CONSIDERATIONS IN RECYCLING OF WOOD-PLASTIC COMPOSITES

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Abstract

Wood-plastic composite decking has made major advances in material performance, processing and user acceptance. The growth of wood-plastic composite decking in North America has grown from less than 1 % in mid-90's to over 10% today with growth projected by several studies to reach +20% before the end of this decade (2010). Preservative-treated wood decking experienced a very similar market entry and growth to market dominance over the 1970's and 80's in this same outdoor decking market when treated-wood supplanted naturally-durable redwood and cedar decking materials. Now that wood-plastic composites have become a major player in the North American decking market, many of the lessons learned in how treated-wood decking has historically been used, removed from service, and then discarded or recycled may help the wood-plastic composites industry and the recycling industry prepare for their future materials and their needs. This paper will discuss the materials and process issues of wood-plastic composites related to future recycling efforts. It will then detail how wood-plastic composite decking may be used and later discarded based on a combination of material property and durability issues, as well as consumer perceptions, needs, and non-performance issues. Each may significantly affect how soon and how much WPC decking material is removed from service. The recycling industry must be prepared to handle these materials in the near future.

Introduction

Wood-plastic composite (WPC) decking has made major advances in material performance, processing and user acceptance. This paper will discuss the materials and process issues of WPC related to future recycling efforts. It will then detail how WPC have and soon may be used and later discarded based on a combination of material property, durability issues, and changing consumer needs and their perceptions on non-performance issues. We believe that a huge potential exists for the development of new markets for virgin and recycled WPC. This product growth will be aided in part by research at the USDA, Forest Service's Forest Products Laboratory in Madison, WI USA and elsewhere around the world on wood-plastic composites and other wood-alternative material composites.

Markets

A recent analysis of WPC market growth concluded that while to date WPC's have mostly gained access to the wood products markets, as new product lines in siding, roofing and fencing continue to be introduced, other vulnerable materials now include vinyl, concrete and aluminum (Morton et al 2003).

Decking and Fencing

In 2002, 1.4 million new single-family homes and 0.3 million new multi-family homes were built in the U.S. (US Census Bureau, 2001a, 2001b). The average size of these single-family homes was 215 m^2 (Smith and Bailey 2002). Each required durable roofing and siding. In addition, over 50% of these new homes have adjacent or adjoining exterior decks installed at the time of construction or will have decks added within 5-years of initial construction. The average size of these decks was 26 m^2 (Smith and Bailey 2002). This U.S. decking market alone used a sum total of nearly 18.5 million m^3 of treated wood (90%) or WPC (10%) materials in 2000 (Smith and Bailey 2002).
The U.S. fencing market was estimated at $US 2.6 billion in 2002 and is expected to grow approximately 5% per year to $US 3.3 billion by 2007 (Freedonia 2003b). Currently the U.S. fencing market is 45% wood, 44% metal, 7% plastic and 5% other materials. There are currently several manufacturers producing WPC building products under various tradenames in the United States (Table 1).

WPC producers have aggressively marketed their products as environmentally safer than treated wood with better performance (Smith and Bailey 2002). WPC's are currently used for about 10 percent of decking for homes and there share is expected to increase to 20 percent by 2005 (P.Smith 2001). Expenditures for WPC decking were about $65 million in 2000 (P.Smith 2001) and total WPC production was $90 million (Smith and Bailey 2002). In 2002, over 685,000 metric tonnes of wood-polymer composites were produced with 87% of that being WPC and 13% being natural-fiber composites (Morton et al 2003). From 1998 to 2002, the use wood fiber as the filler in plastic-based building products grew from 66% to 80% (Morton et al 2002). Market growth between 2001 to 2010 is predicted to reach 270,000 tonnes in Europe and 1.7 million tonnes in North America for an 8-year average growth rate of 14% per year (Morton et al 2003). Polyethylene is projected to remain the dominant resin in North American WPC market with its current 83% market share, while polypropylene will continue to be most used in Europe (Morton et al 2003). Polyvinyl chloride resins are expected to average 20% growth per year until 201 0.

The projected growth of WPC over wood decking is due to public perception for greater durability and reduced maintenance with wood-plastic composites. In addition, as of January 2004, EPA restricted the residential use of CCA-treated lumber in the U.S. Before that time, CCA was the most common and economical preservative treatment for decking materials. Newer alternative wood treatments cost more and this will narrow the price difference between treated wood and WPC decking. The reduced price differential will probably further encourage the growth of the WPC decking market.

Siding and Roofing

The U.S. siding (i.e., exterior cladding) market was estimated at 960 million square meters (10.2 billion square feet) in 2002 and currently is comprised of 37% vinyl, 17% stucco, 17% wood, 115 brick, 10% WIC, and 8% other materials (Freedonia 2003a).

Just as greater durability has resulted in increasing use of WPC's in decking, recent and future research on WPC's will continue to provide more durable siding and roofing products to better meet needs for new housing and repair and remodeling. WPC is just beginning to be used as siding. In June of 2003, a major US wood products manufacturer recently began production and is trial marketing in the Northwest region of U.S. of a WPC siding product that they promise has enhanced performance over vinyl, aluminum or wood siding materials. The raw materials used in its manufacture are post-commercial, wood waste recycled from pallets and crates and recycled LDPE from shopping bags. It is expected that this one WPC siding manufacturing facility will annually divert 55 million kg of plastic and 77 million kg of urban wood waste from landfills. In the manufacturing process a factory-applied primer to its surface so it can be latter finished by the homeowner or contractor with paint or opaque stain.

Recent roofing market forecasts project that the the 2.2 billion square meter, U.S. roofing market will exceed $1 1 billion by 2007 (Freedonia 2003c). They project that the market growth of plastic-based roofing materials will continue, but that asphalt shingles will remain dominant in the U.S. market. WPC use in roofing is still limited but underway. At least one manufacturer is offering a WPC roofing product to replace wood shakes, and more are under development.

Many research organizations and institutes around the world, including the Forest Products Laboratory, have or are currently conducting research on wood-plastic composites (WPCs) that will provide even more durable and cost competitive decking, fencing, roofing and siding products for building construction and remodeling. Based on the sum analyze of several complementary market projections, we believe that a sizable portion of this growth in both decking, fencing, roofing and siding will involve WPC materials based on low maintenance, decreased price differential with competing materials and continued research resulting in enhanced serviceability and performance. One of the biggest technical challenges in creating plastic-based building materials has been finding just the right mix of plastic, fibers, and additives. They need to resist the sun, retain their color and shape, and repel moisture–a tall order (Power 2004).

Use of Recycled materials in WPC's

In 1994, about 190 million metric tonnes of municipal solid waste was generated in the United States (Falk 1997). Waste wood, waste paper, and waste plastics are major components of municipal solid waste (MSW) and offer great opportunities as recycled ingredients in wood fiber-plastic composites (Youngquist 1992). Recycled sources of both wood and plastic are commonly used in WPC's (Table 2). Both post-consumer and post-industrial materials are used. Finding an inexpensive, yet suitable source, with consistent and sufficient performance can present challenges but the broad use of recycled materials in WPC's demonstrates its feasibility. Big companies see the use of their own waste by-products as a shrewd business decision that happens to spare landfills from tons of material.

Wood-based Materials

Roughly one-half of all industrial materials used in the United States are wood-based (Falk 1997). Wood flour is the most common wood filler used in WPCs. It is typically a post-industrial source consisting of wood shavings, chips, and sawdust produced by secondary wood product manufacturers. Post-consumer sources can include wood pallets, building construction waste, and old newspapers. Currently, waste wood fiber-recycling is a large part of the wood pallet industry with an estimated 44% rate of reclamation (Bush et al 1995). Many commercial WPC products currently use recycled wood fiber (Table 2). For example, *Trex* decking uses about 50% reclaimed wood fiber (Table 1) and *CorrectDeck* uses 60 percent oak and pine sawdust primarily from shavings from wood flooring manufacturers (Table 1). Other fillers besides wood are also used in plastic composites. Nexwood used approximately ~9.1 million kg of rice hulls in 2002 (Principia 2003).

Recycled Plastics in WPCs

Combining cellulose fibers with post-consumer waste plastic is more economical than using fiber for composites with thermoset phenolic resins (Hettinga 1997). Power (2004) reviewed the use and development of WPC lumber in the U.S. residential construction market and he cited several examples of various commercial WPC manufactures using recycled polymers, recycled fiber or both. In 2002, Trex, the largest supplier of wood-plastic composite lumber, purchased on average over 227,000 kg of plastic scrap each day (Principia 2002). *CorrectDeck* uses about half virgin plastic and the other half (20 percent) is obtained from recycled grocery bags and used pallet wrap (Powers 2004). Anderson developed engineered WPC materials for its *Renewal* line of windows from a wood-PVC composite material made from wood and PVC material partially reclaimed from its wood window plants (Table 1 and 2). Boise has recently developed and introduced its new *HomePlate* siding made with 50 percent recycled polyethylene and 50 percent reprocessed “urban” wood fiber. In total, the wood-plastic industry in North America consumed an estimated 204 million kg of plastic in 2001, of which more than 95% of it was recycled (Principia 2002). Of all the polyolefins reclaimed from the post-consumer waste stream, 38% ended up in wood-plastic composites. (Principia 2002). Because a large portion of the plastic waste stream is already commonly used in WPCs, it is becoming more difficult to secure recycled raw material sources. Many commercial WPC manufacturers use a combination of recycled wood-based materials and recycled plastics.

Potential for use of other recycled sources

Wood flour or fiber bundles (often generically, but mistakenly referred to as “wood fiber”) are often used in WPC’s in the US. The wood flour is clean, consistent, inexpensive, free flowing, and is readily available as a waste byproduct from secondary manufacturing operations. However, this approach does not efficiently use the potential strength of the individual wood fiber. Possibilities exist for using recycled or “waste” wood fibers as reinforcements in WPC’s rather than the commonly used fillers provided processing and handling issues could be overcome and that the fibers are well bonded to the plastic matrix.

For example, Youngquist et al (1993) found that using fiber from old newspapers as reinforcing fiber provided measurable property advantages over wood flour. Also, these recycled newsprint WPC systems could themselves be recycled (re-extruded and injection molded) numerous times with little or no apparent loss in mechanical properties. Stark (1 999) found that reinforcing polypropylene with wood fiber derived from recycled hardwood and softwood pallets provided improved bending and tensile strength over the use of wood flour. Stark (1999) also found that the use of maleated PP as a coupling agent further enhanced the mechanical properties of these recycled wood fiber-PP composites. Other recycled sources that are being investigated include waste paper mill sludge and commingled plastic-wood fiber sources such as plastic coated paper milk and juice box containers.

Ultimately, additional research is needed on WPC’s made from recycled wood fiber and plastics to improve properties and processing and thereby increase the number of potential applications. To do this we must learn to improve melt-blending processes to achieve better fiber dispersion with minimal fiber breakage, improve the bonding between the wood fiber and plastic matrix especially as this is related to more variable recycled materials, and improve the mechanical performance of these WPC versus impact energy and creep. Improving the resistance of WPC’s (both virgin and recycled systems) to moisture, to biodegradation, and to fire are important properties that also need to be addressed. Such investigations continue at FPL and worldwide.

Challenges in Recycling WPC’s

Though WPC’s can divert recyclable wood and plastic from the landfill and into durable building applications, additional environmental benefit could be obtained if the composites themselves are recycled at the end of their useful life. The thermoplastic nature of the waste materials used in WPCs facilitates makes this possible (Boeglin 1997). However, there are a number of challenges that may impede recycling.

“Useful service life” varies depending on product and the perception of the user. For example, some studies suggest that the normal US. decking material (i.e., the deck surface, not the deck substructure) is replaced in about 8-14 years because of non-durability related reasons (Smith 2001). The most often given reason was that the checking and splitting of the deck surface due to cyclic wetting and drying and poor maintenance caused significant enough aesthetic degrade that the user was no longer satisfied with its appearance and wanted to replace it. Another prime reason was related to remodeling or a change in the deck use-pattern or design resulting in deck-surface replacement.

If recycling of the base polymer used in WPC results in WPC products having less UV- or biological-resistance or reduced structural capacities when compared to virgin polymer-based WPC, then user acceptance will lessen. Some of the primary advantages of WPC’s over treated-wood decking are its reduced maintenance and the fact that it does not check and split resulting in reduced aesthetic-appeal. Manufacturers of Recycled WPC must keep these issues in mind when further developing their WPC products or when modifying their processing procedures. This will become an even greater issue as WPC’s enter markets requiring even greater durability.

Raw Material Effects

Youngquist et al. examined the effect of virgin versus recycled raw materials on the properties of WPCs. There was virtually no difference in the performance values of test panels on either mechanical or physical property tests when virgin and recycled polyethylene terepthalate were compared, or when hemlock fiber was compared with demolition wood fiber (Youngquist 1993). Further, demolition wood fiber performed as well as panels made from virgin hemlock fiber and compression molded WPC’s containing recycled high density polyethylene from milk bottles were equivalent to WPC’s containing virgin high density polyethylene. They found that using fiber from old newspapers as reinforcing agent provided measurable property advantages over wood flour, which is currently the most commonly used filler in commercial composites. Also, these recycled newsprint WPC systems could themselves be recycled (re-extruded and injection molded) numerous times with little or no apparent loss in mechanical properties.

Processing Effects

Processing WPCs can result in the potential for thermal degradation of each of the components. For example, exposing polyethylene to high heat during processing can result in cross-linking, or a increase in brittleness. The wood-based fiber may also degrade due to repeated heat cycle exposures. Mechanical degradation of the fiber, often seen as fiber attrition, can also be a recycling concern. Balatinecz et al. (1998) studied the effect of recycling on old newsprint filled polyethylene and polypropylene composites. They found that successive recycling resulted in a slight decrease in the mechanical properties of the boards obtained. The viscosity of neat polypropylene decreased with repeated recycling indicating some thermo-oxidative degradation and these polypropylene-based composites, showed increasing melt flow with increasing processing (Balatinecz 1998).

Laboratory investigations have shown that prevention of extensive fiber attrition through the use lubricants should result in significant improvements in composite properties (Sanadi et al 1994). Other have found that to successfully recycle WPC materials and commingled plastics waste that contains paper waste, a hydrolytic treatment is needed prior to conventional processing (Mehrabzadeh 2001).

Environmental Effects

How the WPC is used can also influence its suitability for recycling. Since most WPC’s are used in exterior applications, environmental exposure degrades material performance and reducing the recycling potential. Both fungal decay and UV exposure can change the structure of WPCs during their service life.

Pendleton (2001) evaluated WPC formulations that exhibited decay and noted it was often concentrated on the exterior of the specimen. Mycelium also appeared to be concentrated in the interfacial gaps between the wood and thermoplastic component near the specimen surface. They also noted that the decay was manifested as surface erosion. In their analysis of potential treatments to address decay, they noted that zinc borate treatment would take at least 20 years to completely leach from WPC material (Pendleton 2001). WPC formulations using more than 60 percent wood fiber seem to experience greater fungal decay and loss in flexural strength than those using less than 60% wood fiber (Naghipour 1997). In general, the higher the wood fiber content, the greater the potential for biological decay to occur.

Another aspect of consideration is UV-degradation. The surface of the WPC oxidizes upon UV exposure. In the polyolefins, the presence of oxygenated functional groups leads to further photooxidation. Therefore increases in photooxidation occur more readily in post-consumer polyolefins already exposed to UV light than virgin polyolefins. For example, it has been shown that increasing the oxidation of PE results in a decrease in tensile strength and elongation (La Mantia 2004). The addition of wood to plastic further results in oxidation sites, and an increased change in properties after weathering (Stark 2003).

Significant research has recently been done or is underway addressing, quantifying, and limiting UV-degradation of WPCs around the world including the on-going development of WPC materials with improved UV and thermal performance for use as siding or roofing (Falk et al 2001, Stark 2003). This work includes a long-term field-monitoring program to define and understand the critical issues of durability, color stability, and ultraviolet (UV) weathering of wood–thermoplastic roofing shingles (Winandy et al 2004).

Collection issues

As with any recycling, collection of materials at the end of their use comes at a price. How to collect this material could be a major hurdle. The varied formulations of these composites also present major challenges (Table 1 and 2).

Each polymer system has unique processing and performance characteristics. Comingling of these systems over multiple recycling regimes will undoubtedly occur. Recyclers and WPC manufacturers will need to develop in-line monitoring systems to help them identify the changing material characteristics of these recycled wood-polymer systems. Also, determining the resistance of these recycled composite systems to relatively extreme environments and develop means to enhance that resistance will be critical to their use. When combined with a fundamental understanding of the material properties and processing characteristics of comingled systems, in-line monitoring will facilitate modifications in processing regimes based on a knowledge of the altered characteristics of the comingled polymer systems. Again, manufacturers of recycled WPC must keep these issues in mind when further developing there WPC products or when modifying their processing procedures.

However, another important viewpoint says we should not have as a goal the total reuse of wood fiber. While large quantities of forest products are disposed of in landfills annually, the placement of forest products in landfills serves as a significant carbon sink and its importance in the global carbon balance should not be overlooked (Micales and Skog 1997). The fate of this vast pool of carbon is important since carbon sequestration and the generation of landfill gases has important implications for global warming (Micales and Skog 1997). They also found that only 30% of the carbon from paper and 3% of the carbon from wood was ever emitted as landfill gas.

Summary

Recycling and reuse of wood fiber, thermoplastics and their virgin composite products has great potential. One complication is that the application of using recycled wood fiber, thermoplastic or their composites are limited by the greater variability resulting from the myriad of recycled materials in solid waste streams. These waste streams yield materials that are more complex in that they are often more contaminated than are virgin sources of materials. Degradation of WPCs due to repeated processing cycles and environmental exposure also complicates recycling. These are not insurmountable issues, but they will require focused research. A coordinated research approach is needed to address these fundamental issues and significantly advance this science rather than piecemeal science.

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Table 1. Listing of some commercial wood-plastic composite products commercially marketed in United States[1]. All information was obtained from each products website.

Company Name	Brand Name	Plastic Type	Plastic Content (~%)	Wood Content (~%)
Trex	Trex	PE mix	50	50
Crane Plastics	Timbertech	HDPE	50	50
Fiber Composites	Fiberon	HDPE, LDPE, PVC	50	50
AERT	ChoiceDek	PE		
USPL	Carefree Composite	HDPE	65	35
Anderson	Fibrex	PVC	50	50
Nexwood	Nexwood	HDPE	40	60
LP Specialty Products	WeatherBest	PE	50	50
Mikron	MikronWood	HDPE, LDPE		
CertainTeed	Boardwalk	PVC	max. 65	max. 45
Kadant Composites	GeoDeck	HDPE	40	60
Dura Products	DuraDeck	HDPE		
Correct Building Products	CorrectDeck	PP	40	60

[1]*The use of commercial tradenames is solely intended for the information of the reader and does not constitute an endorsement by the U.S Department of Agriculture, Forest Service.*

Table 2. Listing of common sources for the plastic and wood fiber used in some commercial wood-plastic composite products commercially marketed in United States'. All information was obtained from each products website.

Company Name	Plastic Source	Wood Source
Trex	recycled	pallets and furniture waste
Crane Plastics	virgin	recycled oak wood flour
Fiber Composites	recycled and virgin	oak and pine from millwork
AERT	recycled and virgin	reclaimed cedar wood chips, oak millwork
USPL	recycled	wood and natural fiber
Anderson	recycled and virgin	pine scrap
Nexwood	recycled	rice hull flour
LP Specialty Products	recycled	all sawmill waste
Mikron	virgin	hardwood and softwood flour
CertainTeed		recycled fiber
Kadant Composites	recycled	recycled paper fiber
Dura Products	recycled	pallets and post-industrial oak fiber
Correct Building Products	virgin	oak and pine wood fiber

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