Instrumented Impact Testing of Kenaf Fiber Reinforced Polypropylene Composites: Effects of Temperature and Composition

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ABSTRACT: An instrumented Izod test was used to investigate the effects of fiber content, coupling agent, and temperature on the impact performance of kenaf fiber reinforced polypropylene (PP). Composites containing 0–60% (by weight) kenaf fiber and 0 or 2% maleated polypropylene (MAPP) and PP/wood flour composites were tested at room temperature and between −50°C and +50°C. At room temperature, kenaf greatly reduced energy to maximum load (EML) in reversed notch tests but had little effect in notched tests. MAPP improved all test values. At –25°C, PP specimens changed from ductile to brittle. Kenaf composites containing MAPP consistently yielded higher EML values than did both unfilled PP specimens and wood flour composites in notched impact tests, over the temperature range investigated. The EML values for kenaf composites were about half those for unfilled PP specimens in reversed notch tests at room temperature, but performance was similar at low temperatures.

KEY WORDS: impact, polypropylene, kenaf, natural fibers.

INTRODUCTION

THE TREMENDOUS GROWTH of wood-plastic composites in exterior housing applications in the United States has captured the attention of industry. Commercial wood-plastics processing has focused on the use of wood flour as a filler in extruded composite products. The greatest growth has been in exterior building products that have limited structural requirements, such as decking and railing. However, the reinforcing potential of natural fibers other than wood remains largely untapped in the United States.

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Figures 3–6, 8 and 9 appear in color online: http://jrp.sagepub.com

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Natural fibers are advantageous as reinforcement in thermoplastics because of their low cost, low density, and good mechanical properties. Kenaf fibers are extracted from the base of the plant *Hibiscus cannabinus*. Filament lengths of 1 m are common. The filaments consist of discrete individual fibers, generally 2–6 mm long, which are composed of cellulose, lignin, pectins, and hemicellulose. The properties of the fibers depend on various parameters, such as the relative quantity of the constituents and the degree of polymerization and orientation of the reinforcing crystalline cellulose.

The specific moduli (i.e., initial tangent modulus per unit weight) of kenaf-polypropylene composites are comparable to that of glass-polypropylene composites and have potential for the automotive, building, and furniture industries [1]. Sanadi et al. [1–3] have investigated many mechanical properties of kenaf-polypropylene composites. The instrumented impact performance of these composites is presented in the work reported here.

Despite recent criticism, the Izod and Charpy impact tests (ASTM D256) are still the most common tests for relative comparisons between plastic materials at high strain rates. The Izod impact test is not a measure of a fundamental material property but changes with test and specimen geometry. However, this test can give a quick indication of relative performance at high strain rates, as well as the notch sensitivity of the material. By instrumenting the tup (impacting head), a full load-deflection curve can be obtained, yielding more information. Though by no means a complete solution to the limitations of the Izod impact test, instrumenting the tup provides more information on impact performance.

The toughness of thermoplastics reinforced with glass fiber has been heavily researched [4–6]. However, far fewer researchers have investigated the impact toughness of thermoplastics reinforced with natural fiber. Even though researchers have reported the impact performance of such thermoplastics [2,7,8], these tests have not been instrumented and the information gained is limited. Additionally, the effect of temperature on the impact performance of the composites has not been investigated.

In the research reported here, we used an instrumented Izod impact tester to investigate the effects of fiber content, coupling agent, and temperature on the impact performance of fiber-plastic composites.

EXPERIMENTAL

Materials

The polypropylene (PP) was a homopolymer with a melt flow index of 12 g/10 min (Fortilene 1602, Solvay Polymers, Inc., Deer Park, TX). A maleated polypropylene (MAPP) coupling agent (G-3015, Eastman Chemical, Kingsport, TN) was added to some blends to improve fiber-matrix adhesion. The wood flour was nominal 40-mesh (particles that pass through 420-micron mesh screen) western pine from American Wood Fibers (Schofield, WI). Wood flour is comprised of wood fiber bundles and has a low aspect ratio, typically five or less. The kenaf fibers were obtained from Ken-Gro Corporation (Charleston, MS) and had a significantly higher aspect ratio than that of the wood flour.

Blends of PP and 0%, 20%, 30%, 40%, 50%, and 60% kenaf (by weight) were prepared with and without 2% MAPP. Samples of unfilled PP and PP filled with 50% wood flour were also prepared with and without MAPP.

Specimen Preparation

The PP, MAPP, and kenaf or wood fibers were compounded in a 1 liter high-intensity thermokinetic mixer (K Mixer, Synergistics, Inc., St. Remi de Napierville, Quebec). The thermokinetic mixer is a simple batch mixer in which several high-speed blades supply the energy to melt the polymer and blend the material. An infrared sensor monitors the temperature of the material. The blended material is discharged at a pre-set temperature, cooled in a cold press, and granulated. Batches of 150 g material were processed between 5,500 and 5,700 rpm (rotor tip speed of about 30 m/s) with a discharge temperature between 395°C and 405°C, depending on the amount of fiber in the composite. The discharge temperature was varied to provide sufficient time to adequately disperse the fibers in the polypropylene melt, yet properly discharge the molten blend.

The compounded material was dried at 105°C for at least four hours prior to injection molding using a 33 ton reciprocating-screw injection molder (Vista Sentry VSX-33, Cincinnati Milacron, Batavia, OH). For impact tests, specimens were 63.5 by 12.7 by 3.2 mm. The specimens were notched with a fly cutter (V-notch, 45° angle) to a depth of 2.54 mm according to ASTM D256 [9].

Mechanical Testing

Specimens were tested at 1 m/s using a GRC 8250 instrumented impact tester (Instron Corp., Canton, MA) with an Izod test jig. For each composite, five specimens were struck on the notched side (notched impact test) and five specimens were struck on the side opposite the notch (reversed notch test). An EC 8250 environmental chamber (Instron Corp.) was used to control the temperature. Specimens were allowed to equilibrate at each temperature for approximately 15 min before testing to ensure that their temperature was the same as the chamber temperature. All composite blends were tested at −25°C and 25°C. The unfilled PP specimens and composites containing 50% kenaf fiber or wood flour were also tested at 50°C, 0°C, and −50°C.

Dynamic effects are common in instrumented impact tests and can limit the information that can be acquired, especially in tests of brittle material. Because the dynamic effects were large in many tests, the dynamic modulus was not determined. However, the general shape of the curve was noted, and the values for maximum load, energy required to reach maximum load (EML), and deflection at maximum load (DML) were determined. The specimens were tested at a tup velocity of only 1 m/s to minimize oscillations.

Dynamic Mechanical Thermal Analysis

For dynamic mechanical thermal analysis (DMTA), dynamic properties were measured using a Rheometrics DMTA MKIII analyzer (Rheometrics Scientific, Inc., Piscataway, NJ). Specimens (25 by 5 by 1 mm) were cut from injection molded specimens. The specimens were tested in single cantilever mode with a 14 mm span, 16 μm deflection amplitude, 1 Hz frequency, and heating rate of 2°C/min. The temperature at which the

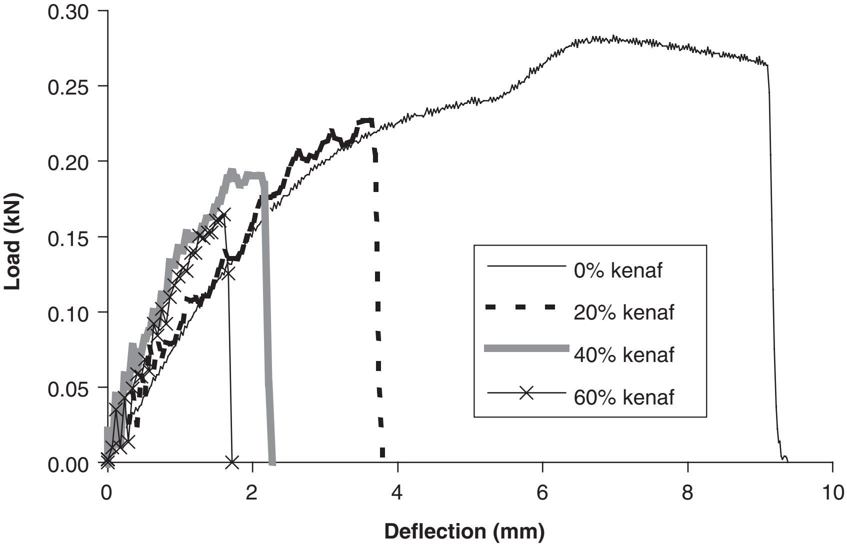

Figure 1. *Effect of kenaf fiber content on reversed notch Izod impact performance of specimens without coupling agent.*

tan δ peak occurred was determined to get an indication of the ß transition temperature (T_g) of the composite.

Microscopy

Fracture surfaces were sputtered with a gold-palladium alloy and analyzed on a scanning electron microscope (JSM-840, JEOL USA, Inc., Peabody, MA) at a working distance of approximately 25 mm.

RESULTS AND DISCUSSION

Fiber Content and Coupling Agent Effects at Room Temperature

We explored the effects of fiber content and coupling agent at high strain rates using instrumented Izod impact tests and PP-kenaf composites. Both notched and reversed notch tests were conducted.

Load-deflection curves for reversed notch impact tests on unfilled PP specimens and PP-kenaf composites with and without coupling agent are shown in Figures 1 and 2, respectively. In both notched and reversed notch tests, all specimens except the unfilled PP failed catastrophically once the maximum load was reached. The inflection point for the unfilled (0% kenaf) PP sample was thought to be caused by indentation of the thin, soft samples during testing. This inflection point was found only in reversed notch tests of unfilled PP specimens. Though not easily and precisely quantified because of the dynamic effects, adding kenaf fibers to the PP specimens increased stiffness. However, adding fibers to the PP also reduced deflection at failure. As fibers were added, polymer movement was restricted and stress concentrations were created at the fiber ends when the composite was put under strain. These stress concentrations led to the formation of cracks.

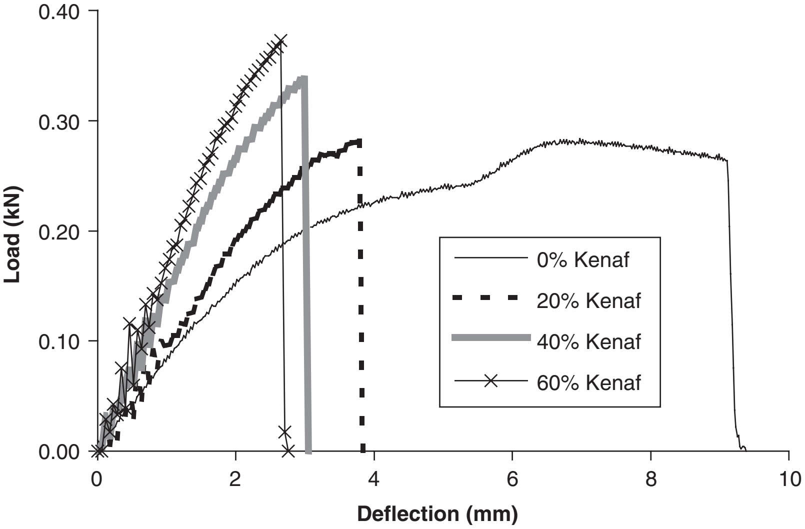

Figure 2. *Effect of kenaf fiber content on reversed notch Izod impact performance of specimens containing 2% coupling agent.*

The effects of coupling agent can be seen in a comparison of Figures 1 and 2. Most notable was the increased reinforcement of PP specimens with the addition of MAPP. In previous research, MAPP was found to be an effective coupling agent for natural fibers and PP [2,10–13]. The coupling agent improved fiber-matrix adhesion by bonding with the hydroxyl groups of the wood fiber and entangling its polymer chains in the bulk PP matrix [10]. Polypropylene nucleation by kenaf fiber (transcrystallinity) in both coupled and uncoupled kenaf composites also appears to play an important role in stress transfer at the fiber-matrix interface [13]. Adding coupling agent to PP-natural fiber composites improves strength and sometimes failure strain, but it has been shown to have little or no effect on stiffness [14]. The coupling agent also changes the crystallization and melting behavior of the composites [15]. Dynamic mechanical thermal analysis has suggested that better adhesion in coupled blends results in a higher number of restricted amorphous molecules, therefore changing the glass transition temperature [13].

Instrumented impact properties of PP-kenaf and PP-wood flour composites are presented in Table 1 and Figures 3–6. For specimens without MAPP, maximum load changed little with fiber content in notched impact tests (Table 1) but decreased with fiber content in reversed notch impact tests (Figure 3). However, for composites containing 2% MAPP, maximum load increased in both notched and reversed notch tests.

Figure 4 shows the superior reinforcing ability of composites made with kenaf fibers compared to those made with wood flour. This result is not surprising, considering the higher aspect ratio of kenaf fiber relative to wood flour.

Differing trends in the effect of kenaf fiber content on deflection at maximum load (DML) were found for notched and reversed notch impact tests (Table 1). For notched tests, slight increases in DML were found in composites with coupling agent and 20%–40% fiber content, but these gains were lost at 60% fiber content. This suggests that at low fiber contents, the reinforcing fibers can dissipate stress near the notch, making crack initiation more difficult. At high fiber content, as the number of stress concentrations and polymer restraint increase, specimens fail at lower deflections.

Table 1. Properties of PP-kenaf and PP-wood flour composites in instrumented notched and reversed notch impact tests at 25°C.[a]

			Notched Izod impact			Reversed notch Izod impact		
Fiber type	**Fiber content (%)**	**MAPP content[b] (%)**	**Max.load (kN)**	**DML[c] (mm)**	**EML[d] (J/m)**	**Max.load (kN)**	**DML (mm)**	**EML (J/m)**
Kenaf	0	0	0.096 (0.003)	1.06 (0.10)	17.0 (1.6)	0.271 (0.008)	6.76 (0.75)	381 (64)
	20	0	0.119 (0.004)	1.18 (0.22)	22.7 (4.2)	0.223 (0.016)	3.24 (0.37)	141 (22)
	30	0	0.113 (0.003)	1.10 (0.09)	21.4 (1.0)	0.213 (0.016)	2.56 (0.20)	107 (18)
	40	0	0.120 (0.006)	1.04 (0.13)	20.5 (1.9)	0.205 (0.019)	2.14 (0.09)	88 (5)
	50	0	0.125 (0.003)	0.77 (0.07)	16.3 (2.9)	0.183 (0.008)	2.10 (0.20)	74 (6)
	60	0	0.112 (0.004)	0.75 (0.10)	15.4 (3.2)	0.170 (0.014)	1.70 (0.32)	55 (16)
Kenaf	20	2	0.122 (0.009)	1.21 (0.16)	23.4 (3.2)	0.260 (0.019	3.71 (0.13)	189 (9)
	30	2	0.148 (0.007)	1.32 (0.09)	29.1 (2.6)	0.289 (0.024)	3.39 (0.16)	185 (22)
	40	2	0.167 (0.011)	1.24 (0.08)	33.3 (5.1)	0.307 (0.019)	3.09 (0.08)	185 (5)
	50	2	0.174 (0.004)	1.03 (0.04)	29.4 (1.9)	0.312 (0.014)	2.62 (0.10)	157 (14)
	60	2	0.178 (0.013)	0.97 (0.09)	28.2 (4.2)	0.360 (0.015)	2.54 (0.15)	164 (14)
Wood flour	50	0	0.108 (0.007)	0.63 (0.06)	11.8 (1.9)	0.180 (0.014)	1.696 (0.54)	46 (8)
	50	2	0.118 (0.006)	0.64 (0.03)	12.5 (2.9)	0.250 (0.011)	1.81 (0.04)	79 (5)

[a] Averages of five replicates. Values in parentheses are one standard deviation.
[b] MAPP is maleated polypropylene coupling agent.
[c] DML is deflection at maximum load.
[d] EML is energy required to reach maximum load.

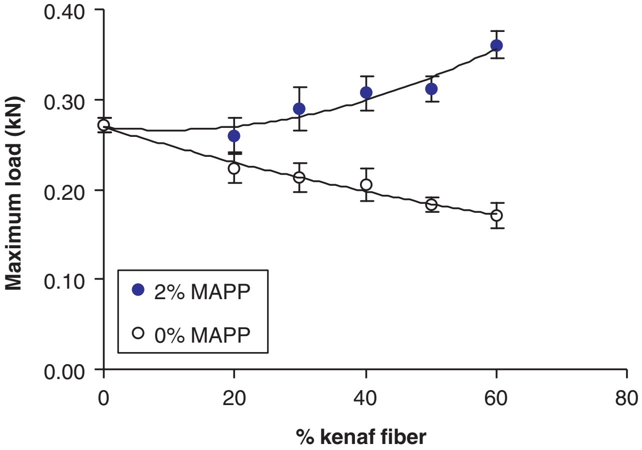

Figure 3. *Effect of fiber content and coupling agent (MAPP) on maximum load in reversed notch impact tests.*

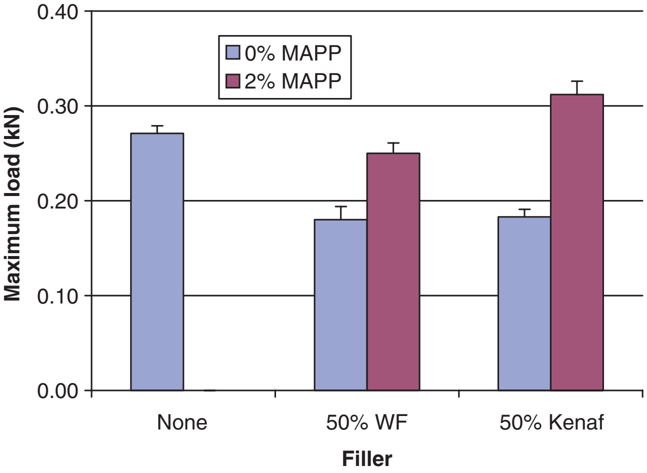

Figure 4. *Effect of wood flour (WF) and kenaf fiber as reinforcing fiber in specimens with and without MAPP in notched impact tests.*

For reversed notch tests, DML dropped sharply for composites with 20% kenaf, but this decrease moderated with the addition of more fiber.

Figures 5 and 6 show the effect of fiber content on energy to maximum load (EML) for notched and reversed notch impact tests. Since all but the unfilled PP specimens failed at maximum load, EML represents the total energy absorbed by the composites during failure. The values for the composites are consistent with previously reported uninstrumented Izod impact values [2].

In notched impact tests, EML reached a maximum and then, in the case of the uncoupled composite, decreased (Figure 5). The initial increase in EML was due to an increase in maximum load as stresses concentrated at the notch were distributed over a larger volume by the fibers or were dissipated by mechanisms such as fiber debonding or pullout. At high fiber content, the composite fractured at low deflections before high loads were reached, limiting EML values.

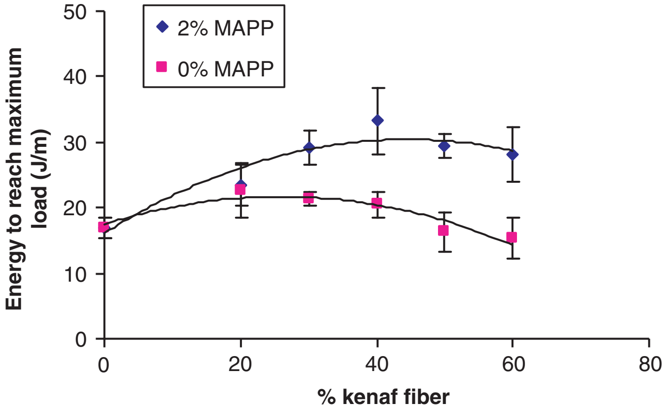

Figure 5. *Effect of fiber content and MAPP on energy to reach maximum load (EML) in notched impact tests.*

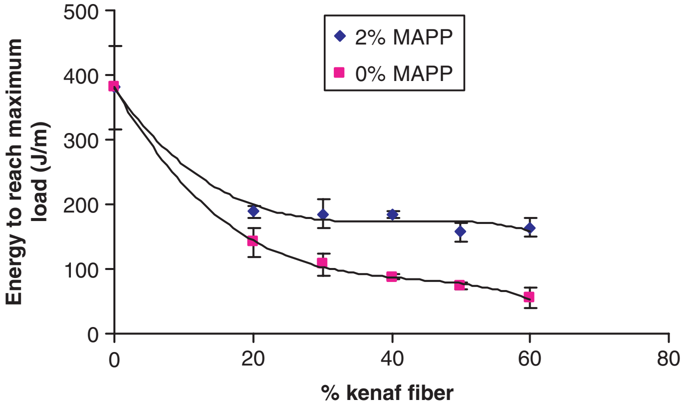

Figure 6. *Effect of fiber content and MAPP on EML in reversed notch impact tests.*

In reversed notch impact tests, EML was greatly reduced with the addition of 20% fiber (Figure 6). Polymer mobility was restricted, stresses were concentrated at the fiber ends, and the composite failed at low deflections. After the initial drop in EML with the addition of fiber, the change in EML moderated as DML reductions attenuated and maximum load increased (Table 1). Composites containing MAPP required about double the EML at high fiber contents than did composites without the coupling agent. Because of the interaction between the fiber, PP, and coupling agent, these composites can withstand greater deflections and reach higher stresses as a result of better fiber-matrix stress transfer.

Temperature Effects

In semi-crystalline polymers, the type and amount of the amorphous and crystalline phases govern the viscoelastic response during dynamic loading. The presence of kenaf fibers or wood flour creates further complexity in the morphology of the system.

Table 2. ß transition temperatures (T_g) of polypropylene (PP) and PP-kenaf composites.[a]

Material	T_g (°C)
Polypropylene (0% kenaf)	11.63
PP-kenaf composites	
20% kenaf	6.13
30% kenaf	6.03
40% kenaf	5.47
50% kenaf	6.10
60% kenaf	6.60

[a] Composites were made with coupling agent.

The surface properties of the fiber/filler and the use of a coupling agent or additives can alter the morphology of the bulk polymer phase and that of the interphase. This in turn influences the mechanical and dynamic properties of the composite.

Researchers have used dynamic mechanical analysis methods to investigate the thermal transitions of PP. The β transition (T_g) is due to molecular motions associated with unrestricted amorphous PP molecules [16]. Table 2 shows T_g values for unfilled PP specimens and kenaf composites. Although T_g can be designated by other methods, we used the temperature of the tan δ peak to assign T_g to the composites. Details on morphological effects and subsequent dynamic behavior can be found elsewhere [15,17]. Note that T_g is affected by frequency and can also change with the heating rate of the sample. However, as Table 2 indicates, T_g appears well below and above that of the testing temperatures of +25°C and −25°C, respectively. Consequently, ductile failure would be expected at 25°C and brittle failure at −25°C during impact tests on PP.

Results of instrumented impact tests for all composites at +25°C and −25°C are summarized in Tables 1 and 3, respectively. Unfilled PP specimens and selected composites were tested at 50°C, 0°C, and −50°C as well, to further explore the effects of the ductile-to-brittle transition of the matrix on impact performance and to compare wood flour and kenaf as filler. The results of these tests over the full range of temperatures are summarized in Table 4. In both notched and reversed notch impact tests, all specimens failed catastrophically once the maximum load was reached, except unfilled PP specimens at 0°C, 25°C, and 50°C (i.e., those temperatures near or above T_g).

In notched impact tests, maximum load values were similar at +25°C and −25°C. However, DML values were greatly reduced when the temperature was reduced to −25°C, as the PP matrix dropped below its T_g. This embrittlement of the PP matrix consequently resulted in large reductions in EML values of the composites.

Figure 7 summarizes EML for notched impact test on unfilled PP specimens and composites containing 50% wood flour or kenaf, over a wide range of temperatures. Although the temperature data for this impact test were quite variable, several conclusions can be drawn. First, for both unfilled PP specimens and composites, EML increases with temperature; EML increased 50% for kenaf-reinforced PP and 200% for unfilled PP when the temperature was increased from −50°C to +50°C. Second, the EML values for kenaf composites are higher than those for unfilled PP and wood flour composites. Adding 50% kenaf to PP doubled the maximum load and EML at low temperatures, presumably by distributing stresses at the notch tip over a larger volume or dissipating the stresses by mechanisms such as fiber debonding or pullout. However, adding 50% wood flour to PP did little to improve EML, probably because of the low aspect ratio of wood flour.

Table 3. ***Properties of PP-kenaf and PP-wood flour composites in instrumented notched and reversed notch impact tests at −25°C.***[a]

Fiber type	Fiber content (%)	MAPP content (%)	Notched Izod impact			Reversed notch Izod impact		
			Max.load (kN)	DML (mm)	EML (J/m)	Max.load (kN)	DML (mm)	EML (J/m)
Kenaf	0	0	0.096 (0.009)	0.51 (0.03)	8.0 (1.0)	0.332 (0.004)	2.25 0.12	122 (1)
	20	0	0.134 (0.009)	0.58 (0.04)	12.5 (1.6)	0.33 (0.014)	1.74 (0.11)	101 (10)
	30	0	0.141 (0.005)	0.57 (0.04)	12.8 (1.3)	0.324 (0.004)	1.52 (0.06)	86 (1)
	40	0	0.144 (0.004)	0.55 (0.04)	12.8 (1.3)	0.309 (0.005)	1.43 (0.04)	79 (35)
	50	0	0.135 (0.008)	0.53 (0.02)	11.5 (0.6)	0.268 (0.015)	1.21 (0.14)	58 (10)
	60	0	0.096 (0.009)	0.51 (0.03)	8.0 (1.0)	0.246 (0.010)	0.93 (0.26)	39 (16)
Kenaf	20	2	0.141 (0.007)	0.55 (0.22)	12.2 (1.0)	0.390 (0.025)	1.78 (0.11)	121 (16)
	30	2	0.145 (0.009)	0.54 (0.03)	12.2 (1.3)	0.410 (0.024)	1.81 (0.06)	126 (4)
	40	2	0.174 (0.007)	0.62 (0.06)	17.0 (3.5)	0.453 (0.012)	1.91 (0.04)	149 (8)
	50	2	0.190 (0.008)	0.60 (0.02)	17.3 (1.0)	0.460 (0.034)	1.66 (0.16)	135 (17)
	60	2	0.184 (0.012)	0.55 (0.05)	15.7 (1.9)	0.469 (0.033)	1.49 (0.12)	117 (17)
Wood flour	50	0	0.110 (0.005)	0.43 (0.03)	7.7 (1.0)	0.230 (0.006)	0.96 (0.04)	36 (3)
	50	2	0.124 (0.009)	0.47 (0.04)	9.0 (1.6)	0.324 (0.020)	1.32 (0.01)	71 (10)

[a] Averages of five replicates. Values in parentheses are one standard deviation.

Table 4. *Properties of PP-kenaf and PP-wood flour composites in instrumented notched and reversed notch impact tests at various temperatures.*[a]

		Notched Izod impact			Reversed notch Izod impact		
Filler	**Temperature (°C)**	**Max.load (kN)**	**DML (mm)**	**EML (J/m)**	**Max.load (kN)**	**DML (mm)**	**EML (J/m)**
None	−50	0.100 (0.010)	0.48 (0.08)	8.0 (1.0)	0.330 (0.010)	2.10 (0.15)	114 (16)
	−25	0.096 (0.009)	0.51 (0.03)	8.0 (1.0)	0.332 (0.004)	2.25 0.12	122 (1)
	0	0.104 (0.003)	0.63 (0.05)	10.6 (1.3)	0.008 (0.003)	4.03 (0.09)	289 (15)
	+25	0.096 (0.003)	1.06 (0.10)	17.0 (1.6)	0.271 (0.008)	6.76 (0.75)	381 (64)
	+50	0.093 (0.010)	1.55 (0.09)	24.3 (3.2)	0.211 (0.010)	7.83 (0.22)	339 (13)
50% kenaf	−50	0.228 (0.012)	0.57 (0.06)	20.2 (3.2)	0.530 (0.021)	1.69 (0.06)	155 (7)
	−25	0.190 (0.008)	0.60 (0.02)	17.3 (1.0)	0.460 (0.034)	1.66 (0.16)	135 (17)
	0	0.227 (0.010)	0.67 (0.05)	24.0 (3.2)	0.469 (0.011)	1.91 (0.09)	163 (5)
	+25	0.174 (0.004)	1.03 (0.04)	29.4 (1.9)	0.312 (0.014)	2.62 (0.10)	157 (14)
	+50	0.185 (0.005)	0.97 (0.01)	29.8 (1.3)	0.319 (0.011)	2.64 (0.22)	164 (11)
50% wood flour	−50	0.130 (0.010)	0.43 (0.05)	8.3 (1.6)	0.350 (0.010)	1.32 (0.11)	73 (13)
	−25	0.124 (0.009)	0.47 (0.04)	9.0 (1.6)	0.324 (0.020)	1.32 (0.01)	71 (10)
	0	0.163 (0.013)	0.52 (0.04)	13.4 (1.9)	0.319 (0.022)	1.36 (0.10)	76 (6)
	+25	0.118 (0.006)	0.64 (0.03)	12.5 (2.9)	0.250 (0.011)	1.81 (0.04)	78 (5)
	+50	0.129 (0.007)	0.79 (0.03)	17.0 (1.3)	0.231 (0.004)	2.02 (0.06)	90 (5)

[a] All composites contained 2% maleated PP. Averages of five replicates. Values in parentheses are one standard deviation.

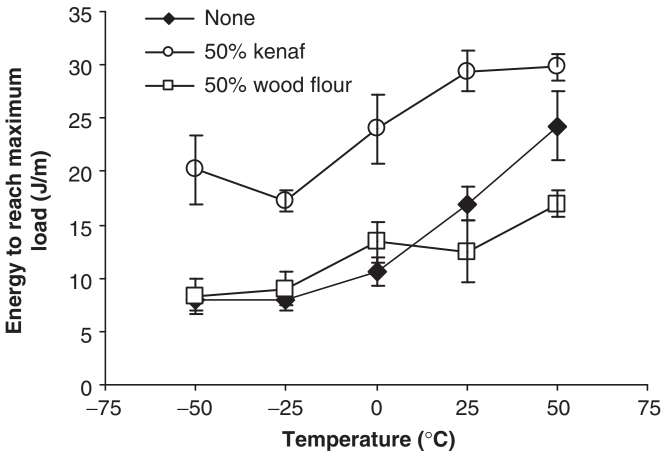

Figure 7. *Effect of temperature on EML of unfilled PP specimens and composites made with kenaf or wood flour in notched impact tests.*

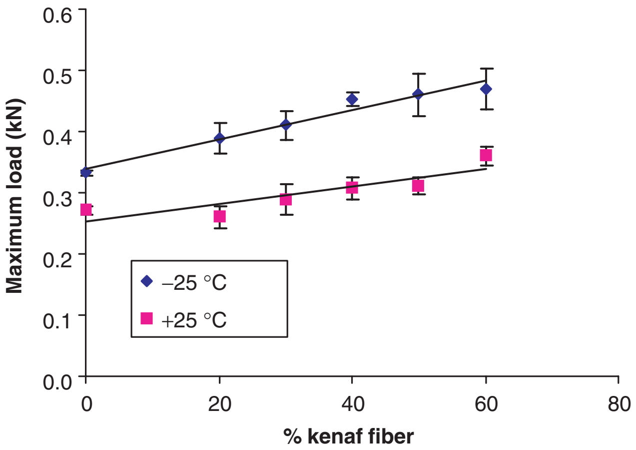

Figure 8. *Maximum load values for reversed notch impact tests above and below the β transition temperature (T_g) of PP.*

In reversed notch impact tests, maximum load increased from +25°C to −25°C as matrix yield strength increased (Figure 8). At +25°C, the ductile PP was embrittled by the addition of kenaf, resulting in low DML and EML values (Figure 9). However, because PP was already brittle at −25°C, adding fiber had little effect on either DML or EML.

Figure 10 summarizes the EML for reversed notch impact tests on unfilled PP specimens and selected composites over a wide range of temperatures. Although the PP-kenaf composites absorbed about half the EML than did unfilled PP specimens at high temperatures, reversed notch test performance was slightly higher at low temperatures. The low aspect ratio of wood flour limited its reinforcing ability, resulting in lower EML values for wood flour composites at all temperatures when compared to that of either unfilled PP or PP reinforced with kenaf.

The effect of temperature on impact behavior in reversed notch tests can be seen more clearly by examining deflection as a function of applied load in tests at +50°C (Figure 11)

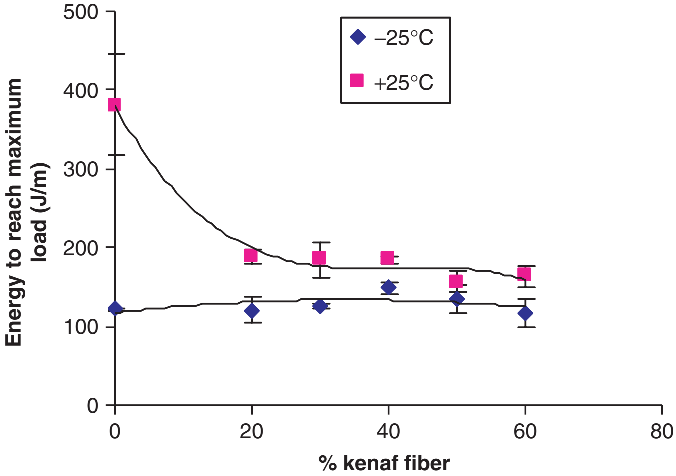

Figure 9. *EML for reversed notch impact tests above and below* T_g *of PP.*

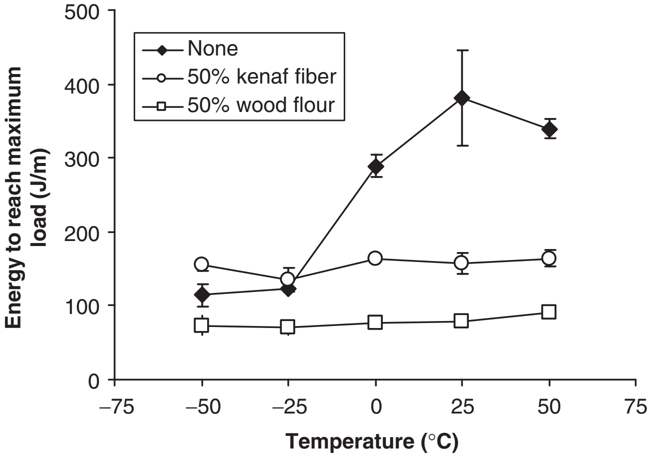

Figure 10. *Effect of temperature on EML of unfilled PP specimens and composites in reversed notch impact tests.*

and −50°C (Figure 12). At +50°C, considerable yielding was found for the PP specimens. Though slight deviations from linearity were evident, indicating some yielding or damage accumulation prior to failure, the restriction of polymer movement and subsequent low deflection at failure resulted in considerably less energy absorption during failure, and low EML values. The fracture surfaces of the kenaf composites did show some microductility near the notch at high temperature (Figure 13).

The situation was quite different at the low temperature (Figure 12). The behavior of the unfilled PP specimens appeared to be linear elastic. These specimens failed at less than 3 mm of deflection, more than five times lower than the deflection at high temperature. At the low temperature, the reinforcing ability of the kenaf fiber resulted in greater EML values for the composites compared to that of the unfilled PP specimens.

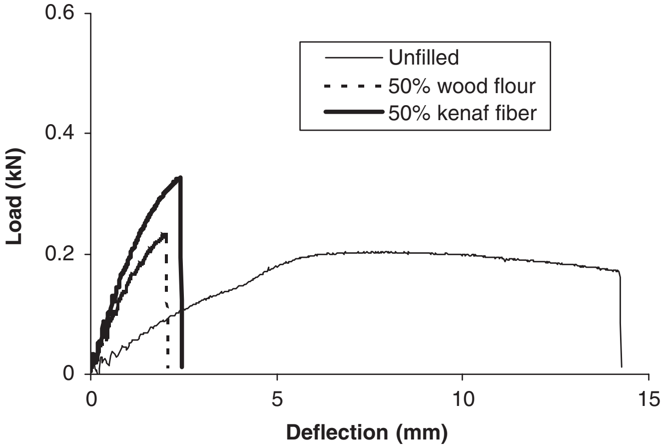

Figure 11. *Load-deflection curves for reversed notch impact tests on PP specimens and several composites at +50°C.*

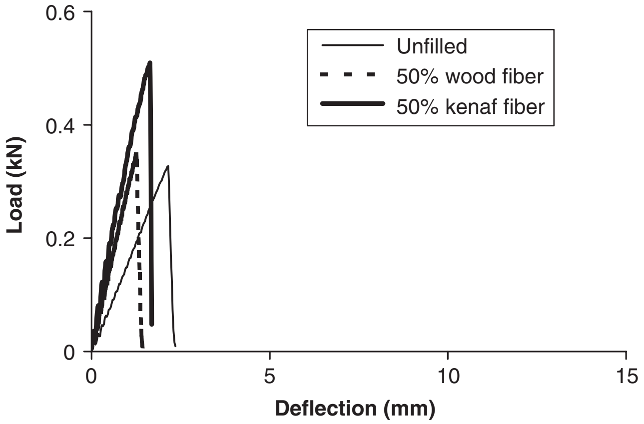

Figure 12. *Load-deflection curves for reversed notch impact tests on PP specimens and several composites at −50°C.*

CONCLUSIONS

This investigation shows how instrumenting the tup in an Izod impact test can increase the information gained on the impact performance of composites made from polypropylene (PP) reinforced with kenaf fiber. Rather than yielding a single energy value, the results show the shape of the load-deflection curve, which leads to greater insight into the behavior of the material.

In our study, the unfilled PP homopolymer yielded high values in reversed notch impact tests at room temperature. Notching the specimens greatly reduced impact performance. Adding fibers to PP greatly reduced energy to reach maximum load (EML) in reversed notch impact tests but had little effect on EML values in notched impact tests. When a coupling agent was added, the kenaf fibers reinforced the matrix, improving all measured values in both notched and reversed notch impact tests.

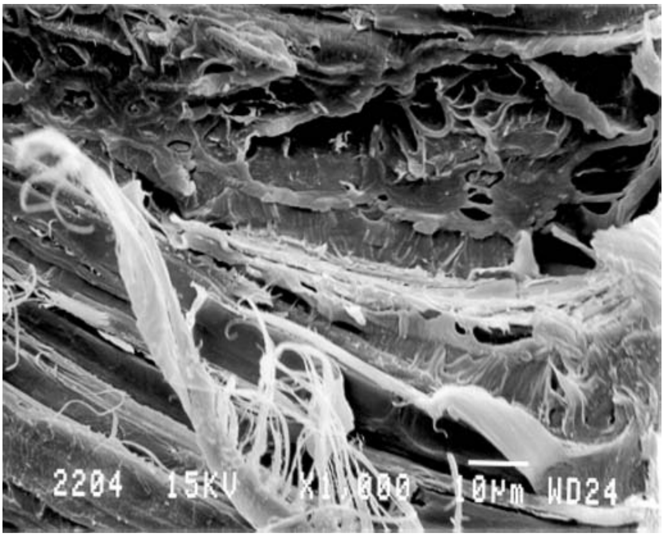

Figure 13. Notch tip area after impact test at +50°C for composites containing 20% kenaf fiber and 2% MAPP.

When the temperature was decreased, PP dropped below its glass transition temperature and became brittle. The PP-kenaf composites consistently yielded higher EML values in notched impact tests compared with both the unfilled PP specimens and wood flour composites over the temperature range investigated. Although EML values for kenaf composites in reversed notch impact tests were about half those of unfilled PP specimens at +25°C, EML values were slightly higher at −25°C. Kenaf fibers can offer significant benefits in impact performance over wood flour at both low (−50°C) and high (+50°C) temperatures.

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