Abstract
Research on wood and natural fiber–plastic composites has spanned several decades. However, there was relatively little market activity in the United States outside of the automotive industry prior to the last 5 years. Recently, however, the U.S. wood–plastic composites industry has grown tremendously. Although its total market size is small relative to the traditional wood composites industry, the U.S. wood–plastic composites industry is growing quickly and has attracted the interest of both the plastics and the forest products industries. Researchers, raw material suppliers, equipment manufacturers, and end product manufacturers often work together to develop, produce, and market these composites.

History
Wood and other natural fibers offer a number of advantages over inorganic fillers and reinforcements in thermoplastics; they are lighter, less abrasive, and renewable [1]. Wood flour can be used as a filler to reduce raw material costs, improve stiffness, and improve dimensional stability with temperature changes with minimal weight increase. When appropriate coupling agents are added to improve fiber–matrix adhesion, wood and other natural fibers can also be used as a reinforcing fiber to strengthen thermoplastics (Table 1).

Although researchers have touted the advantages of wood and other natural fibers as fillers and reinforcements in thermoplastics for decades, it wasn’t until recently that more than a few manufacturers in the United States produced thermoplastic composites with them.

Perhaps the most common reason for the historically low use of these natural fibers in thermoplastics was unfamiliarity. The plastics and wood industries know little about each other. They have few material and equipment suppliers in common and often process materials very differently and on different scales [2]. Historically, many thermoplastic and thermoplastic composite manufacturers who did try using wood or other natural fibers were unaware of or did not address the issues of natural fiber’s hygroscopicity and thermal degradation. However, natural fiber’s advantages of low cost, low weight relative to inorganic fillers and reinforcements, and ready availability are attracting more and more manufacturers. A few of the historical developments in the U.S. wood–plastic composites industry are mentioned here.

In 1983, American Woodstock (Sheboygan, Wisconsin) began producing automotive interior substrates using Italian extrusion technology. Polypropylene with approximately 50% wood flour was
compounded in-line and extruded into a flat sheet that was then formed into various shapes for interior automotive applications. This was one of the first large applications of wood-plastics technology in the United States.

In 1991, the First International Conference on Woodfiber Plastic Composites in Madison, Wisconsin, was convened with the intent of bringing together researchers and industrial representatives from both the plastics and forest products industries to share ideas and technology on woodfiber-plastics composites. Similar conferences in alternating years began in Toronto, Ontario, the following year. These conferences grew steadily in the 1990s.

In the early 1990s, Advanced Environmental Recycling Technologies (AERT, Junction, Texas) and a division of Mobil Chemical Company (Winchester, Virginia) began producing solid wood-plastic composites consisting of approximately 50% wood fiber in polyethylene. These composites were used as deck boards, landscape timbers, picnic tables, and industrial flooring [2]. Today the decking market is the largest and fastest growing woodfiber–thermoplastic composite market. Similar composites were milled into window and door component profiles.

In 1993, Andersen Corporation (Bayport, Minnesota) began producing woodfiber-reinforced polyvinyl chloride (PVC) subsills for French doors. These components typically contain 40% wood in PVC extruded to net shape. Further development led to a wood–PVC composite window line [3]. These products allow Andersen to recycle their own wastes from both their wood and plastic processing operations. The window and door profile market is the second largest woodfiber-plastic composite application today.

In 1996, a few U.S. companies that specialize in wood or natural fiber–plastic composites began producing a pelletized feedstock for the wood-plastic composites industry. These companies provide compounded pellets for many processors who do not do their own compounding.

Current Markets

Since the early 1990s, the wood-plastic composite industry has grown significantly. Today, wood and other natural fibers account for 7% of the 2.5 x 10^9 kg market for fillers and reinforcements [4]. This represents a 135% increase in natural fiber demand since 1990 with most of the growth in the past 5 years [4]. The price of wood fiber is comparable with inorganic fillers such as talc and calcium carbonate. Low wood fiber cost can be attributed to the considerable amount of wood residues generated from the U.S. wood industry. For example, 60 million metric tons of wood residues were generated just from primary timber processors in 1998 [5]. Although many wood residues are recovered, combusted, or not usable, large amounts are still readily available for use as fillers and reinforcements in thermoplastics.

The growth of wood flour and fiber use in thermoplastics has outpaced that of natural fiber. The relatively high bulk density of wood flour compared with longer natural fibers, as well as its low cost, familiarity, and availability, is attractive to building and construction industries.

Although wood flour is used most often, the use of other natural fibers is also increasing, particularly in automotive applications. Natural fibers are roughly twice as expensive as wood fiber but are still well below most other reinforcements such as glass fibers [4]. Despite lower strength relative to glass fibers, natural fibers are attractive due to their lower density. Recent growth in natural-fiber-reinforced thermoplastics has led to reports of large glass fiber manufacturers considering partnerships with natural fiber producers [6]. However, natural fiber availability is regional and high transportation costs and storage issues are limiting their growth [4].

Figure 1 is a list of some wood-plastic composite products currently available in North America [7]. The decking, window and door profile, and automotive markets represent the majority of the wood-plastics manufactured in the United States.

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1-2
Decking

The most growth in the wood–plastic composites industry is in building products, especially decking, although fencing, industrial flooring, landscape timbers, railings, and molding are also produced.

The U.S. decking market is large. In 1987, homeowners built approximately 3.6 million decks and spent an estimated US$1.9 x 10^9 (0.9 million DM, 1.8 Euro) on lumber for these decks [6]. The decking market has remained relatively steady during the last decade. Pressure-treated lumber is still by far the most commonly used decking material [6], but wood–plastic composite decking is growing quickly and some estimate it as high as 7% of the market [7].

Although wood–plastic decking is more expensive than pressure-treated wood, manufacturers promote its low maintenance, lack of cracking or splintering, high durability, and environmental preference relative to pressure-treated lumber. The actual lifetime of wood-plastic lumber is currently in debate [8]. Increased stiffness and reduced thermal expansion are promoted as advantages compared with unfilled plastic lumber. Solid, rectangular profiles are manufactured as well as more complex hollow and ribbed profiles. Wood fiber, wood flour, and rice hulls are the most common fillers used in decking. Typically 50% wood fiber is used, although some products contain as much as 70%. A polyethylene matrix is used almost exclusively. At least ten manufacturers produce decking from natural-fiber-filled thermoplastics, but the market is dominated by the largest manufacturers. One leading manufacturer is seeking to build a network of 2,500 dealers by year-end [9].

Window and Door Profiles

Window and door profile manufacturers are another large industrial segment that uses wood plastic composites. Fiber contents range from 30% to 70%. PVC is most often used as the thermoplastic matrix in window applications, although other plastics and plastic blends are also used. Though wood-filled PVC is more expensive than unfilled PVC, some success has been realized with wood-filled PVC due to its balance of thermal stability, moisture resistance, and strength [10]. Patent activity is very high in this area.

Several industry leaders are offering wood–plastic composite profiles in their product line, but their approaches vary. One leading manufacturer coextrudes a wood-filled PVC with an unfilled PVC capstock for durability. Another manufacturer coextrudes a PVC core with a wood-filled PVC surface that can be painted or stained [3]. A third manufacturer offers two different composites: (1) a highly wood-filled PVC for stiffness, and (2) a composite with a foamed interior for easy nailing and screwing [10].

Automotive Applications

Wood–polypropylene sheet for interior substrates is still made in the United States by several manufacturers. However, manufacturers are beginning to use natural fibers other than wood as reinforcements. However, the growth in use of natural-fiber-reinforced thermoplastics in automotive applications has been slower in the United States than in Europe.

One U.S. tier I processor used German technology to produce door quarter panels from natural fiber composites with polypropylene and polyester that achieved a 4-star side impact rating [11]. Panel inserts, package trays, and structural headliners are also being made with similar technology. Flax-reinforced polypropylene is being used in rear shelf trim panels using nonwoven mat technology. Other products being tested include instrument panels, package shelves, load floors, and cab back panels [11].

Other

Although not a large percentage of the total market, many other products are beginning to be made with wood and natural-fiber-filled thermoplastics. Products such as imitation wood shingles, pallets, flower pots, tool handles, hot tub siding, and office accessories are currently manufactured [7].
Compounders specializing in wood and other natural fibers mixed with thermoplastics have fueled growth in many of these recent markets. These compounders make it much easier for manufacturers who do not typically do their own compounding, or do not wish to compound in-line, to use wood–plasticcomposites (for example, most single screw profilers or injection molding houses). Compounds sold typically contain 30% to 70% natural fiber in polypropylene, polyethylene, polystyrene, and PVC. Although formulations are highly proprietary, coupling agents, ultraviolet (UV) stabilizers, lubricants, and foaming agents are all used to some extent in the natural fiber–thermoplastic composites industry. Some additive suppliers are specifically targeting this new industry.

**Equipment Manufacturers**

Major equipment manufacturers, particularly twin screw extruder manufacturers, have developed processing equipment specifically for wood–plastics composite manufacturing (some in cooperation with European manufacturers). Recent innovations include feed sections that can accommodate low bulk density fibers, in-line drying, and processing lines that can handle very high fiber contents. Twin screw, die, and downstream equipment manufacturers are partnering to develop complete processing lines specifically for wood-plastic composites. Several manufacturers of drying lines also are manufacturing systems specially designed for wood flour.

**Future Markets**

Wood and other natural fibers have become a major part of the thermoplastic filler and reinforcement market. Sufficient market growth has attracted the attention of material suppliers, equipment manufacturers, and end-product manufacturers.

Wood and natural fibers are one of the fastest growing fillers–reinforcements in the United States. For the next 5 years, 50% growth has been projected for the wood–plasticcomposites in building products [4]. Much of this growth is fueled by the tremendous growth in decking. There are reports that some decking manufacturers may not be able to keep up with demand [4].

Growth in the automotive sector is expected to be more modest than the building market at approximately 15% during the next 5 years [4]. Much of this growth will depend on availability and transportation costs of natural fibers.

Future growth may well be accelerated by the research and development efforts by both industry and university–government researchers. For example, researchers are developing new additives for performance enhancement and improved processability, developing and optimizing processing methods, developing new performance and microstructural characterization techniques, and investigating fundamental mechanisms of fiber-matrix stress transfer. These research efforts may allow better use of raw materials, increased efficiency in processing, improved performance, and new product opportunities.

Market growth for wood and other natural fibers in thermoplastics will not be limited by a lack of discussion. Wood–plasticcomposites have been featured in a number of trade magazines (e.g., 3,11) in the past several years. Woodfiber–plasticcomposites have been well represented at major industrial exhibitions. Increased interest has also spawned a number of conferences in the United States and Canada. From May 1999 to May 2001, six conferences on wood–plasticcomposites will have been held.

**References**


Table 1. Mechanical properties of wood–polypropylene composites [12]<sup>a</sup>

<table>
<thead>
<tr>
<th>Composite&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Density (g/cm&lt;sup&gt;3&lt;/sup&gt;) (lb/ft&lt;sup&gt;3&lt;/sup&gt;)</th>
<th>Tensile Strength (MPa (lb/in&lt;sup&gt;2&lt;/sup&gt;))</th>
<th>Modulus (GPa (lb/in&lt;sup&gt;2&lt;/sup&gt;))</th>
<th>Elongation (%)</th>
<th>Flexural Strength (MPa (lb/in&lt;sup&gt;2&lt;/sup&gt;))</th>
<th>Modulus (GPa (lb/in&lt;sup&gt;2&lt;/sup&gt;))</th>
<th>Notched Izod impact energy (J/m (ft-lbf/in))</th>
<th>Unnotched Izod impact energy (J/m (ft-lbf/in))</th>
<th>Heat deflection temperature (°C (°F))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polypropylene</td>
<td>0.9 (56.2)</td>
<td>28.5 (4,130)</td>
<td>1.53 (221,000)</td>
<td>5.9 (0.39)</td>
<td>38.3 (5,550)</td>
<td>1.19 (1 73,000)</td>
<td>20.9 (656)</td>
<td>656 (57)</td>
<td></td>
</tr>
<tr>
<td>PP + 40% wood flour</td>
<td>1.05 (65.5)</td>
<td>25.4 (3,680)</td>
<td>3.87 (561,000)</td>
<td>1.9 (1.4)</td>
<td>44.2 (6,410)</td>
<td>3.03 (439,000)</td>
<td>22.2 (73)</td>
<td>73 (89)</td>
<td></td>
</tr>
<tr>
<td>PP + 40% hardwood fiber</td>
<td>1.03 (64.3)</td>
<td>28.2 (4,090)</td>
<td>4.20 (609,000)</td>
<td>2.0 (1.7)</td>
<td>47.9 (6,950)</td>
<td>3.25 (471,000)</td>
<td>26.2 (91)</td>
<td>91 (100)</td>
<td></td>
</tr>
<tr>
<td>PP + 40% hardwood fiber + 3% coupling agent</td>
<td>1.03 (64.3)</td>
<td>52.3 (7,580)</td>
<td>4.23 (613,000)</td>
<td>3.2 (3.0)</td>
<td>72.4 (10,500)</td>
<td>3.22 (467,000)</td>
<td>21.6 (162)</td>
<td>162 (105)</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Properties measured according to ASTM standards for plastics.

<sup>b</sup>PP is polypropylene; percentages based on weight.
Figure 1: Percentage of market of wood–plastic composite products currently available in North America [5].
3rd International Wood and Natural Fibre Composites Symposium

Kassel / Germany

September 19 - 20, 2000

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