NEW Technology for Enhancing Wood-Plastic Composites

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INDUSTRY BACKGROUND

Wood-plastic composites (WPC) are the combination of wood fibers, most commonly wood flour waste, and a thermoplastic such as high density polyethylene (HDPE), polypropylene (PP), or PVC. The polymer content is generally 40–50% by weight. WPCs are extruded into profile shapes via continuous extrusion for the building and construction products industry as an alternative to wood and treated wood. Consumers are choosing WPC over wood, even though it costs more, because of lower maintenance requirements and aesthetic appeal. WPC does not require painting, resists warping and termite attack, and is generally resistant to moisture-related issues such as mold development.

The WPC industry has been growing faster than any other plastics industry since its emergence in the late 1980s.[1] The market segments that have supported the annual growth rates of over 25% since 1998 have been largely decking and railing. The overall WPC industry has recently surpassed one billion pounds per year of manufactured composites in North America.[1,2,5] In decking, WPC have assumed nearly 20% market share versus treated lumber.[1,3] Even though the recent multi-year boom in the housing industry helped buoy the continued industry growth, Wall Street analysts still predict a bright outlook for the industry even though the housing industry has officially softened.[3] The prediction is for WPC to continue to capture upwards of 20% unit share (40% dollar share) relative to treated wood.[4] This continued growth is due to several key factors such as the increasing access and availability of products through retailers and contractor distributors as well as continued consumer demand, especially in outdoor living structures.

Despite the healthy outlook, industry observers and analysts predict a period of consolidation that may result in two to three major players and 5–10 niche players.[3] The keys to success during this phase will be distribution, capital, brand, and process and product innovation.[3] Arguably, companies such as Universal Forest Products, Plygem, Louisiana-Pacific, CertainTeed,

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Above photo courtesy of CertainTeed.

and other broad-based building and construction products companies will have advantages in terms of distribution and capital. With prudent decision making relative to incorporation of incremental advancements in processing and additive technologies, these same companies should win the brand recognition battles due to broader product offerings and greater market availability. Furthermore, the industry faces tough challenges for substantial growth into new markets for WPC, such as fencing, window and door trim/profiles, and siding. In order for WPC to be acceptable for these applications, significant product improvements are required. Therefore, any WPC producer at this time has the opportunity to become a major player by winning the process and product innovation battle.

PROBLEMS NEED TO BE SOLVED

While the WPC industry has continuously made improvements in aesthetics and final product performance over the last 10–15 years, significant performance deficits will still limit future growth potential. Specific deficiencies include color and appearance retention over time, scratch and mar resistance, and ability to be painted different colors by owners. UV exposure and moisture absorption over time contribute substantially to the long-term degradation of WPC materials. The degradation predominantly involves aesthetics, with color fading and mold development as well as modest losses in physical properties. As WPC products have experienced many years in outdoor service, there are reports of staining and other maintenance oriented issues. It is now recognized that within 60–90 days of outdoor installation, the color of pigmented WPC begins to fade. As a marketing reaction, many WPC producers claim on their websites that this fading phenomenon makes the product look "rustic" and more like "real wood."[4] There have been some modest improvements in addressing these issues such as the incorporation of additives to improve the bonding between the wood and polymer matrix.[5] This has proven to reduce moisture absorption but has not proven to eliminate it long term. Other issues have arisen from these additives, such as unwanted reactions with the lower cost lubricant additives resulting in higher material costs and burdens on operations to balance new formulations. The pigment suppliers have also been working diligently to develop next generation pigment systems that resist fading; however, no cost-effective solutions are apparent on the horizon.

Since the introduction of WPC products, consumers have shown that they hold synthetic products to much more scrutiny than wood. For the premiums they pay, there is a clear expectation of a flawless product that requires no maintenance and looks as good five years out as it does when initially installed. This is a good and a bad thing for the WPC industry. It shows again that consumers are willing to pay for what they want. However, the progression of technology has yet to deliver all the value elements the consumer seeks in aggregate. One of the more profound deficiencies of WPC is the lack of coatability.

TECHNOLOGY OVERVIEW

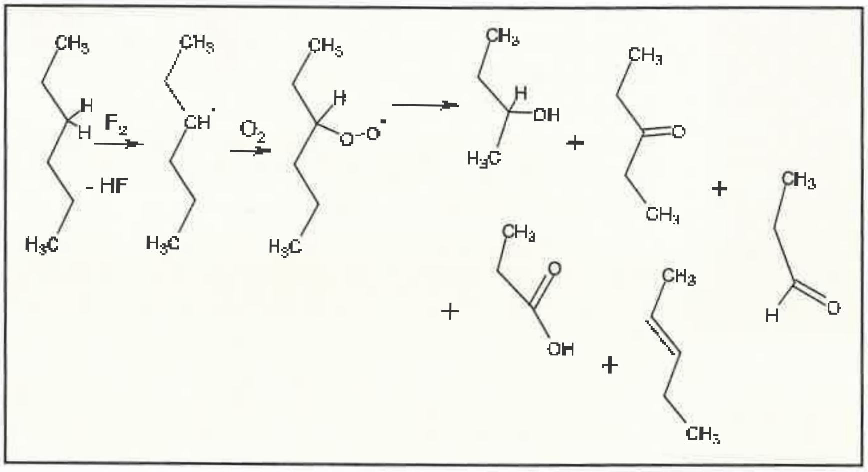
This article discusses an approach to solve the major deficiencies of WPC as detailed. Basically, the technology consists of performing a surface modification on the WPC followed by application of an appropriate coating. By applying a high performance coating, such as the aliphatic polyurethane systems used on automobiles, WPCs can be colored and glossy, with 30 years projected durability. Appropriate coatings can provide outstanding scratch and mar resistance, as well as provide a surface that is easy to clean. Appropriate coatings can seal the WPC to prevent moisture absorption, mold growth, and physical property reduction. Using coating systems can also enable homeowners to repaint their WPC to match new decoration schemes.

Surface Modification

To the uninitiated, coating WPC lumber sounds quite simple and straightforward. But it is not. When WPC is extruded there is a thermodynamic driving force that causes the thermoplastic to end up on the exterior surface. This thermoplastic layer has a low surface energy, which makes it difficult to wet and coat with a paint or coating (and which give very poor adhesion). This same phenomenon makes it difficult to impossible to adhere adhesives.

The plastics industry has developed several useful methods for surface-modifying low energy plastics to enable adherence. These processes oxidize the surface, creating high surface energies. Examples of surface-modification processes routinely used on plastics include corona discharge, flame treatment, and plasma.

Figure 1—Reaction mechanism for fluorooxidation of polyethylene.



The presence of the polar groups on the surface is also important because they provide sites for strong adhesion of the coating to the surface through a variety of bonding mechanisms ranging from hydrogen bonds to covalent bonds. Our tests showed that fluorooxidation of WPC substrates resulted in excellent adhesion of many types of conventional and UV-curable paints. The coatings industry standard test for coating adhesion is ASTM D 3359. In this test, the coating surface is cut using a sharp razor blade cutting device to produce a series of cross-hatched cut marks. Then a standardized piece of tape is pressed onto the cut area and removed. Based on the amount and distribution of paint pulled off on the tape, a rating is derived.

However, these do not work on WPC. The reason is that the lignin in the wood flour is an effective antioxidant that inhibits the surface oxidation chemistry. In order to successfully oxidize the surface, a much more potent process is required.

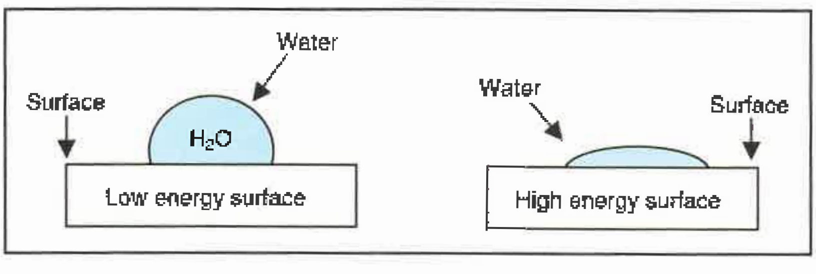
Inhance/Fluoro-Seal has developed a reactive gas treatment that quickly and effectively oxidizes the surface, and facilitates coating and adhesion. The process uses elemental fluorine as an initiator for the permanent oxidation of the composite surface. Reaction of substrates with elemental fluorine (F_2) and oxygen (O_2) is termed fluorooxidation or oxyfluorination. The reaction mechanism for fluorooxidation of polymers, such as polyolefins, begins with a fluorine atom abstracting a hydrogen atom from the carbon backbone to create a carbon radical. Once the carbon radical is formed, oxygen preferentially reacts with it to form a peroxy radical. Peroxy radicals subsequently undergo various reactions to form hydroxyl, carboxy, and other polar functionalities. *Figure* 1 illustrates the fluorooxidation chemistry. Due to the high oxidation potential of F_2, the presence of lignin, cellulose, and hemi-cellulose have minimal effect on the reaction.

The creation of polar functional groups during fluorooxidation is very important for facilitating wetting of the WPC surface with a coating liquid. Improved wetting is important because it enables coating liquids to thoroughly and intimately associate with the WPC surface. A higher surface energy in general means greater interaction between the coating liquid and the substrate surface, as illustrated in *Figure* 2. *Table* 1 summarizes the change in water contact angle and surface energy caused by fluorooxidation of a WPC sample.

The initial experiments used ChoiceDeck® brand railing products from AERT, Inc. and Strandex® composites from Strandex Corporation. Seven different paints were used on two variations of fluorooxidation —moderate and aggressive. The difference between moderate and aggressive treatment conditions in this case was that the concentration of fluorine was doubled in the aggressive conditions. *Table 2* summarizes the results. *Figure* 3 illustrates the results, showing the amount of coating remaining on WPC after tape test.

There are additional attributes of the fluorooxidation process that make it ideal for this application. One major attribute is that the surface modification is permanent. There is a small amount of crosslinking at the surface that helps stabilize oxidation groups from rotating into the first several molecular layers, which is common with other treatment methods that fade after days or weeks. Another attribute is that the chemistry is extremely rapid. Since the oxidation occurs in less than one second, the process can easily be done in-line or in an off-line operation. The commercial significance of this will be discussed below. Since the process only

Figure 2—Wetting performance. With low surface energy on substrate (left), there is minimal attraction between coating liquid and surface. With high surface energy on substrate (right), there is high interaction between coating liquid and surface.



modifies the outer few molecular layers, there is no visible change in topography. Thus, embossed patterns are unaffected.

The results of the initial phase of experimentation proved three very important outcomes.

- The fluorooxidation chemistry is rapid and the process window is wide, which means that it is a robust, low cost operation that does not require sophisticated control systems and highly trained personnel.
- A wide range of commercially available coatings can be used on a fluorooxidized WPC substrate.
- The technology works well on WPC made from different producers using different polyethylenes, wood flour sources, and additives.

Coating Material and Process

Achieving an effective surface modification is only part of the solution to deficiencies of WPC. It is also necessary to select the right coating system that meets all of the performance requirements for specific applications, and that it be economical. It is also noteworthy that WPC profiles for different applications can have totally different coating coverage requirements. For example, for siding applications, only the top and sides of the boards need to be coated, whereas in other applications the entire board might need to be coated. For decking and railing products, full encapsulation is most desirable for durability, aesthetics, and composite protection from the environment.

Several polymer systems as well as hybrid systems can be used to create coatings. Each system provides a unique set of performance characteristics, unique application/curing requirements, and economics. Coatings economics are determined by many factors including costs of coating resins, solvent (VOC) abatement, coatings application methods, efficiency of coating usage (overspray losses), space requirements, cure energy (drying) requirements, and capital costs.

From the WPC producer's perspective, there are several options for using a system to adhesion treat, paint, and cure WPC products. Since the WPC extrusion process is an inherently linear process, adding the fluorooxidation adhesion treatment and coating/curing processes can be easily added in-line. Depending on the coating type and curing method, the process can run anywhere from 10 fpm to >100 fpm. Since the average WPC extrusion process operates at 8–12 fpm, the adhesion treatment and coating/curing process could be under utilized. There are advantages however to operating the process in-line with an extruder. For example, several extrusion lines can share a single source of reactive gas that would enable WPC lines to employ multiple coating types and curing methods.

Another approach would be to operate the adhesion treatment and coating/curing processes off-line using lateral in and out feeds. This might be done at the WPC extruder's location or on a toll-basis by another firm. In this manner, boards or profiles are fed continuously as cut stock into the process. Using conventional paints and coatings, the maximum line speeds are estimated at 30–50 fpm and infrared curing is employed. Even though conventional paints are low cost, they do present potential limitations. One issue is being able to repack and bundle boards immediately after curing. With conventional paints and coatings, there is a reasonable potential for blocking. A more substantial limitation is being able to coat all sides of the board or profile in a single pass, which is desirable for both decking and railing products. Of course, WPC boards or profiles can be coated in multiple stages for applications requiring full surface coverage using conventional curing methods; however, the capital requirements and process floor space would be incrementally larger.

With 100% solids UV-curable coatings, each gallon is used fully with no volatiles or hazardous waste streams. It is known that UV-curable coatings are much

Table 1—Surface Energy of WPC Before and After Fluorooxidation

	Water Contact Angle[a]	Surface Energy (dynes/cm)
Untreated WPC	100.5°	22
Fluorooxidized WPC	30.4°	64

(a) Dr. Marie Laborie, Washington State University

Table 2—ASTM D 3359 Cross-Hatch Adhesion Results

Coating Type	Treatment Conditions A	Treatment Conditions B	Control	WPC Type
Zinsser pre-wall covering primer (1)	Strong	Strong	Poor	C-Deck
Glidden interior/exterior latex enamel (2)	Very strong	Very strong	Weak	C-Deck
Kilz latex interior/exterior water-based paint (3)	Strong	Strong	Poor	C-Deck
American Tradition exterior oil primer (4)	Very strong	Very strong	Weak	C-Deck
DuPont IMRON® 1.5 ST-D™ Satin waterborne PU copolymer	Very strong	Very strong	Weak	Strandex
DuPont IMRON 3.5 ST-D Satin gloss PU, solventborne	Very strong	Very strong	Modest	Strandex
Finishes Unlimited, developmental acrylic latex	Very strong	Very strong	Modest	Strandex

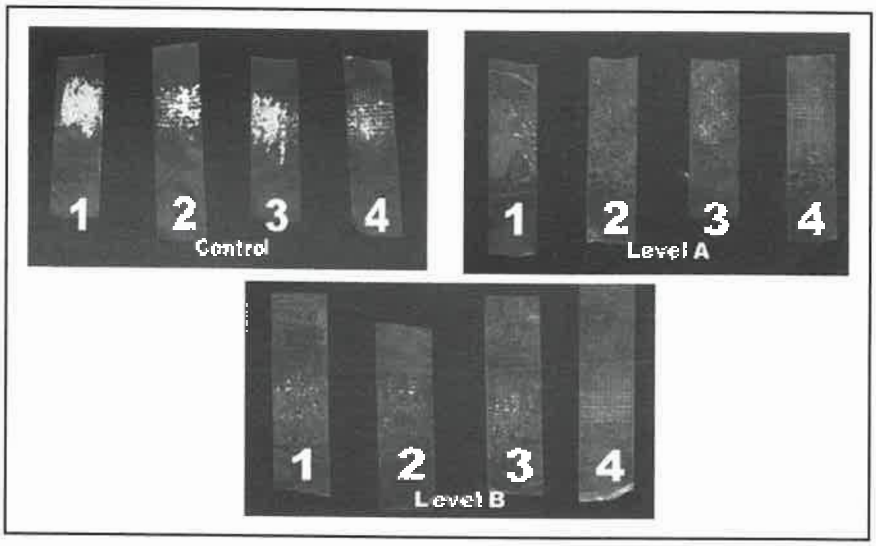
Table 3—UV-Cured Paint Performance Results

Liquid Paint Standards		Cured Film Properties: (at 1-mil on Fluorooxidized Strandex)	
Gallon weight (± 0.2 lb):	9.26	60° Gloss ASTM D 523	85+ units
Weight solids:	100%	Adhesion ASTM D 3359	Excellent
Volume solids:	100%	Freeze resistance, 96 hr @ 20°F, -25°F	No effect
Viscosity #4 Zahn @ 77°F:	50–60 in.	Adhesion ASTM D 3359	Excellent
VOC sans water:	None	Heat resistance, 144 hr @ 120°F	No effect
VOC as supplied:	None	Adhesion ASTM D 3359	Excellent
		Flexibility/impact resistance	Excellent
		Immersion testing, 48 hr immersed in Olympic Premium Deck Cleaner	No effect
		QUV Weathering Test ASTM G 154 (cyclical 4 hr UV Light/4 hr condensation)	1000 hr
		Gloss retention (85° meter)	70%
		Color change (ΔE CIELAB)	1.35 units
		Repaint adhesion, lightly sanded and repainted with Behr Porch & Floor Paint	Excellent

more costly on a per gallon basis versus conventional waterborne coatings, yet many companies that have made the conversion are still recognizing net economic benefit with greater flexibility and performance. To date, many manufacturers of fabricated wood products have made the switch from clear solventborne coatings to UV clearcoats. UV clearcoats are also prevalent in exterior automotive plastic components and many types of rigid and flexible packaging. The introduction of pigmented UV curable paints is now emerging as formulations are being developed that allow full penetration of UV light.

UV-curable 100% solids coatings are an ideal class of coating materials for WPC products, and for the business model of WPC production and distribution. In the building and construction products industry it is customary for products to be shipped by truck to various regional distribution points. Shipping truckloads of WPC boards or profiles to centralized regional locations for painting operations has economic feasibility. Allowing many different types of products to be shipped to a regional location from multiple producing locations allows measurable advantages, especially for the larger building and construction products companies. UV-curable coatings offer further advantages, such as being able to coat all sides of a board or profile in a single pass. One of the more recognized benefits of UV is being able to cure within seconds. Assuming the WPC being coated is long enough to coat and extend into a curing chamber, a bottom side lamp cures the area prior to reaching the supporting roller or belt. The full encapsulation process is capable of running in excess of 100 fpm.

Figure 3a–3c: ASTM D3359 tape test results. WPC samples showing amounts of coating remaining after tape test. Labels 1–4 correspond to *Table* 2.



The primary goal of this research was to develop a series of UV-curable paints and an off-line process to coat long, flat WPC stock, specifically decking, flooring, and railing profiles. *Appendix* A illustrates the basic process schematic for a system designed by Shield Finishing (Big Rapids, MI). This system is designed for full process integration of the fluorooxidation adhesion treatment process and a coating and curing scheme that enables full encapsulation in a single pass up to 1.5 mil at speeds ranging from 50 fpm to >100 fpm. The UV-curable coatings were developed by Finishes Unlimited, Inc. (Sugar Grove, IL). UV-curable systems can be formulated to meet performance demands, such as toughness, flexibility, weatherability, etc. In this case, Finishes Unlimited developed a base formulation that is analogous to automotive exterior topcoats. This approach enabled the best balance of superior weatherability, impact, and abrasion resistance and overall adhesion to this new family of substrates. *Table* 3 details the performance results of the developed coating applied to WPC boards.

As can be seen from *Table* 3, the UV-curable coating developed for WPC substrates provides an excellent balance of toughness, weathering, and chemical resistance. This coating was developed for outdoor decking and flooring substrates. Due to the weathering performance and ability to tailor gloss and color, this same coating system is ideal for railing and siding products. For applications such as home siding, the performance requirements would likely dictate a different formulary approach since mar and abrasion resistance is not as critical as color retention, weathering, and re-paintability. Furthermore, the siding market also shows a higher preference for primed panels that are engineered for painting at the construction site.

CONCLUSION

In order for the use of WPC to continue to grow and extend into new market segments, some of the deficiencies of WPC must be overcome. Performing fluorooxidation on WPC followed by appropriate coating has been demonstrated to solve these problems. Furthermore, today's customers want a product with eye-popping aesthetics that stay that way for many years, that is not tainted when scuffed, and which requires little to no maintenance—and, they are willing to pay for these benefits. CT

References

(1) Rossi, L., Principia Partners, "Current and Emerging Applications for Natural & Wood Fiber Composites," 7th Intern. Conference of Woodfibre-Plastic Composites, Madison, WI, May 19-20, 2003.

(2) Winandy, J., Stark, N., and Clemons, C., "Considerations in Recycling of Wood-Plastic Composites," 5th Global Wood and Natural Fibre Composites Symposium, Kassel, Germany, April 27-28, 2004.

(3) Baugh, J. and Nicolaus, S., "What's Ahead for the WPC Industry? An Analyst's Perspective," Wood-Plastic and Natural Fiber Composites 2006, Baltimore, MD, September 25-26, 2006.

(4) http://www.trex.com/Universal/product_info/workingwithtrex/weathering.asp.

(5) Stark, N., Laurent, M., and Clemons, C., "Effect of Processing Method on Surface and Weathering Characteristics of Wood-Flour/HDPE Composites," *J. Appl. Polym. Sci.*, Vol. 93, Wiley Periodicals, Inc., 1021-1030 (2004).

Appendix 1