Factors that Affect the Application of Woodfiber-Plastic Composites

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Abstract

The use of reinforcement and fillers in thermoplastic materials has a lengthy and well-documented history. Generally speaking, stiffness, strength, and stability of filled thermoplastic materials increase, although other properties decrease, such as impact performance. Fillers are typically inorganic materials, such as calcium carbonate or glass fiber. The use of wood fiber, or other natural fibers, for these applications has only recently gained acceptance. One of the largest commercial applications for woodfiber-plastic composites is in automotive interior substrates, but commercial applications also exist in furniture, packaging, and housing. In this paper, we discuss several key factors that affect the application of woodfiber-plastic composites, including cost and processing considerations, physical properties, and in-service performance.

Introduction

The use of reinforcements and fillers in thermoplastic materials has a lengthy and well-documented history. Generally speaking, filled thermoplastics are stiffer, stronger, and more stable than their unfilled counterparts. However, other properties decrease, such as impact performance. Fillers are typically inorganic materials, such as calcium carbonate or glass fiber. The use of wood fiber (or other natural fibers) for these applications has only recently gained acceptance.

One of the largest commercial applications for woodfiber-plastic composites is in automotive interior substrates; however, commercial applications also exist in furniture, packaging, and housing. This paper will discuss several key factors that affect the application of woodfiber-plastic composites, including cost and processing considerations, physical properties, and in-service performance factors.

Cost and processing considerations

Cost

Thermoplastics often use some type of filler to decrease cost, while at the same time increasing performance. Fillers are often less expensive than the polymer, on a price per weight basis, although the cost of compounding or blending the materials partially or completely offsets this price differential. Wood and paper fibers are generally cost-competitive with inorganic fillers or reinforcements, although the variable wastepaper market can make this comparison conditional.

Hygroscopicity

Wood fiber differs from inorganic fillers in several ways. The most important is that wood fiber is hygroscopic. Although most conventional plastic processes have little tolerance for water, vented equipment exists and the plastic industry is familiar with some hygroscopic materials, such as nylon. At normal processing temperatures, any water in the wood turns to steam and expands, causing the plastic to foam. In some applications this is desired; water is occasionally used for a foaming agent in plastic lumber profiles. However, when foamed parts are not desirable, the moisture of the feed stock should be kept less than 0.1 to 0.2 wt%.

Thermal sensitivity

Wood fiber will release volatiles or even burn at the temperatures required for processing many thermoplastics. As a rule of thumb, if melt temperatures are kept below 200°C and processing times are kept to a reasonable limit, devolatilization should not occur. This limits the use of wood fiber fillers to lower melting polymers, such as polypropylene, low- and high-density polyethylene (LDPE, HDPE), polystyrene, and polyvinyl chloride (4).

Bulk density

Wood fibers also have a lower bulk density than inorganic fillers. This is especially true with wastepaper fiber, where hammermilling can produce a fiber with a bulk density as low as 25 kg/m^3. This condition seriously effects the paper's ability to be fed into compounding equipment, and the resultant throughput can be quite low. Several strategies have been developed to moderate this problem. A common strategy is to install crammer-type feeders on the processing equipment, but this can be expensive, and throughput can still be compromised.

Another strategy is to predensify the wastepaper fiber to a density of 150 to 350 kg/m^3, and process it using conventional feeders. This strategy is somewhat of a balancing act. The material has to be dense enough to feed, and yet still retain its ability to break up and disperse in the melted thermoplastic. Predensification can be achieved in several ways. One common system uses a pellet mill to densify hammermilled paper. Wet pulping processes can also be used, but the material has to be dried before compounding.

Another strategy is to cut the wastepaper into platelets. These platelets (typically <40 mesh) flow and feed extremely well. Paper milled into platelets have a bulk density between 250 and 300 kg/m^3.

Other wood fiber sources, such as wood flour, feed satisfactorily with conventional feeding equipment. Wood flour is commercially available in a variety of mesh sizes from 20 to 800 mesh, and is available in both hard- and softwoods. Bulk density of wood flour is around 250 kg/m^3.

Fiber loading limits

A continuous thermoplastic matrix is required for woodfiber-plastic composites to be processed in conventional plastics processing equipment. In most cases, the upper fiber loading limit is about 70 wt%. In fact, most producers limit fiber addition to about 50 weight percent to keep melt viscosity at workable levels (3). Of course, woodfiber-plastic composites can be made with more than 70 percent wood using other processes, such as compression molding.

Other considerations

For many applications, wood is used for aesthetic purposes. This is true of woodfiber-plastic composites as well. When used with natural or clear resins, the composite takes the color of the wood element. The composites can also be colored, although they do not usually take the high gloss of unfilled thermoplastics. Composites made from old newspapers take on a dark gray or black color derived from the carbon black in the ink. Bleached paper fibers can be used to make white or colored composites too.

From an environmental perspective, waste wood and paper fiber are often preferred, because using wood as a filler extends the use of nonrenewable petroleum products. Woodfiber-plastic composites can be as recyclable as the plastic component.

Perhaps the most significant factor that has limited the broader use of woodfiber-plastic composites is educational. Many users of filled and unfilled thermoplastics say they have tried wood fibers once and they didn't work. The failure of the composites in the manufacturing environment can almost always be traced to a lack of understanding about the water absorption and thermal sensitivity characteristics of wood fiber. If these conditions are understood and accommodated for, woodfiber-plastic composites can be manufactured using conventional plastic processing technologies without tooling changes.

Physical properties

Weight and abrasion

Wood fibers have an advantage over inorganic fillers when weight and abrasion are considered. Even at their maximum densified specific gravity of 1.3 to 1.4, wood fibers are considerably lighter than other common fillers, such as calcium carbonate at 2.9 or glass fiber at 2.5. Therefore, composites made of equal weight percentages of filler fibers will have more polymer displaced when made with wood fiber. In addition, higher strength-to-weight ratios make these composites attractive for automotive and packaging applications. Although wood fiber can be mildly abrasive to processing equipment, it is much less so than inorganic materials.

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Water absorption

Woodfiber-plastic composites absorb very little water if they are made in such a way that the wood component is fully encapsulated by the plastic. For injection-molded parts (where the plastic is forced to the surface of the mold under heat and pressure), water absorption values are typically less than 2 percent, even after several days of immersion. Research has shown that dimensional changes as a result of humidity variation are very slight (11). Extruded profiles can absorb more water than injection-molded parts, because when these profiles are cut to length, the wood fiber is exposed. The use of contaminated post-consumer resins and degradation by ultraviolet light can also negatively affect water absorption.

Thermal linear expansion

Thermoplastics are much more sensitive to linear expansion from temperature variations than from humidity variations. Adding wood to thermoplastics significantly decreases thermal linear expansion; however, woodfiber-plastic composites are considerably more thermally sensitive than solid wood. Table 1 compares the coefficient of thermal linear expansion of LDPE and HDPE with various wastepaper-fiber filler content levels (5). Increasing the fiber content substantially decreases the coefficient of thermal linear expansion, but the lowest value is still approximately 250 times that reported for solid wood. Minimizing the thermal expansion of woodfiber-plastic composites is important, so these composites can be used compatibly with other materials exhibiting lower thermal expansion rates, such as solid wood.

Other considerations

Depending on the application, other physical properties for the user to consider may include coefficient of friction, machinability, and sound absorption.

Structural applications

All materials or products must be evaluated to ensure that they will perform adequately in their end-use application. For woodfiber-thermoplastic composites, important characteristics requiring evaluation include ultraviolet light durability, engineering properties, creep, and thermal effects. Testing, design, and evaluation standards are needed to measure and maintain the required performance.

Ultraviolet light durability

Considerable controversy exists regarding the durability of woodfiber-plastic composites in exposed conditions, and failures have been reported (2). Although the information about these failures is mostly anecdotal and has been offered by nonscientific observers, it appears that the failures result from a combination of poor manufacturing techniques (such as poor blending) and a lack of understanding of how to build with this type of composite.

Durability can be enhanced by ultraviolet light stabilization of the polymer and a complete encapsulation of the wood component. Depending on the surface condition of the composite element, paints and other finishes may enhance durability as well. Properly manufactured, and properly specified, woodfiber-plastic composites should have excellent durability in exposed conditions.

Engineering properties

Performance requirements for structures and structural components are expressed in terms of designated design loads and displacements; therefore, characterization of structural performance must encompass these two aspects of product, component, or system behavior. In designing any product, the first concern is the capacity to resist expected loads safely. The second concern is to ensure that the product performs within acceptable limits of serviceability (usually short- and/or long-term deflection) when subjected to loads not exceeding the design load.

For example, to be used in building construction, woodfiber-plastic composite products must be able to resist a design load with a low probability of causing member failure and a stiffness sufficiently high to meet acceptable limits. The design load can be established through short-term engineering strength and stiffness testing as well as long-term creep and duration of load evaluation.

TABLE 1.—*Coefficient of thermal linear expansion.*[a]

Plastic type	Wastepaper fiber content	Coefficient
	(%)	(mm/°C)
LDPE	0	0.0141
	8	0.0114
	12	0.0108
	25	0.0073
HDPE	0	0.0093
	8	0.0085
	12	0.0078
	25	0.0059
Solid wood[b]		0.000024 to 0.000035

[a] Values derived from testing –18°C to 49°C.
[b] Source: (9).

One difficulty in determining design loads for woodfiber-plastic composites is the tendency for the test specimens to deform excessively before failure. This is especially true for testing bending specimens, when the stroke capacity of the testing machine is reached before the specimens fail. Generally, increasing the fiber content of the woodfiber-plastic composite increases the bending capacity (Table 2). In regard to deflection resistance, the addition of wood fiber to plastic results in a composite with greater stiffness than the plastic itself and increasing the fiber content generally increases the stiffness. In spite of the addition of wood fiber to plastic, the resulting composites generally exhibit strength and stiffness levels significantly lower than conventional wood products.

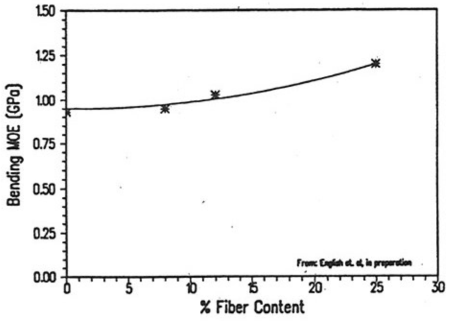

FIGURE 1.—*Effect of wastepaper fiber content on woodfiber-plastic composite stiffness.*

When comparing the engineering properties of plastics or woodfiber-plastic composites to solid lumber products, it is important to compare similar-sized specimens. Wood is generally tested as either a small, clear specimen (generally 2 by 2 in., dependent on type of test) or as full-size lumber. Because small, clear specimens do not contain the defects (knots, slope of grain, etc.) found in full-size lumber, they generally exhibit strength levels greater than full-size lumber.

As shown in Table 2, small, clear specimens of southern pine or Douglas-fir exhibit both strengths and stiffness levels that are significantly greater than that of plastics (polyolefins) or a woodfiber-plastic composite. When considering full-size lumber profiles, the differences in these properties are not as great (Table 3).

Thermal effects on stiffness

The stiffness, or modulus of elasticity, of a woodfiber-plastic composite decreases significantly with increasing temperature. Figure 1 shows this trend for formulations of HDPE-based plastic lumber with varying amounts of fiber content (6). The curves shown are fairly typical of unfilled polyethylenes for normal temperature ranges (10). Adding fiber to the polymer decreases the rate of stiffness loss, and for applications that undergo temperature variation this characteristic must be considered.

TABLE 2.—*Small, clear specimen property comparison.*

	Specific gravity	Average modulus of rupture strength	Average modulusof elasticity
		(MPa)	(MPa)
Polyolefins[a]	0.92 to 0.96	8 to 50	200 to 2,000
Wood-plastic composites[b]	0.95 to 1.10	30 to 100	3,000 to 6,000
Southern pine/Douglas-fir[c]	0.50	85 to 98	13,000+

[a] Average values from manufacturer literature.
[b] Source: (12).
[c] Source: (9).

TABLE 3.—*Large profile property comparison.*

	Specific gravity	Average modulus of rupture strength	Average modulusof elasticity
		(MPa)	(MPa)
Plastic lumber profile[a]	0.70 to 0.95	--[b]	300 to 1,400
Wood-plastic lumber profile[b]	0.95 to 1.10	11 to 28	1,400 to 4,000
Southern pine/Douglas-fir[c]	0.50	41	11,000+

[a] Average values from various manufacturer literature.
[b] Excessive defections often preclude failure.
[c] Source: (5).
[d] No. 2, 2 by 8 lumber (7).

Creep

An important characteristic of wood behavior has to do with the time-dependent, load-carrying ability of wood products, known as creep. Creep is the continuing deflection of a structural member subjected to sustained load. Comparisons of woodfiber-plastic composites with conventional wood products indicates that the woodfiber-plastic composites suffer from a low resistance to creep deflection, which could severely limit structural applications (8). Research is needed to more fully define the creep performance of woodfiber-plastic products.

Codes and standards

To ensure that new products meet or exceed existing requirements for use as building components, and to avoid confusion for the consumer, newly developed woodfiber-plastic composite products will likely be evaluated against performance criteria for existing solid wood and engineered wood products. In some cases, it will be necessary to modify existing standards, or develop new standards to evaluate these newly developed products.

Engineering standards organizations such as the American Society for Testing and Material and the American National Standards Institute develop test standards and performance criteria for comparing properties across a range of products intended for a specific application. The development of such "consensus" standards is the keystone to equitable treatment of properties across product lines and generates confidence in product performance and safety. Such standards are essential for the acceptance of product performance criteria by building code authorities and need development for woodfiber-plastic composites.

Other considerations

Key properties such as durability, engineering properties, and creep need to be fully investigated and compared with end-use standards; material science issues such as the inherent incompatibility of wood and paper and most thermoplastics also need to be investigated. This incompatibility prevents efficient transfer of stress to the load-bearing fiber and ultimately results in poorer composite performance.

The use of additive technology (compatibilizers, fire retardants, impact modifiers, ultraviolet light stabilizers) or actual chemical modification of the wood/paper fiber or plastic can be used to overcome some of the possible shortcomings of the composites. It is expected that as more is learned about these areas, additional commercial applications for woodfiber-plastic composites will develop.

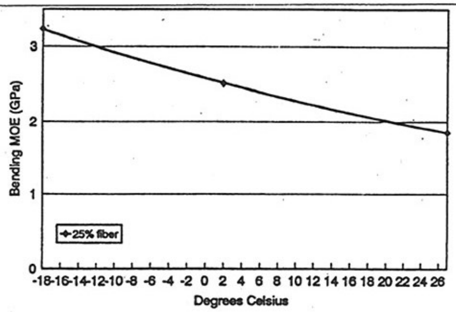

FIGURE 2.—*Effect of temperature on HPDE plastic lumber bending stiffness.*

Concluding remarks

Woodfiber-plastic composites can be manufactured on conventional plastics processing equipment if conditions relating to the woods hygroscopicity and thermal sensitivity are accommodated. Wood fiber is lighter weight and less abrasive than other reinforcing fillers typically used in thermoplastics. Woodfiber-plastic composites can often be used to fill a performance gap between unfilled thermoplastics and solid wood.

Proper comparison of engineering properties is important if woodfiber-plastic composites are to be used in traditional solid-wood applications.

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