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Weight Reduction: Wood versus Mineral Fillers in Polypropylene

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Abstract

This paper compares various wood fillers to commercially available mineral and glass fillers in injection-molding-grade polypropylene. Although the data presented is previously reported, this paper places an emphasis the weight reduction afforded by wood fillers for packaging and transportation applications. Data for both homopolymer and high impact block copolymer is presented. Comparisons were made at both equal weight and approximately equal volume filler loadings. This distinction is important because the specific gravity of most minerals is around 2.7 to 2.8, and fiberglass is 2.5. Wood, when compressed to its maximum density by the melt pressures incurred during compounding and injection molding, has a specific gravity of approximately 1.3 to 1.4. Therefore, wood displaces roughly twice the volume of polymer as minerals at the same weight loadings. The same processing and test equipment was used throughout the study.

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Introduction

The transportation and packaging industry strives to use lightweight, high-performance, low-cost materials whenever possible. Reducing part weight for automobiles makes cars lighter, quicker, and more fuel-efficient. Reducing packaging weight reduces the gross weight of the finished goods being shipped, meaning more finished goods can be placed on a truck.

The use of plastics in automobiles and packaging is growing. Engineers are always trying to make plastic components lighter, stronger, and cheaper. This can be accomplished by good engineering (i.e., part design) and by adopting materials that inherently offer the best performance for the application.

This paper discusses the results of a filler study conducted to compare various wood fillers to commercially available mineral and glass fillers in injection-molding-grade polypropylene (1). The study was intended to make a comparison between wood fillers and mineral fillers using the same polymers, same industrial-scale processing equipment, and standard test methods.

Comparisons were made at both equal weight and approximately equal volume filler loadings. This distinction is important because the specific gravity of most minerals is around 2.7 to 2.8 and fiberglass is 2.5. Wood, when compressed to its maximum density by the melt pressures incurred during compounding and injection molding, has a specific gravity of approximately 1.3 to 1.4. Therefore, wood displaces roughly twice the volume of polymer as minerals at the same weight loadings.

Experimental

Materials

Formulations chosen for evaluation are shown in Table 1. Formulations were made in either homopolymer or high-impact block copolymer polypropylene. The homopolymer was Solvay 3907, with a 36.5 melt index. The high-impact copolymer was Montell Pro-fax SB-642 with a 22 melt index. Data on the unfilled performance of the polymers is included for comparison basis.

The wood fillers were either pine wood flour or demolition waste wood fiber. The wood flour selected was nominal 40-mesh pine and supplied by American Wood Fibers, Schofield, Wisconsin. Wood flour is typically derived from clean post-industrial sources, such as the residue from window and door manufacture. The demolition wood fiber was supplied by Wood Recycling, Inc., Woburn, Massachusetts. Demolition wood comes from post-consumer recycled sources, such as demolished buildings, old pallets, and urban tree trimmings. It is currently used for hydromulch and a few select composite applications. For purposes of this stud!; it was screened to 40 mesh to approximate the physical size of the wood flour.

Minerals were recommended and supplied by their respective manufacturer for the homopolymer. The calcium carbonate used was Optifil-T (treatment with 0.75 to 1.5% stearic acid as a dispersing agent), supplied by J. M. Huber, Quincy, Illinois. The fiberglass was 144A supplied by Owens Corning, Toledo, Ohio. The talc used was Vertal 710 and supplied by Luzenac America, Englewood, Colorado. Variations of these fillers, perhaps with additives, may provide more optimal performance.

All formulations reported are based on weight percent. Wood-filled formulations with 20 percent loadings are intended to approximate the same volumetric polymer displacement as the 40 percent mineral- and glass-filled formulations. Average list price for truckload quantities, standard packaging (bags or boxes on pallets), FOB location of manufacture, for mid-June 1996 are included in Table 2.

Processing

Compounding was conducted using a 32-mm Davis Standard Corporation (Pawcatuck, Conn.) corotating

TABLE 1.—Formulations based on weight percent.

Code	Polypropylene content and type	Filler amount and type
	(%)	
PI-20-H	80 homopolymer	20 Pine wood flour
DW-20-H	80 homopolymer	20 Screened demolition — wood fiber
PI-40-H	60 homopolymer	40 Pine wood flour
DW-40-H	60 homopolymer	40 Screened demolition — wood fiber
TA-40-H	60 homopolymer	40 Talc
FG-40-H	60 homopolymer	40 Fiberglass
CC-40-H	60 homopolymer	40 Calcium carbonate
PP-00-H	100 homopolymer	
PI-20-C	80 copolymer	20 Pine wood flour
DW-20-C	80 copolymer	20 Screened demolition — wood fiber
PI-40-C	60 copolymer	40 Pine wood flour
DW-40-C	60 copolymer	40 Screened demolition — wood fiber
TA-40-C	60 copolymer	40 Talc
FG-40-C	60 copolymer	40 Fiberglass
CC-40-C	60 copolymer	40 Calcium carbonate
PP-00-C	100 copolymer	

TABLE 2.—Average list price of materials FOB point of manufacture, mid-June 1996.

Material	Price
	($)
Pine	0.176
Demolition wood	0.242
Talc	0.270
Fiberglass	1.784
Calcium carbonate	0.299
Homopolymer polypropylene	1.060
Copolymer polypropylene	1.630

intermeshing twin-screw extruder. The extruder had segmented screws with a length-to-diameter ratio of 32 to 1. There were eight electrically heated, water-cooled barrel sections with vent zones at the fourth and seventh sections. Power was supplied by a 15-hp DC drive and a four-hole strand die was fitted to the discharge end. All materials were compounded with the same screw configuration, but rotation speed and feed rates varied somewhat to keep melt temperatures relatively equal at about 190°C. Discharge rates were between 20 and 40 kg/hr. The extruded compound was cooled in a water trough and cut into pellets.

All materials were dried in an oven at 105°C for at least 24 hours before injection molding into standard ASTM test specimens at 190°C. The injection molder was a 33-ton Cincinnati Milacron (Batavia, Ohio) reciprocating screw type. All materials were molded under the same conditions.

Testing

All testing was conducted according to ASTM standards for plastics (1). Notched and unnotched Izod impact testing was carried out according to ASTM D 256. Flexural and tensile properties were determined using ASTlM D 790 and D 638. Shrinkage rates were determined using ASTM D 955. Heat deflection temperatures were taken according to ASTM D 648 (264 psi). Melt flow index measurements were performed according to ASTM D 1238 with one notable exception. The melt index for polypropylene is normally measured at 230°C, which is well above the thermal degradation point for wood. The melt index for all materials was therefore taken at 190°C.

Scanning electron micrographs

Izod impact fractured surfaces were coated with gold and examined using a JSM-840 scanning electron microscope (SEM). The condition of the fibers after processing was also examined with a SEM after extracting the polypropylene from the composite specimens in xylene.

Results

Figures 1 through 6 are scanning electron micrographs of the fracture surface of the Izod impact specimens. They are included to show filler dispersion, distribution, and fiber length retention. Results of the testing for the homopolymer copolymer formulations are shown in Table 3.

Discussion

SEM discussion

Figures 1 through 6 show representative micrographs of the SEM investigations. Photos of fracture surfaces of the various composites as well as fibers extracted from the fiberglass are shown. Different magnifications were used for the different fillers in order to adequately show the microstructure of the composites. No visual differences were found between the filled homopolymer and filled copolymer, so only homopolymer micrographs are included.

Several general observations were made. First, the fracture surfaces show void-free composites with

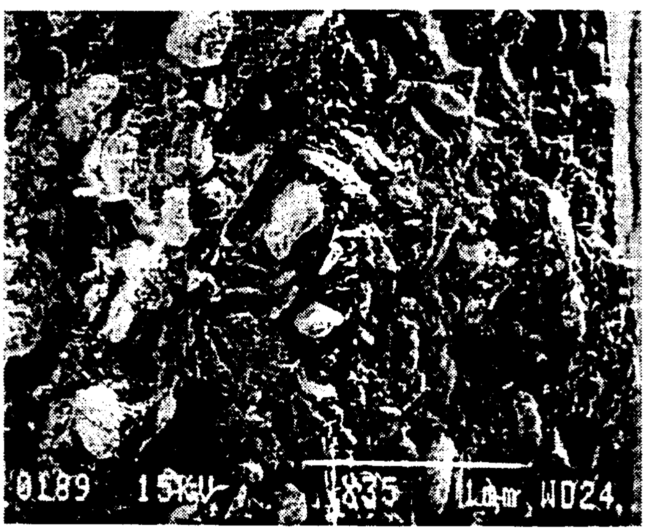

FIGURE 1.—Fracture surface of 40 percent pine wood flour (x30).

FIGURE 2.—Fracture surface of 40 percent talc (x1000).

well-dispersed and distributed fillers, and good contact between filler and matrix. Second, the varying nature of the fillers represented in this study are readily apparent. For instance, it is easy to see the difference between pine flour and demolition wood fiber. Third, a fiberglass length of approximately 0.1 to 1.0 mm can be seen, indicating good length retention after compounding and injection molding.

Specific gravity

Values reported agree with other sources (2,3). The slightly lower specific gravity of demolition wood fiber compared to pine flour may be due to minor processing losses incurred handling this relatively low bulk density material.

Melt index

Melt index measurements were taken at 190°C instead of 230°C to keep the wood fillers from degrading. The lower temperature resulted in a significant drop of the measured melt index for the unfilled polymers, indicating that melt indexes taken at this low temperature should be used for comparative purposes only.

FIGURE 3.—Fracture surface of 40 percent calcium carbonate (x1 0 0 0).

FIGURE 4.—Fracture surface of 40 percent demolition wood (x220).

FIGURE 5.—Fracture surface of 40 percent fiberglass (x1 2 0).

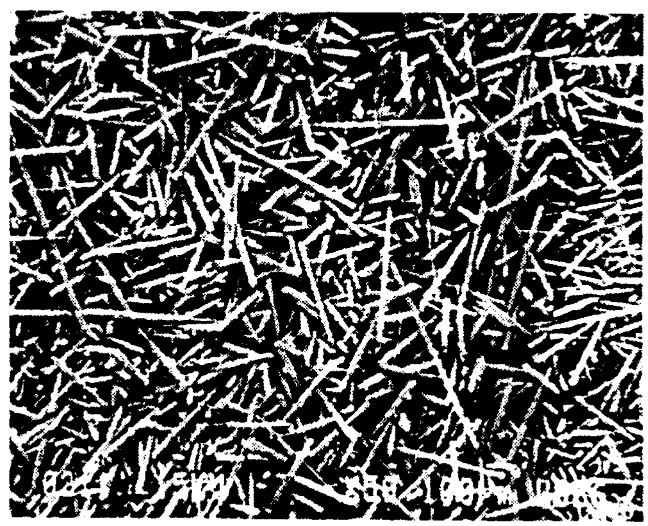

FIGURE 6.—Extracted fiberglass (x5 0)

The formulations containing calcium carbonate had the highest melt index of the filled formulations, and this was probably helped by the stearic acid added by the supplier. As might be expected, 20 percent wood-filled formulations had higher readings than 40 percent wood-filled formulations. Twenty percent wood-filled formulations were similar to fiberglass, suggesting fibrous materials at relatively equal volume fractions may have similar melt index. The experience of the authors suggests that wood-filled formulations actually suit injection molding much better than indicated by the melt indexes taken at 190°C. Viscosity data at shear rates typical of injection molding would be useful to understand this observation.

Mold shrinkage

Values reported for the minerals agree with published sources (3). As a group, all of the 20 percent wood-filled specimens had similar shrinkage, as did all of the 40 percent wood-filled specimens.

Impact performance

Calcium carbonate is known for its excellent impact performance, and the numbers indicate its overall superior performance. The pine flour and demolition wood had similar performance at either 20 or 40 percent loadings.

The notched copolymer data show that the 20 percent wood-filled and talc specimens had similar performance. Unnotched copolymer data for talc was superior to all of the wood fillers. The relatively poor performance of fiberglass in the copolymer can reasonably be attributed to a lack of coupling agent. Statisitical variability in the notched homopolymer data precludes definitive discussion.

Tensile properties

For all practical purposes, the pine flour and demolition wood performed about the same, with elongation reducing and modulus increasing with fiber content. As a class, all of the wood fillers outperformed the calcium carbonate, but fiberglass had better overall performance. In the homopolymer, talc performed better than any of the wood fillers, but not quite as good as fiberglass. In the copolymer, talc performed about in the middle of the range described by the wood fillers.

TABLE 3.—Summary of properties and performance.

				Izod impact		Tensile properties			Flexural properties		Heat
Formulation	Specific gravity	Melt index at 190°C	Mold shrinkage	Notched	Unnotched	Strength	Elongation	Modulus	Strength	Modulus	deflection temperature
		(g/10 min.)	(%)	(J/m)	(J/m)	(MPa)	(%)	(GPa)	(MPa)	(GPa)	(°C)
Homopolymer											
PI-20-H	1.00	8.6	0.94	13	110	26.4	4.9	2.3	43.7	1.7	69
DW-20-H	0.99	7.8	0.92	12	130	26.7	4.4	2.3	44.7	1.9	77
PI-40-H	1.10	1.9	0.50	16	60	24.4	2.1	3.7	44.7	3.1	90
DW-40-H	1.07	2.9	0.47	13	80	26.0	2.2	3.5	46.4	3.1	100
TA-40-H	1.23	12.2	0.89	17	115	32.3	2.1	5.0	54.6	3.3	91
FG-40-H	1.24	9.6	0.41	17	90	35.4	2.0	5.1	58.6	3.5	111
CC-40-H	1.24	15.1	1.34	19	470	21.8	3.8	2.2	39.8	1.8	57
PP-00-H	0.90	16.5	1.91	17	540	30.9	9.7	1.4	40.7	1.2	55
Average coefficient (%)				11	11	1	6	7	1	3	3
Copolymer											
PI-20-C	0.98	3.5	0.99	80	160	14.5	3.8	1.5	23.9	1.0	58
DW-20-C	0.97	2.9	0.96	77	180	14.1	3.6	1.4	22.6	1.0	60
PI-40-C	1.08	0.5	0.50	45	75	15.0	2.0	2.9	26.5	1.9	69
DW-40-C	1.07	0.5	0.32	37	75	17.2	1.3	3.2	28.9	2.3	80
TA-40-C	1.25	1.8	0.59	78	430	16.9	2.6	2.3	27.1	2.0	63
FG-40-C	1.22	4.5	0.40	54	140	23.8	3.5	3.7	37.3	2.2	85
CC-40-C	1.19	7.3	1.61	458	745	13.3	2.3	1.4	21.8	0.9	52
PP-00-C	0.90	7.4	2.02	675	780	14.6	9.1	0.7	18.2	0.5	47
Average coefficient (%)				8	10	2	7	8	2	3	2

Flexural properties

Strength values for demolition wood and pine flour were about the same with modulus increasing with filler amount. All of the wood-filled formulations were nearly equal to or better than calcium carbonate in respect to strength and modulus. Talc and fiberglass were somewhat stronger than the wood-filled formulations, but the 40 percent wood-filled formulations had similar modulus.

Heat deflection temperatures

Fiberglass had the highest heat deflection temperatures, with the 40 percent demolition wood formulations a close second. Talc performed about the same as the 40 percent pine flour and demolition wood in the homopolymer. In the copolymer, talc performed about the same as 20 percent pine flour and demolition wood. Pine flour and demolition wood performed better than calcium carbonate regardless of the loading.

Specific performance

Differences in mineral and wood fillers become more apparent when they are compared on the basis of their specific gravity. This is important when part weight is critical to overall product performance. The properties discussed above are derived by testing samples of a given volume, but differing densities. Testing of equal weight samples is impractical, so discussion in this section is based on the results of dividing the property value of a given formulation by its specific gravity. This was done for tensile strength, flexural modulus of elasticity (MOE), and notched Izod impact (Table 4). Figures 7 through 12 show the relative performance for both test values and specific performance values.

TABLE 4.—Summary of specific properties (value/specific gravity).

Formulation	Specific notched Izod	Specific flexural MOE	Specific tensile strength
	(J/m)	(GPa)	(MPa)
Homopolymer			
PI-20-H	13	1.7	26.4
DW-20-H	12	1.9	27.0
PI-40-H	15	2.8	22.2
DW-40-H	12	2.8	24.3
TA-40-H	14	2.7	26.3
FG-40-H	14	2.8	28.6
CC-40-H	15	1.4	17.6
Copolymer			
PI-20-C	84	1.1	14.8
DW-20-C	79	1.1	14.5
PI-40-C	41	1.8	13.9
DW-40-C	35	2.2	16.1
TA-40-C	62	1.6	13.5
FG-40-C	45	1.8	19.5
CC-40-C	385	0.8	11.2

Notched Izod (specific performance)

The relative performance of the fillers could be considered equal for the homopolymer. For the copolymer, calcium carbonate had the best performance, followed by the 10 percent wood loaded formulations. Talc performed about midway between the range described by the wood fillers. The poor performance of fiberglass is likely attributable to the lack of coupling agent.

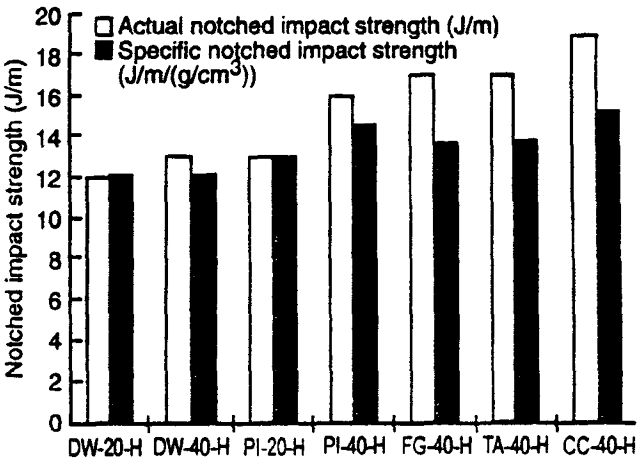

FIGURE 7.—Homopolymer notched impact strength.

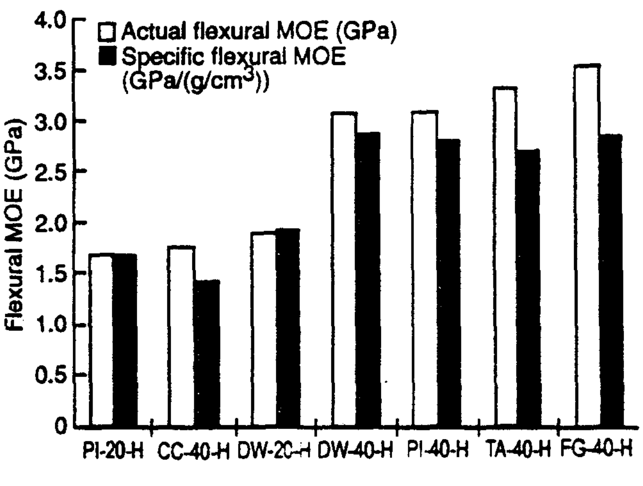

FIGURE 8.—Homopolymer flexural MOE.

Flexural modulus of elasticity (specific performance)

In the homopolymer, 40 percent demolition wood and pine flour had nearly identical performance to fiberglass and talc. The 20 percent demolition wood and pine flour had similar performance to each other, followed by calcium carbonate.

For the copolymer, the 40 percent demolition wood had better performance than talc or fiberglass. Forty percent loaded pine flour, fiberglass, and talc had equivalent performance. Calcium carbonate had the lowest performance of any of the fillers in this category.

Maximum tensile strength (specific performance)

For the homopolymer, fiberglass, talc, and 20 percent pine flour and demolition wood had nearly equivalent performance, perhaps due to the approximately same polymer displacement. Forty percent pine flour and demolition wood performed better than calcium carbonate, which had the poorest performance in this class.

For the copolymer, fiberglass had the best performance, followed by 40 percent demolition wood. The performance of talc, 20 and 40 percent pine flour, and 20 percent demolition wood was about the same. Calcium carbonate had the lowest performance.

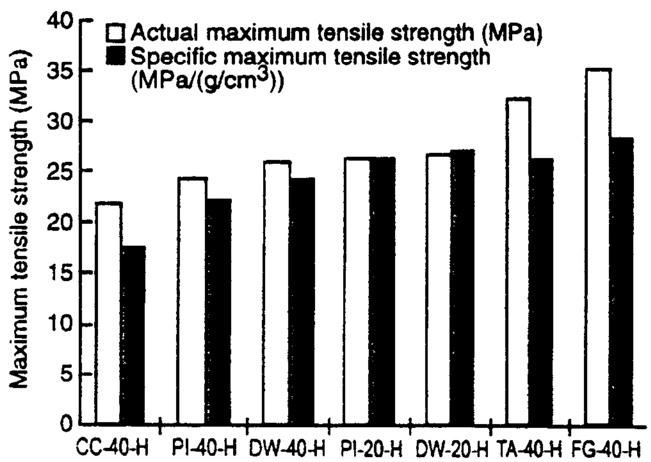

FIGURE 9.—Homopolymer maximum tensile strength.

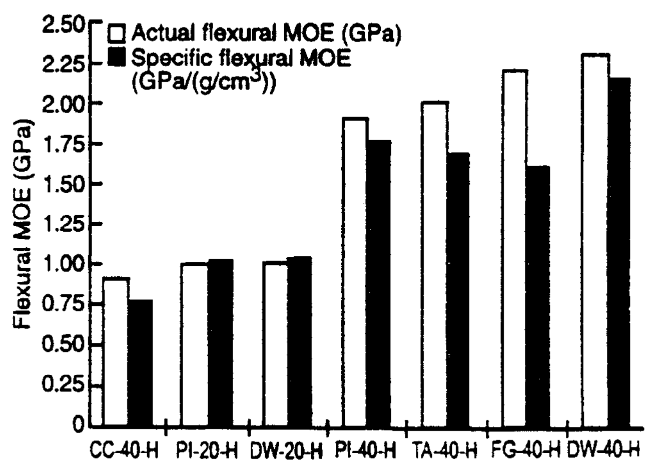

FIGURE 11.—Copolymer flexural MOE.

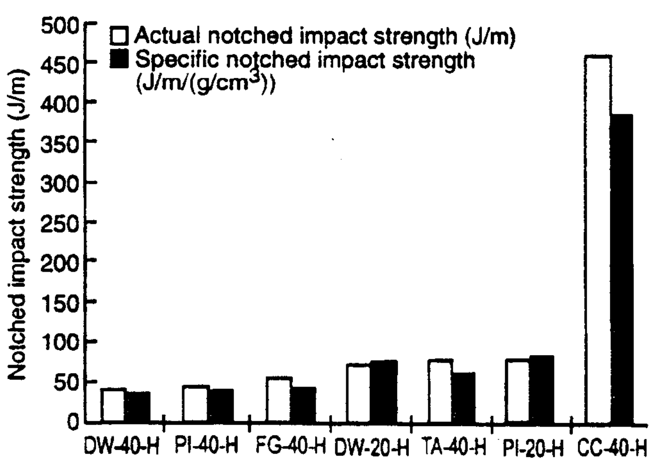

FIGURE 10.—Copolymer notched impact strength.

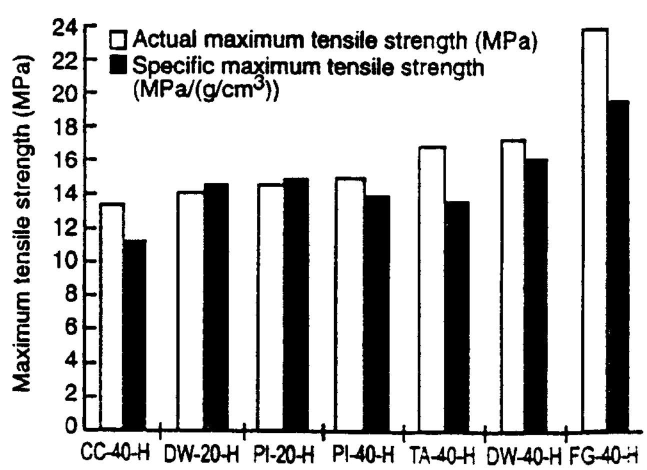

FIGURE 12.—Copolymer maximum tensile strength.

Conclusions

This study provides useful data to the automotive or packaging engineer. For the fillers and polymer used in this study, the following conclusions can be made:

1. Fiberglass is a useful filler for applications needing high MOE and high maximum tensile strength, where cost and specific gravity are of minimal concern.
2. Calcium carbonate is a useful filler for impact properties, but gains in MOE and maximum tensile strength were minimal.
3. For the homopolymer polypropylene, wood fillers had similar performance to talc, with lower specific gravity.
4. For the copolymer polypropylene, wood fillers also had similar performance to talc with lower specific gravity, with the exception of unnotched Izod impact performance.
5. The data do not substantiate a consistent relationship between equivalent volume percent loadings (20% wood-filled formulations vs. 40% mineral- or glass-filled formulations).

Literature cited

1. American Society of Testing and Materials. 1990. Annual Book of ASTM Standards. Vol. 8. Philadelphia, Pa.
2. English, B., N. Stark, and C.M. Clemons. 1997. Wood and mineral fillers for injection molding grade polypropylene. *In:* Proc. 6th Intl. Conf. Additives 1997. Executive Conference Management, Inc., Plymouth, Mich.
3. Modern Plastics Encyclopedia. 1989. McGraw Hill, New York, N.Y.

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