

Composite of Polyethylene and Kenaf, a Natural Cellulose Fiber

INTRODUCTION

There is a growing interest in the uses of natural fibers as the reinforcements for synthetic polymers.^{1,2} Since natural fibers are biodegradable, the composites of natural fibers and synthetic polymers may offer a new class of materials which can provide environmental protection. In addition, the low cost and high specific properties of natural fibers imply a significant property potential for the commodity synthetic polymers. These appealing features place the development of these composites in good perspective.

Kenaf is the fiber extracted from the bast of the plant, *Hibiscus cannabinus*.³ The major chemical composition of Kenaf is cellulose which accounts for 72.8 wt %.³ Kenaf is now a crop grown commercially in the U. S., and has already been used to produce papers. Kenaf fibers have a high reported tensile modulus of 60 GPa and a tensile strength of 11.9 GPa.¹ These good tensile properties qualify Kenaf fibers as a good reinforcement for the common synthetic polymers that have moduli around 1 GPa.

Because Kenaf starts to degrade thermally at about 200°C, it cannot be used as the reinforcement for polymers whose processing temperatures are higher than 200°C. Nevertheless, Kenaf appears to be an attractive reinforcement for the low melting and widely used polyolefins. The high tensile properties of Kenaf fibers can reinforce the polyolefin matrices considerably. The disadvantage of these fibers is a high moisture absorption which may be overcome by imbedding the fibers in the polyolefin matrices. In this article, we report a study on the composites of polyethylene (PE) and continuous Kenaf fibers. The effect of Kenaf fibers on the crystallization of PE and the tensile properties of PE/Kenaf composites are reported.

EXPERIMENTAL

The PE used for preparing the composites is Du Pont Alathon 7026, with the weight average molecular weight of 128,000. The fibers were obtained from Kenaf Co., Ltd., McAllen, Texas. The average length of the fibers used in this study was about 8 cm, and they were dried at 95°C for 12 h before use. A schematic sketch for the preparation of PE/Kenaf fiber composites is shown in Figure 1. The Kenaf fibers were aligned uniaxially on a mold by fixing the ends with scotch tape. The composites were then pre-

pared by compression molding at 160°C for 5 min followed by a quench into cold water.

The volume fraction of Kenaf fibers in the composite was approximated from the enthalpy of melting of PE. Assuming the presence of the fibers did not significantly affect the ultimate crystallinity of the PE matrix, the weight fraction of the fiber in the composite can be calculated by

$$w_{\text{kenaf}} = 1 - \frac{\Delta h_f}{\Delta h_{fp}} \quad (1)$$

where Δh_f is the measured enthalpy of melting of the composite and Δh_{fp} is that measured for the pure PE. The enthalpy of melting of pure PE prepared in this study is 183 J/g, which corresponds to the crystallinity of 63%. The weight fraction of Kenaf fibers in the composite was then converted to volume fraction by

$$\phi_{\text{kenaf}} = \frac{(\rho_{PE}/\rho_{\text{kenaf}})w_{\text{kenaf}}}{(1 - w_{\text{kenaf}}) + (\rho_{PE}/\rho_{\text{kenaf}})w_{\text{kenaf}}} \quad (2)$$

where ρ_{PE} and ρ_{kenaf} are the densities of PE and Kenaf fiber, respectively. The densities were determined by density titration using carbon tetrachloride and ethanol as the titration liquids. The results gave $\rho_{PE} = 0.96 \text{ g/cm}^3$ and $\rho_{\text{kenaf}} = 1.38 \text{ g/cm}^3$.

RESULTS AND DISCUSSION

Crystallization Kinetics

The presence of Kenaf fibers may affect the crystallization kinetics of polyethylene. It is known that the reinforcements may act as the nucleation sites, which may consequently promote crystallization. The effect of Kenaf fibers on the crystallization kinetics of the PE matrix was examined by DSC. The composites were first annealed at 160°C for 2 min in a Perkin-Elmer DSC 7 followed by cooling scans at 20°C/min. The peak temperatures of the crystallization exotherms during cooling are shown in Table I. It can be seen that within the experimental error of $\pm 2^\circ\text{C}$, the peak temperatures are virtually the same for all composites investigated. In addition, the peak temperatures do not vary systematically with fiber concentration. Therefore, Kenaf fibers do not appear to act as the nucleation sites for the PE matrix. The observation by optical microscopy also confirms that the crystal nucleation does not occur preferentially on the Kenaf fibers.

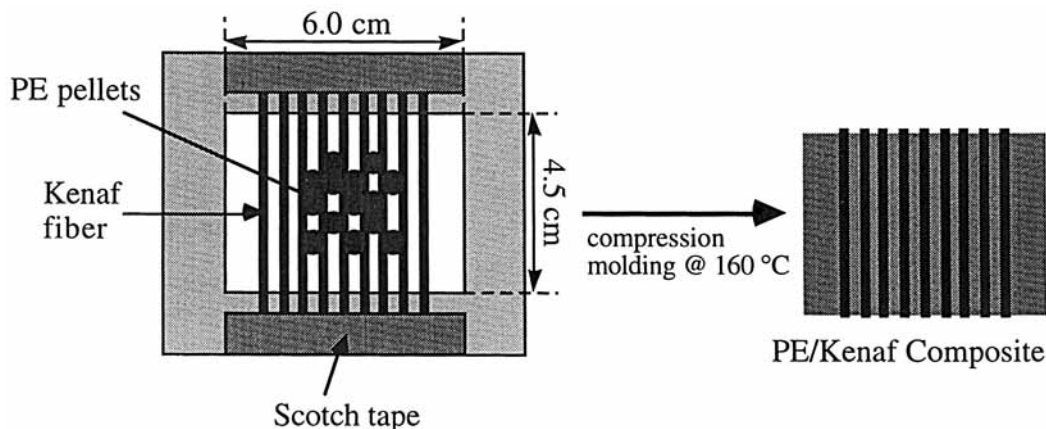


Figure 1 Schematic sketch of the preparation of PE/Kenaf fiber composites in this study. Uniaxial fibers shown only partially covered by PE.

Since polyethylene molecules are nonpolar, but the cellulose compositions of Kenaf are polar, the interfacial bonding between Kenaf and PE is not favored. Consequently, nucleation of polyethylene on the surfaces of the Kenaf fibers is not significant.

Mechanical Properties

The tensile properties along the fiber direction of PE/Kenaf composites were investigated. The tensile tests were carried out in an Instron at the stretching rate of 0.1 cm/min. The stress-strain curves of the PE matrix and its composites are shown in Figure 2. It can be seen that the tensile modulus, given by the initial slope of the stress-strain curve, increases with increasing fiber concentration in the composites. For the composites, a sudden drop in tensile stress is observed at low strain. This is due to the breakage of the Kenaf fibers during the tensile test. After the breakage of the fibers, it was observed that the remaining polyethylene matrix can still keep being elongated.

The tensile moduli of the composites are plotted against the fiber concentration in Figure 3. It can be seen that

the tensile modulus increases with increasing fiber concentration, and the linear additivity appears to provide satisfactory prediction for the tensile moduli of the composites. The composite of the highest fiber concentration prepared in this study is 57 vol %, for which the tensile modulus is increased by as much as 7 times over the value for the matrix polyethylene. It is noted that the tensile modulus of the pure Kenaf fibers used in this study is only about 4 GPa, which is much lower than the literature value of 60 GPa.² This indicates that the fibers used in this study are far from perfect. As Kenaf fibers of better perfection become available, the moduli of the composites can be even higher than those reported here.

CONCLUSION

We have shown in this short article that the composites with Kenaf fibers provide a promising way to improve the

Table I Peak Temperatures of the Crystallization Exotherms (T_p) of PE/Kenaf Fiber Composites

Volume Fraction of Kenaf	T_p (°C)
0.00	109.1
0.13	107.7
0.18	107.3
0.21	106.3
0.44	107.1

The DSC cooling scans were conducted at $-20^\circ\text{C}/\text{min}$ from 160°C .

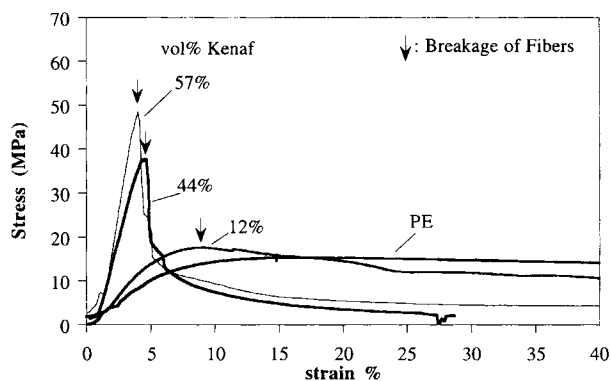


Figure 2 Stress-strain curves of PE/Kenaf fiber composites. The volume fraction of Kenaf fiber is indicated in the figure.

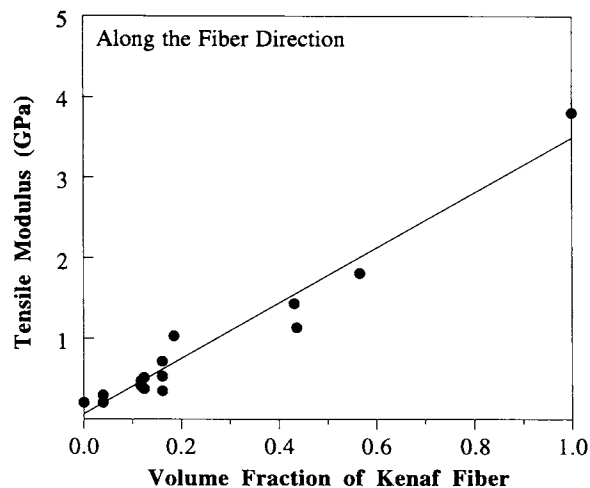


Figure 3 The variation of tensile moduli of PE/Kenaf fiber composites with the volume fraction of Kenaf fiber.

stiffness of polyethylene considerably. The crystallization kinetics study of PE in the composites has suggested that the interfacial bonding between Kenaf and PE appears to be unfavored. Future studies should be focused on the improvement of the interfacial bonding. Such improvement may possibly be achieved by incorporating polar groups onto the polyolefin molecules; examples include maleic-anhydride-grafted polyolefins and the ionomers of polyolefins.

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