New Technology for Enhancing Wood Plastic Composites

By Kelly Williams and Bernard Bauman

Industry Background

Wood-plastic composites (WPCs) 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's more costly, because of lower maintenance requirements and aesthetic appeal. WPCs do not require painting, resist warping and termite attack, and is generally resistant to moisture-related issues such as mold development. However, WPC products can fade, develop mold, generally stain, scratch easily, and do require more maintenance than advertised.

This paper describes a unique approach for rendering WPC to adhere to coatings and new 100% solids UV-curable coatings that are engineered for exterior durability and can be pigmented any desired color. Furthermore, these coatings provide a surface that can be repaired over time or fully repainted with any exterior grade latex, stain or sealant.

The WPC industry has grown faster than any other plastics industry since its emergence in the late 1980s.[1] The market segments that have supported annual growth rates of more than 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, WPCs have assumed nearly 20% market share versus treated lumber.[1,3]

Even though the housing market is in a recession, the remodeling sector is still healthy—helping to buoy continued industry growth. Given tough times, Wall Street analysts predict a bright outlook for the industry.[3] The prediction is for WPCs to continue to capture upward

FIGURE 1

Reaction mechanism for fluoro-oxidation of polyethylene

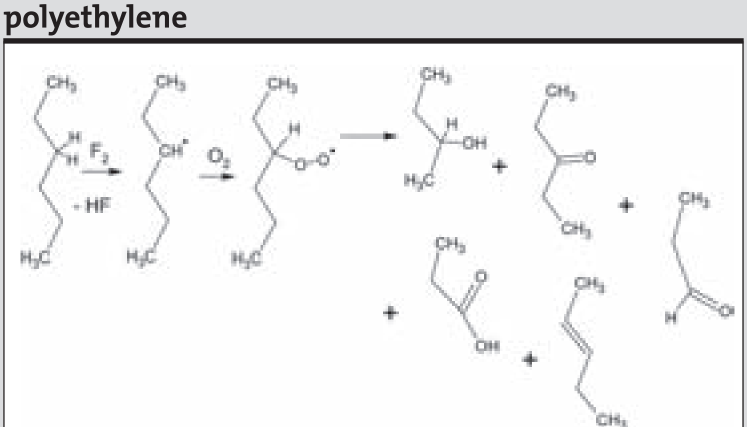


Figure 2

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.

of a 20% unit share (40% dollar share) relative to treated wood.[3] 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 fewer major players and a group of niche players.[3] The keys to success during this phase will be distribution, capital, brand, process and product innovation.[3] Arguably, companies such as Universal Forest Products, Plygem, Louisiana-Pacific, 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 WPCs, such as fencing, window and door trim/profiles, and siding. In order for WPCs 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 that Need to be Solved

While the WPC industry has continuously made improvements in aesthetics and final product performance over the last two decades, significant performance deficits will still limit future growth potential. Specific deficiencies include color and appearance retention over time; scratch and mar resistance; and the 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 many reports of staining and other maintenance-oriented issues. It is well 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 Web sites 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. This has proven to reduce moisture absorption but has not proven to eliminate it in the long term. Other issues have arisen from such additives, including 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 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 in 5-10 years as it does when initially installed. This is a good and a bad thing for the WPC industry. It shows again that the consumer is willing to pay for what they want. But, 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 paper will discuss an approach to solve the major deficiencies of WPCs detailed above. 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

Table 1

Surface energy of WPC before and after fluoro-oxidation

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

(a) Dr. Marie Laborie, Washington State University

or clear coated with 30-plus years of projected durability!

Appropriate coatings can also provide outstanding scratch and mar resistance, as well as providing 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. With the application of the proper coating system (such as UV-curable coatings designed for exterior durability), when decks get scratched or marred, installers or consumers can "touch up" the damaged area using any off-the-shelf exterior latex, stain or clear coat sealer.

Surface Modification

To the uninitiated, coating WPC lumber sounds quite simple and straightforward—but it's 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 gives very poor adhesion. This same phenomenon makes it difficult and nearly impossible for use of 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. However, these do not work on WPCs. 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.

We have developed a reactive gas treatment that quickly and effectively oxidizes the surface and facilitates coating and tenacious 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 fluoro-oxidation or oxy-fluorination. The reaction mechanism for fluoro-oxidation of polymers (such as polyolefins) begins with a fluorine atom abstracting a hydrogen atom from the carbon backbone to create a carbon

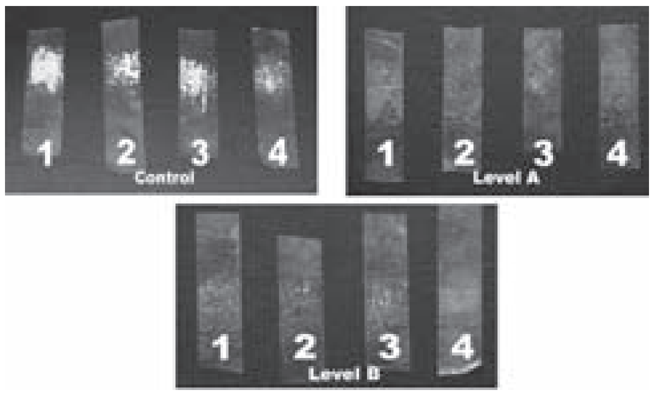
Table 2

ASTM D-3359 cross-hatch adhesion results

Coating Type	Treatment Conditions A	Treatment Conditions B	Control	WPC Type
(1) Zinsser pre-wall covering primer	Strong	Strong	Poor	C-Deck
(2) Glidden interior/exterior latex enamel	Very Strong	Very Strong	Weak	C-Deck
(3) Kilz latex interior/exterior water-based paint	Strong	Strong	Poor	C-Deck
(4) American Tradition exterior oil primer	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, solvent-borne	Very Strong	Very Strong	Modest	Strandex
Finishes Unlimited, developmental acrylic latex	Very Strong	Very Strong	Modest	Strandex

Figure 3a, 3b, 3c

ASTM D-3359 tape test results



WPC samples showing amounts of coating remaining after tape test. Labels 1-4 correspond to Table 2.

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 fluoro-oxidation 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 fluoro-oxidation 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 fluoro-oxidation of a WPC sample.

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 fluoro-oxidation 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 onto the tape, a rating is derived.

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 fluoro-oxidation—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 the WPC after tape test.

There are additional attributes of the fluoro-oxidation process that make it ideal for this application. One major attribute is that the surface modification is permanent. There is a small amount of cross-linking 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 as well as in an off-line operation. The commercial significance of this will be discussed below. Since the process only 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 fluoro-oxidation 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 fluoro-oxidized WPC substrate.
- The technology works well on WPCs made by different producers using different polymers, wood flour sources and additives.

Coating Material and Process

Achieving an effective surface modification is only part of the solution to alleviate the deficiencies of WPCs. 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 WPCs profiles for different applications can have totally different coating coverage requirements. Siding applications, for example, only need the top and sides of the boards to be coated; whereas, other applications might require the entire profile 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 and has 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, the fluoro-oxidation adhesion treatment and coating/curing processes can be easily added in-line or operated off-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 employing infrared curing. 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

Figure 4

Process schematic

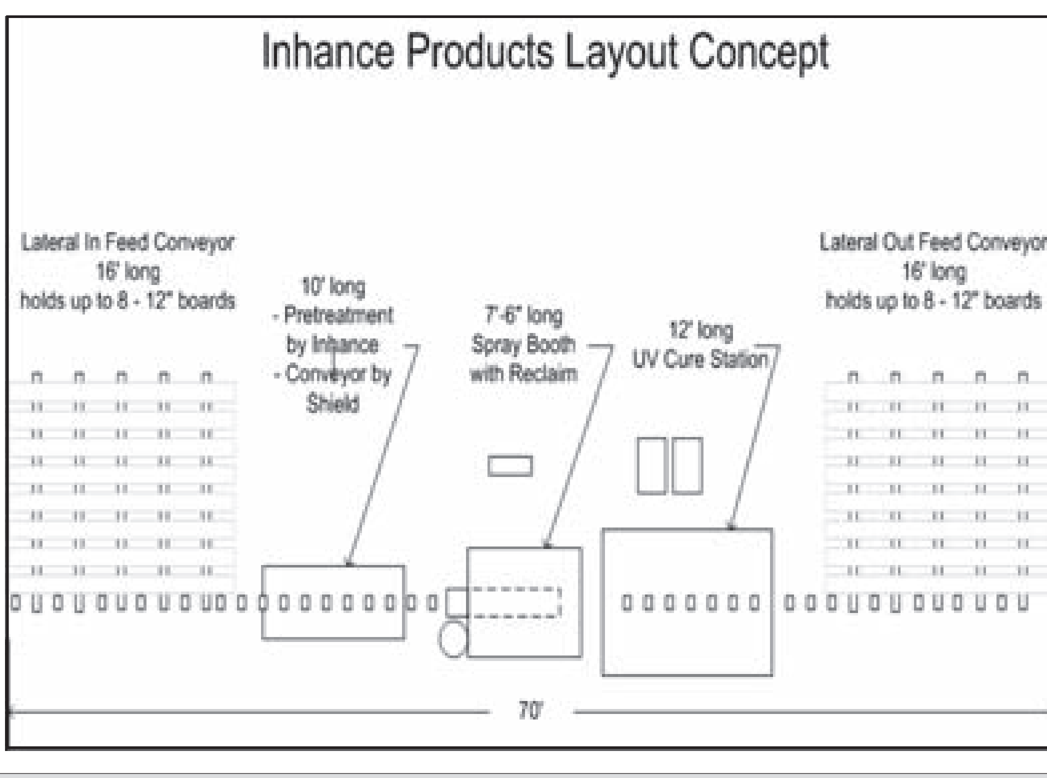


Table 3

UV-cured paint performance results

Liquid Paint Standards		Cured Film Properties (at 1-mil on Fluoro-Oxidized Strandex®)	
Gallon Weight (+/- 0.2 lbs)	9.26	60° Gloss ASTM D-523	85+ units
Weight Solids	100%	Adhesion ASTM D-3359	Excellent
Volume Solids	100%	Freeze Resistance, 96 hrs @ 20F, -25F	No Effect
Viscosity #4 Zahn @ 77F	50″-60″	Adhesion ASTM D-3359	Excellent
VOC sans water	None	Heat Resistance, 144 hrs @ 120F	No Effect
VOC as supplied	None	Adhesion ASTM D-3359	Excellent
		Flexibility/Impact Resistance	Excellent
		Immersion Testing, 48 hrs immersed in Olympic Premium Deck Cleaner	No Effect
		QUV Weathering Test ASTM G-154 (Cyclical 4 hrs UV Light/4 hrs Condensation)	1000 hrs
		Gloss Retention (85° meter)	70%
		Color Change (ΔE CIELAB)	1.35 units
		Repaint Adhesion, lightly sanded and repainted with Behr Porch & Floor Paint	Excellent

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. With the fluoro-oxidation process, all process gasses are run through a scrubber, which neutralizes any HF and unreacted F_2. One good aspect of working with very reactive chemicals such as HF and F_2 is that they are easy to scrub (neutralize). The fluoro-oxidation process is extremely safe and environmentally friendly, and the treated WPC poses no hazards for handling or incineration.

It is known that UV-curable coatings are much more costly on a per gallon basis versus conventional coatings, but when comparing desired film build to percent solids of the coating, the UV coating becomes more economical. Many companies that have made the conversion to 100% solids UV are also recognizing its net economic benefits, greater flexibility and performance. To date, many manufacturers of fabricated wood products have made the switch from clear solvent-borne coatings to UV clear coats. The introduction of pigmented UV-curable paints, for both interior and exterior applications, 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 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. Some of the more recognized benefits of UV is being able to cure within seconds, and the ability to coat and cure complicated profile geometries as well as 3-dimensional parts or circular shapes.

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 and flooring profiles. Figure 4 illustrates one basic process schematic for a system. It was designed by Finishing Technology Solutions (Vermilion, Ohio). Alternative systems have been designed by DV-Systems (Charlotte, N.C.) based on vacuum coating. These systems are designed for full-process integration of the fluoro-oxidation adhesion treatment process and a coating and curing scheme that enables full encapsulation in a single pass up to 3 mil at speeds ranging from 50 fpm to >100 fpm. The UV-curable coatings were developed by Finishes Unlimited, Inc. (Sugar Grove, Ill.). 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 top coats. This approach provides 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 Strandex® WPC composite boards. This specially formulated coating system is being marketed under the InFin® trade name.

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 the ability to tailor gloss and color, this same coating system is ideal for railing, siding, roofing, trim/fascia and fencing products. Siding in particular is an ideal market for which UV-curable coatings and the benefits of the process have great potential value, especially for pre-finished siding. Using UV technology, siding can be processed in any color on demand with the same service times as existing primed and pigmented siding products. The greatest value is in the distribution points of the siding market. Special order colors can be processed fast and efficiently, and existing color portfolios can be more easily and cost-effectively managed with much lower raw material stock-keeping units (SKUs) and inventory carrying costs.

Conclusion

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

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