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Influence of photostabilizers on wood flour–HDPE composites exposed to xenon-arc radiation with and without water spray ☆

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Abstract

The weathering of wood–plastic composites changes their appearance and/or mechanical properties. These changes can be slowed through the addition of ultraviolet absorbers and pigments. The first phase of this study examined the effect of incorporating different concentrations of an ultraviolet absorber and/or pigment into wood-flour-filled high-density polyethylene (WF/HDPE) composites. Lightness and flexural properties of the composites were determined periodically during exposure to UV radiation and water spray in a xenon-arc type weathering apparatus. The influence of exposure type (UV radiation, with or without water spray) on the properties of photostabilized WF/HDPE composites was determined in the second phase of the study. The results showed that both ultraviolet absorbers and pigments provide protection against weathering of wood–plastic composites. The amount of protection can be influenced by both photostabilzer concentration and exposure variables. Published by Elsevier Ltd.

Keywords: Wood–plastic composites; Weathering; Wood flour; High-density polyethylene (HDPE); Ultraviolet absorber; Pigment

1. Introduction

Although inorganic fillers currently dominate the thermoplastic industry, wood-derived fillers are gaining acceptance. To a great extent, the increase in the use of wood fibers in plastics is due to growth in the use of wood–plastic composites (WPCs) by the construction industry for such applications as decking, siding, roof tiles, and window frames. Decking, the largest construction application, is experiencing tremendous growth. It is estimated that between the years 2004 and 2009, WPC decking will grow by 23% annually [1].

Part of the reason for this growth is that WPC lumber is promoted as a low-maintenance high-durability product [2]. However, its use by the construction industry has resulted in concern about exterior durability. Weathering is of particular concern because it has been well documented that WPCs exposed to accelerated weathering may experience color change, which affects their aesthetic appeal [3–7], as well as mechanical property loss, which limits their performance [4–11].

Changes in properties due to accelerated weathering can be a result of changes upon exposure to ultraviolet (UV) radiation and/or moisture. Exposure to UV radiation can result in changes in both the polymer matrix and the wood component. Photodegradation of polyethylene results in free radical generation, which may lead to termination via cross-linking or chain scission. While cross-linking and chain scission are competitive mechanisms of UV degradation, cross-linking has been shown to be the preferred mechanism during accelerated weathering [12]. Chain scission can result in more chain mobility and secondary recrystallization. The physical result of

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photodegradation is surface cracking and loss in strength and stiffness. Wood also undergoes photodegradation. Degradation primarily occurs in lignin at the wood surface and results in a cellulose-rich surface. As wood undergoes photodegradation, the cellulose-rich oxidized surface becomes more wettable [13].

Wood–plastic composites are detrimentally affected by the presence of moisture, primarily because of the wood component. Wood is a naturally hydrophilic material. As a result, wood cell walls swell when penetrated by water, facilitating deeper light penetration and providing sites for further degradation [14]. In addition, some water-soluble extractives are removed. In WPCs, swelling of the wood fiber compromises the wood/matrix interface and creates microcracks in the matrix [15]. The result is a change in appearance and deterioration of mechanical properties.

Although both UV radiation and moisture can degrade WPCs, exposure to the combination of UV radiation and moisture is more detrimental to WPCs than is exposure to UV radiation alone [9]. Several factors likely contribute to this phenomenon. The presence of water accelerates oxidation reactions, and the swelling of wood fibers facilitates light penetration into the composite. The water spray also washes away the degraded layer and removes natural wood extractives [9].

Enormous efforts have been put into the development of photostabilizers and other compounds to protect polyolefins against UV degradation [12,16]. Ultraviolet absorbers and hindered amine light stabilizers are two important photostabilizers. In addition, pigments are often used as photo-blockers. While pigments are not technically photostabilizers, they will be referred to as such in this paper.

The effect of pigments on lightness and flexural properties of wood flour (WF) filled polyethylene (PE) and polypropylene composites after accelerated weathering has been investigated [4]. The results of that study showed that pigments could be effectively used to mitigate the increase in lightness and significantly increase the flexural property retention of WF/PE composites after accelerated weathering. While this study clearly showed the effectiveness of pigments in preventing lightening and mechanical property loss, the effect of pigment concentration on the durability of composites exposed to UV radiation was not determined.

Lundin [5] investigated the effect of hindered amine light stabilizer (HALS) content on the lightness and mechanical property loss of 50% WF-filled PE composites weathered for 1500 h. The author reported that the addition of HALS (0.25% and 0.5% by weight) to the composites did not affect color change caused by accelerated weathering. Weathering decreased stiffness of the composites between 26% and 30% regardless of the addition of HALS. On the other hand, the addition of 0.5% HALS reduced loss in flexural strength by 3%, though its statistical significance was not reported.

We previously employed a full-factorial experimental design to examine the effect of a low molecular weight HALS, a high molecular weight HALS, an ultraviolet absorber (UVA), and a pigment on the lightness and mechanical properties of WF/HDPE composites exposed for up to 2000 h of accelerated UV weathering [6]. Only the UVA and pigment significantly reduced composite lightening and loss in mechanical properties. Regardless of molecular weight, HALS was found to be ineffective in protecting the composite against surface discoloration and flexural property loss. Prior research has not examined the effect of photostabilizer content on UV durability of WF/HDPE composites.

In a previous study, we stabilized WF/HDPE composites with a pigment or UVA and exposed them to accelerated weathering [17]. Fourier transform infrared spectroscopy (FTIR) was used to determine functional groups present on the surface of the composites before, after 1000 h, and after 2000 h of weathering. By following the carbonyl growth, we were able to determine significant growth in surface oxidation for all composites after the first 1000 h of weathering. The growth in surface oxidation from 1000 to 2000 h of weathering was significant only for composites without pigment or UVA. FTIR was also used to follow the crystallinity of the HDPE. After 1000 h of exposure, there was a significant increase in crystallinity for all composites. Between 1000 and 2000 h of exposure, the crystallinity of the unstabilized composites decreased, while that of the stabilized composites did not change. We concluded that both the pigment and UVA delayed the eventual increase in surface oxidation and decrease in HDPE crystallinity that would occur at later exposure times.

The main objective of the present study was to determine the effect of stabilizer concentration on changes in lightness and mechanical property loss of WF/HDPE composites after accelerated UV weathering. The results reported in this paper will promote the understanding of the efficiency of photostabilizers in protecting WPCs against exposure to UV radiation with and without water spray.

2. Methods

This study was conducted in two phases. The first phase examined the influence of photostabilizer concentration on WPC performance. The effect of the exposure type was determined in the second phase.

2.1. Materials

The materials used in this study are listed in Table 1. Combinations of WF (a hydroxy phenyl benzotriazole UVA) and zinc ferrite pigment (an inorganic pigment in a carrier wax, P) were added to HDPE. The HDPE was a virgin material with a melt index of 0.72 g/10 min and density of 0.963 g/cm^3.

Table 1
Materials used in composite blends

Variable	Supplier	Trade name
Wood flour (WF)	American Wood Fibers	AWF 4020
Ultraviolet absorber (UVA)	Ciba Specialty Chemicals	Tinuvin 328
Zinc ferrite pigment (P)	Holland Colors Americas, Inc.	Cedar TI-8536
High-density polyethylene (HDPE)	Solvay Polymers, Inc.	Fortiflex A60-70-162

The WF was maintained at 50% by weight of the composite. The manufacturer-recommended concentration of UVA was 0.5% and that of P was 1%. In the first phase of the study, UVA and P were added at either one or two times the recommended concentration. Table 2 shows the seven composite formulations manufactured.

2.2. Processing

The WF was dried for 24 h at 105 °C to remove moisture before being dry-blended with photostabilizers and HDPE. Compounding was accomplished using a 32-mm Davis Standard (Pawcatuck, CT) co-rotating twin-screw extruder to produce homogeneous composite pellets. The melt temperature varied between 196 °C and 204 °C. All composite pellets were dried at 105 °C for at least 24 h to <1% moisture content prior to injection molding. Test specimens were molded in a 33-ton Cincinnati Milacron (Batavia, OH) reciprocating screw injection molder. The nozzle temperature was set to 204 °C. The dimensions of the American Society for Testing and Materials (ASTM) mold cavity used for the flexural samples were 120 by 3 by 12 mm [18].

2.3. Testing and analysis

2.3.1. Weathering

All composite samples were placed in a xenon-arc-type light exposure apparatus that filtered the radiation source with borosilicate filters (Weather-Ometer 65-WT, Atlas Materials Testing Technology, Chicago, IL). Xenon-arc radiation is similar to solar radiation, consisting of UV, visible, and infrared radiation. Because the UV wavelengths are the most damaging to WPCs, in this paper the exposure is referred to as exposure to UV radiation.

During exposure, the samples were mounted on a drum that rotated around the xenon-arc bulb at 1 rpm. In the first phase of the study, all composite formulations were exposed to both UV radiation and water spray. The exposure was a 2-h cycle consisting of 108 min of UV radiation followed by 12 min of simultaneous water spray and UV radiation. To understand the effect of weathering duration on composite properties, samples were removed periodically for analysis. In the second phase of the study, samples were exposed to continuous UV radiation. The two exposure cycles are shown in Table 3. In each case, an irradiance sensor was used to measure light intensity for wavelengths from 300 to 400 nm (XenoCal, Atlas Materials Testing Technology, Linsengericht, Germany). The irradiance was monitored, and voltage to the bulb was changed periodically to maintain constant irradiance. Irradiance follows an inverse square law with distance. The irradiance the samples received (I_2) was calculated using Eq. (1):

$$I_2 = I_1 \left(\frac{D_1}{D_2}\right)^2 \quad (1)$$

where D_1 and D_2 are distance to sensor and samples, respectively, and I_1 is irradiance measured by the sensor.

The radiant energy to which the samples were subjected was then determined (time integral of irradiance). To compare results of composites exposed to UV light and water spray to that of composites exposed to UV light alone, the cycles were run in a manner such that the radiant exposure and exposure time were similar (Table 3).

Table 2
Formulations of wood–plastic composites manufactured

Formulation	WF (%)	UVA (%)	P (%)	HDPE (%)
1	50	0	0	50.0
2	50	0.5	0	49.5
3	50	1	0	49.0
4	50	0	1	49.0
5	50	0	2	48.0
6	50	0.5	1	48.5
7	50	1	2	47.0

Table 3
Weathering cycles and conditions of exposure

Weathering cycle	Exposure time (h)	Radiant exposure* (J/m^2)	Water spray cycles (no.)
With water spray	1000	54	500
	2000	109	1000
	3000	163	1500
Without water spray	2985	165	NA

* Radiant exposure at 300–400 nm

2.3.2. Color analysis

A Minolta CR-200 Chroma Meter (Minolta Corporation, Ramsey, NJ) was used to measure color using the CIELAB color system. CIELAB is a three-dimensional color space measuring the lightness of the sample (L^*) and color coordinates (a^* and b^*). L^* ranges between 0 and 100 (black and white, respectively). An increase in L^* means the sample is lightening. The color coordinates a^* and b^* range from −150 to +150. They are defined as the red/green coordinate, a^* ($+\Delta a^*$ signifies a color shift toward red, $-\Delta a^*$ toward green) and the yellow/blue coordinate, b^* ($+\Delta b^*$ toward yellow, $-\Delta b^*$ toward blue). Color was measured for five replicate samples.

2.3.3. Flexural property analysis

Samples were oven dried at 105 °C for 24 h before testing. This ensured the same conditioning for samples before and after exposure. Flexural tests were carried out according to ASTM D790 (ASTM 8.01) on an MTS 810 Material Test System (MTS Systems Corp., Eden Prairie, MN). A three-point loading system was utilized with a crosshead speed of 1.3 mm/min, which corresponds to an outer fiber strain rate of 0.01 mm/mm min. The exposed surface was placed away from the center load to place that part of the sample in tension. At least four replicate specimens were tested for each formulation. The stress at maximum load and modulus of elasticity (MOE) were calculated according to the above-mentioned standard.

2.3.4. Data analysis

Differences between unexposed and exposed values were reported in terms of percentage of change. The percent change in property was calculated using Eq. (2):

$$\Delta X(\%) = \frac{\overline{X}_{\mathrm{Ex}} - \overline{X}_{\mathrm{Unex}}}{\overline{X}_{\mathrm{Unex}}} \times 100 \quad (2)$$

where $\overline{X}$ is the mean of any property and subscripts Unex and Ex refer to that property before and after exposure, respectively. Significant differences between unexposed and exposed values were determined using Student's *t*-test. It was assumed that the two groups being compared had unequal variance, and the hypothesis was two-tailed. Significance was determined at $\alpha = 0.05$.

3. Results and discussion

3.1. Phase 1. Influence of photostabilizer concentration on WPC performance

3.1.1. Color analysis

Composite samples were exposed to UV radiation and water spray for a total of 3000 h. Samples were removed periodically for analysis during the exposure time. Fig. 1 shows that for all composite formulations L^* increased, but the increase in L^* was not linearly related to exposure time. The largest increases in L^* occurred after 1000 h of exposure time, when a difference in the lightening characteristic of stabilized composites was evident. The difference in L^* between the formulations became more pronounced as the exposure continued.

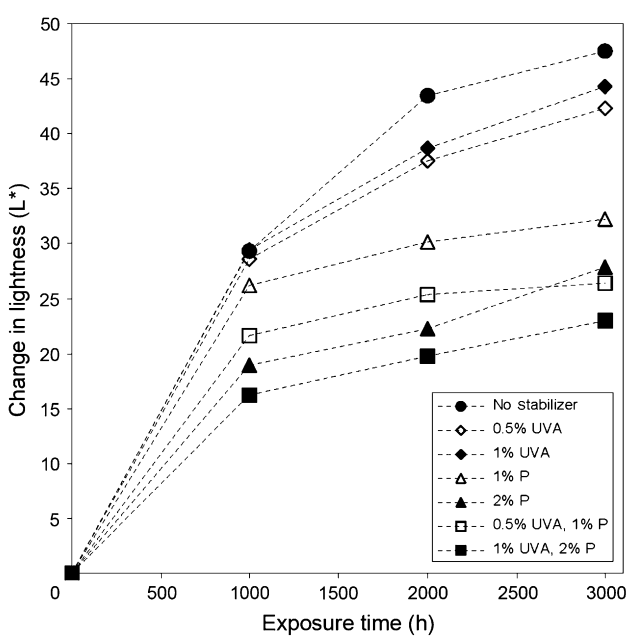

Fig. 1. Change in lightness as a function of exposure time for photostabilized WF/HDPE composites after exposure to UV radiation with water spray.

The percent change in L^* for all formulations after 3000 h of exposure is reported in Table 4. The results clearly show that composites with UVA or P did not lighten as much as the unstabilized composite. The samples with UVA alone lightened slightly less than did the unstabilized composite; all composites with P had less lightening than the composites without P. As expected, the addition of 1% P had a greater effect on L^* than did the addition of 1% UVA. Therefore, P was more efficient at preventing composite lightening than was UVA. The amount of lightening decreased with the increase in pigment concentration. By contrast, increasing the UVA content had little, if any, influence on composite lightness. The composites with the least amount of lightening had a combination of UVA and P.

Composite lightening was mainly due to bleaching of the wood component. Both the UVA and P are incorporated into the HDPE matrix, but each works to reduce composite lightening via a different method. The UVA reduces lightening by absorbing some UV radiation, resulting in less UV radiation available to bleach the wood component. The addition of P physically blocks UV radiation, which also results in less available UV radiation to the wood component. In addition, P masks some lightening. Therefore, P was more important for preventing lightening than was UVA, and the two in combination provided the most protection against lightening.

3.1.2. Flexural property analysis

The change in flexural MOE and strength during exposure is shown in Figs. 2 and 3, respectively. The MOE and strength of the unstabilized composites decreased throughout the cycle. The unstabilized composites experienced higher losses in flexural properties throughout exposure than did their counterparts with UVA and/or P added.

After 1000 h of exposure, both UVA and P appeared to aid in the retention of flexural MOE; however, the type or concentration of the stabilizer did not appear as important as the addition of a stabilizer (Fig. 2). As the exposure continued, UVA continued to facilitate MOE retention only when added at the higher concentration of 1%. The addition of P also continued to facilitate MOE retention, independent of concentration.

Similarly, the photostabilized composites showed greater strength retention than did the unstabilized composites after

Table 4
Change in properties of photostabilized 50% wood-flour-filled HDPE composites after exposure to UV radiation and water spray

Formulation	Change in property (%)		
	L^*	MOE	Strength
No stabilization	115	−33	−27
0.5% UVA	98	−32	−20
1% UVA	107	−21	−15
1% P	73	−18	−13
2% P	59	−18	−5
0.5% UVA, 1% P	61	−15	−9
1% UVA, 2% P	50	−16	−2 (NS)

NS: change from unexposed to exposed value was not significant at $\alpha = 0.05$.

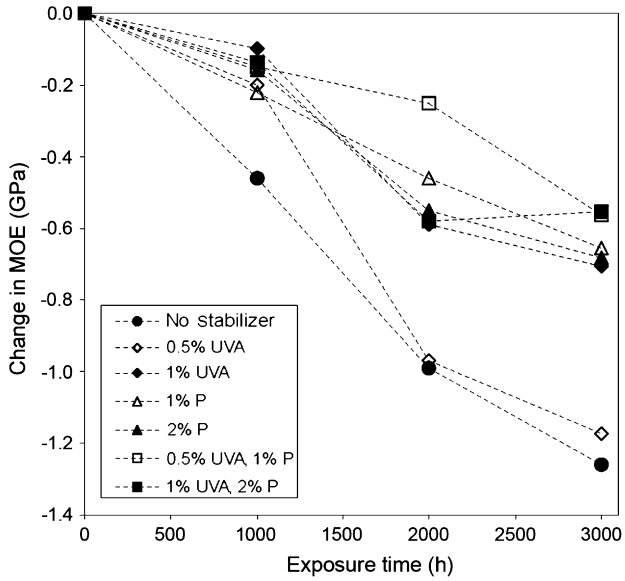

Fig. 2. Change in flexural MOE as a function of exposure time for photostabilized WF/HDPE composites after exposure to UV radiation with water spray.

exposure (Fig. 3). Composites with P added generally performed better than composites with UVA added; composites with the higher concentrations of both UVA and P performed the best.

Table 4 lists percentage of loss in flexural properties after 3000 h of exposure to UV radiation and water spray. The results show that adding 0.5% UVA did not greatly influence the loss in MOE but did improve the loss in strength. Increasing the UVA concentration to 1% resulted in further retention of MOE and strength. Adding P at 1% resulted in smaller MOE and strength losses than did adding 1% UVA. Increasing the concentration of P did not change the loss in MOE but

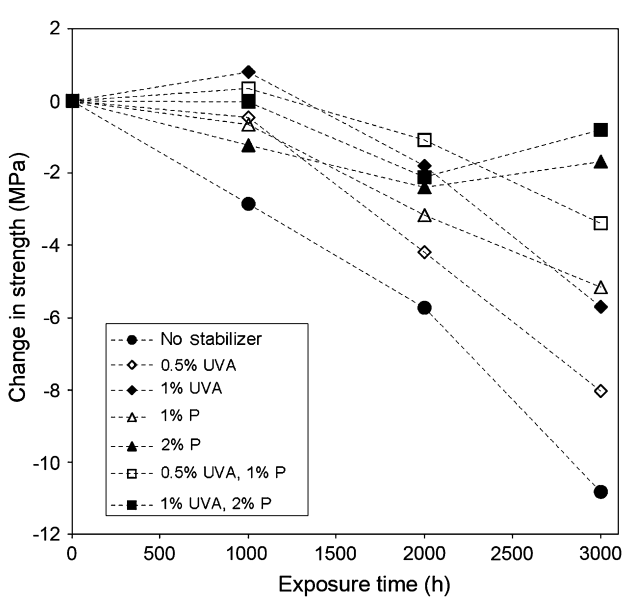

Fig. 3. Change in flexural strength as a function of exposure time for photostabilized WF/HDPE composites after exposure to UV radiation with water spray.

decreased the loss in strength. The best results were obtained when UVA and P were added to the composite together.

All composite samples were exposed to both UV radiation and water spray. Both UV radiation and water spray cause loss in mechanical properties. Exposure to UV radiation with water spray can change the crystallinity of HDPE. Research has shown that the crystallinity of WF/HDPE composites initially increases during exposure to UV radiation and water spray; as exposure continues, the crystallinity decreases [8]. As HDPE is exposed to UV radiation, chain scission occurs. Initially, the more mobile shorter chains recrystallize [12]. As chain scission continues, the crystalline regions are affected and crystallinity decreases. It is expected that after 3000 h of exposure, there would be a decrease in the crystallinity of HDPE, resulting in a decrease in MOE of the composite. We previously showed that both UVA and P delay the drop in crystallinity at longer exposure time [8], which would facilitate MOE retention.

Additionally, exposure to water degrades mechanical properties of WPCs, mainly due to swelling of the wood particles. The swelling particles cause microcracks in the matrix, causing a decrease in MOE, and reduce efficiency of stress transfer from the fiber to the matrix, causing a decrease in strength. For example, after 3000 h of soaking in a water bath, 40% WF-filled polypropylene composites lost 36% of their initial MOE and 22% of their initial strength [19].

Theoretically, UVAs are not exhausted during the course of photodegradation. They return to their original stage after releasing UV radiation that had been absorbed. However, UVAs have been shown to degrade with time [20]. This may explain why the loss in mechanical properties of composites with 0.5% and 1% UVA added was not very different initially; the higher UVA concentration was necessary to counteract consumption of UVA during longer exposure times. Improvements in mechanical property retention were also observed after adding 1% P to the composites. However, increasing the concentration of P content from 1% to 2% resulted in a dramatic improvement in strength retention. This may be a result of the nature of the pigment, zinc ferrite in a carrier wax. Wax aids in dispersing the pigment but may also find its way to the wood/polymer interface. The wax may be protecting WF, causing a hydrophobic surface and resulting in less degradation of the interface. The strength of a composite is largely dependent upon interfacial quality to transfer stress from matrix to the fiber. As P concentration increases, protection from UVA becomes less important in preventing strength loss.

3.2. Phase 2. Influence of exposure type on performance of photostabilized WPCs

To understand how exposure to both UV radiation and water spray influences the performance of photostabilizers, WF/HDPE samples were exposed to UV radiation with or without water spray. To allow for comparison between exposure cycles, the time of exposure and radiant energy were similar ($\sim$3000 h and $\sim$165 J/m^2) for both the exposure to UV

radiation with water spray and the exposure to UV radiation alone (Table 3).

3.2.1. Color analysis

The lightness (L^*) and color coordinates (a^* and b^*) of the WF/HDPE composite samples exposed to UV radiation with and without water spray are shown in Figs. 4–6. Lightness of the composites increased after exposure to UV radiation, with and without water spray (Fig. 4). However, further increases in L^* were observed when the samples were exposed to UV radiation with water spray compared with exposure to UV radiation only. Similar to the results from phase 1, the results readily show that the addition of P to the composites resulted in less lightening after exposure to UV radiation with water spray. After exposure to UV radiation alone, final L^* of all the composites was similar.

The percentage of change in L^* after each exposure is reported in Table 5. Both UVA and P exerted some influence on L^* after exposure. However, the addition of P was more effective than the addition of UVA at protecting against increases in L^*, regardless of exposure. Incorporating P into the composites was a much more effective way of preventing increases in L^* when the composites were exposed to UV radiation with water spray versus exposure to UV radiation alone. This further indicates that the carrier wax of P protected the composites from some degradation caused by moisture.

Shifts in color after weathering are also of interest, and they can contribute to the whitening of the composite. A decrease in a^* signifies a color shift away from red, or a loss of redness. Generally, the exposure of all the composites to UV radiation, with or without water spray, resulted in a decrease in redness (Fig. 5). Initially, the redness values of the photostabilized composites were similar to those of the unstabilized composites. Exposure to UV radiation with water spray resulted in a complete loss of redness for samples without P, resulting in a ''whiter'' appearance as the color values shifted toward zero and L^* increased. When the samples were exposed to UV radiation alone, both the unstabilized composite and the composites with UVA added retained more redness than did the composites with P added (Table 5). This suggests that the composites experienced some loss in P. It could be that as exposure to UV radiation occurs, the surface of the composite begins to crack. Some of the inorganic pigment particles at the surface, which are incorporated into the PE matrix, may fall out when they are exposed by surface cracking.

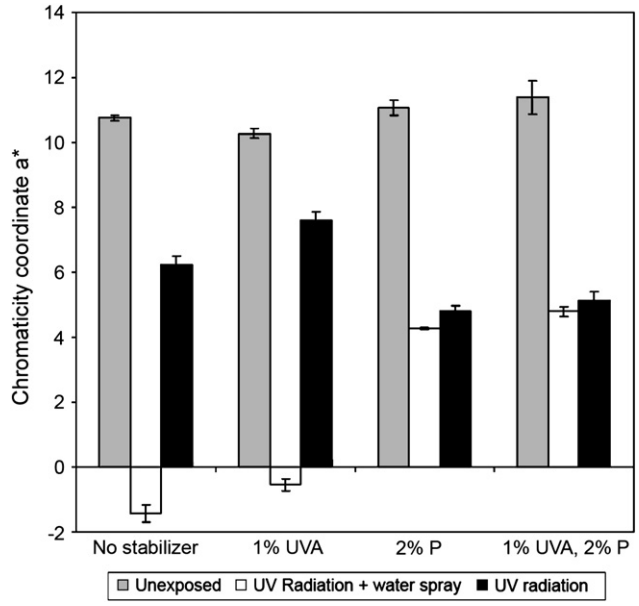

Fig. 5. Effect of exposure type on color parameter a^* of photostabilized WF/HDPE composites.

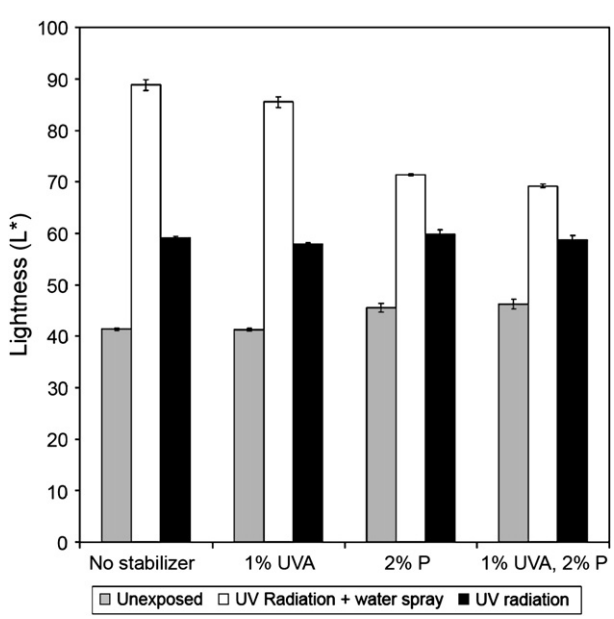

Fig. 4. Effect of exposure type on final lightness of photostabilized WF/HDPE composites.

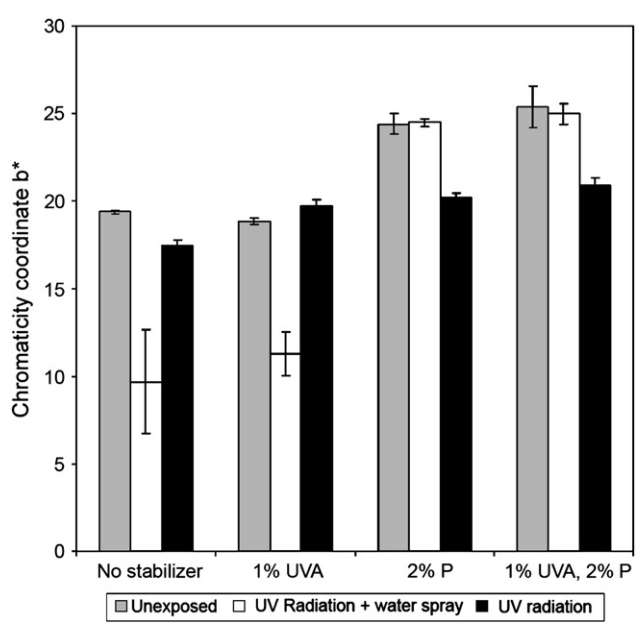

Fig. 6. Effect of exposure type on color parameter $b^*$of photostabilized WF/HDPE composites.

Table 5
Change in color of photostabilized 50% wood-flour-filled HDPE composites after exposure to UV radiation with or without water spray

Formulation	Change in color (%)					
	*L**		*a**		*b**	
	UV + water	UV alone	UV + water	UV alone	UV + water	UV alone
No stabilization	115	43	−113	−42	−50	−10
1% UVA	107	41	−105	−26	−40	5
2% P	59	31	−61	−57	0 (NS)	−17
1% UVA, 2% P	50	27	−58	−55	−2 (NS)	−17

NS: change from unexposed to exposed value was not significant at $\alpha = 0.05$.

The yellowness of a sample is indicated by a positive *b**. As *b** decreases, the yellowness of the sample decreases. The *b** values of the unexposed composite samples with P added were higher than that of the unstabilized composites or those with UVA added (Fig. 6). Exposure to UV radiation and water spray resulted in loss of yellowness for composites without P added and resulted in retention of yellowness or a small increase in yellowness for composites with P added. Exposure to UV radiation alone resulted in a small change in yellowness for samples without P and a larger decrease in yellowness for samples with P. This further reinforces that some P is lost from the composite surface (Table 5).

3.2.2. Flexural property analysis

Differences in mechanical property performance were also observed after composites were exposed to either UV radiation with water spray or UV radiation alone. Exposing the composites to UV radiation with water spray resulted in a decrease in MOE, while exposure to UV radiation alone resulted in an increase in MOE (Fig. 7). The strength of the composite also decreased after exposure to UV radiation with water spray. After exposure to UV radiation alone, the strength of the composite did not change or increased slightly (Fig. 8).

The losses in MOE and strength occurred when composites were exposed to UV radiation with water spray. This confirmed that much of the loss in flexural properties was due to the negative effects of moisture penetration during exposure. The increase in MOE after exposure to UV radiation alone was likely due to a combination of responses of HDPE to UV radiation. As discussed earlier, when composites are exposed to UV radiation with water spray, the crystallinity of HDPE initially increases, then decreases [8]. The presence of water may accelerate the chain scission reactions. It may be that for the same period of exposure to UV radiation, crystallinity only increases. The HDPE matrix is also likely experiencing some cross-linking. Cross-linking competes with recrystallization and is an influential mode of photodegradation during accelerated weathering [12].

Adding UVA and/or P delayed or prevented some changes in MOE and strength after exposure to UV radiation and water spray or exposure to UV radiation alone (Table 6). Changes in MOE, either a decrease after exposure to UV radiation with water spray or an increase after exposure to UV radiation alone, were mitigated through the addition of UVA and P. This suggests that both UVA and P prevent some of the degradation in mechanical properties that stems from moisture penetration and some of the degradation that stems from UV degradation.

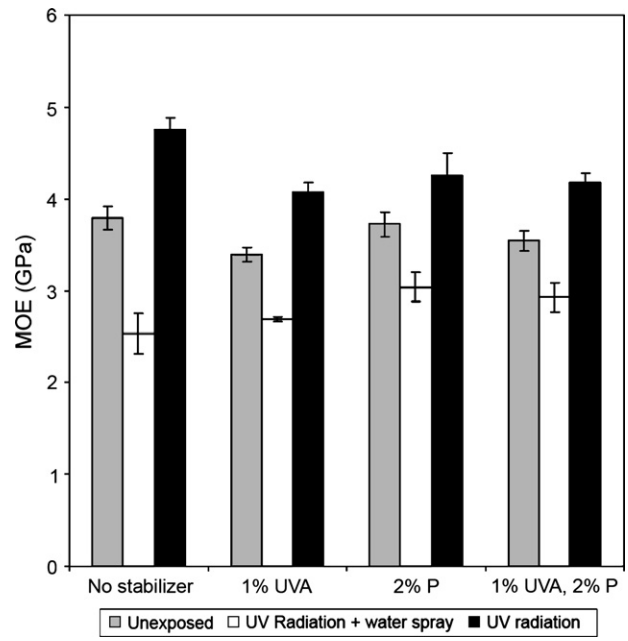

Fig. 7. Effect of exposure type on flexural MOE of photostabilized WF/HDPE composites.

4. Conclusions

Wood–plastic composites experience both changes in color and mechanical property loss after weathering. Adding an

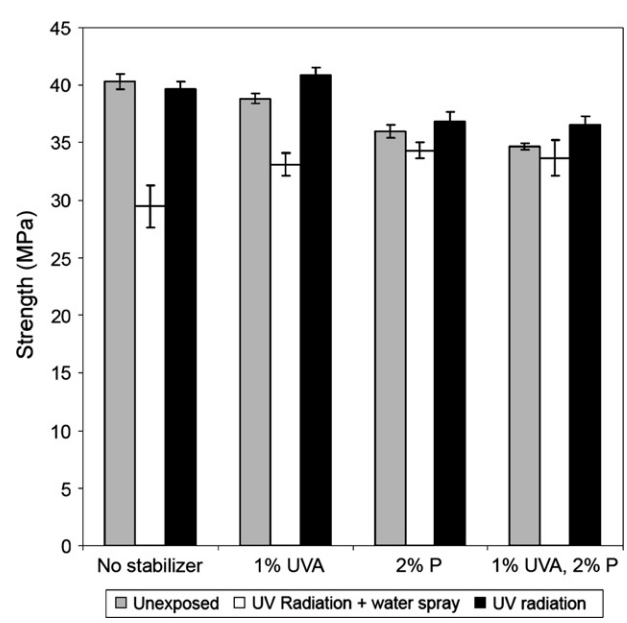

Fig. 8. Effect of exposure type on flexural strength of photostabilized WF/HDPE composites.

Table 6
Change in mechanical properties of photostabilized 50% wood-flour-filled HDPE composites after exposure to UV radiation with or without water spray

Formulation	Change in property (%)			
	MOE		Strength	
	UV + water	UV alone	UV + water	UV alone
No stabilization	−33	25	−27	−2 (NS)
1% UVA	−21	20	−15	5
2% P	−18	14	−5	2 (NS)
1% UVA, 2% P	−16	18	−2 (NS)	5

NS: change from unexposed to exposed value was not significant at $\alpha = 0.05$.

ultraviolet absorber (UVA) and/or pigment (P) has been shown to protect against increases in lightness and mechanical property loss. This study demonstrated that changing the concentration of a hydroxyl phenyl benzotriazole UVA and an inorganic pigment (zinc ferrite) in a carrier wax (P) can influence the photostabilization of WF/HDPE composites. Changing the exposure cycle was also shown to have an effect on photostabilized WF/HDPE composites.

Adding UVA or P resulted in less lightening of the composites after 3000 h of exposure to UV radiation and water spray, compared with that of unstabilized composites. Increasing the concentration of UVA did not change the amount of lightening, while increasing the concentration of P resulted in less lightening. The composite samples that lightened least included combinations of UVA and P; however, P was more efficient at preventing composite lightening than was UVA. Although both UVA and P helped to protect the composites from UV radiation, P was also able to camouflage the lightening that did occur.

Mechanical properties generally decreased after composites were exposed to UV radiation and water spray. When either UVA or P was added, the composites retained flexural properties to a greater extent than did the unstabilized composites. Increasing the concentration of UVA resulted in less loss of MOE and strength. Increasing the concentration of P did not change the loss in MOE but did decrease the loss in strength. The loss in MOE and strength was to a great extent the result of moisture effects. As wood fiber absorbs moisture, it expands, resulting in the formation of microcracks in the matrix and degradation of the WF/HDPE interface. Increasing both UVA and P affected flexural strength loss. As the concentration of P in the composite was increased, the addition of UVA became less important for retaining flexural strength. This may be attributable to the carrier wax of the pigment. The wax may protect the composites by making the wood fiber surface more hydrophobic, thereby protecting the interface.

The change in composite color and action of the photostabilizers was different when composites were exposed to UV radiation with water spray versus exposure to UV radiation alone. The composites experienced much less lightening when exposed to UV radiation alone. In general, the color of the composites was more stable, i.e., the changes in a^* and b^* were less, after exposure to UV radiation alone versus exposure to UV radiation with water spray. The addition of UVA had little influence on the color of the composites—the addition of P was more important. However, the results suggest that some P was lost during exposure to UV radiation.

Exposing the WF/HDPE composites to either UV radiation with water spray or UV radiation alone showed that the majority of the loss in mechanical properties after weathering was caused by moisture effects. In addition to the acceleration of oxidation reactions caused by water absorption, the swelling of the wood cell wall compromises the interface between the wood and HDPE. Interfacial cracks contribute to the decrease in MOE, and the less efficient stress transfer between the wood and HDPE contributes to the decrease in strength.

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