

Thermal and mechanical analysis of lignocellulosic- polypropylene composites

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Abstract

Lignocellulosic-polypropylene composites have complex morphologies that influence their behavior. The interaction and adhesion between the fiber and matrix has a significant effect in determining the mechanical and physical behavior of fiber composites. Details such as whether the composite is above or below the glass transition, and the nature and degree to which crystallinity affects the stress transfer efficiency are impor-

tant. Thermal analysis methods are useful in evaluating the effects of fiber content and fiber-matrix adhesion in the composite. Furthermore, information on the dynamic mechanical response of the material can be evaluated over a wide range of temperatures.

This paper deals with the effects of the fiber content and the interphase on the dynamic and mechanical behavior of kenaf fiber composites. The use of coupling agents is imperative for achieving good stress transfer efficiency. The dynamic bending storage modulus of a 40 percent by weight coupled composite is higher than the storage modulus of a 50 percent by weight uncoupled composite, throughout the temperature range of -70°C to 160°C. Furthermore, the coupled composite has a slightly higher softening temperature than the uncoupled system. The improved properties are due to morphological and interphasial changes in the composite triggered by the coupling agent. Thermal analysis helps in gathering information on the changes and helps explain the reasons for the property changes.

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The effects of particle size and interface on the dynamic and mechanical behavior of wood flour composites are presented. Particle size and inter-particle distance can influence the morphology and therefore the mechanical response of the system. The thermomechanical responses of wood flour composites are compared with those of talc- and calcium carbonate-filled polypropylene.

Introduction

Kenaf fibers are extracted from the bast of the plant *Hibiscus cannabinus*. Filament lengths longer than 1 m are common. These filaments consist of discrete individual fibers, generally 2 to 6 mm long, which are themselves composites of predominantly cellulose, lignin, and hemicelluloses. Filament and individual fiber properties can vary depending on the source, age, separating techniques, and history of the fiber. Furthermore, the properties of the fibers are difficult to measure and we have made no attempt to measure the properties of kenaf. The choice of the fiber for plastics applications depends on the availability of the fiber in the region and also on the ultimate composite properties needed for the specific application. Kenaf was chosen for the study because it is now a fiber crop grown commercially in the United States. Several other fibers isolated from annual growth crops have potential as reinforcing fillers in plastics. The specific moduli of kenaf polypropylene composites are comparable to those of glass polypropylene composites and have potential in the automotive, building, and furniture industries. More details on the mechanical properties of kenaf composites can be found elsewhere (10-12).

In semicrystalline polymers, the type and amounts of the amorphous and crystalline phases govern the linear viscoelastic response during dynamic loading. Furthermore, the presence of fillers and fibers in the polymer creates further complexities in the morphology of the system. The surface properties of filler and fibers and the use for coupling agents and other 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 system.

Thermal methods are useful in obtaining morphological information for polymers, blends, and

composites. Dynamic mechanical analysis is a sensitive technique that characterizes the mechanical responses of materials by monitoring property changes in a material with respect to the temperatures and/or frequencies. The technique separates the dynamic response of materials into two distinct parts: an elastic part (E') and viscous or damping component (E''). The elastic process describes the energy stored in the system, while the viscous component describes the energy dissipated during the process.

The analyzer measures the modulus (stiffness) and damping (energy dissipation) properties of materials when deformed under periodic stress. Such data provide quantitative and qualitative information about material behavior. If the material is entirely elastic (e.g., steel), the phase lag (δ) between the stress and strain waves is 0° . If the material is purely viscous (e.g., non-Newtonian fluids), the phase difference is 90° . Polymers are viscoelastic and exhibit a phase difference, between those of purely elastic and purely viscous materials. In addition to storage and loss modulus ($\tan \delta$) and other viscoelastic parameters, it is also possible to get information on the molecular transitions. Effects of matrix and interphase modification in composites can be monitored by the shifts in the peak temperature of relaxation transition, when the material is scanned through a temperature range. Frequencies or time scale of the applied strain can be changed to observe changes in behavior.

A study on the dynamic and mechanical behavior of kenaf fiber-reinforced polypropylene composites will be presented here. We will also compare the mechanical and dynamic responses of wood flour-filled polypropylene (with different wood particle sizes) to those of talc- and calcium carbonate-filled polypropylene. The effect of fiber amount and the presence or absence of a coupling agent will be presented in some detail.

Experimental methods

Materials

Kenaf filaments, a few centimeters long, harvested from mature plants were obtained from Ken-Gro Corp., Miss., and cut into lengths of about 1 cm. The fibers were not dried to remove any of the moisture present, and the moisture content of the fibers varied from 5 percent to

about 9 percent by weight (%wt). In all our experiments the weight and volume percent reported is the amount of dry fiber present in the blend. The homopolymer was Fortilene-1602 (Solvay Polymers, Tex.) with a melt flow index of 12 g/10 min. as measured by ASTM D 1238. A maleic anhydride grafted polypropylene (MAPP) was used as a coupling agent (at 3% of total composite weight) to improve the compatibility and adhesion between the fibers and matrix.

The short fibers, MAPC and polypropylene (the latter two in pellet form) were compounded in a high-intensity kinetic mixer where the only source of heat was generated through the kinetic energy of rotating blades. The blending was accomplished at 4,600 rpm (blade-tip speed about 30 m/sec.) and then automatically discharged at 190°C. A total weight (fibers, MAPE and polypropylene) of 150 g were used for each batch. About 1.5 kg of blended material was prepared for each set of experiments. The total residence time of the blending operation depended on the proportions of fiber and polypropylene present and averaged about 2 minutes. The mixed blends were then granulated and injection-molded.

The wood flours were ponderosa pine and were screened to designated sizes by American Wood Fibers. The notations and size distributions are:

- WF35: 30 to 40 mesh (0.425 to 0.600 mm); and
- WF235: 200 to 270 mesh (0.053 to 0.075 mm).

The talc, Vertal-710, was supplied by Luzenac America. The talc was not treated and the specific gravity was 2.8. The size of the particles ranged from 0.4 μm to 30 μm , with a median diameter of 6.8 μm . The calcium carbonate used was Optifil-T (treated), supplied by J.M. Huber of Quincy, Ill. The median particle size was 2 μm .

An injection-molding grade polypropylene (Fortilene 3907, Solvay Polymers), with a melt index of 36.5 g/10 min. was used for the organic-filled composites and the wood flour composites. Filler was kept at 40%wt in all the wood flour, talc, and calcium carbonate runs. Coupling agents were not used for the talc and calcium carbonate runs, while both uncoupled and coupled (3%wt MAPP) systems were prepared for the wood flour.

The fillers and the matrix were dry blended and then compounded using a 32-mm Davis and Standard twin-screw extruder. The melt temperature was kept under 190°C to prevent wood deg-

radation. Feed rates varied between 18 and 21 kg/hr. The extruded strands were cooled in a water trough and pelletized.

Measurements

Prior to molding, the granules (thermokinetic mixer) or pellets (granules) were dried at 105°C for 4 hours. Test specimens were injection-molded at 190°C using a Cincinnati Milacron Molder and injection pressures varied from 2.75 MPa to 8.3 MPa depending on the constituents of the blend. Specimen dimensions were according to the respective ASTM standards.

The blended specimens were stored under controlled conditions for 3 days before testing. Tensile tests were conducted according to ASTM 638-90, Izod impact strength tests according to ASTM D 256-90, and flexural testing using the ASTM 790-90 standard. The crosshead speed during the tension and flexural testing was 5 mm/min. The experiments were designed around the weight percent of kenaf in the composites, but fiber volume fractions can be estimated from composite density measurements and the weights of dry kenaf fibers and matrix in the composite. The density of the kenaf present in the composite was estimated to be 1.45 g/cm³.

Dynamic properties of the composites were measured using a Rheometrics DMTA MKIV. The samples were cut to size from injection-molding flexural samples and efforts were made to get the sample from identical spots on samples. A single cantilever test was used for the testing with a span of 14 mm, width of 5 mm, and depth of 1 mm. The deflection amplitude was 16 μm and the frequency was 1 Hz and the heating ramp rate was 2°C/min. The modulus (E'), loss modulus (E''), and tan δ of the samples were collected during the run.

A Perkin Elmer DSC was used to evaluate the crystallization and melting behavior of some of the blends. The samples were first heated to 220°C at 20°C/min. and then held isothermally for 1 minute. The samples were then cooled at 10°C to collect crystallization data, and then heated again at 10°C to observe the melting transition. The sample sizes were kept between 9 to 11 mg.

Results and discussion

Kenaf blends

The addition of fibers and the coupling agent does, as expected, have quite a profound influ-

ence on composite properties. The strength and modulus increases with fiber addition and the failure strain decreases with an increase in fiber content (Table 1). Detailed results and discussion regarding coupling agent effects can be found elsewhere (10-12). It is important to note that the low strengths of the composites are essentially due to fiber factors. Low aspect ratios of the fibers, predominantly due to the fibers being in a bundle, and defects in the fibers can make a dramatic difference in composite efficiency (4). Fiber separation techniques for commercial use need to be developed to achieve better properties.

Figure 1 shows the change in storage modulus at different temperatures of kenaf-polypropylene composites and pure polypropylene. Two consis-

tent variations of the E' with temperature can be observed for all the systems and are marked with arrows in Figure 1:

- a sharp drop in E' from -10°C to about 10°C ; and
- a reduction in the rate of drop in E' with temperatures above 75°C .

The first change between -10° and 15°C is the relaxation associated with the amorphous phase (β relaxation). In this case, the glassy state of the amorphous phase goes through its glass transition and there is a sharp drop in E' . At about 15°C , E' continues to fall and the slope is similar to that before the β relaxation started. From 70°C to 80°C , depending on system, the reduction in E' is less severe until the softening point (T_s) and then the

Table 1. ~ Mechanical properties of kenaf-polypropylene blends.

Kenaf fiber	Coupling agent	Tensile strength	Tensile modulus	Tensile failure strain	Flexural strength	Flexural modulus	Izod notched	Izod unnotched
----- (%) -----		(MPa)	(GPa)	(%)	(MPa)	(GPa)	----- (J/m) -----	
0	0	33	1.7	> 10.0	41	1.4	24.0	--
20	3	38	3.0	4.1	51	3.0	24.9	153.1
30	3	43	4.1	3.3	62	3.9	31.0	160.3
40	3	50	5.5	2.8	73	5.1	32.0	162.4
50	0	33	9.3	1.1	55	8.0	33.9	87.6
50	3	57	8.3	2.2	88	6.7	34.0	167.5
60	3	67	10.2	1.9	105	9.0	37.9	166.0

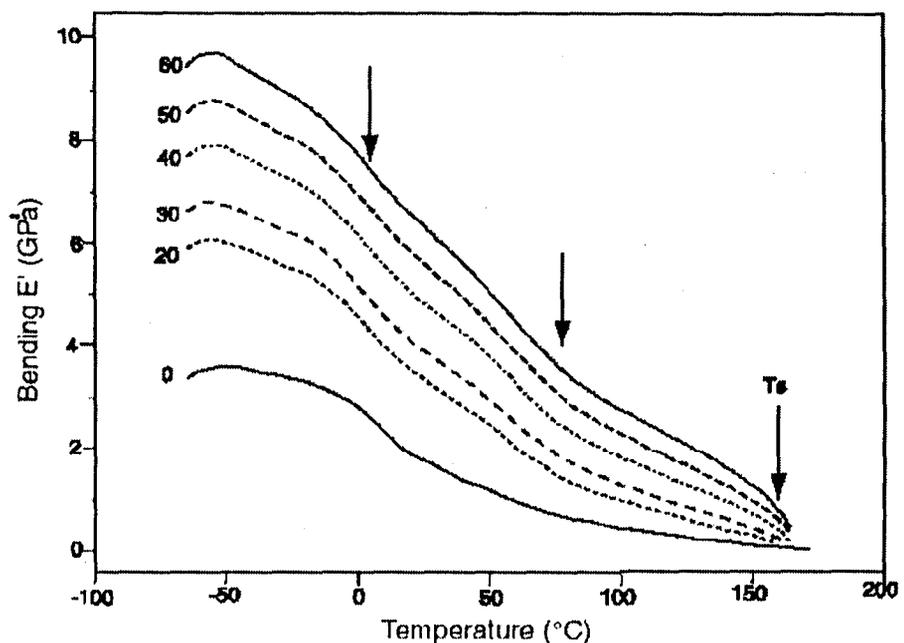


Figure 1. ~ Variation of storage modulus versus temperature in coupled kenaf composites. The numbers to the left of the curve indicate the amount of kenaf by weight.

melt region is reached. It is interesting to note that the dynamic storage modulus of polypropylene at about 10°C is about the same as a 60 percent kenaf-polypropylene composite at around 100°C.

Figure 2 shows the loss modulus (E'') of polypropylene and kenaf-polypropylene composites and the dependence of temperature. The relaxations can be easily seen. The β transition peak can be observed between 0° to 10°C, while the α relaxation peak can be seen between 70° and 80°C.

The α transition is related to the relaxation of restricted polypropylene amorphous chains in the crystalline phase. Crystals are needed for this transition to occur. The β transition is related to the glass transition, due to the motions associated with unrestricted amorphous polypropylene (McCrum et al. 1967). Since the β transition peak temperatures are different for all three curves (E' , E'' , and $\tan \delta$), it is difficult to pinpoint the T_g . Some authors have suggested that from a material design point of view, E' is the most important parameter necessary, and therefore the T_g should be assigned to the transition in the E' curve.

The β peak of the polypropylene is at a higher temperature than the kenaf-polypropylene composites. Several factors need to be considered to understand transitions occurring in the system, and also the crystallization and melting behavior of these blends:

- presence of a low molecular weight polymer, which is the coupling agent (MAPP) and/or a lubricant, and their lubricating effect on the higher molecular weight matrix polymers;
- presence of a coupling agent that results in interactions between the anhydride and the hydroxyl groups on the lignocellulosic surface; and
- interaction between the anhydride groups among themselves, within the same molecule, or between neighboring MAPP molecules. Thermodynamic segregation of the MAPP to the lignocellulosic surface could play a major role in determining the morphology around the fiber.

The presence of low molecular weight MAPP could reduce the transition temperature by enhancing the ability of the polymer to undergo a glass-rubber transition (8). The molecular mobility associated with this transition is complicated, and not yet thoroughly understood in semicrystalline polymers (2). The presence of the fibers adds to the complexity. On the other hand, good interaction (covalent or acid-base) between MAPP and the lignocellulosic surface restricts the mobility of the molecules. In general, the increase in peak temperature indicates decrease in chain mobility, and the E'' peak amplitude is directly related to the amount of amorphous polypropylene chains involved in the transition. The transition

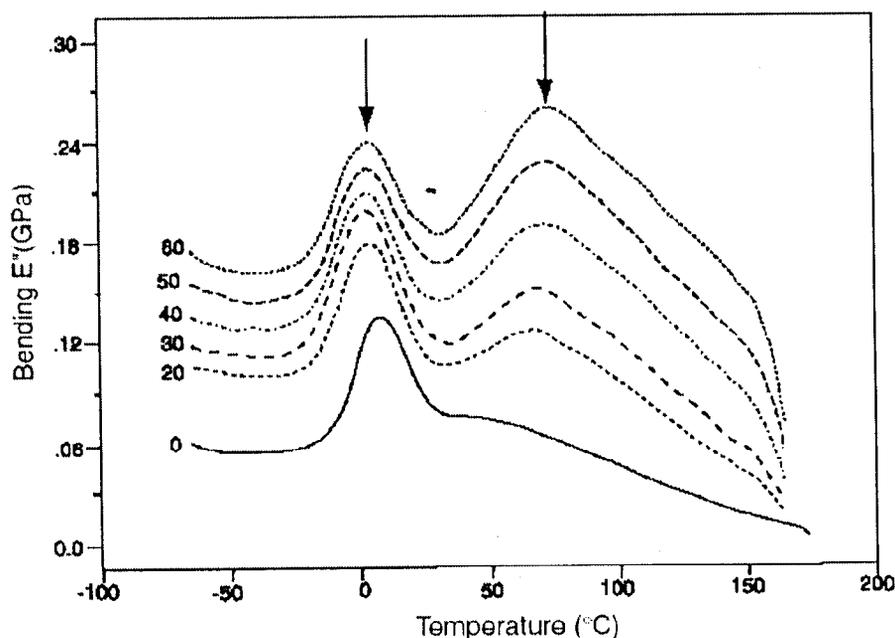


Figure 2. ~ Variation of loss modulus versus temperature in coupled kenaf-polypropylene composites. The numbers to the left of the curve indicate percent of kenaf by weight.

behavior in the system would thus depend on which of the above factors are dominant,

The lower β peak amplitude of kenaf-polypropylene composites as compared to the polypropylene indicates that the lubricating effect of MAPP dominates. A very important factor is that some of the surface matrix material in the kenaf fibers themselves is sheared off from the fiber during blending and added to the matrix. This sheared material could have lignin, amorphous cellulose, oils, and other surface extractives that are inherently present in the fiber. This can be clearly seen as the dark brown tinge of the polymer matrix after blending. In other words, the matrix material is a blend of polypropylene and several constituents that are contributed by the fiber, and it may be erroneous to model the system as a pure polypropylene matrix. This "new" matrix may also contribute to the reduced T_g . Interactions between MAPP and the kenaf can reduce the mobility of the polymer near to the fiber surfaces, but the lubricating effect does seem to dominate.

The T_g of the 20 percent blend was higher than the other kenaf. This shift to higher T_g for the 20 percent formulation is possibly due to the relatively larger amount of MAPP available. All composites had 3%wt of MAPP but due to the small amount of fiber present (in the 20% formulation) there is enough MAPP to interact with most of the available fiber surface. The interactions between

the excess anhydride groups themselves can restrict molecular mobility and shift the β peak to a higher temperature.

The T_α relaxation in semicrystalline polymers are due to the presence of amorphous chains in the crystalline phase (defects), also known as rigid amorphous molecules (3,14). The increase in T_α peak with fiber content is interesting.

An interesting empirical relationship was observed. The ratio of the peak amplitudes of the 20, 30, 40, and 50 percent blends to the 60 percent fiber blend are about the same as the ratios of their respective fiber volume fractions (V_f). This does not hold true for the comparison with the matrix volume fractions or to the amorphous polymer volume fractions. It is interesting that the ratio of amplitudes (related to the amount of "rigid amorphous" molecules) are related to the fiber volume fractions, or in other words the fiber surface area. Is it possible that the rigid amorphous molecules in the crystal that cause the T_α transition for the kenaf-polypropylene composites could be present near the fiber-matrix interface, perhaps as transcrystallinity? The crystallinity of polypropylene in all the composites was about the same from preliminary DSC data. The higher relaxation strengths with fiber content can only mean that the number of defects increases with fiber content, and possibly exist mainly in the transcrystalline zone. Further work is needed to con-

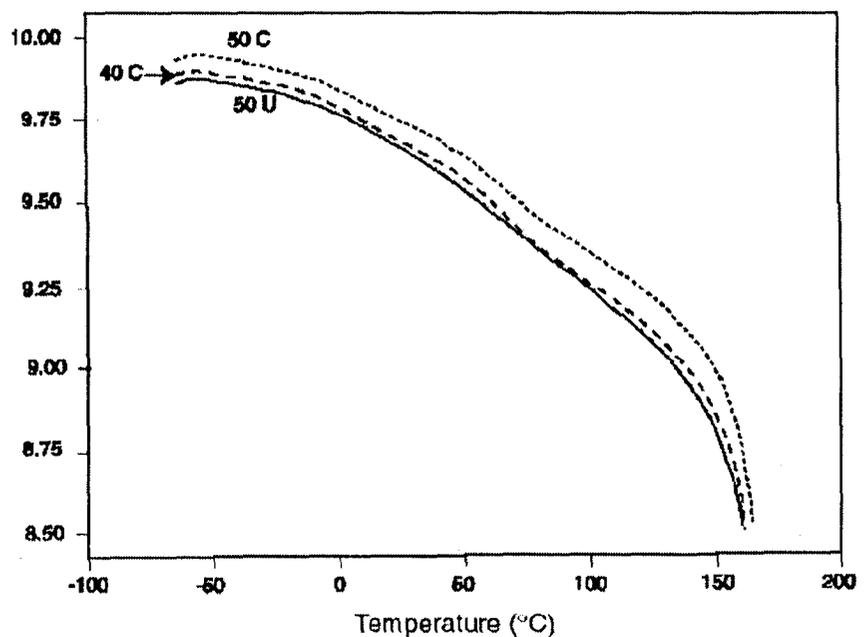


Figure 3. ~ Variation of storage modulus with temperature in coupled (C) and uncoupled (U) kenaf-polypropylene composites. The numbers near the curves indicate the percent of kenaf by weight.

firm any relationship to the surface of the fiber and whether it is related to the interparticulate distance.

Figures 3 and 4 show the temperature dependence of E' and E'' of three systems: one uncoupled (40%wt) and two coupled (40%wt and 50%wt) of kenaf-polypropylene blends. The uncoupled system (50%wt) had a lower modulus, all through the temperature range, than even the 40%wt coupled blend. The softening temperatures of the coupled blends were higher than the uncoupled blend. This clearly demonstrates the effectiveness of the MAPP in improving composite efficiency. The transition, seen as the drop in modulus, at around 75°C appears to be stronger for the coupled systems.

In Figure 4, the α transition peak temperature of the 50%wt coupled formulation was higher than the others. However, the α amplitudes of coupled blends were significantly higher than the uncoupled blends. This suggests that the coupled blends had a higher amount of rigid amorphous molecules in the crystal. The presence of these defects results in the transition, seen in Figure 3 as the drop in modulus, at around 75°C and is greater for the coupled systems. Work by Duvall (5) suggested that low anhydride content MAPP can co-crystallize with polypropylene. This co-crystallization may be responsible for the larger number of defects present (higher α amplitude)

in coupled composites than in uncoupled composites.

Comparing the 50%wt blends, the β relaxation strength is slightly higher for the uncoupled system, which indicates more amorphous polypropylene chains were involved in the transition. This higher amplitude for the uncoupled blends and the lower amplitude of the α relaxation could suggest that the crystallinity of the 50%wt coupled system is higher than the 50%wt uncoupled blend. This could suggest the existence of enhanced transcrystallinity around the fibers for the coupled composites. The α amplitude of the 40%wt coupled is also higher than the 50%wt uncoupled blend, indicating a higher number of defects, but also a possibility of higher transcrystallinity.

Increased transcrystallinity may thus explain the higher storage modulus of the 40%wt coupled blend as compared to the 50%wt uncoupled blend. In general, transcrystalline zones are formed parallel to the flow direction where the fibers are predominantly oriented during injection-moldings (9). This would lead to a higher modulus in the direction of flow (same as the testing direction and fiber orientation) because of the higher stiffness of the transcrystalline morphology (7).

Wood flour studies

Table 2 shows the mechanical properties of the uncoupled wood-flour (WF35 and WF235) and

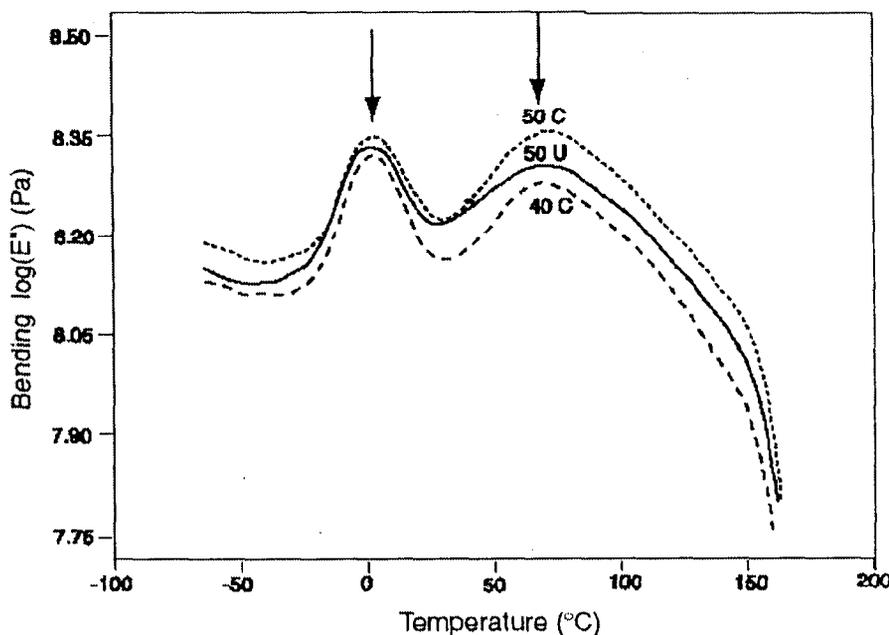


Figure 4. ~ Variation of loss modulus with temperature in coupled (C) and uncoupled (U) kenaf-polypropylene composites. The numbers near the curves indicate the percent of kenaf by weight.

coupled (WF35 MAPP and WF235 MAPP) blends. Data on talc and calcium carbonate are also shown.

The tensile properties of the 235-mesh composites were about 10 percent higher and unnotched Izod impact strength was about 70 percent higher than the 35-mesh composites. Several factors could be responsible for this behavior. The surfaces of the two wood flours can be different from each other. As the wood flour size is reduced, new surfaces are exposed that will have different surface chemical structures. This could have some effect on the polymer morphology of the composites. The higher unnotched impact strength indicates that the smaller WF235 particles result in less severe stress concentrations and therefore higher crack initiation energies. Apart from the size differences that lead to different stress concentrations, the possibility exists that the interfacial strength is higher and/or the morphology of the interphase region between the WF235 particles and the matrix is tougher than the WF35 interphase. The difference in particle size and interparticular distances could result in different molecular morphologies that influence the composite behavior (1).

When comparing the two sizes of coupled wood flour, the tensile properties of the WF235 mesh were greater than the WF35 mesh, with the differences being about 29 percent and 19 percent for strength and modulus, respectively. The unnotched impact strength was again higher for the smaller sized wood flour, but the difference (about 50%) was less than the uncoupled blends. The factors mentioned previously appear to be responsible for this behavior.

Comparing the coupled and uncoupled wood flour blends of the same particle size, the cou-

pling agent improves the strength for both sizes of wood flour, but the effect seems to be enhanced for the WF235 mesh. There is little difference in the moduli with the use of the coupling agent.

The wood flour blends had a higher modulus than the calcium carbonate composite, but the strengths were about the same. It should be noted that although the calcium carbonate was surface treated, samples with coupling agents were not prepared. The talc had the highest modulus and strength among all the uncoupled blends, while the calcium carbonate had, by far, the highest unnotched impact strength.

Figure 5 shows the storage and loss moduli comparing the two wood flour coupled composites with different particle sizes. The WF235 composite had a higher E' throughout the temperature range. The two transitions, α and β , can be seen for both composites. The α peak was much higher for WF235, while the β peak was higher for the WF35 composites. The higher β peak for WF35 indicates that the amorphous molecules are more restricted. The higher α peak for WF235 suggests that the defects in the crystals relax at higher temperatures than the WF35 mesh. Two factors need to be considered to explain the above results. First, the two sizes will have different surface properties since different regions of the cell walls are likely to be exposed. Second, the interparticular area will be smaller for the WF235 composites, leading to different morphologies of the matrix phase in the system.

Figures 6 and 7 show the storage and loss modulus of the coupled and uncoupled WF235 and WF35 composites, respectively.

In Figure 6, the β peak temperatures were about the same for the uncoupled and coupled

Table 2. ~ Mechanical properties of woodflour-polypropylene blends: effect of particle size and comparison with talc and calcium carbonate composites (13).

Composite type	Tensile strength	Tensile modulus	Tensile failure strain	Flexural strength	Flexural modulus	Izod notched	Izod unnotched
	(MPa)	(GPa)	(%)	(MPa)	(GPa)	(J/m)	
40%wt WF35	21.8	3.2	2.3	38.7	2.7	22	54
40%wt WF235	24.3	3.5	2.1	41.4	2.9	16	91
40%wt WF35 MAPP	27.0	3.1	2.0	47.3	2.8	21	54
40%wt WF235 MAPP	34.8	3.7	2.3	56.0	3.2	19	81
40%wt talc	32.3	5.0	2.1	54.6	3.3	17	115
40%wt calcium carbonate	21.8	2.2	3.8	39.8	1.8	19	470

systems, but the coupled system had a higher α peak temperature. The α relaxation was not as broad as the uncoupled system. The coupled composites had a higher amplitude of the β relaxation, and a lower α amplitude that could indicate that the crystallinity is higher for the coupled systems. The E' for the coupled system was higher throughout the temperature range.

The E' and E'' for the WF35 composites are shown in Figure 7. In this case, the T_{β} peak was about the same for the coupled and uncoupled systems, but the T_{α} peak was higher for the coupled composite. The β amplitude was lower for the coupled system, indicating a lower purely amorphous content. In this case the E' was lower for the coupled composite below the T_g but higher

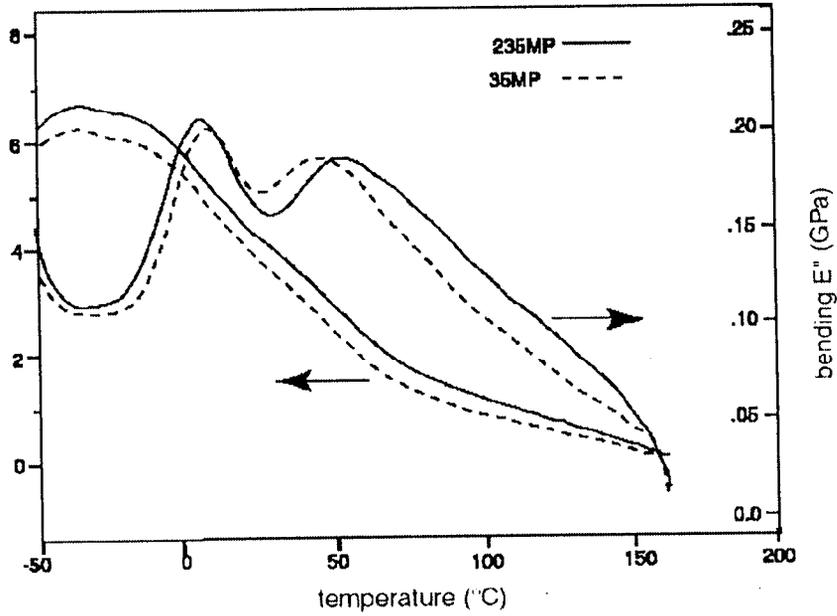


Figure 5. ~ Storage and loss modulus for the wood flour composites for two particle sizes, MP = MAPP coupling agent.

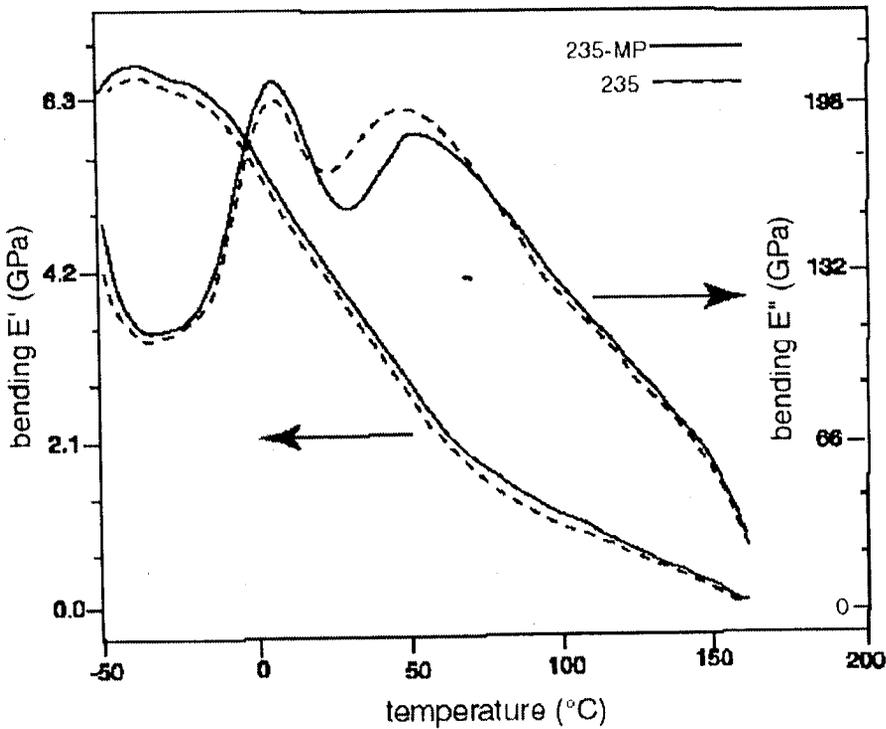


Figure 6. ~ Storage and loss modulus for the wood flour composites for two particle sizes, MP = MAPP coupling agent.

after the T_g . The differences between the WF35 and WF235 composites probably reflect the different surface contributions of the two mesh sizes and also the different average interparticulate distances.

The E' (Fig. 8) for the talc composites were higher than the other composites at temperatures below about 105°C. The wood flour composites were stiffer above this temperature. This

could be due to higher filler and lower matrix volume fractions of the wood flour composites that provide the stiffness at higher temperatures.

In the case of E'' (Fig. 9), the β peak temperature was marginally higher for the wood flour composites, but the talc had the highest α peak temperature. The talc composites also had the highest α amplitude, indicating the highest amount of defects present in the crystals. Considering the

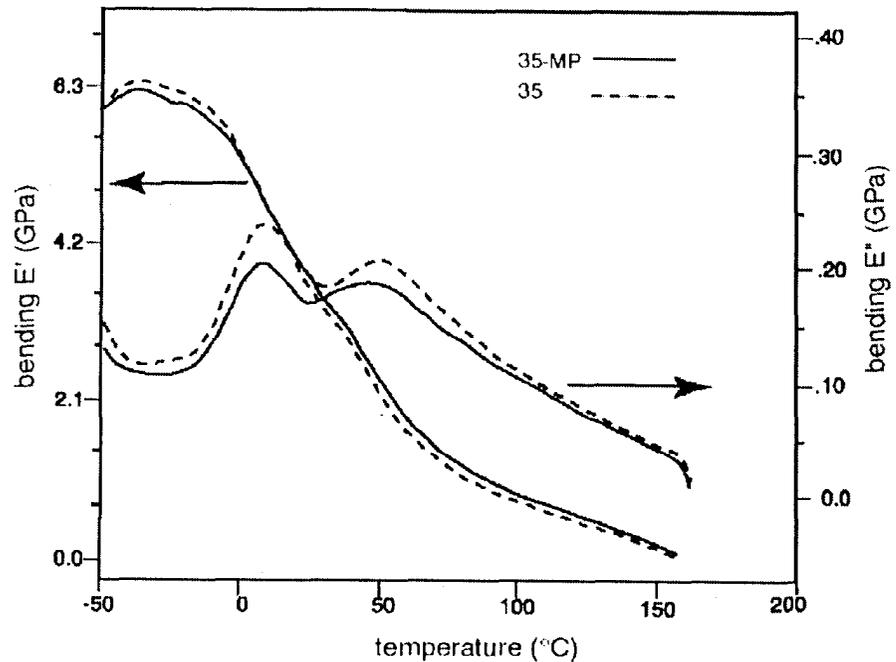


Figure 7. ~ Storage and loss modulus for the wood flour composites for coupled and uncoupled WF35 composites. MP = MAPP coupling agent.

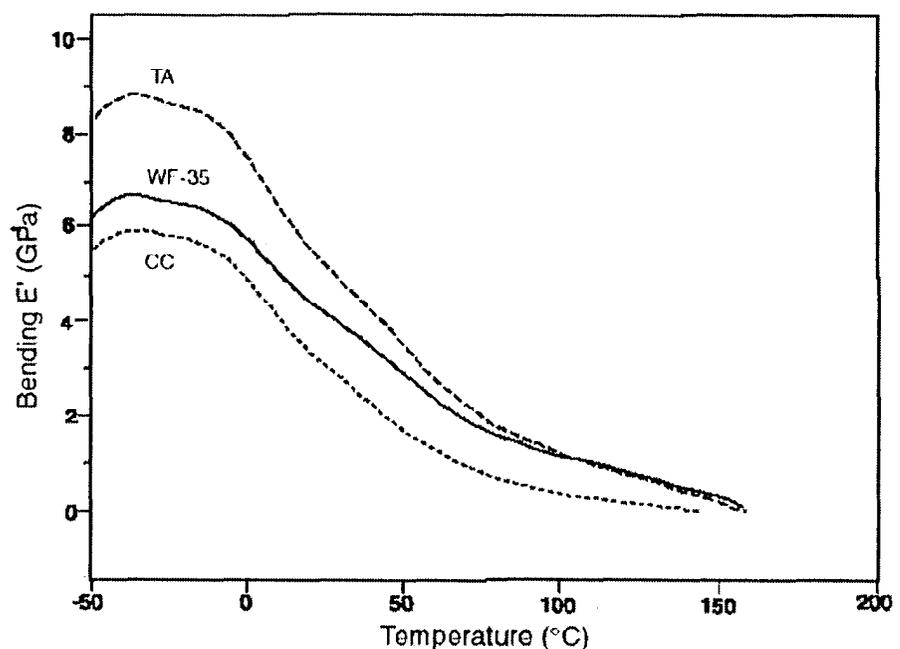


Figure 8. ~ Storage modulus for the uncoupled wood flour (WF35), talc (TA), and calcium carbonate (CC) composites.

volume fractions of the particulates, the calcium carbonate composites appeared to have the least amount of defects in the crystals.

The $\tan \delta$ (Fig. 10) of the calcium carbonate composite was the highest above the onset of the glass-rubbery transition and this can be observed indirectly by the much higher unnotched impact strengths of these composites. However, below the T_g onset, the $\tan \delta$ for the wood flour composites was marginally higher than that for the cal-

cium carbonate composites. This could result in better low temperature impact properties that may be useful for some applications.

Low temperature impact of kenaf composites

Some preliminary experiments were performed at lower temperatures using an instrumented impact tester. Uncoupled kenaf composites (50%wt) were compared with uncoupled talc and calcium carbonate composites (40%wt). Coupled kenaf composites (20%wt to 60%wt) were also tested.

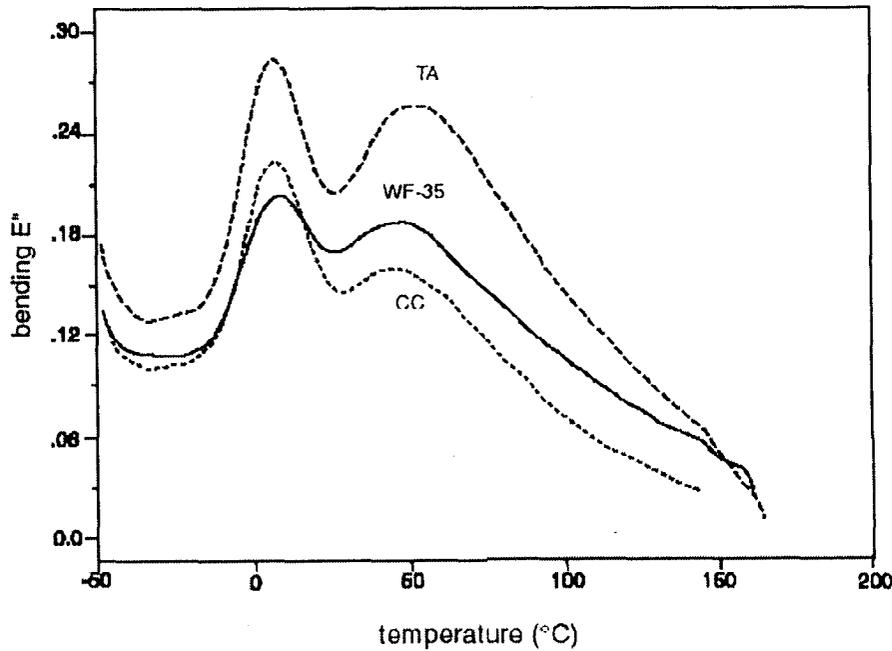


Figure 9. ~ Loss modulus for the uncoupled wood flour (WF-35), talc (TA), and calcium carbonate (CC) composites.

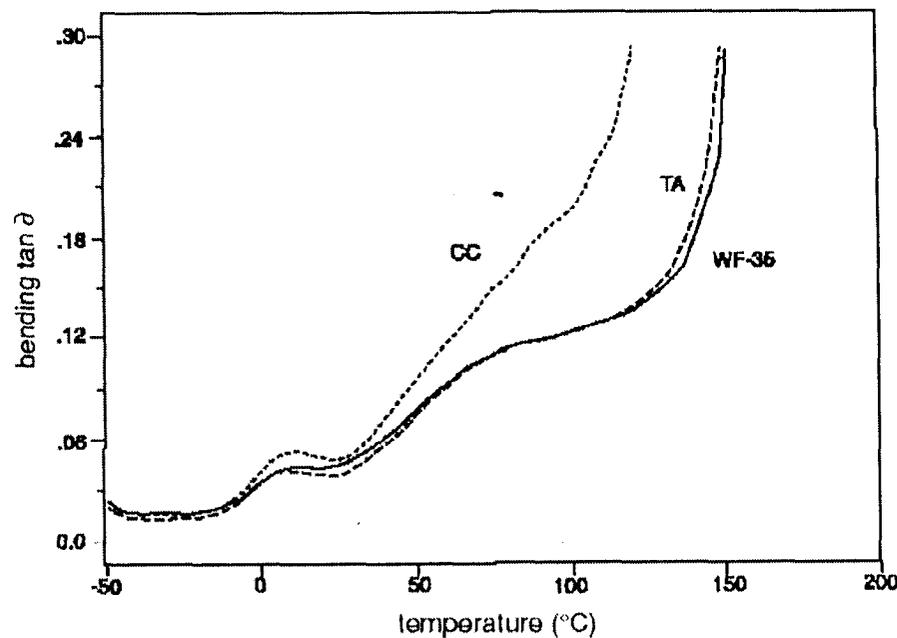


Figure 10. ~ Tan δ for the uncoupled wood flour (WF-35), talc (TA), and calcium carbonate (CC) composites.

Table 3. ~ Unnotched Izod impact strengths of coupled kenaf composites.

Fiber content (%wt)	Izod impact	
	20°C	-20°C
	----- (kJ/m ²) -----	
20	17.2	15.3
30	14.8	19.7 ^a
40	13.5	13.6
50	12.0	14.2
60	13.2	18.1

^a Only one test was run successfully.

Testing was conducted at two temperatures, -20°C and 20°C (Table 3 and 4).

The -20°C impact properties of the kenaf composites were not much different from the impact at 20°C. However, there appeared to be quite a bit of difference between the strengths at higher and lower temperatures for the talc and calcium carbonate composites. It must be pointed out that only two tests were conducted for each set, and thus the preliminary nature of these experiments. However, results appear consistent since all the kenaf composites showed the same trend.

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Table 4. ~ Unnotched Izod impact of filled uncoupled composites.

Type	Filler content (%wt)	Izod impact	
		20°C	-20°C
		---- (kJ/m ²) ----	
Kenaf	50	8.4	8.4
Talc	40	12.0	7.6
Calcium carbonate	40	13.5 ^a	10.3

^a Indicates that the samples did not fail in the time frame of the test and thus values should be higher than indicated. If tested using typical test equipment, the unnotched impact of calcium carbonate at 20°C is above 40 kJ/m².

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