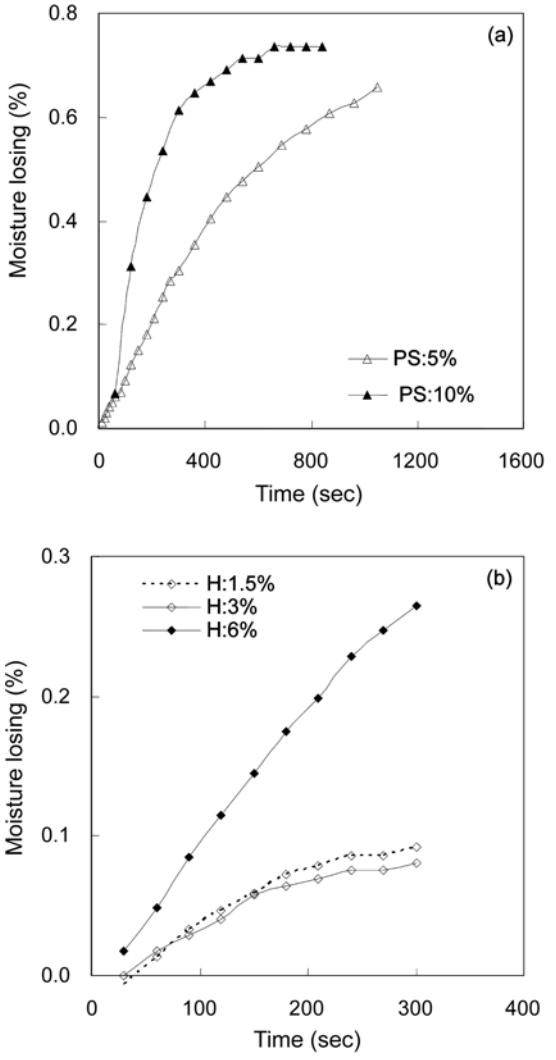


**Figure 5.** Moisture losing curves; (a) pine sawdust fibres and (b) hemp fibres.

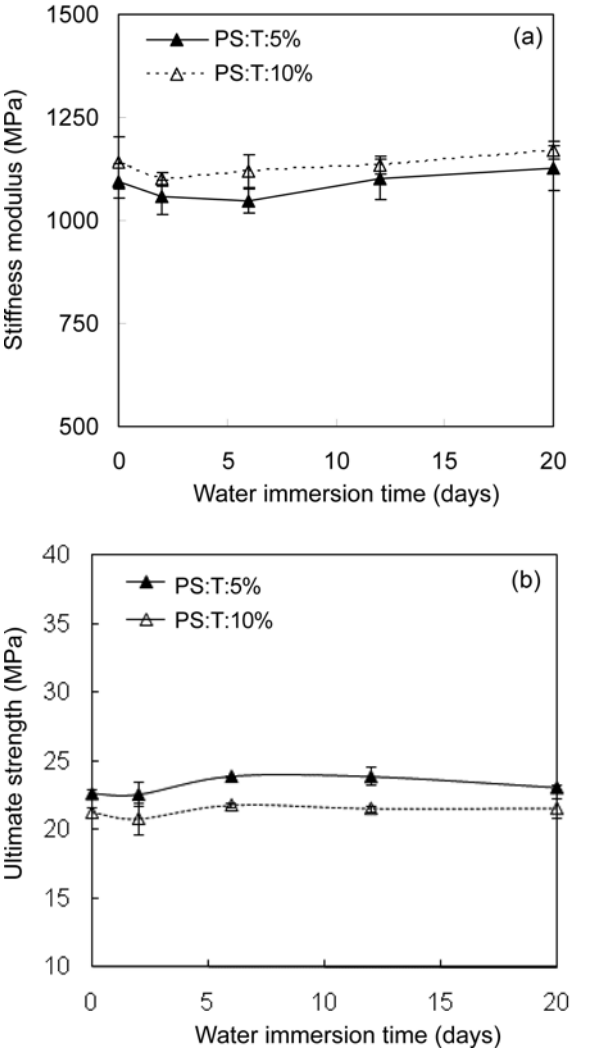


**Figure 6.** (a) Stiffness modulus against the water immersion time. and (b) ultimate strength against the water immersion time.

properties and by other side the immersion time was enough to promote significant blister. Furthermore, the greater effect of water would be provided for the degradation of the interface, which in this case had a weak adhesion even in the absence of water.

## Conclusion

The effects of fibre weight fraction, fibre type on tensile and bending properties of hemp short fibres and pine sawdust with polypropylene matrix were assessed and discussed. For 4PB tests pine sawdust reinforced composites show a significant increasing on the stiffness modulus with the increase of fibre content while for tensile the effect of fibre content was negligible. The hemp reinforced composites shows an increasing of the stiffness modulus fibre volume fraction. Ultimate strength tends to increase slightly with fibre content for bending loads, but for tension and particularly for low fibre content (lesser than a critical value) a slight decreasing tendency can be observed. Composites with low pine sawdust fibre content did not present water degradation effect on the stiffness modulus and ultimate strength until 20 days of the specimen immersion in water in spite of the quick water absorption observed.

## References

1. P. Mapleston, *Modern Plastics International*, **May**, 39 (1997).
2. A. K. Bledzki, S. Reihmane, and J. Gassan, *Polym. Plast. Technol. Eng.*, **37**, 451 (1998).
3. J. Gassan, *Composites Part A: Appl. Sci. Manufact.*, **33A**, 369 (2002).
4. J. George, M. S. Sreekala, and S. Thomas, *Polym. Eng.*

*Sci.,* **41**, 1471 (2001).
5. K. Jayaraman, *Comp. Sci. Technol.*, **63**, 367 (2003).
6. E. T. N. Bisanda and M. P. Ansell, *J. Mater. Sci.*, **27**, 1690 (1992).
7. A. Espert, W. Camacho, and S. Karlson, *J. Appl. Polym. Sci.*, **89**, 2353 (2003).
8. J. Gassan and A. K. Bledzki, *Appl. Compos. Mater.*, **7**, 373 (2000).
9. K. M. M. Rao, K. M. Rao, and A.V. R. Prasad, *Materials and Design*, **31**, 508 (2010).
10. S. Jain, R. Kumar, and U. K. Jindal, *J. Mater. Sci.*, **27**, 4598 (1992).
11. G. F. Torres and M. L. Cubillas, *Polym. Testing*, **24**, 694 (2005).
12. P. J. Herrera-Franco and A. Valadez-González, *Compos. Part B: Eng.*, **36**, 595 (2005).
13. M. Tajvidi and G. Ebrahimi, *J. Appl. Polym. Sci.*, **88**, 941 (2003).
14. A. Espert, F. Vilaplana, and S. Karlson, *Compos. Part A: Appl. Sci. Manufact.*, **35A**, 1267 (2004).