Cellulose-Reinforced Polypropylene: A Processing Study

Composites made with wood-based cellulose were found to offer advantages in terms of molding cycle times, part weight, and more

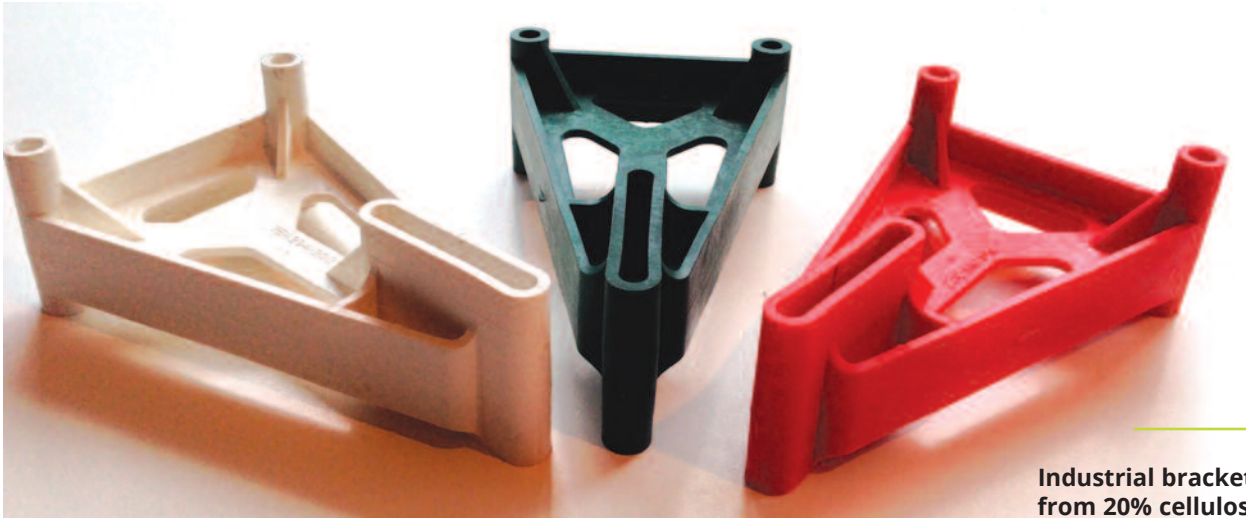
By Mark Rosen

In the past few years, wood-fiber reinforced plastics, sometimes called "thermoplastic biocomposites," have generated considerable interest due to their renewable features and potential for reducing dependency on petroleum-based feedstock. This article discusses the initial results of an experimental study of Weyerhaeuser Thrive™ composites, a nearly lignin-free, cellulose-filled polypropylene (PP). (Weyerhaeuser is a global leader in sustainable forestry, wood products, and cellulose fiber technologies; it owns or manages more than 20 million acres of forestland in North America.)

These findings showed that this material, at loads of 20% and 30% cellulose, is a cost-effective choice for applications requiring stiffness, faster cycle times, and lower part mass. In fact, this material has passed stringent automotive standards and will be included in Ford Motor Company's 2014 Lincoln MKX crossover vehicle.

These initial tests demonstrate that Thrive composites:

- are rigid materials with a flexural modulus as high as 422,000 psi (2.91 GPa) at 30% fiber loading;
- can reduce cycle time by up to 50%, or more, compared to other resins and compounds with a similar modulus;
- can reduce part weight up to 30%, compared to other reinforced plastics;
- minimize surface sink and internal voids;
- reduce sink and warpage, compared to other filled crystalline materials;
- can lower energy costs due to lower molding processing temperatures and faster cycle times;
- produce a more scratch-resistant surface than the base polypropylene homopolymer material itself;
- are not abrasive to tool steel; and
- demonstrate excellent bonding strength for TPE overmolding and wood and plastic inlays.



Industrial bracket made from 20% cellulose-filled PP

Collection of industrial fluid housings, brackets, end caps, and a large tray—all molded of cellulose-filled polypropylene

Based on these results and market acceptance, Weyerhaeuser is currently working to expand this proprietary technology to polymeric families beyond polypropylene.

Cellulose Fiber-Reinforced PP: What is it?

Cellulose fiber is a natural polymer which gives trees, in part, their remarkable strength. It is one of the most abundant renewable materials in nature. The same purified cellulose fiber, used as a reinforcement for plastics, is also used in applications including baby diapers, absorbents, and food thickeners.

Some key benefits of cellulose fibers as reinforcement in plastics are that it is sustainable, strong, flexible, and non-abrasive to tooling, and it has a considerably (~40%) lower density than glass fiber. One of the key challenges of using cellulose as a reinforcement in plastics has been the difficulty in achieving a strong bond of the hydrophilic fibers to the hydrophobic PP resin.

Testing Process

The study's goal was to better understand the molding characteristics of Weyerhaeuser Thrive composites. The material grades were 20DXMV235B4 (20% cellulose-filled PP) and 30DXMV235B4 (30% cellulose-filled PP).

Several parallel study paths were taken. Structured tests, using ASTM molds, established quantitative data for processing windows. A variety of actual injection molds were sampled to understand the molding behavior in real-world parts and tool designs. Material characterization for mold-filling analysis was verified using actual molded parts. Alternate molding technologies were tested, including foaming, overmolding, insert molding, and co-injection molding, as well as various postmold assembly processes.

Test Results

Melt temperature

As with many bio-filled plastics, this material needs to be run at lower temperatures to prevent browning of the organic fiber. Recommended processing at melt temperatures between 350° and 370°F (177°-188°C) resulted in low levels of color shifting and low odor. (Melt temperatures were taken from air shots using a preheated temperature probe.)

At a typical screw RPM for molding, the thermocouples on the heater bands on the barrel indicated a shear heating of 20-30°F (11-17°C) higher than the set points. After several minutes of running, almost all the heating was generated by the friction effects of the screw. The heater bands essentially stopped drawing electrical power.

Flow length and fill pressure

The results of 0.12-inch (3-mm) thick spiral melt-flow testing, ASTM D3123, showed that the material flows fairly well, as long as adequate pressure is applied. These tests were run with a peak injection pressure of 10,000 psi (69 MPa) and screw injection velocity of 2.5 inches/second (6.4 cm/sec). For the 20%-filled grade run at 350°F (177°C), the flow distance was 18 inches (46 cm). This resulted in an L/D ratio of 150:1. At 18,000 psi (124 MPa), the flow distance increased to 24 inches (61 cm) (L/D=200:1). For the 30%-filled grade, the flow distance at 350°F was 14 inches (36 cm) (L/D=116:1). At 19,000 psi (131 MPa), the flow distance increased to 19.5 inches (49.5 cm) (L/D=158).

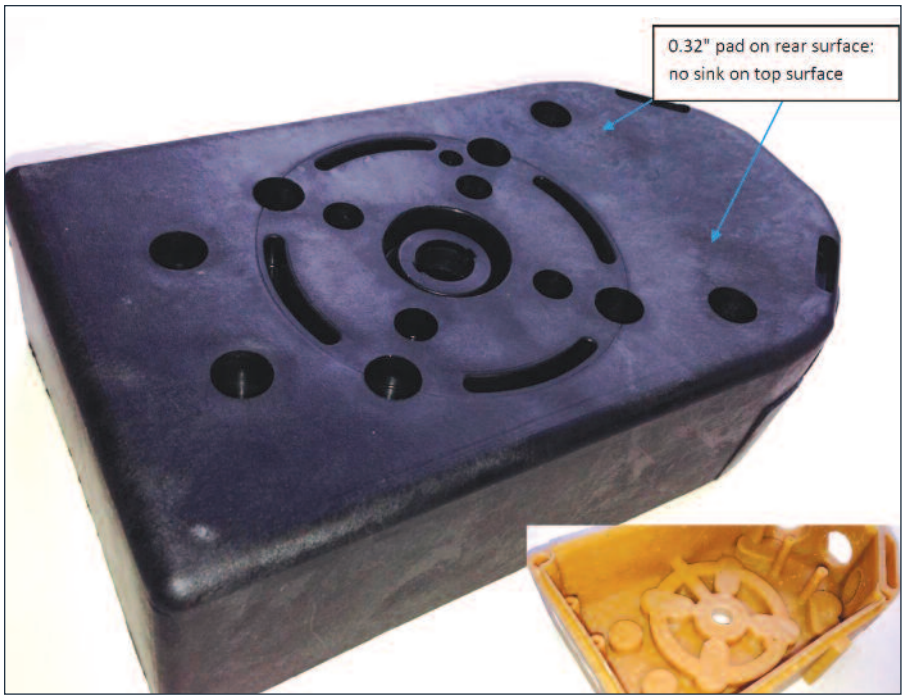
As a result, generally thicker walls (greater than 0.10 inches (2.5 mm)) are recommended for Thrive composites. In smaller parts less than approximately 8 inches (20 cm) in length, however, walls as thin as 0.060 inches (1.5 mm) can be used. In all cases, it was important that parts were designed to minimize flow hesitation. This was due to the rapid solidification rates of the material.

It should be noted that larger gates (about 60% to 75% of wall thickness) and less restrictive runners are recommended to reduce pressure loss in the runner. This allows for maximum flow length and also reduces shearing of the fiber. However, smaller parts were molded with gates as small as 0.050 inches (1.3 mm) in diameter.

Mold-filling analysis is recommended for all new molds to verify fill pressures and to optimize gating. (Verification of the material characterization data for Thrive composites was tested with both SIMPOE and Moldflow software.)

Packing/hold and cooling requirements

The molding tests showed that Thrive composites require short packing/hold and cooling times. This is contradictory to most fiber-filled resins, since these materials typically



Industrial fluid housing made from 30% cellulose-filled Thrive: no sink on surfaces adjacent to thick inner features (inset)

require higher melt and mold temperatures than the neat resin, resulting in longer packing and cooling times.

Parts with thick internal ribs and bosses were molded with almost no internal voids or sink on the visible surface. The reason was not clear. It may be due to a stiffening effect of the filler, or perhaps some outgassing occurs as the cellulose heats up.

The testing also showed that lower pack pressures were required, typically around 4,000 psi (28 MPa). Again, this is contradictory to most glass-filled crystalline materials, which typically require longer pack times and higher pressures to reduce warpage of the molded parts.

Table 1 compares estimated packing/hold and cooling times required for various materials to mold a part 0.200-inches thick.

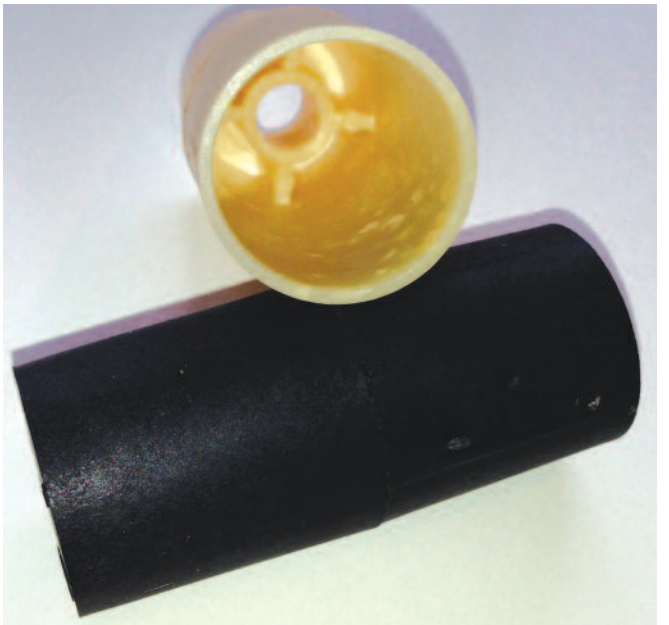
Cosmetics and odor

The Thrive material has a natural beige color with a light speckling from small amounts of non-dispersed white cellulose fiber. The 30% cellulose-filled grade is slightly darker than the 20% grade in its natural color.

Color was added with masterbatches of 3% white, 2% black, 2% blue, 3% red, and 2% green. The molded parts showed good consistent color. There was some white speckling due occasional non-dispersed fiber particles; however, this was less evident than with the natural colored parts.

The surface of the part ranged from glossy to slightly textured, similar to that of glass-filled PP, but with a significantly different surface feel.

There was a little odor (burnt wood smell) at molding, but this almost disappeared after a few days. This low odor is unusual for bioplastics and other natural fiber-filled polymers (for example, Ford Motor Co. tested more than forty materials for odor before they selected Thrive composites for an application).



Leg end cap made from 20% cellulose-filled PP, shown in natural and black

Table 1: Comparison of estimated packing/hold and cooling times* for 0.200-inch (5.1-mm) thick part for various materials (modulus shown for comparison)

	Thrive 20DXV235B4	Thrive 30DXV235B4	PP Homo-polymer	PP 20% Glass	ABS General Purpose	HIPS	PPE Noryl Unfilled
Tensile Modulus (psi)	370,000	490,000	195,000	479,000	310,000	270,000	282,000
Pack/Hold & Cool Time (sec)	28	30	57	65	82	62	52

*Cooling times for Thrive composites based on actual mold samplings; other materials calculated using SIMPOE mold filling analysis software.

Examples of Good Candidate Parts

The composites are ideal for generally thicker parts (0.100 inches (2.54 mm) or greater) in applications requiring strength, stiffness, fast molding cycle times, low sink/warpage, and good chemical resistance. In fact, in thicker and/or larger parts, substantial cost saving can be achieved via lower cycle-time costs due to faster cooling times.

Parts designed for materials such as pure PP or HDPE can be downgauged with Thrive composites due to higher part rigidity. And both small and large parts can be molded; to minimize cycle time, however, the press needs to be able to generate shot volume fast enough to keep up with rapid cooling rates.

Molds should be designed with larger gates and runners with minimum gate depth between 60% and 70% of wall thickness. Minimum gate diameters of 0.050 inches (1.3 mm) can be used for smaller parts. The nozzle ID should be as large as possible for the sprue or hot manifold bore diameter.

While hot runners are acceptable, larger flow-through tips or valve gates are preferred, and the lower processing temperatures of cellulose composites should be accounted for when using manifolds designed for materials with high melt temperatures. And to ensure good mold ejection, large ejector pins and stripper plates are preferred.

For the part example shown in *Table 2*, the mold-closed time was reduced from 137 seconds to 46.2 seconds, and part weight was reduced from 379 g to 280 g. The Thrive materials demonstrated almost no surface sink at thick sections (versus significant sink with 30% nylon 6), and parts molded with them were easier to handle postmolding due to lower ejection temperatures. It should be noted that 30% glass-filled nylon 6 is stiffer than the 30% cellulose fiber-filled composite, with a flexural modulus of 1,200,000 psi (8.3 GPa) versus 422,000 psi (2.91 GPa). For many structural components, however, Thrive represents a cost-effective reinforced engineering resin with mechanical properties similar to those of 20% glass-filled PP. Tests also showed that the composites exhibited low moisture absorption rates.

In the *Table 3* example, the flexural moduli of ABS and the 20% cellulose fiber-filled composite were almost identical, at 320,000 psi versus 307,000 psi (2.2 vs. 2.1 GPa). The composite produces a lighter part with faster cycle time at

Table 2: Industrial fluid housing example (wall thickness ranging from 0.236 to 0.560 inches (6-14 mm); single-cavity mold with cold sprue; molded in black and natural; mold runs on 200-ton press with several hand-loaded inserts)

	Thrive 30DXV235B4	Production Part Zytel 30% Glass-filled Nylon 6	Comparison
Melt Temperature **Mold Temperature**	355°F 90°F	530°F 190°F	
Molding Closed Time Fill Pack/Hold Cool	**46.2 seconds** 1.2 seconds 15 seconds at 4000 psi 30 seconds	**137 seconds** 2 seconds 20 seconds at 5400 psi 115 seconds	**90.8-second (66%) reduction in total cycle time**
Part Weight	280 grams	379 grams	**99 grams (26%) lighter**

Table 3: Industrial bracket example (nominal wall thickness of 0.156 inches (4.0 mm); two-cavity mold with cold runner and side tab gates (0.080 inches by 0.50 inches (2 by 12.7 mm); molded in red, white, and green on a 300-ton press)

	Thrive 20DXV235B4	Production Part (2 Cavity) General Purpose ABS	Comparison
Melt Temperature	350°F	500°F	
Mold Temperature	70°F	125°F	
Molding Closed Time	**29.3 seconds**	**51.3 seconds**	**22-second (43%) reduction in cycle time**
Fill	2.3 seconds	2.8 seconds	
Pack/Hold	2.0 seconds at 4000 psi	3.5 seconds at 4000 psi	
Cool	25 seconds	42 seconds	
Part Weight	272 g	321 g	**49 g (15%) lighter**

equivalent stiffness. In addition, there was no surface sink at rib intersections for the Thrive part, versus noticeable sink with the ABS component.

In the *Table 4* example, the mold-closed time was reduced from 32.1 seconds to 15 seconds. There were no ejection issues with the cylindrical core, and a small gate resulted in more dispersed fibers on the surface of the part.

Summary

The results of this testing showed that Thrive composites composed of cellulose fiber-reinforced PPs have a structural engineering-level stiffness equivalent to 20% glass-filled PP. The composites reduced cycle times by one-half or more, and parts molded with the composites were as much as 30% lighter than glass-filled materials. In addition, parts with thick internal features that were molded with the composites demonstrated little or no surface sink. And not only does the composite reduce the molded costs for many plastic parts, but this sustainably-produced material also replaces as much as 30% of the petroleum-based feedstock of plastic with renewable organic fibers.

About the author: *For additional information on the test results in this article, or for more details about Thrive composites, the author, Mark Rosen, can be reached at 201-891-1650. Rosen is principal of Corex Design Group Inc. (*www.corexdg.com*) of Franklin Lakes, New Jersey, USA.*

Table 4: Leg end cap example (wall thickness ranging from 0.070 to 0.135 inches (1.8-3.4 mm); four-cavity mold with cold runner and 0.050-inch (1.3-mm) diameter pin gates; molded in black and natural on a 90-ton press)

	Thrive 20DXV235B4	Production Part 4 Cavity HIPS	Comparison
Melt Temperature	350°F	395°F	
Mold Temperature	70°F	110°F	
Molding Closed Time	**15.0 seconds**	**32.1 seconds**	**17.1-second (53%) reduction in cycle time**
Fill	1.4 seconds	2.8 seconds	
Pack/Hold	1.6 seconds at 4000 psi	1.3 seconds at 6000 psi	
Cool	12 seconds	28 seconds	
Part Weight	109.2 grams	125.2 grams	**16 grams (13%) lighter**

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