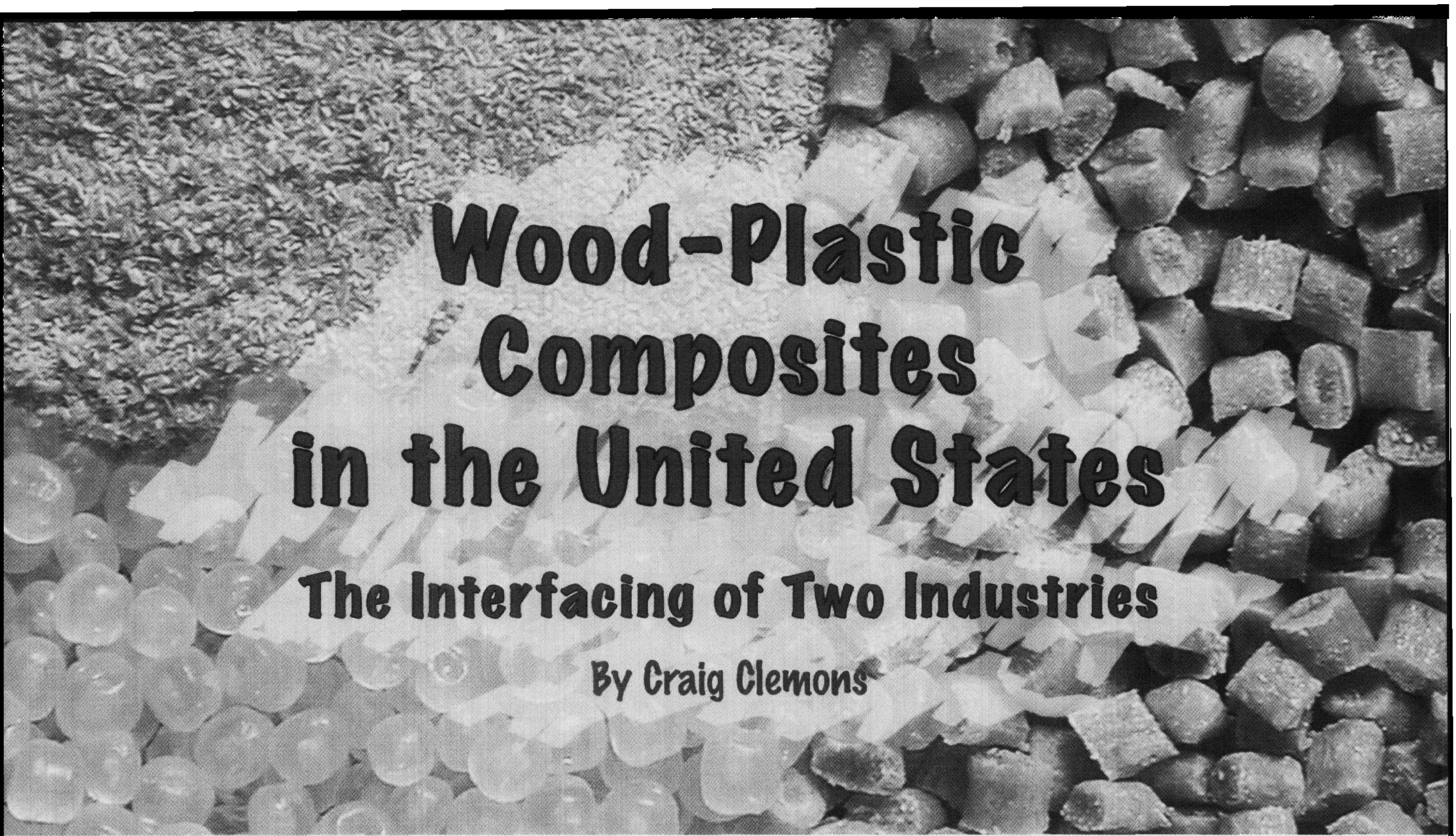

Wood-Plastic Composites in the United States

The Interfacing of Two Industries

By Craig Clemons

The term *wood-plastic composites* refers to any composites that contain wood (of any form) and thermosets or thermoplastics. *Thermosets* are plastics that, once cured, cannot be melted by reheating. These include resins such as epoxies and phenolics, plastics with which the forest products industry is most familiar. *Thermoplastics* are plastics that can be repeatedly melted, such as polyethylene and polyvinyl chloride (PVC). Thermoplastics are used to make many diverse commercial products such as milk jugs, grocery bags, and siding for homes.

Wood-thermoset composites date to the early 1900s. An early commercial composite marketed under the trade name Bakelite was composed of phenol-formaldehyde and wood flour. Its first commercial use was reportedly as a gearshift knob for Rolls Royce in 1916 (Gordon 1988). Wood-thermoplastic composites have been manufactured in the United States for several decades, and the industry has experienced tremendous growth in recent years. This article focuses on wood-thermoplastic composites, which are most often simply referred to as wood-plastic composites (WPCs) with the understanding that the plastic is a thermoplastic.

The birth of the WPC industry involved the interfacing of two industries that have historically known little about each other and have very different knowledge, expertise, and perspectives. The plastics industry has knowledge of plastics processing, and the forest products industry has more experience and resources in the building products market. Not surprisingly, some of the earliest companies to produce WPCs were window manufacturers that had experience with both wood and plastics.

The plastics industry has traditionally used talc, calcium carbonate, mica, and glass or carbon fibers to modify the performance of plastic; about 2.5 billion kg (5.5 billion lb.) of fillers and reinforcements are used annually (Eckert 2000). The industry was reluctant to use wood or other natural fibers, such as kenaf or flax, even though these fibers are from a renewable resource and are less expensive, lighter, and less abrasive to processing equipment than conventional fillers. Most plastics processors ignored wood fiber because of its low bulk density, low thermal stability, and tendency to absorb moisture. The majority of thermoplastics arrive at a manufacturer as free-flowing pellets or granules with a bulk density of about 500 kg/m^3 (31 pcf). The plastics processor is faced with the problem of how to consistently meter and force the low bulk density wood fiber into small feed openings typical of plastics processing equipment. In addition, the processing temperature for even low melting point plastics is often too high for incorporating wood fiber without thermal degradation. The high moisture content of wood and other natural fibers is also problematic to the plastics industry, which considers about 1 to 2 percent moisture content high. Even plastics processors with vented equipment capable of removing moisture during processing were averse to removing 5 to

7 percent moisture from wood fibers. Resin dryers, which are occasionally needed to dry plastics, are not appropriate for wood particles or fibers, and drying the fine wood particles poses a fire hazard. Plastics processors who tried to use wood or other natural fibers often lacked knowledge about wood, and their failed attempts made the industry generally skeptical of combining wood and plastic.

For the wood products industry, thermoplastics were a foreign world, albeit one that occasionally intruded on traditional markets (e.g., vinyl siding). Competing in different markets, forest products and plastics industries had few material and equipment suppliers in common and they processed materials very differently and on entirely different scales (Youngquist 1995).

The perspective of some plastics industries has changed dramatically in the last decade. Interest has been fueled by the success of several WPC products, greater awareness and understanding of wood, developments from equipment manufacturers and additive suppliers, and opportunities to enter new markets, particularly in the large-volume building applications sector. Forest products industries are changing their perspective as well. They view WPCs as a way to increase the durability of wood with little maintenance on the consumer's part (one of the greatest selling points). Some forest products companies are beginning to manufacture WPC lumber and others are distributing this product. These ventures into WPCs are being driven by customer demand and opportunities based on the industry's experience in building products (Anonymous 2001).

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In the United States, WPCs have been produced for several decades, but they were produced even earlier in Europe. However, major growth in the United States did not occur until fairly recently. This section describes some historical developments in the U.S. WPC industry through the mid-1990s.

In 1983, American Woodstock, now part of Lear Corporation in Sheboygan, Wisconsin, began producing automotive interior substrates using Italian extrusion technology (Schut 1999). Polypropylene with approximately 50 percent wood flour was extruded into a flat sheet that was then formed into various shapes for interior automotive paneling. This was one of the first major applications of WPC technology in the United States.

In the early 1990s, Advanced Environmental Recycling Technologies (AERT, Junction, Texas) and a division of Mobil Chemical Company that later became Trex (Winchester, Virginia) began producing solid WPCs consisting of approximately 50 percent wood fiber in polyethylene. These composites were sold as deck boards, landscape timbers, picnic tables, and industrial flooring (Youngquist 1995). Similar composites were milled into window and door component profiles. Today, the decking market is the largest and fastest growing WPC market.

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Also in the early 1990s, Strandex Corporation (Madison, Wisconsin) patented technology for extruding high wood fiber content composites directly to final shape without the need for milling or further forming. Strandex has continued to license its evolving technology.

Andersen Corporation (Bayport, Minnesota) began producing wood fiber-reinforced PVC subsills for French doors in 1993. Further development led to a wood-PVC composite window line (Schut 1999). These products allowed Andersen to recycle wastes from both wood and plastic processing operations. The market for WPC window and door profiles has continued to grow.

In 1996, several U.S. companies began producing a pelletized feedstock from wood (or other natural fibers) and plastic. These companies provide compounded pellets for many processors who do not want to blend their own material. Since the mid-1990s, activity in the WPC industry has increased dramatically. Technology is developing quickly and many manufacturers have begun to produce WPCs.

In 1991, the First International Conference on Woodfiber-Plastic Composites was convened in Madison, Wisconsin, with the intent of bringing together researchers and industrial representatives from both the plastics and forest products industries to share ideas and technology on WPCs. A similar conference (Progress in Woodfibre-Plastic Composites) began in Toronto, Ontario, the following year and is being held in alternating years. These conferences have grown steadily in the 1990s, and additional conferences have been held in North America and elsewhere as the market has grown. For example, a WPC conference was held by Plastics Technology Magazine and Polymer Process Communications in December 2000, in Baltimore, Maryland.

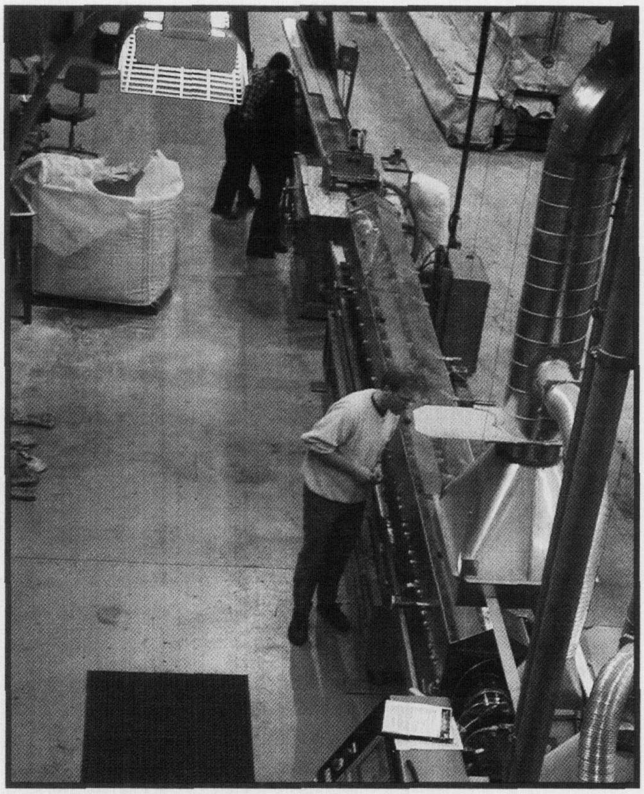

Figure 1a. – Profile extrusion line at the University of Maine.

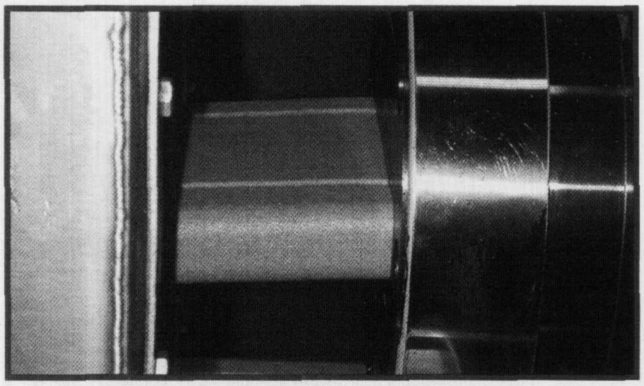

Figure 1b. – WPC (center) exiting extrusion die (right) and entering cooling tank (left).

Although the WPC industry is still only a fraction of a percent of the total wood products industry (Smith 2001), it has made significant inroads in certain markets. Current end product manufacturers are an interesting mix of large and small manufacturers from both the plastics and forest products industries. According to a recent market study, the WPC market was 320,000 metric tons (700 million lb.) in 2001, and the volume is expected to more than double by 2005 (Mapleston 2001b).

Materials

Because of the limited thermal stability of wood, only thermoplastics that melt or can be processed at temperatures below 200°C (392°F) are commonly used in WPCs. Currently, most WPCs are made with polyethylene, both recycled and virgin, for use in exterior building components. However, WPCs made with wood-polypropylene are typically used in automotive applications and consumer products, and these composites have recently been investigated for use in building profiles. Wood-PVC composites typically used in window manufacture are now being used in decking as well. Polystyrene and acrylonitrile-butadiene-styrene (ABS) are also being used. The plastic is often selected based on its inherent properties, product need, availability, cost, and the manufacturer's familiarity with the material. Small amounts of thermoset resins such as phenol-formaldehyde or diphenyl methane diisocyanate are also sometimes used in composites with a high wood content (Wolcott and Adcock 2000).

The wood used in WPCs is most often in particulate form (e.g., wood flour) or very short fibers, rather than longer individual wood fibers. Products typically contain approximately 50 percent wood, although some composites contain very little wood and others as much as 70 percent. The relatively high bulk density and free-flowing nature of wood flour compared with wood fibers or other longer natural fibers, as well as its low cost, familiarity, and availability, is attractive to WPC manufacturers and users. Common species used include pine, maple, and oak. Typical particle sizes are 10 to 80 mesh.

Wood and plastic are not the only components in WPCs. These composites also contain materials that are added in small amounts to affect processing and performance. Although formulations are highly proprietary, additives such as coupling agents, light stabilizers, pigments, lubricants, fungicides, and foaming agents are all used to some extent. Some additive suppliers are specifically targeting the WPC industry (Mapleston 2001a).

Processing

The manufacture of thermoplastic composites is often a two-step process. The raw materials are first mixed together in a process called compounding, and the compounded material is then formed into a product. Compounding is the feeding and dispersing of fillers and additives in the molten polymer. Many options are available for compounding, using either batch or continuous mixers. The compounded material can be immediately pressed or shaped into an end product or formed into pellets for future processing. Some product manufacturing options for WPCs force molten material through a die (sheet or profile extrusion), into a cold mold (injection molding), between calenders (calendering), or between mold halves (thermoforming and compression molding) (Youngquist 1999). Combining the compounding and product manufacturing steps is called in-line processing.

The majority of WPCs are manufactured by profile extrusion, in which molten composite material is forced through a die to make a continuous profile of the desired shape (Fig. 1). Extrusion lends itself to processing the high viscosity of the molten WPC blends and to shaping the long, continuous profiles common to building materials. These profiles can be a simple solid shape, or highly engineered and hollow. Outputs up to 3 m/min. (10 ft./min.) are currently possible (Mapleston 2001b).

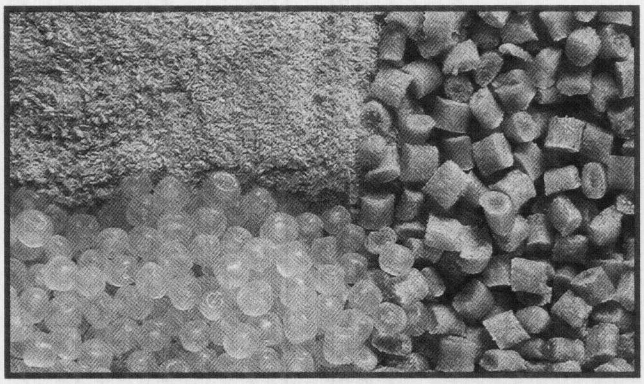

Figure 2. – Compounded pellets (bottom) made from wood (upper right) and plastic (upper left).

Although extrusion is by far the most common processing method for WPCs, the processors use a variety of extruder types and processing strategies (Mapleston 2001c). Some processors run compounded pellets through single-screw extruders to form the final shape. Others compound and extrude final shapes in one step using twin-screw extruders. Some processors use two extruders in tandem, one for compounding and the other for profiling (Mapleston 2001c). Moisture can be removed from the wood component before processing, during a separate compounding step (or in the first extruder in a tandem process), or by using the first part of an extruder as a dryer in some in-line processes. Equipment has been developed for many aspects of WPC processing, including materials handling, drying and feeding systems, extruder design, die design, and downstream equipment (i.e., equipment needed after extrusion, such as cooling tanks, pullers, and cut-off saws). Equipment manufacturers have partnered to develop complete processing lines specifically for WPCs. Some manufacturers are licensing new extrusion technologies that are very different from conventional extrusion processing (Mapleston 2001c,d).

Compounders specializing in wood and other natural fibers mixed with thermoplastics have fueled growth in several markets. These compounders supply preblended, free-flowing pellets (Fig. 2) that can be reheated and formed into products by a variety of processing methods. The pellets are a boon to manufacturers who do not typically do their own compounding or do not wish to compound in-line (for example, most single-screw profilers or injection molding companies).

Other processing technologies such as injection molding and compression molding are also used to produce WPCs, but the total poundage is much less than what is produced with extrusion (English et al. 1996). These alternative processing methods have advantages when processing of a continuous piece is not desired or a more complicated shape is needed. Composite formulation must be adjusted to meet processing requirements (e.g., the low viscosity needed for injection molding can limit wood content).

Performance

The wide variety of WPCs makes it difficult to discuss the performance of these composites. Performance depends on the inherent properties of

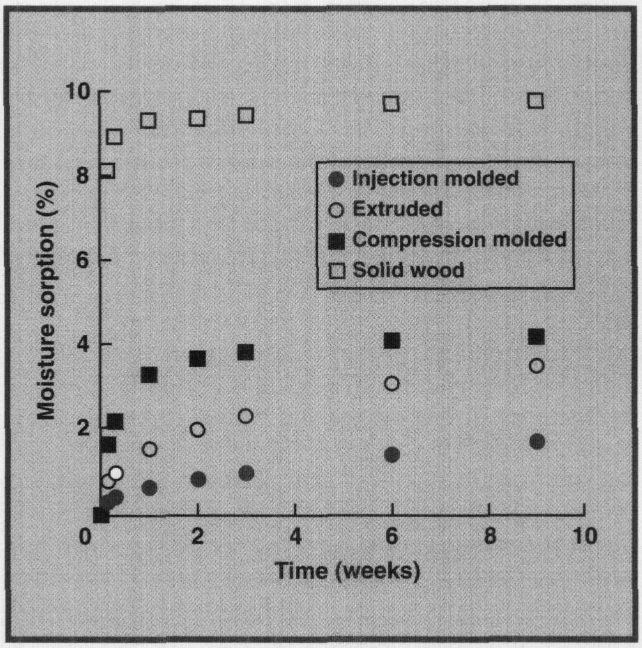

Figure 3. – Moisture sorption of solid wood and high-density polyethylene containing 50 percent wood flour processed by various methods. Conditions: 27°F (80°F) and 65 percent relative humidity (unpublished data).

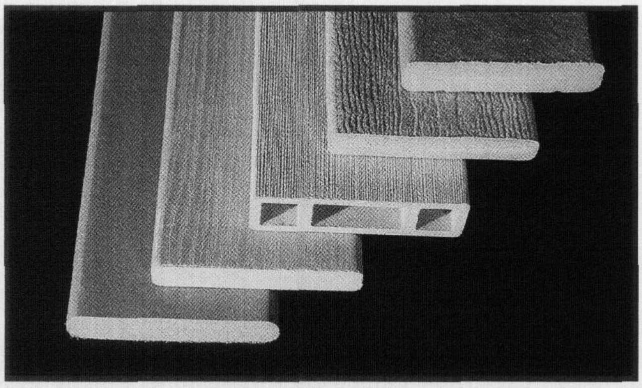

Figure 4. – Deck boards made from WPCs.

the constituent materials, interactions between these materials, processing, product design, and service environment. Moreover, new technologies are continuing to improve performance (Mapleston 2001d). General comments regarding performance can be made, but there are exceptions.

Adding wood to unfilled plastic can greatly stiffen the plastic but often makes it more brittle. Most commercial WPC products are considerably less stiff than solid wood. Adding fibers rather than flour increases mechanical properties such as strength, elongation, and unnotched Izod impact energy (Table 1). However, processing difficulties, such as feeding and metering low bulk density fibers, have limited the use of fibers in WPCs.

Because WPCs absorb less moisture and do so more slowly than solid wood (Fig. 3), they have better fungal resistance and dimensional stability when exposed to moisture. For composites with high wood contents, some manufacturers incorporate additives such as zinc borate to improve fungal resistance. Unfilled plastics absorb little, if any, moisture, are very resistant to fungal attack, and have good dimensional stability when exposed to moisture. However, most plastics expand when heated and adding wood decreases thermal expansion.

The fire performance of WPC materials and products is just beginning to be investigated (Malvar et al. 2001, Stark et al. 1997). These composites are different from many building materials in that they can melt as well as burn, making testing for fire resistance difficult. Light stability is also an area of considerable investigation (Lundin 2001). Most WPCs tend to lighten over time (Falk et al. 2001). Some manufacturers add pigments to slow this effect. Others add a gray pigment so that color change is less noticeable. Still others co-extrude a UV-stable plastic layer over the WPCs.

Markets

The greatest growth potential for WPCs is in building products that have limited structural requirements. Products include decking (Fig. 4), fencing, industrial flooring, landscape timbers, railings, and moldings. Pressure-treated lumber remains by far the most commonly used decking and railing material (80% of the approximately $3.2 billion market) but the market for WPC decking is growing rapidly (Smith 2001). Market share grew from 2 percent of the decking market in 1997 to 8 percent in 2000 (Smith 2001), and it is expected to more than double by 2005 (Eckert 2000, Smith 2001, Mapleston 2001e).

Although WPC decking is more expensive than pressure-treated wood, manufacturers promote its lower maintenance, lack of cracking or splintering, and high durability. The actual lifetime of WPC lumber is currently being debated; most manufacturers offer a 10-year warranty. Compared with unfilled plastic lumber, the advantages of WPC lumber include increased stiffness and reduced thermal expansion. However, mechanical properties such as creep resistance, stiffness, and strength are lower than those of solid wood. Hence, these composites are not currently being used in applications that require considerable structural performance. For example, WPCs are used for deck boards but not the substructure. 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 organic fillers used in decking. About 50 percent wood is typically used, and some products contain as much as 70 percent wood. A polyethylene matrix is used most often, but manufacturers of decking made with PVC and polypropylene have recently entered the market. At least 20 manufacturers produce decking from WPCs; the market is currently dominated by large manufacturers (Smith 2001).

Window and door profile manufacturers form another large industrial segment that uses WPCs. Fiber contents vary considerably. PVC is most often used as the thermoplastic matrix in window applications, but other plastics and plastic blends are also used. Although more expensive than unfilled PVC, wood-filled PVC is gaining favor because of its balance of thermal stability, moisture resistance, and stiffness (Defosse 1999).

Several industry leaders are offering WPC profiles in their product line. Their approaches vary. One manufacturer co-extrudes a wood-filled PVC with an unfilled PVC outside layer for increased durability. Another manufacturer co-extrudes a PVC core with a wood-filled PVC surface that can be painted or stained (Schut 1999). Yet another manufacturer offers two different composites: a wood-filled PVC and a composite with a foamed interior for easy nailing and screwing (Defosse 1999).

In Europe, decks are not common and the WPC decking market is virtually nonexistent. However, other product areas are possible. Anti-PVC sentiment (because PVC is a chlorinated compound) and fears over possible legislation are concerning PVC window manufacturers and creating possibilities for replacing PVC with WPCs (Mapleston 2001d). The European market for wood profiles, particularly door frames and furniture, is actively being pursued.

In Japan, promising end uses such as decking, walls, flooring, louvers, and indoor furniture have been reported (Leaversuch 2000). At least one Japanese company is seeking to license WPC extrusion technology in the United States (Mapleston 2001c).

Wood-polypropylene sheets for interior substrates are still made in the United States, but manufacturers are beginning to use natural fibers other than wood (e.g., kenaf or flax) in air-laid processes. Growth in the use of natural-fiber-reinforced thermoplastics, rather than unfilled plastics, in automotive applications has been slower in the United States than in Europe, where environmental considerations are a stronger driving force. One market analyst cites the lack of delivery channels and high transportation costs as major factors that slow growth in the United States (Eckert 2000). One major U.S. company has used German technology to produce automotive door quarter panels from natural fiber composites with polypropylene and polyester; the doors achieved a 4-star side impact rating (Manolis 1999). A number of other interior automotive components are being made with similar technology. Nonwoven mat technology is being used to make rear shelf trim panels with flax-reinforced polypropylene (Manolis 1999). Other products being tested include instrument panels, package shelves, load floors, and cab back panels (Manolis 1999).

Considerable market growth is expected in the near future. Although WPC sales slumped alongside that of many other building materials in mid-2001, sales have regained momentum in 2002. Companies reported first-quarter sales far exceeding those in 2001 and surpassing 2002 forecasts (DeRosa 2002). Growth of the WPC market may be helped by the phase-out of chromated copper arsenate (CCA) treated wood for residential uses such as decks, playgrounds, and fencing (EPA 2002). The replacement of CCA with new, and probably more costly, wood preservatives will reduce the price gap between WPCs and lumber treated with the new preservatives and will give WPC manufacturers an opportunity to increase awareness of alternatives to CCA-treated lumber. The WPC decking market is projected to more than double, reaching a 20 percent market share by 2005 (Smith 2001). Analysts expect a handful of nationally recognized producers to dominate the WPC market, but there are also a large number of small, regional producers (Mapleston 2001e).

Figure 5. – Roof shingles made from natural fibers and thermoplastic on the demonstration house at the Advanced Housing Research Center, Forest Products Laboratory, USDA Forest Service, Madison, Wisconsin.

Figure 6a. – In-ground field tests on WPC durability.

Figure 6b. – Aboveground field tests on WPC durability.

Wood-thermoplastic composites are moving out of the backyard and into other parts of the house as new building products are developed. For example, preprimed WPC planks manufactured specifically for front porches are being produced (DeRosa 2002). Roof shingles with a class A fire rating made from recycled natural fibers and polyethylene will soon be available from Teel-Global Resource Technologies LLC (undated). Boise Cascade will open a major siding plant in Satsop, Washington, later this year. The siding will be manufactured from urban woodwaste and recycled plastic film from shrink wrap, bubble wrap, and plastic grocery bags (DeRosa 2002).

Waterfront applications for Navy facilities are a major research and development effort (Smith 2001). Advanced WPCs are being investigated to replace treated timber currently used to support piers and absorb the shock of docking ships. Other products include pallets, flowerpots, shims, cosmetic pencils, grading stakes, tool handles, hot tub siding, and office accessories (Anonymous 1999; Teton West Composites).

There is a strong movement in research towards more highly engineered WPCs with greater structural performance and more efficient design. One extrusion technology licensor claims it will unveil technology for manufacturing WPC roofing timber and wall studs at a lower price than wood (Mapleston 2001d). Other researchers are working with high-performance thermoplastics (so called "engineered plastics" such as nylon) and pulp fibers (Sears et al. 2001). Other strategies for improving the structural performance of WPCs include: using natural fibers other than wood, combining glass or carbon fibers with wood fibers, and adding small amounts of thermosets.

Foaming technologies are continuing to be developed that reduce weight and raw materials cost and result in profiles that would accept fasteners better than unfoamed profiles (Schut 2001). However, foaming reduces the stiffness and strength of a profile. Processors are developing multi-layered profiles that incorporate combinations of foamed and unfoamed composite layers and unfilled plastic cap layers to achieve the right balance of weight reduction and performance. Currently, there is little consensus on the best polymer type, wood loading, density reduction, and layering approach (Schut 2001).

The interaction between wood and plastic components has long been the subject of intense

Table 1. – Mechanical properties of wood-polypropylene composites.[a]

Composite[b]	Tensile: Density (g/cm³ [pcf])	Tensile: Strength (MPa [psi])	Tensile: Modulus (GPa [psi])	Tensile: Elongation (%)	Flexural: Strength (MPa [psi])	Flexural: Modulus (GPa [psi])	Izod impact energy: Notched (J/m [ft.-lbf/in.])	Izod impact energy: Unnotched (J/m [ft.-lbf/in.])	Heat deflection temperature (°C [°F])
Polypropylene	0.9 [56.2]	28.5 [4,130]	1.53 [221,000]	5.9	38.3 [5,550]	1.19 [173,000]	20.9 [0.39]	656 [12.3]	57 [135]
PP + 40% wood flour	1.05 [65.5]	25.4 [3,680]	3.87 [561,000]	1.9	44.2 [6,410]	3.03 [439,000]	22.2 [0.42]	73 [1.4]	89 [192]
PP + 40% hardwood fiber	1.03 [64.3]	28.2 [4,090]	4.20 [609,000]	2.0	47.9 [6,950]	3.25 [471,000]	26.2 [0.49]	91 [1.7]	100 [212]
PP + 40% hardwood fiber + 3% coupling agent	1.03 [64.3]	52.3 [7,580]	4.23 [613,000]	3.2	72.4 [10,500]	3.22 [467,000]	21.6 [0.41]	162 [3.0]	105 [221]

[a] Data from Stark (1999); properties measured according to ASTM standards for plastics.
[b] PP is polypropylene; percentages based on weight.

research because of its importance in the performance of the composite. The interaction is complex because wood and plastics bond poorly and wood can nucleate crystal growth in polymers. Lu et al. (2000) recently reviewed the considerable research on the use of coupling agents and treatments to improve the bonding between wood and plastics. Interactions between coupling agents and other additives become increasingly important as formulation becomes more complex.

Additives to improve performance and production are being specifically developed for this growing industry. As profiles become more sophisticated and move into more demanding applications, more is required of additive technology. Formulation becomes more complex as different matrices and a larger array of additives are used to reduce profile density or improve processing, output, and product durability. Additive packages are being developed that perform multiple functions and avoid negative interactions between additives (Mapleston 2001a).

Much research worldwide is concentrating on the durability and service life of WPCs because these composites are increasingly being used in exterior applications (Fig. 5). Recent conferences (Forest Products Society 2001) have focused on resistance to insects and fungal attack (Fig. 6), fire performance, moisture sorption properties, degradation from ultraviolet light, and creep performance.

Equipment manufacturers continue to improve processing technology to better accommodate the unique challenges of processing WPCs. Researchers are investigating how materials flow during processing and how the final structure that is formed during processing affects performance. Wood fiber orientation and fiber length, or the cellular (if foamed) or crystal structures of the plastic, can greatly affect composite performance.

Standards are being identified, modified, or developed to determine WPC performance appropriately and consistently. Depending on the formulation, product, or research objectives, various standards have been used to test these composites, e.g., plastics, plastic lumber, wood, and WPC standards. Researchers and code agencies are attempting to determine the most appropriate test standards. For example, the American Society for Testing and Materials (ASTM) has developed a two-prong approach to developing WPC standards appropriate for building profiles. ASTM plastic lumber standards (Committee D20) cover manufactured products containing more than 50 percent (by weight) resin. This would include WPCs with low wood contents. Separate standards for WPC products containing at least 50 percent wood are being developed under Committee D7 on wood.

Market growth for WPCs will not be limited by lack of discussion, as evidenced by many recent conferences. From May 1999 to May 2001, six conferences on WPCs were held in the United States and Canada alone; WPCs are also commonly discussed at forest products conferences. The use of wood and other natural fibers has also received considerable press, especially in plastics industry trade journals (Schut 1999, 2001; Mapleston 2001b-e; Defosse 2000; Leaversuch 2000; Manolis 1999; DeRosa 2002; Colvin 2000).

The future of WPCs will ultimately depend on many factors, including new product identification, product quality, consumer reaction/perceptions, and success of research and development efforts. Success will also depend on how well the forest products and plastics industries continue to establish relationships and work with each other.

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