The Effects of Weathering on Wood-Thermoplastic Composites Intended for Outdoor Applications

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Abstract

Development of the wood-thermoplastic composite market has been hampered by a lack of data on durability and reluctance by homebuilders to utilize undemonstrated products. This paper presents an overview of research at the Forest Products Laboratory to evaluate the durability performance of natural fiber-thermoplastic composites intended for use in roofing applications. An accelerated aging device was used to evaluate the effect of ultraviolet light exposure on the fading of various composites as well as the effect of weathering on the degradation of engineering properties. The results indicate low variability in fading and mechanical properties.

Introduction

Several manufacturers are producing wood-thermoplastic composites from recycled materials. In a little over a decade, the use of plastics and fiber-thermoplastic composites for decking has grown to about 6 percent of the exterior decking market (1). Larger markets within the building industry could be developed, such as the roofing market, but a lack of durability performance data and a reluctance of homebuilders to utilize undemonstrated products have hampered market development.

Thermoplastics have several favorable characteristics as components in composites, including recyclability, moldability, and low cost. However, thermoplastics undergo degradation from oxidation reactions that result from any combination of the following processes: melt degradation, thermal degradation, and photodegradation. Of these processes, photodegradation due to ultraviolet (UV) light exposure is of primary importance for products intended for outdoor applications.

The objectives of the ongoing study reported here are a) to evaluate the photostability of thermoplastic natural fiber composites intended for roofing applications and b) to evaluate the effect of weathering on the degradation of engineering properties.

Materials and Specimen Manufacture

Teel-Global Resource Technologies, LLC (Teel-GRT) compounded the fiber-thermoplastic formulations evaluated in this study. The formulations included two plastics-high density polyethylene (HDPE) and polypropylene-and wood flour (50% and 70% by weight). These formulations were compounded using a Teel-GRT proprietary process, and the material was compression molded into 6- by 6- by 1/8-in. (150- by 150- by 3-mm) flat plates. Test specimens (1 by 2.5 by 1/8 in. (25 by 64 by 3 mm)) were cut from the manufactured plates. The specimen size was chosen to allow for flexural testing after accelerated aging in accordance with

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American Society of Testing and Materials (ASTM) Standard D790 (2).

Tests and Measurements

Accelerated Aging

Specimens were subjected to UV radiation exposure referenced in the International Conference of Building Officials (ICBO) *Acceptance Criteria for Special Roofing Systems* (3). This set of acceptance criteria describes durability test procedures for synthetic roofing systems; the tests include resistance to water, UV radiation, freezing and thawing, and temperature cycling. A weatherometer was used as described in the ICBO standard; this device is described in detail in ASTM G26-96 (4). A specimen drum inside the weatherometer chamber was operated at 1 r/min. and set to a standard exposure cycle (102 min. of light followed by 18 min. of light and water spray exposure).

Measurement of Fading

The color intensity of the exposed and unexposed (control) specimens was measured using a Minolta CR-200 Chroma Meter, a compact tri-stimulus color analyzer that measures the reflective colors of a surface. Absolute chromaticity measurements were taken using three-parameter CIE (International Commission on Illumination): $L^\star$, $a^\star$, and $b^\star$. The parameter $L^\star$ is the lightness factor (amount of reflected light); $a^\star$ and $b^\star$ are the chromaticity coordinates (chroma and hue, respectively).

Our primary interest was measurement of $L^\star$. This factor provides a quantitative measure of the intensity of fading and would indicate the most ideal formulation (from a color fade standpoint) for roofing applications. A higher $L^\star$ value indicates greater fading (higher reflectivity). In addition to evaluating $L^\star$, the total color difference (ΔE) was calculated. ΔE is the square root of the sum of the squares of the chromaticity coordinates. Specimen color intensity was measured and reported at 0, 200, 400, 700, 1,000, and 1,500 hr. of exposure.

Flexural Strength and Stiffness Measurement

Evaluation of specimen flexural properties was performed referencing ASTM D790-90 (1). All strength and stiffness testing was performed at the Engineering Mechanics Laboratory at the Forest Products Laboratory. The specimens were tested according to Test Method I, a three-point loading system utilizing center loading on a simply supported beam (Fig. 1). Specimens were deflected until failure or until 5 percent strain was reached in the outer fibers. Translational deflection was measured by the use of a linear variable differential transformer (LVDT) that was located at the base of the support head and recorded relative displacement between the loading head and supports. Flexural strength, as measured by modulus of rupture (MOR), and flexural stiffness, as measured by modulus of elasticity (MOE), were determined. MOR was calculated using standard equations in ASTM D790. Because of the nonlinear stress-strain behavior of natural fiber-thermoplastic composites, a modified method for determining MOE was used (MOE at initial slope) (4). A total of 15 specimens of each formulation were tested.

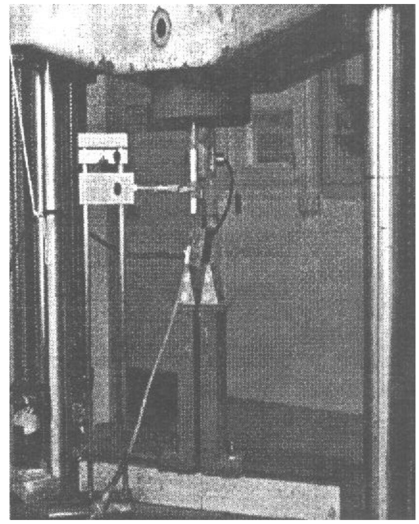

Figure 1.—*Bending test of specimen.*

Results

The durability performance of the potential roofing tile formulations was evaluated by measuring individual specimen resistance to accelerated UV aging. Data on the fading and flexural properties of the natural fiber-thermoplastic composites were analyzed and plotted to indicate trends in performance. A statistical evaluation of the test results for each formulation indicated that variability in fading and mechanical properties was low (5% to 10% coefficient of variation). For this reason, only average values are presented.

Effects of Accelerated Aging on Fading

Nearly all exposed specimens experienced fading after 1,500 hr. of weatherometer exposure. Specimen chromaticity response over 1,500 hr. of accelerated aging was nonlinear (Fig. 2). The exposed specimens generally exhibited greater fading between 0 and 400 hr. than between 1,000 and 1,500 hr. It is apparent from Figure 2 that the polypropylene-based composites faded at a more rapid rate than did the HDPE-based composites. In addition, the specimens with higher wood flour content faded somewhat more than did specimens with lower wood flour content. We believe this has to do with

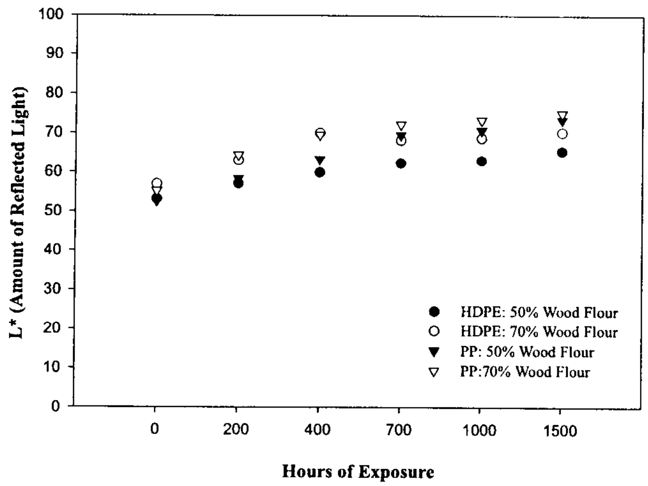

Figure 2.—*Fading of HDPE and polypropylene-wood flour composites.*

the tendency of the wood particles to bleach with UV exposure. Typical specimens are shown in Figure 3.

A common method for increasing the photostability of thermoplastics is through the use of UV absorbers (colorants). Table 1 and Figure 4 show the effect of red and black pigments on the color fade of HDPE and polypropylene composites containing 50 percent wood flour. It is apparent that the addition of colorant to 50 percent wood flour composites effectively reduced both average change in L^{*} and ΔE for both HDPE and polypropylene.

Effects of Accelerated Aging on Flexural Properties

Several specimen formulations were subjected to flexural testing. Bending tests were performed on both unexposed and exposed specimens of the same formu-

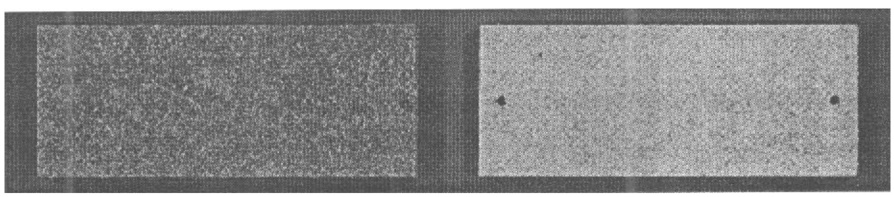

Figure 3.—*Polypropylene test specimens with 50% wood flour: unweathered specimen (left), weathered specimen (right) (1,500-hr. exposure).*

Table 1.—*Effect of colorants and weatherometer exposure on color fade of HDPE and polypropylene composites.*

Resin type	Colorant	Average L^{*} for two exposure times (%)[a] 0 hr.	1,500 hr.	Average change	Total color difference
				(%)	(ΔE)
HDPE	None	63.4 (0.8)	83.7 (0.1)	32.1	24.86
	Red	48.3 (2.6)	54.7 (0.9)	13.1	7.48
	Black	41.3 (5.0)	40.9 (5.0)	-0.8	4.00
Polypropylene (PP)	None	61.6 (2.1)	90.3 (0.8)	46.7	33.91
	Red	50.1 (1.3)	66.6 (3.7)	33.0	17.49
	Black	37.4 (2.8)	51.9 (1.6)	38.7	15.04

[a] Values are coefficients of variation.

Table 2.—*Effect of colorants and weatherometer exposure on flexural properties of HDPE and polypropylene composites with 50% wood flour.*

		Unweathered		Weathered		Change (%)	
Resin type	Colorant	MOR	MOE	MOR	MOE	MOR	MOE
		(lb./in.^{2})	($\times 10^6$ lb./in^2)	(lb./in.^{2})	($\times 10^6$ lb./in.^{2})	(lb./in.^{2})	($\times 10^6$ lb./in.^{2})
HDPE	Red	7,556	0.42	6,091	0.32	19.39	23.81
	Black	6,681	0.36	6,340	0.34	5.10	5.56
Polypropylene	Red	8,321	0.49	6,462	0.35	22.3	28.6
	Black	7,559	0.44	6,073	0.34	19.7	22.7

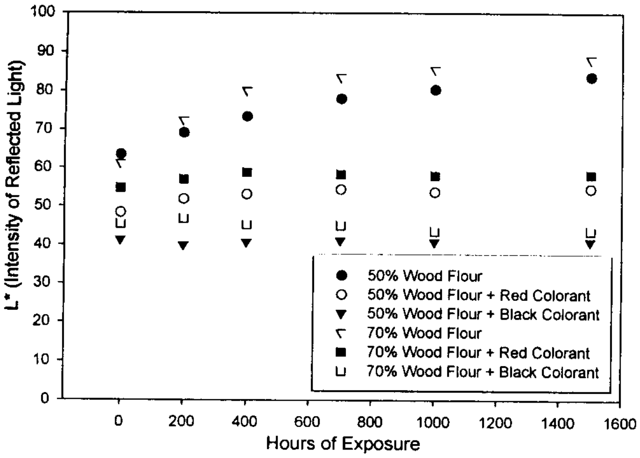

Figure 4.—*Effect of added colorants on fading of HDPE-wood flour composites.*

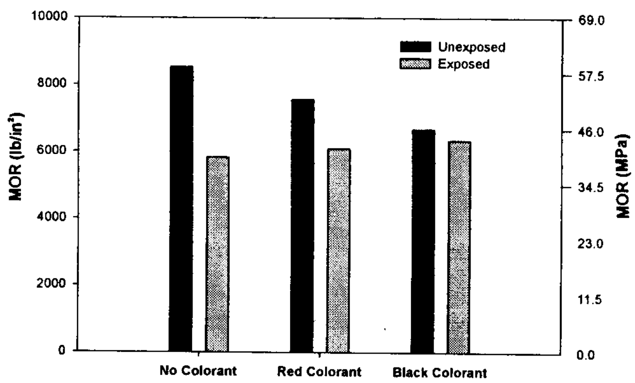

Figure 5.—*Effect of UV exposure on bending strength of wood flour composites.*

lations. In all cases, the specimen was oriented with the exposed face on the tension side. Specimens containing red and black colorant were also evaluated. Table 2 shows the effects of colorants on HDPE and polypropylene composites containing 50 percent wood flour. Although the addition of colorant decreased both MOR and MOE of unexposed specimens, the flexural properties of the exposed specimens were increased (Figs. 5 and 6).

Roofing Panels

Once relatively photostable formulations were identified through testing, full-sized architectural roofing panels were molded in cooperation with Teel-GRT The panels consisted of 50 percent recycled HDPE from milk cartons and 50 percent recycled natural fiber and wood flour, as well as a variety of additives. The panels measured approximately 2 ft. (600 mm) by 4 ft. (1,200

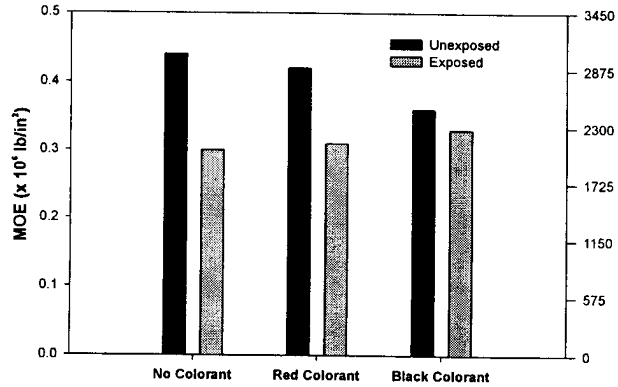

Figure 6.—*Effect of UV exposure on bending stiffness of E-70% wood flour composites.*

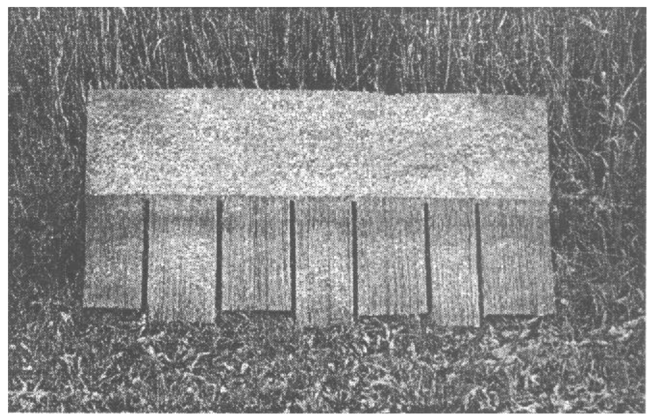

Figure *'I.-Individual* roof ***panel, cedar shake style.***

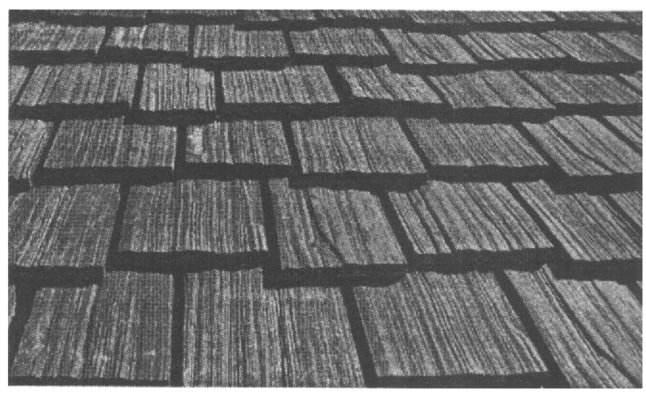

Figure 8.—*Section of completed roof:*

mm) and consisted of seven individual shakes per panel. A typical panel is shown in Figure 7.

Demonstration Project

The Dane County Heritage Center at Lake Farm County Park in Wisconsin was selected for the Wisconsin Department of Natural Resources project, Demonstrating the Performance of Recycled Content Fiber-Plastic Composite Roof Panels in Building Construction. This project allowed for evaluation of both installation and durability of the developed natural fiber-thermoplastic roof panels. An approximately 4,000-ft.^{2} (370-m^2) roof was sheathed with the panels; a section of this roof is shown in Figure 8. Fading of these in-place roof panels is being evaluated by ongoing field tests.

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