WOOD FIBER DERIVED FROM SCRAP PALLETS USED IN POLYPROPYLENE COMPOSITES

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ABSTRACT

Wood pallets and shipping crates represent a large source of raw material available for use in value-added composites. To determine the feasibility of using wood fibers derived from pallets in wood-plastic composites, this study compared the mechanical properties of polypropylene (PP) composites combined with either wood flour or wood fiber. Wood flour is the most common wood-derived filler used in the plastics industry. Moving from a particulate filler like wood flour to a reinforcing fiber results in property enhancements. In this study, the use of fiber derived from wood pallets and shipping crates as a filler for PP resulted in tensile and flexural strength improvements compared with wood-flour-filled PP. The addition of stearic acid to these composites to increase dispersion of the wood filler in the PP did not improve properties; however, the addition of maleated PP to improve the interfacial adhesion between the two phases resulted in strength improvements.

As the plastics industry becomes more receptive to the use of wood-derived fillers for thermoplastics, further effort is required to improve upon the properties of these materials. Although wood flour (WF), a commercially available resource derived from post-industrial scrap, is the most commonly used wood-derived filler in thermoplastics today, opportunity exists for other sources of wood to be used as filler materials for thermoplastics. These sources may include fibers derived from post-consumer waste, woodwaste such as standing dead and small-diameter trees, or agricultural residues. Filled thermoplastics achieve better strength properties as the aspect ratio of the tiller increases; therefore, moving from a particulate filler such as WF to a reinforcing wood fiber should result in strength improvements.

A large source of wood fiber is available in the form of used pallets and shipping containers. Recycling is already a large part of the pallet business. As early as 1992, 44 percent of U.S. pallet manufacturers were involved in recycling (2). However, there continues to be considerable volumes of pallets in municipal solid waste. In 1995 alone, landfills processed around 880×10^3 metric tons of pallets from the municipal solid waste stream. That same year, construction and demolition sites processed approximately 162×10^3 metric tons of pallets (3). This represents a large amount of material that can be used in such value-added applications as woodfiber-plastic composites.

Although wood fiber may be used in place of flour to improve the properties of wood-filled thermoplastic composites, chemical additives may improve the properties even further. Two ways of improving the properties are: 1) improve the distribution of wood filler throughout the thermoplastic matrix using a dispersing agent; and (2) increase the interfacial adhesion between the wood filler and thermoplastic with a coupling agent.

An agglomeration of filler particles would adversely affect properties. Stearic acid (SA) has been shown to facilitate the dispersion of 20 percent by weight kraft pulp fibers in a polypropylene (PP) matrix. Raj et al. (6) determined that 3 percent by fiber weight stearic acid was sufficient to achieve maximum reduction in the size and number of aggregates. The adhesion between the polymer matrix and wood filler can account for some of the final strength of the composite material. A coupling agent can be used to improve the interfacial adhesion between the polymer and wood interface. Maleic anhydride modified polypropylene (MAPP) has been shown to provide a bond between fillers con-

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TABLE 1. -Formulations based on weight percentage of the composites examined.[a]

Material	Polymer	Wood filler	Additive
	----------(%)----------		
HW-20-XX	80 PP	20 HW	--
HW-20-SA	77 PP	20 HW	3 SA
HW-20-MA	77 PP	20 HW	3 MAPP
HW-40-XX	60 PP	40 HW	--
HW-40-SA	57 PP	40 HW	3 SA
HW-40-MA	57 PP	40 HW	3 MAPP
SW-20-XX	80 PP	20 SW	--
SW-20-SA	77 PP	20 SW	3 SA
SW-20-MA	17 PP	20 SW	3 MAPP
SW-40-XX	60 PP	40 SW	--
SW-40-SA	57 PP	40 SW	3 SA
SW-40-MA	57 PP	40 SW	3 MAPP
WF-20-XX	80 PP	20 WF	--
WF-20-SA	77 PP	20 WF	3 SA
WF-20-MA	77 PP	20 WF	3 MAPP
WF-40-XX	60 PP	40 WF	--
WF-40-SA	57 PP	40 WF	3 SA
WF-40-MA	57 PP	40 WF	3 MAPP

[a] HW = hardwood; SW = softwood; WF = wood flour; XX = no additive; SA = stearic acid; MA = maleic anhydride; PP = polypropylene; MAPP = maleic anhydride modified polypropylene.

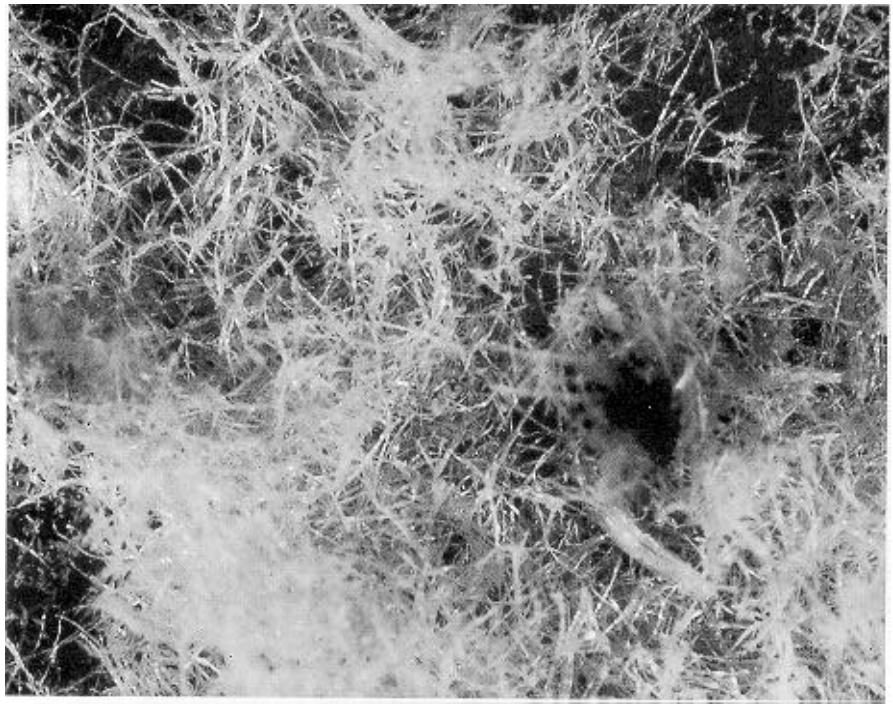

Figure 1.—Hardwood fiber derived from pallets.

taining hydroxyl groups and the polymer matrix (4).

The objective of this study was to determine the feasibility of using pallets and shipping containers as a raw material source for wood-filled plastic composites. To accomplish this, PP composites filled with fibers derived from wood pallets and shipping crates were produced and then compared with those filled with the more traditional WF. Either SA or MAPP was also added to the composite, which was then examined for property characteristics.

EXPERIMENTAL

MATERIALS

An injection-molding grade of PP with a melt flow index of 36.5 g/10 min. was used in this study. The PP was Fortilene 3907, supplied by Solvay Polymers, Inc. (Deer Park, Tex.). Hardwood (HW) and softwood (SW) chips were supplied by Woodcycle, Inc. (Sullivan, Wis.) in sizes ranging from 2.5 to 12.5 cm long and 1.3 to 3.8 cm wide. The HW chips were derived from wood pallets, and the SW chips were derived from shipping crates. The WF, a 40-mesh (0.42-mm sieve opening) ponderosa pine, was supplied by American Wood Fibers (Schofield, Wis.). To improve the properties, either SA supplied by Aldrich Chemical Company, Inc. (Milwaukee, Wis.) or MAPP, Unite MP 880 supplied by Aristech (Pittsburgh, Pa.), was added to each composite material.

SAMPLE PREPARATION

Fiber preparation. — The HW and SW chips were reduced in size using a Montgomery Ward hammermill using a screen with 3.175-cm holes. The resulting chips were reduced to fibers using a laboratory-scale 300-mm twin-disk Andritz Sprout-Bauer (Muncy, Pa.) Pressurized Refiner. The fibers were then passed through a screen with 0.432-mm openings in the hammermill. The WF was prepared by American Wood Fibers. Postindustrial scrap wood was broken down to the point where 0 to 5 percent of the material was left on a screen with 0.425-mm hole openings.

The HW and SW fiber, as well as the WF, was dried in an oven for at least 24 hours to remove moisture prior to compounding.

Processing. — The 18 composite materials were dry-blended according to the formulations in **Table 1.** They were then compounded in a 32-mm Davis Standard (Pawcatuck, Conn.) co-rotating, intermeshing, 32:1 length-to-diameter ratio, twin-screw extruder. Extrusion melt temperatures were maintained between 185°C and 193°C to prevent thermal degradation of the wood. The barrel of the extruder has two vacuum vents to remove moisture and volatile gases. Output ranged from 13 to 22 kg/hr. The extrusion strands were pelletized after being cooled in a water trough. All composite pellets were dried at 105°C for at least 24 hours prior to injection molding.

All 18 blends and unfilled PP were injection-molded into American Society for Testing and Materials (ASTM) test specimens (1) in a 33-ton Cincinnati Milacron reciprocating screw injection molder (Batavia, Ohio). All injection-molding conditions were maintained constant for the 20 and 40 percent filled blends.

Testing. — The HW and SW fiber and the WF were examined for their characteristics before processing. An optical microscope equipped with a camera was used to examine the materials before processing. The HW and SW fiber were also analyzed in a Kajaani (Norcross, Ga.) FS-100 to determine average fiber length.

Properties were tested according to ASTM standards for plastics (1). Each test series was composed of five specimens of each blend, with the exception of melt flow index tests. The average of each test sequence is reported along with the corresponding standard deviation. For impact, tensile, and flexural tests, specimens were conditioned for at least 40 hours prior to testing.

Notched and unnotched impact tests were conducted using Method A, the Izod type test, of ASTM Standard D 256 on injection-molded samples (3.2- by 12.7-mm cross section). Tensile properties of injection-molded samples (3.2- by 12.7-mm cross section) were determined according to ASTM Standard D 638. A crosshead speed of 5 mm/min. was maintained throughout the test, and an extension indicator was attached to the specimen. The maximum strength and percentage elongation were taken to be the strength and elongation at yield, and the tensile modulus of elasticity (MOE) was found using the initial slope of the stress-strain curve. Flexural testing was carried out on injection-molded bars (127 by 12.7 by 3.2 mm) using a three-point loading system following ASTM Standard D 790. The support span length was 50 mm, and the crosshead speed was maintained at 1.3 mm/min. A load versus deflection curve was plotted during the test. From this, the flexural strength was calculated using the maximum load the material sustained, and the flexural MOE was calculated using the slope of the initial tangent to the curve.

When determining the initial slope to calculate either tensile or flexural MOE, a hyperbolic curve was fit to each graph to compensate for the lack of an initial linear region. However, it was found that while the curve tit the data well, the initial slope obtained from the curve fit did not correspond well with the actual initial slope. Therefore, a linear curve fit was used to determine the initial slope of each test individually.

Heat deflection temperature tests were carried out according to ASTM Standard D 648. These tests were conducted at Plastics Technologies Laboratories, Inc. (Pittsfield, Mass.) at 1.8 MPa (264 psi) as described in the standard. Because the wood component of the composite may degrade at temperatures higher than 200°C one melt flow test was conducted at 190°C following ASTM D 1238 for each material. This is also the temperature at which the materials were proc-

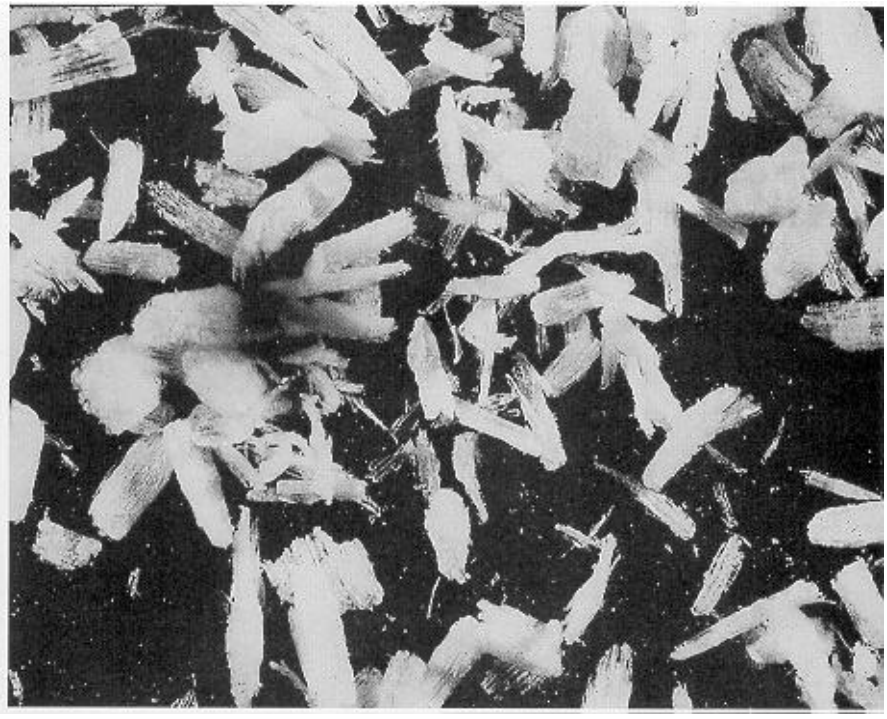

Figure 2. — Commercial 40 mesh (0.42-mm sieve openings) wood flour derived from postindustrial waste.

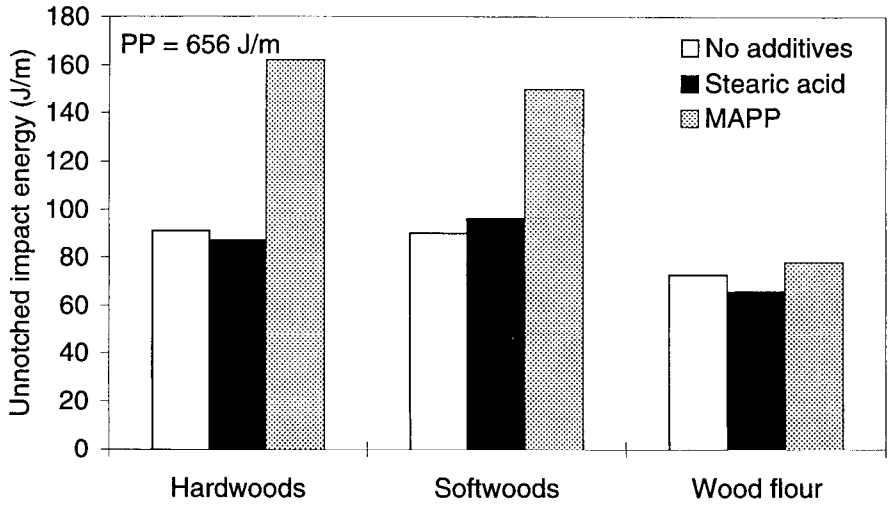

Figure 3. — Effects of filler type and additives on unnotched impact energy for 40 percent wood-filled polypropylene (PP).

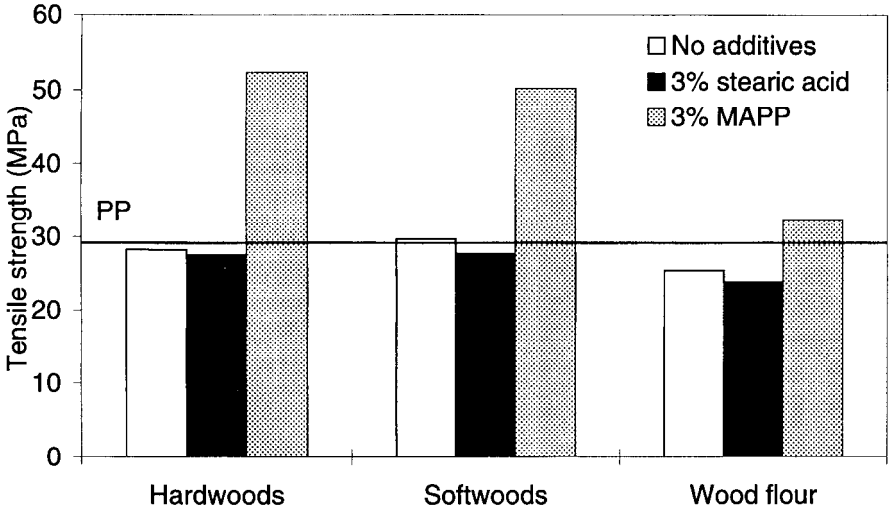

Figure 4. — Effects of filler type and additives on tensile strength for 40 percent wood-filled polypropylene (PP).

essed. The percentage mold shrinkage was calculated using injection-molded specimens following ASTM Standard D 955. Specific gravity was measured by using the flexural bar of the ASTM test specimen. The volume was determined by measuring the length, width, and thickness of each specimen. Mass was measured to determine specific gravity. The average of five replications was reported.

A scanning electron microscope was used to examine the impact fracture surfaces of the composites. The fracture surfaces were coated with gold for examination.

RESULTS AND DISCUSSION

FIBER CHARACTERISTICS

Figures 1 and **2** are optical microscope pictures of the wood fillers used in this study. It is easy to see that the fiber de-

TABLE 2.—Summary of mechanical properties for 20 percent wood-filled polypropylene composite materials.[a]

Material[b]	Izod impact energy		Tensile properties			Flexural properties	
	Notched	Unnotched	Strength	MOE	Elongation	Strength	MOE
	- - - - - - - - (J/m) - - - - - - - -		(MPa)	(GPa)	(%)	(MPa)	(GPa)
HW-20-XX	20.8 (1.7)	141 (12)	26.2 (0.2)	2.27 (0.08)	4.2 (0.1)	42.9 (0.7)	1.88 (0.03)
HW-20-SA	**21.0 (0.9)**	132 (11)	25.4 (0.3)	2.44 (0.02)	3.9 (0.1)	40.7 (0.8)	1.81 (0.03)
HW-20-MA	**22.5 (0.9)**	197 (18)	37.0 (0.4)	**2.31 (0.11)**	4.9 (0.3)	52.2 (1.8)	**1.91 (0.06)**
SW-20-XX	20.0 (1.0)	116 (8)	26.6 (0.3)	2.46 (0.08)	3.7 (0.2)	43.3 (0.3)	1.93 (0.09)
SW-20-SA	**19.8 (1.1)**	123 (8)	25.8 (0.2)	2.11 (0.07)	4.2 (0.2)	41.6 (0.8)	1.80 (0.04)
SW-20-MA	18.4 (0.8)	181 (12)	36.0 (0.2)	2.25 (0.07)	5.1 (0.2)	53.1 (1.2)	**1.80 (0.08)**
WF-20-XX	19.5 (1.4)	119 (16)	25.8 (0.2)	2.23 (0.03)	4.4 (0.2)	43.0 (0.7)	1.84 (0.07)
WF-20-SA	**20.5 (1.0)**	**111(11)**	24.7 (0.2)	**2.18 (0.07)**	**4.7 (0.2)**	39.6 (1.0)	1.65 (0.01)
WF-20-MA	**19.1 (0.6)**	**117 (13)**	29.4 (0.5)	**2.35 (0.13)**	**4.1 (0.2)**	46.9 (0.7)	**1.90 (0.04)**
PP	20.9 (1.2)	656 (31)	28.5 (0.3)	1.53 (0.06)	5.9 (0.1)	38.3 (0.4)	1.19 (0.01)

[a] Values for materials with either SA or MA are shown in boldface if they are not statistically different from the same blend with no additives, within a 99 percent confidence interval. Values in parentheses are standard deviations.
[b] HW = hardwood; XX = no additive; SA = stearic acid; MA = maleic anhydride; SW = softwood; WF = wood flour; PP = polypropylene.

TABLE 3. -Summary of mechanical properties of 40 percent wood-filled polypropylene composite materials [a]

Material[b]	Izod impact energy		Tensile properties			Flexural properties	
	Notched	Unnotched	Strength	MOE	Elongation	Strength	MOE
	- - - - - - - - (J/m) - - - - - - - -		(MPa)	(GPa)	(%)	(MPa)	(GPa)
HW-40-XX	23.2 (1.7)	91 (5)	28.2 (0.3)	4.20 (0.11)	2.0 (0.1)	47.9 (0.9)	3.25 (0.01)
HW-40-SA	**24.6 (1.1)**	**87 (7)**	**27.5 (0.3)**	3.71 (0.07)	**2.0 (0.1)**	46.2 (0.8)	3.13 (0.06)
HW-40-MA	**21.6 (1.5)**	162 (16)	52.3 (0.3)	**4.23 (0.18)**	3.2 (0.2)	72.5 (0.5)	**3.22 (0.14)**
SW-40-XX	22.2 (0.6)	90 (7)	29.7 (0.3)	3.68 (0.02)	2.1 (0.1)	48.9 (0.6)	3.10 (0.06)
SW-40-SA	**21.3 (1.5)**	**96 (10)**	27.7 (0.2)	2.99 (0.10)	2.7 (0.1)	45.6 (0.9)	2.52 (0.05)
SW-40-MA	**21.3 (0.9)**	150 (9)	50.2 (1.1)	3.89 (0.14)	3.2 (0.1)	76.5 (1.1)	3.50 (0.07)
WF-40-XX	22.2 (1.4)	73 (6)	25.4 (0.3)	3.87 (0.21)	1.9 (0.1)	44.2 (0.7)	3.03 (0.13)
WF-40-SA	**21.8 (1.2)**	**66 (8)**	23.8 (0.2)	**3.69 (0.08)**	**2.0 (0.2)**	42.4 (0.8)	**3.05 (0.07)**
WF-40-MA	**21.2 (1.1)**	**78 (7)**	32.3 (0.1)	**4.10 (0.10)**	**1.9 (0.1)**	53.1 (0.9)	**3.08 (0.08)**
PP	20.9 (1.2)	656 (31)	28.5 (0.3)	1.53 (0.06)	5.9 (0.1)	38.3 (0.4)	1.19 (0.03)

[a] Values for materials with either SA or MA are shown in boldface if they are not statistically different from the same blend with no additives, within a 99 percent confidence interval. Values in parentheses are standard deviations.
[b] HW = hardwood; XX = no additive; SA = stearic acid; MA = maleic anhydride; SW = softwood; WF = wood flour; PP = polypropylene.

rived from pallets **(Fig. 1)** had a much larger aspect ratio (length-to-diameter ratio) than did the WF **(Fig. 2).** The weighted average lengths of the HW and SW fiber before processing were 0.66 and 0.81 mm, respectively. This corresponds to an average aspect ratio of around 14 for HW and 17 for SW. In comparison, the average length of the WF before processing was 0.45 mm, with an average aspect ratio of 3.35. The impact, tensile, and flexural properties of the 20 and 40 percent wood content blends are presented in **Tables 2** and **3,** respectively. The specific gravity, melt flow index, mold shrinkage, and heat deflection temperature data are presented in **Tables 4** and **5** for the two wood ratios. The data for unfilled PP as well as the standard deviations for each property except melt index (MI) are presented in all tables for comparison. In **Tables 2** through **5,** values for materials with either SA or MAPP are shown in boldface if they are not statistically different within a 99 percent confidence interval than the same blend with no additives (that is, the additive did not affect properties). For the remaining discussion, the HW and SW fiber may be collectively referred to as pallet fiber (PF). This is done to simplify the discussion, because the HW- and SW-fiber-filled composites exhibited similar results for many of the properties examined.

Figures 3 through **5** represent the results for unnotched impact energy, tensile strength, and flexural strength, respectively. Each bar represents the average results of five tests corresponding to each of the wood filler types with or without additives at 40 percent by weight filler.

EFFECT OF FILLER TYPE

The type of filler did not affect the notched impact energy at either filler level or unnotched impact energies at 20 percent filler level. The unnotched impact energy was improved by the addition of PF rather than WF to PP at 40 percent by weight. Generally, the tensile MOE, percentage tensile elongation, and flexural MOE were unaffected by filler type. At 20 percent filler levels, the flexural strengths were similar between PF and WF, while the tensile strengths were somewhat higher for PF than for WF. However, at 40 percent filler levels, both the flexural and tensile strengths of the PF composites were slightly higher than those of the WF composites.

TABLE 4. — Summary of performance of 20 percent wood-filled polypropylene composites. [a]

Material[b]	Specific gravity	Melt index	Mold shrinkage	Heat deflection
	(g/cm^3)	(g/10 min.)	(%)	(°C)
HW-20-XX	0.954(0.005)	4.6	0.67(0.04)	73(4)
HW-20-SA	0.968(0.003)	4.5	**0.66(0.03)**	65(2)
HW-20-MA	**0.957(0.005)**	4.7	0.76(0.03)	75(2)
SW-20-XX	0.957(0.002)	3.3	0.70(0.04)	72(2)
SW-20-SA	**0.957(0.002)**	4.9	0.84(0.03)	65(2)
SW-20-MA	0.953(0.001)	3.4	0.84(0.02)	**72(3)**
WF-20-XX	0.959(0.004)	7.9	0.87(0.03)	70(2)
WF-20-SA	0.970(0.002)	8.4	**0.87(0.03)**	63(1)
WF-20-MA	**0.962(0.004)**	7.8	0.80(0.02)	**69(1)**
PP	0.902(0.003)	13.9	1.20(0.06)	57(2)

[a] Values for materials with either SA or MA are shown in boldface if they are not statistically different from the same blend with no additives, within a 99 percent confidence interval. Values in parentheses are standard deviations.

[b] HW = hardwood; XX = no additive; SA = stearic acid; MA = maleic anhydride; SW = softwood; WF = wood flour; PP = polypropylene.

TABLE 5. — Summary of performance of 40 percent wood-filled polypropylene composites. [a]

Material[b]	Specific gravity	Melt index	Mold shrinkage	Heat deflection
	(g/cm^3)	(g/10 min.)	(%)	(°C)
HW-40-XX	1.033 (0.002)	0.6	0.31 (0.02)	100(4)
HW-40-SA	**1.032 (0.004)**	0.5	**0.35 (0.05)**	93(4)
HW-40-MA	**1.029 (0.003)**	1.1	0.41 (0.01)	**105(5)**
SW-40-XX	1.008 (0.004)	1.1	0.38 (0.02)	98(1)
SW-40-SA	0.986 (0.001)	2.3	0.45 (0.05)	78(4)
SW-40-MA	1.038 (0.005)	0.6	0.42 (0.01)	120(2)
WF-40-XX	1.045 (0.004)	2.7	0.55 (0.04)	89(2)
WF-40-SA	1.056 (0.004)	2.5	**0.52 (0.02)**	78(3)
WF-40-MA	**1.048 (0.002)**	3	**0.53 (0.01)**	98(3)
PP	0.902 (0.003)	13.9	1.20 (0.06)	57(2)

[a] Values for materials with either SA or MA are shown in boldface if they are not statistically different from the same blend with no additives, within a 99 percent confidence interval. Values in parentheses are standard deviations.

[b] HW = hardwood; XX = no additive; SA = stearic acid; MA = maleic anhydride; SW = softwood; WF = wood flour; PP = polypropylene

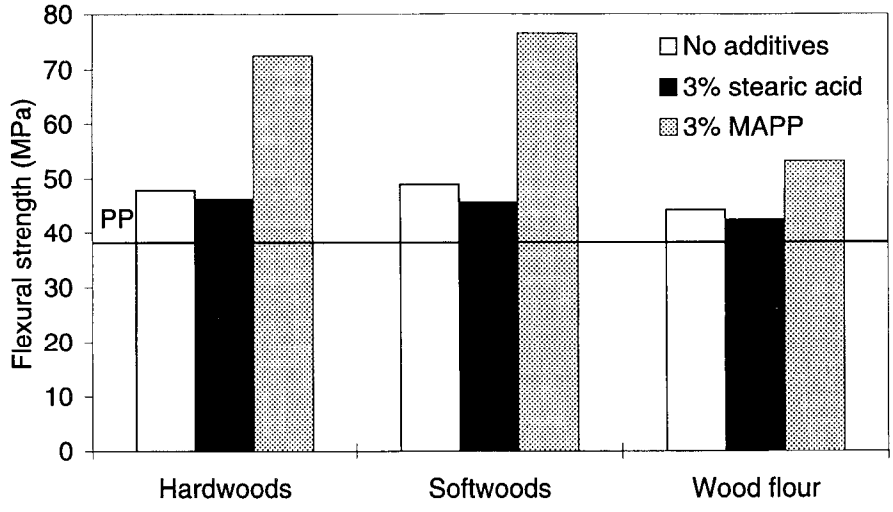

Figure 5. — Effects of filler type and additives on flexural strength for 40 percent wood-filled polypropylene (PP).

The specific gravity typically remained the same regardless of filler type. Melt index values and percentage mold shrinkage increased when WF was used as a tiller compared with when PF was used. This is probably a result of the different geometries of the wood filler. The smaller aspect ratio of the WF allows for larger unfilled regions of polymer. This increases the flow of the composite material under heat but also increases the volume of shrinkage during cooling. As expected, a higher percentage of wood filler in the composite resulted in a lower MI and mold shrinkage. The heat deflection temperature was not dependent on filler type but was improved when 40 percent filler was added.

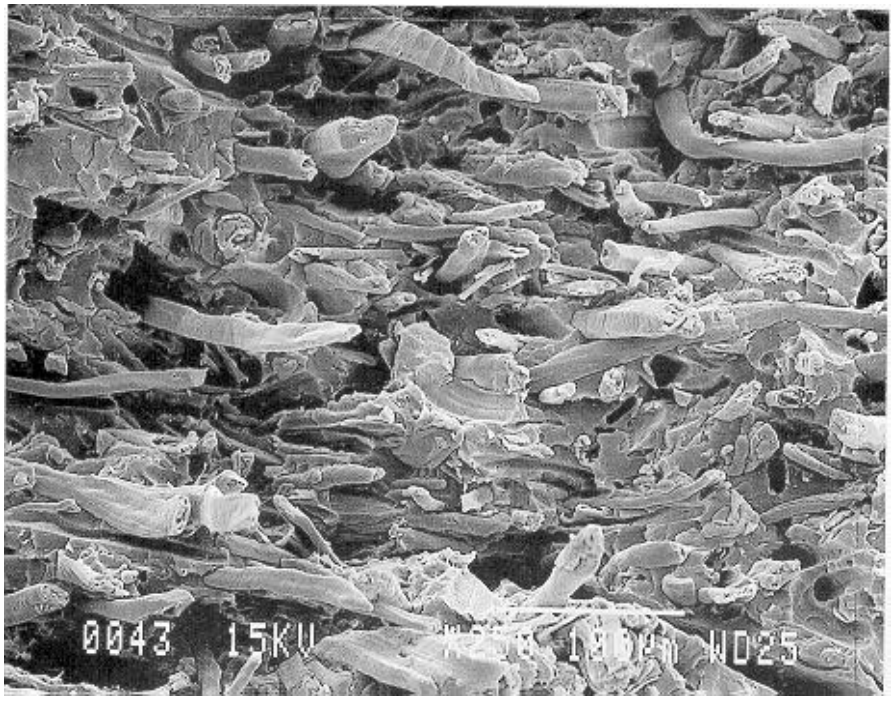

Figure 6. — Overall impact fracture surface of 40 percent hardwood-fiber-filled polypropylene with no additives.

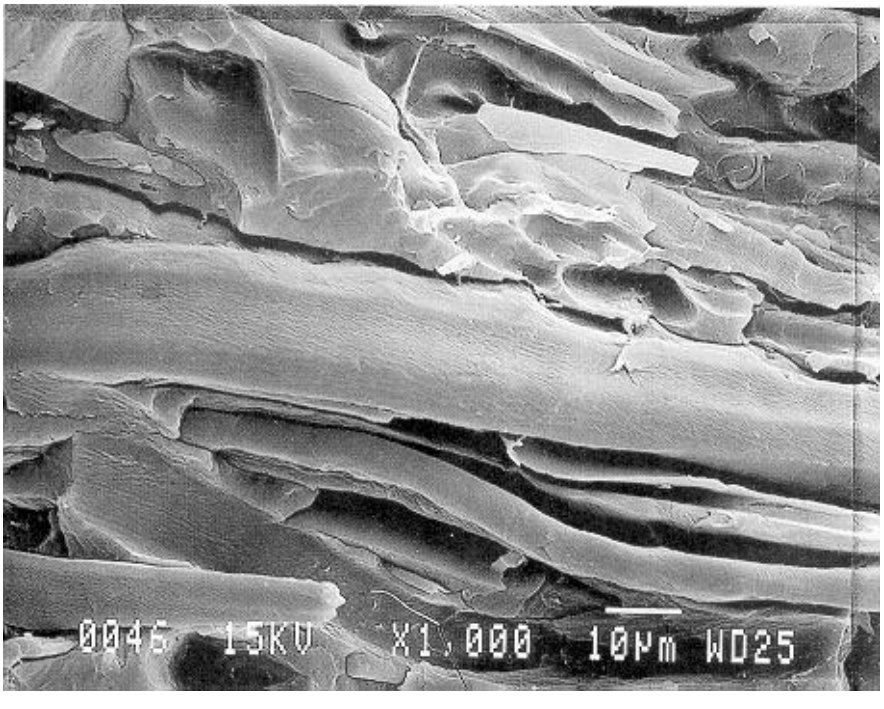

Figure 7. — impact fracture surface of 40 percent hardwood-fiber-filled polypropylene with no additives.

Effect of stearic acid

Stearic acid, when added to WF-filled PP, did not affect the impact strength but decreased the tensile strength, flexural strength, and the flexural MOE at 20 percent filler level with statistical significance. Impact energies were also unaffected by the addition of SA to the PF composites. Generally, for the PF composites, the flexural and tensile strengths and MOEs decreased upon the addition of SA. **Figures 4** and **5** show the relative values of the tensile and flexural strengths, respectively. The average values for the five tests are shown. Specific gravity and mold shrinkage changed slightly upon the addition of SA **(Tables 4** and **5).** The heat deflection temperature was reduced by an average of 12 percent for all composites with the addition of SA.

Previously, Dalväg et al. (4) added SA at 1.8 percent to WF-filled PP and WF-filled high density polyethylene (HDPE) composites. They found that the addition of SA at 1.8 percent loading did not have any effect on the impact strength of composites but improved the dispersion of the WF.

Effect of maleated PP

For all the WF composites, the addition of MAPP did not alter the impact energies, MOEs, or tensile elongation. However, when PF was used as the filler, the addition of MAPP typically did not affect the notched impact energy but increased the unnotched impact energy by 40 to 56 percent at 20 percent filled systems, and 67 to 78 percent for 40 percent filled systems **(Fig. 3).** This agrees with previously reported data (5) and suggests that the addition of MAPP helps deter crack initiation, as revealed by the increased unnotched impact energies, but not crack propagation.

The tensile and flexural strengths significantly increased in the WF-filled composites with the addition of MAPP. Furthermore, this observed increase in strength became more pronounced when

PF was used as a filler at 40 percent filler loading. When MAPP was added, the tensile strengths of the PF and WF systems increased by 38 and 14 percent, respectively, for 20 percent filled systems and 77 and 27 percent, respectively, for 40 percent filled systems **(Fig. 4).** Likewise, upon the addition of MAPP, the flexural strengths of the PF and WF systems increased by 22 and 9 percent, respectively, for 20 percent filled systems and 54 and 20 percent, respectively, for 40 percent filled systems **(Fig. 5).** The strength improvement indicates that a transfer of stress from the polymer matrix to the wood fiber occurs. This is achieved when there is bonding between the matrix and fiber. Generally, the tensile and flexural MOEs remained unaffected by the addition of MAPP at the 20 percent filled level but increased when the filler was 40 percent SW. The percentage tensile elongation slightly increased only when PF was the filler.

Previously reported data agrees with this study in that the addition of MAPP to a WF-PP composite increased the tensile and flexural strength and unnotched impact energy while notched impact energy, flexural and tensile MOE, and tensile elongation remained unchanged (5). As discussed earlier, at the 40 percent filled level, the use of a fiber such as PF reinforces the strength of PP compared with a particulate filler such as WE Upon addition of MAPP, which improves the adhesion between the fiber and the polymer matrix, the PF with a longer aspect ratio than WF uses MAPP more efficiently, resulting in a larger increase in property values.

The specific gravity, MI, mold shrinkage, and heat deflection temperature properties were not influenced by the addition of MAPP.

SCANNING ELECTRON MICROSCOPY

The impact fracture surfaces of each blend at 40 percent filler level were examined using a scanning electron microscope. **Figures 6** through **9** are the resulting micrographs for the HW-PF-filled PP. **Figures 6** and **7** represent the composite with no additive. **Figure 6** shows an overall view of the fracture surface of the composite. The fiber pullout and good dispersion of the fibers are readily seen. The poor bonding between the wood fiber and PP resulted in pullout of the fiber and the resulting pulling away of the PP from the fiber. When SA was added to the composite, the fibers still experienced pullout during fracture. The result was little or no improvement in properties. Also, the SA is well dispersed but can be observed in the polymer matrix. The result of this may be that the SA acted as a filler itself **(Fig. 8).** This

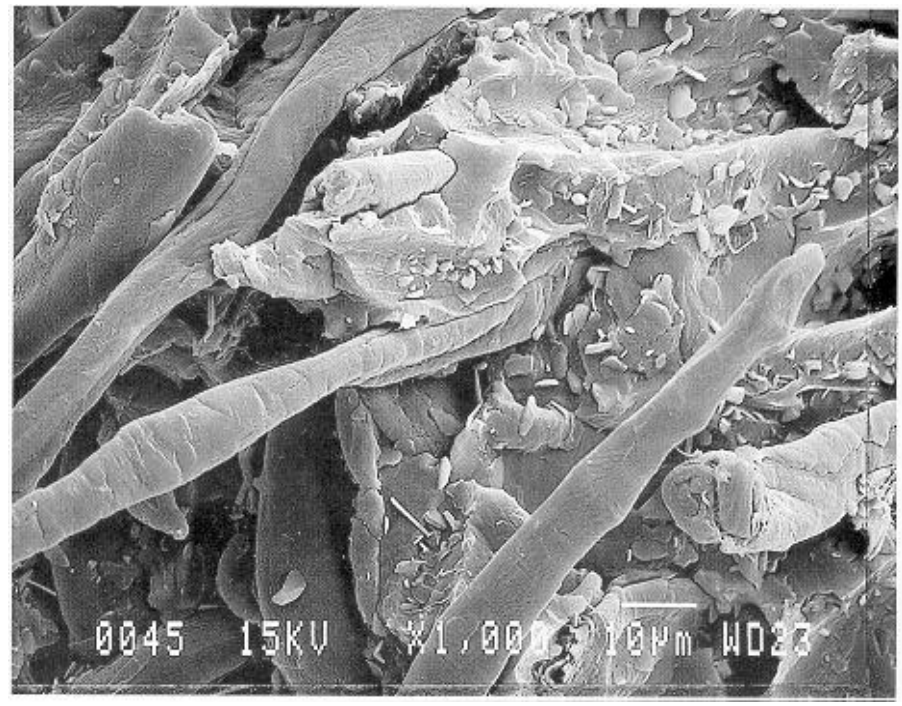

Figure 8. — Impact fracture surface of 40 percent hardwood-fiber-filled polypropylene with stearic acid added.

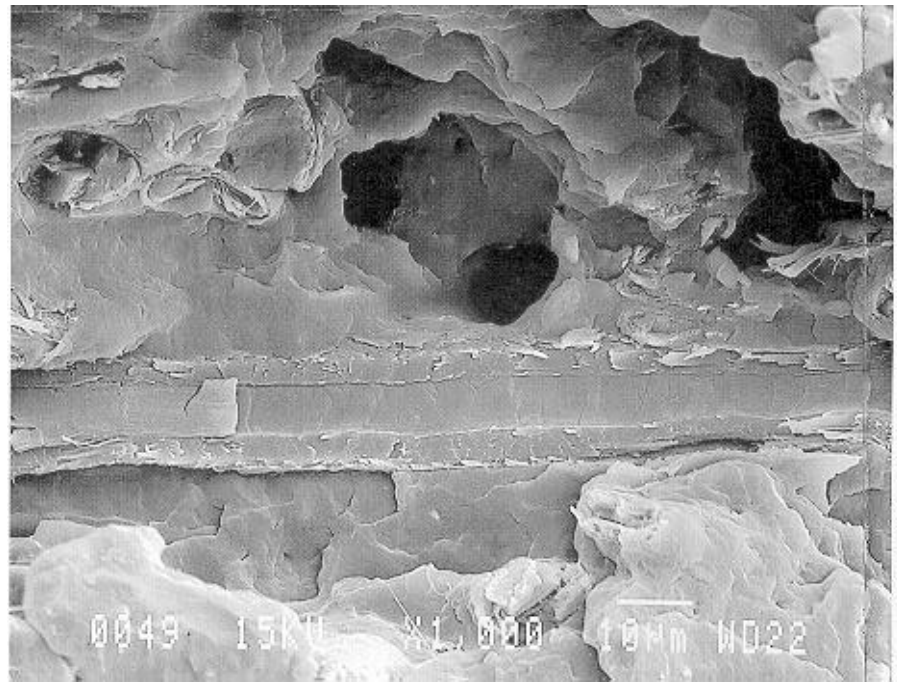

Figure 9. — Impact fracture surface of 40 percent hardwood-fiber-filled polypropylene with maleated polypropylene added.

was the case for all the SA blends and may account for some of the decrease in flexural and tensile properties. When MAPP was added, the tensile and flexural strengths improved. This is a result of good adhesion between the fiber and polymer matrix. **Figure 9** confirms this by showing that rather than fiber pullout during fracture, the fiber itself broke and the PP remained adhered to the fiber.

Conclusions

Pallets represent a large source of raw materials available for use in value-added composites. This study has shown that wood-plastic composites are a valid end product for the use of this abundant resource. Comparisons of the wood-filled PP blends show that the tensile and flexural strengths can be improved when fiber is added as the wood filler as opposed to WF, particularly at higher filler contents. The use of wood fiber instead of WF also decreased the percentage mold shrinkage, which could lead to less warpage of a molded part.

Generally, the addition of either SA or MAPP to the WF-filled composites did not significantly alter any properties except for the tensile and flexural strengths. The strengths decreased with the addition of SA and increased with the addition of MAPP. The addition of SA did not improve any of the material properties and decreased the flexural and tensile strengths and MOE and the heat deflection temperature. Because SA was used as a dispersing agent, the lack of property enhancement could indicate that dispersion of the fibers was already acceptable and that the SA acted almost as a filler itself.

The properties of both the WF and PF composites were greatly enhanced with the addition of MAPP. The addition of MAPP improved the notched impact performance of the composite only when PF was the filler. The tensile and flexural strengths also improved with the addition of MAPP to the composites, but when PF was the filler, the strengths improved more than they did when WF was the filler. As seen in **Figure 9,** the addition of MAPP enhances the adhesion between the wood and polymer interface. This results in a reinforcing effect of the fiber in the polymer matrix.

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