

# Improvement of Photoprotection of Wood Coatings by Using Inorganic Nanoparticles as Ultraviolet Absorbers

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## Abstract

Ultraviolet (UV) light is high-energy radiation that induces degradation of organic compounds, such as wood. To prevent UV damage, several strategies have been used, including creating a UV light barrier at the wood surface. The most common strategy is to apply a coating to the wood surface. However, coating alone may not be effective enough to protect wood exposed outdoors. For example, clear coatings often contain additives to protect the material from UV radiation (hindered amine light stabilizers, quenchers, UV absorbers). This article reports work on the photostability of wood surfaces coated with waterborne nanocomposite urethane-acrylate systems in outdoor conditions. The wood color variation of sugar maple (*Acer saccharum* Marsh) was measured following accelerated aging. Different types of nanoparticles (ZnO, CuO) were used in water in predispersed and powder forms. Once cured, the nanoparticle dispersions were characterized by transmission electron microscopy. The best photoprotection was obtained with ZnO predispersed in water. Our major conclusion is that ZnO nanoparticles are better than CuO nanoparticles as additives intended to reduce the discoloration of clear-coated wood exposed outdoors. The highest increase in gloss was achieved with the mixture of inorganic and organic UV absorbers, which appear to show synergistic behavior.

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Wood is a popular material and has numerous uses in both interior and exterior applications because of its nice appearance, low cost, and renewability. Cellulose, hemicelluloses, lignin, and extractives are the main components of wood. In the presence of ultraviolet (UV) light, lignin may decompose into radicals, which induce degradation of both lignin and cellulose polymers at wood surfaces (Evans et al. 1996, Kiguchi et al. 2001). Such photodegradation is the main cause of the discoloration of wood exposed outdoors, and discoloration is the first sign of the degradation of wood due to UV radiation. Deterioration also occurs due to the effects of heat, water, and microorganisms (Hayoz et al. 2003). These factors cause surface erosion and weathering of wood exposed outdoors (Pastore et al. 2004, Williams 2005, Chou et al. 2008).

To protect wood from weathering, several methods, such as surface coating, chemical modification, and impregnation with chemicals, have been used (Black and Mraz 1974, Feist and Hon 1984, Evans et al. 2002, Evans 2009). Surface coating is the most common method used to protect wood

against deterioration and improve and stabilize its distinctive appearance (Feist and Hon 1984, Evans 2008). Polyurethane resins have good durability and are widely used in coatings because of their great physical and mechanical properties (abrasion resistance, impact strength, hardness, flexibility, adhesion on substrates, good chemical resistance). In addition, urethane emulsions used for wood protection are compatible with water, which is an important environmental point (Fekete and Lengyel 2005, Geurink et

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al. 2006). However, wood photodiscoloration is unavoidable even if the surface is coated with durable, clear coatings, including polyurethane coatings (Chang and Chou 1999, Sigh et al. 2001). Clear coatings do not absorb the whole spectrum of UV light; thus, degradation of the wood surface during UV exposure is inevitable (Ashton 1980, Macleod et al. 1995). To solve this problem, pigmented coatings are recommended on wood used outdoors. Indeed, several pigments efficiently reflect or absorb UV light, but they also change wood's natural color and appearance.

To prevent wood photodegradation while using clear coating, it is reasonable to incorporate additives in the coating that avoid and discourage radical-type reactions while allowing the coating to retain its transparency. The addition of organic additives to protect the underlying substrate from UV light (e.g., chromophores) in formulations is common. These organic UV absorbers sometimes affect coating transparency. In addition, they tend to migrate on the surface, where they may be leached by rain or decomposed during irradiation. These effects partially explain why color protection of clear-coated wood is not permanent (Allen et al. 2004). Because the main role of a transparent coating is to keep the natural appearance of wood, any additive that can interfere with the coating transparency should be considered inappropriate (Kiguchi et al. 2001). Recent research on nanoparticles has resulted in the synthesis of new inorganic UV absorbers that can be used in clear coatings. For example, Aloui et al. (2007) compared the UV absorbing properties of inorganic nanoparticles with those of traditional organic absorbers, and their work showed the potential of inorganic UV absorbers for transparent films.

Previous research has used metal oxide nanoparticles as inorganic UV absorbers to protect biomaterials, such as cellulose in textiles (Wang et al. 2004, 2005). Many nanoparticles have been synthesized for this purpose—e.g., zinc oxides, which are also used for their antibacterial properties (Vigneshwaran et al. 2006). This technology is interesting, because at the nanometer scale, matter has a large specific surface area and different physical properties (Rao et al. 2005, Yadav et al. 2006, Rahman et al. 2007).

In this study, the photodiscoloration of wood coated with different coating formulations and exposed in an artificial weathering test chamber was examined. The properties of different inorganic UV absorbing dispersions added to the coatings (predispersed and powder forms) were studied using transmission electron microscopy (TEM). The predispersed systems were nanoparticle dispersions stabilized in water, and the powder systems consisted of powdered nanoparticles in their solid form. The performance of these inorganic UV absorbers was compared with that of organic UV absorbers. Specifically, the differences in the performance of the coatings on wood during and after weathering exposure were investigated. Coatings were applied on sugar maple wood (*Acer saccharum* Marsh). The inorganic UV absorbers were ZnO (predispersed and powder) and CuO (powder only) nanoparticles. The organic absorbers were Ciba's Tinuvin 292/477DW blend usually used for wood products. The main objective of this work was to study the ability of different nanoparticles to enhance the performance of polyurethane-acrylate coatings on wood exposed to accelerated weathering.

## Experimental

### Materials and methods

*UV absorbers.*—A qualitative analysis of UV absorbing properties of the different UV absorbers was carried out by UV/visible spectroscopy (Lambda 40 UV/VIS Spectrometer; PerkinElmer).

Selected UV absorbers were separated in two categories: inorganic and organic. Organic UV absorbers were a blend of two commercial products from Ciba Company, Tinuvin 477DW and Tinuvin 292; this blend was used as a reference. The inorganic UV absorbers were nanoparticles with different chemical compositions and sizes, but all were compatible with waterborne coatings. ZnO nanoparticles have already been shown to be effective UV absorbers (Hegedus et al. 2008, Lowry et al. 2008), and composites can be protected from UV radiation using CuO nanoparticles (Ono et al. 2006). Therefore, the types of nanoparticles selected were ZnO and CuO in powder form and ZnO predispersed in water. These UV absorbers are described in Table 1.

The effect of concentration of inorganic UV absorbers on color stabilization and on particle dispersion efficiency was examined, because dispersion quality is an important factor affecting particle properties (Landry et al. 2008b). A blend of inorganic and organic UV absorbers was also tested to find a possible synergy between them.

*Coatings.*—A transparent waterborne coating formulation was used for all experiments. This coating was a UV curing aliphatic urethane-acrylate dispersion mixed with an acrylic emulsion resin for reinforcement (Laromer LR8949 with Joncryl 1992; both from BASF). The reinforcement resin was used to enhance the mechanical properties of the coating. These polymers were chosen as they are well established in the industry. The free-radical photoinitiator (Irgacure 500; Ciba) for the coating was a blend of 1-hydroxy-cyclohexyl-phenyl-ketone (50%, wt/wt) and benzophenone (50%, wt/wt). Every nanocomposite coating was prepared with the same neat formulation recipe provided by an industrial partner. UV absorbers were added, and the amount of additives was modified to assess the influence of concentration on the coating properties. All formulations using predispersed nanoparticles were prepared without an additional dispersing agent. However, the formulations using the powder needed premixing in water with a dispersing agent before use. The addition of nanoparticles to the coating was an important step because of the tendency of the particles to agglomerate. So, to integrate and adequately disperse nanoparticles in a coating formulation, a high-speed mixer was used.

High-speed mixing employed a Ragnona mixer custom built for FPInnovations by Custom Machinery Ltd. (speed up to 5,000 rpm). To avoid destabilization of the emulsion, a moderate mixing speed (up to 2,500 rpm) at room temperature was used. Next, microglass beads (diameter, 1 mm) were added to increase the shear rate of the mixing process. At the end of the mixing process, formulations were filtered to remove microglass beads. A good dispersion was obtained with powder, but it was still unstable and separated after a few days.

To avoid sedimentation of nanoparticles the coatings were applied to the wood within 12 hours after they were prepared. A roller-coater (Model KRF-60; TruPro International) was used to apply five layers of each coating to the

Table 1.—Information on the ultraviolet absorbers incorporated into clear coatings.

Type	System	Sample	Based on	Company	Particle size (nm)
Inorganic	Predispersed	NanoByk-3840	ZnO	BYK-Chemie	~40
	Predispersed	NanoShield Zn2000	ZnO	Alfa Aesar	~70
	Powder	NanoArc	CuO	Alfa Aesar	~30
	Powder	VP Adnano ZnO-20	ZnO	Evonik-Degussa	1–100
Organic	—	Tinuvin 477 DW	Hydroxy-phenyl-triazine derivative	Ciba	—
	—	Tinuvin 292	A mix of: • Bis(1,2,2,6,6-pentamethyl-4-piperidyl) sebacate • Methyl 1,2,2,6,6-pentamethyl-4-piperidyl sebacate	Ciba	—

wood surfaces to produce coatings that were 30 to 40  $\mu\text{m}$  thick. After the first and second coatings were applied and cured, they were partially sanded along the grain with 280-grit sandpaper (P280B Premier Red Dri-Lube Aluminum Oxide; Carborundum).

Each coating layer was flashed off at ambient air temperature for 60 seconds before being cured. Formulations dried fast, but they needed to be cured to obtain a higher reticulation rate. The UV oven used was an ATG 160305 from Ayote Techno-Gaz, Inc., with a mercury lamp that emitted UVA with a power of 530 to 600  $\text{mJ}/\text{cm}^2$ . Nanoparticles can have negative effects on UV curing (Landry et al. 2008a). This aspect was not one of the study objectives, so it is not discussed in this article.

Free-standing (i.e., without wood), 30- to 50- $\mu\text{m}$  films were also prepared using a nonadhesive polymer surface on which five layers of each coating were applied with a foam brush. A convection oven at 60°C was used to flash off each coating layer before curing. These free-standing films were used to analyze the nanoparticle dispersions by TEM.

**TEM characterization.**—A TEM (Model JEM-1230; Jeol) was used to analyze the dispersion of nanoparticles in all free-standing films. Free-standing films, without contrast agent, were observed on copper grid supports. An acceleration voltage of 80 kV was used to record images of the different coating films. Each sample was studied in a specimen chamber under pressure of  $10^{-5}$  Pa.

**Wood species.**—Five tangential longitudinal sugar maple (*A. saccharum* Marsh) wood samples were used for each formulation in this experiment. Samples dimensions were 77 by 77 by 19 mm (length by width by thickness), and the samples were cut from planks conditioned for 15 days at 65 percent relative humidity and 20°C (moisture content of the wood was 12%). Surfaces were machine planed using a Unimat 23EL moulder from Weinig.

**Accelerated aging.**—Coated samples were subjected to accelerated aging in a xenon-arc Weather-OMeter (Model 65/DMC-WT; Atlas Company). Coatings were subject to a 100 percent UV direct exposition program under dry conditions during 400 hours of exposure. To simulate natural exposure, S Boro/S Boro filter types with a 340-nm bandwidth and a spectral irradiance of  $0.35 \text{ W}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$  were used. The parameters used for the accelerated aging test are presented in Table 2.

### Wood/coating systems analysis

**Color.**—The discoloration of the wood/coating systems was measured with a colorimeter (BYK-Gardner Colorguide 45/0). Two measurements were taken for each sample and the average calculated as recommended by ASTM

D2244 (American Society for Testing and Materials [ASTM] 1993). Measurements were taken along the grain and perpendicular to the grain to reduce the effect of surface irregularities on colors. The color change was measured every 24 hours for the first 168 hours of aging and then every 48 hours for the rest of the aging cycle. The Commission Internationale de l'Eclairage (CIE)  $L^*a^*b^*$  system (CIE 2004) was used to characterize the specimen discoloration after light irradiation. The initial color value was compared with values obtained during the aging test. The CIE  $L^*a^*b^*$  system uses three axes to define the color (CIE 2004). The chromatic coordinates are  $L^*$ , the lightness from black (0) to blank/white (100);  $a^*$ , the color component from green (−60) to red (+60); and  $b^*$ , the color component from blue (−60) to yellow (+60).

**Gloss.**—The gloss of the different coatings before and during the aging test was measured with a glossmeter (BYK-Gardner Micro-TRI-gloss) according to the ASTM D523 method (ASTM 1994). The measurements were taken along the grain and perpendicular to the grain to reduce the effect of surface irregularities on gloss. The gloss was measured according to the same schedule used for color measurements. The glossmeter used photoelectric measurement of specularly reflected light from the surface. Since wood finishes are usually in the midgloss range, a 60° geometry was used, in accord with international standards.

## Results and Discussion

### Efficiency of UV absorbers

Figure 1 shows the UV absorbing characteristics ( $A:A_{\text{max}}$  ratio) of each of the organic UV absorbers as a function of wavelength.  $A_{\text{max}}$  is the highest absorbance, and  $A$  the absorbance at the corresponding wavelength.

Tinuvin 477DW had a wide absorbance band in the UV zone, especially in the UVA range ( $\lambda = 315$  to 400 nm), but it quickly decreased at higher energy wavelengths ( $\lambda < 315$  nm). Tinuvin 292 showed a narrower absorbance band in the

Table 2.—Accelerated aging test parameters

Parameter	Description/value
Filter	Direct exposure (daylight S Boro/S Boro)
Spectral irradiance	$0.35 \text{ W}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$
Bandwidth	340 nm
Cycle duration	400 h
Relative humidity	Noncontrolled
Black panel temperature	63°C
Water spray	None

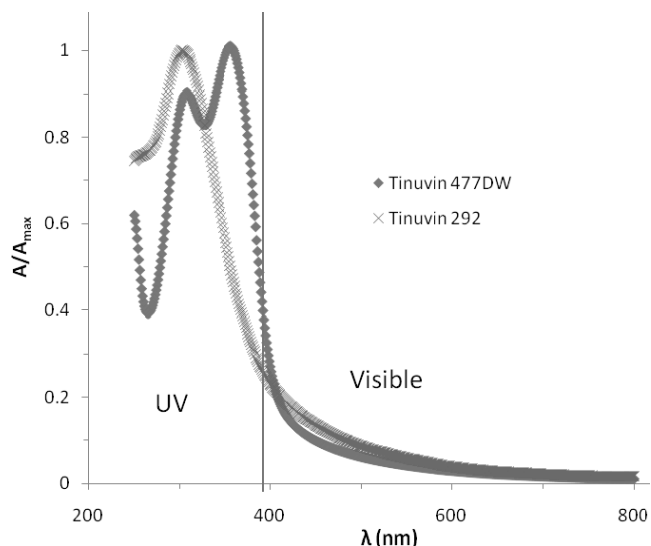


Figure 1.—Absorbance spectra for the organic ultraviolet absorbers.

UV zone, but its maximum absorbance was situated in the UVB range ( $\lambda = 280$  to  $315$  nm). For this reason, and to cover a wider absorbance band in the UV zone, the two organic UV absorbers were mixed to give the best protection, as mentioned above. These spectra showed that the selected organic molecules do not show significant absorption in the visible zone ( $\lambda = 400$  to  $700$  nm), which is important when additives are used in transparent and semitransparent coatings.

The absorbance spectra for inorganic UV absorbers are shown in Figure 2. ZnO nanoparticles had a wide absorbance band in the UV zone. The UV absorption range of ZnO nanoparticles was greater than those of organic absorbers. The absorbance spectrum of CuO was similar to that of Tinuvin 292. Hence, its absorbance range is situated in the UVB range. Nanoparticles showed little absorption in the visible spectrum. Thus, inorganic absorbers have

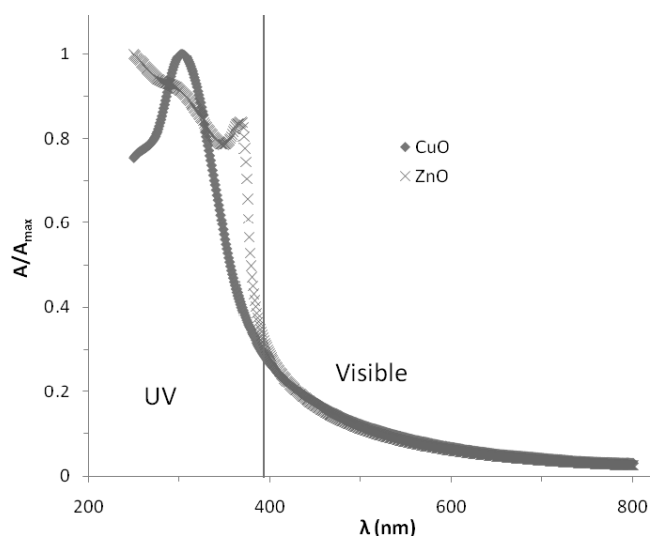


Figure 2.—Absorbance spectra for the inorganic ultraviolet absorbers.

potential to substitute for organic absorbers in transparent and semitransparent coating formulations.

### Nanoparticles dispersion study by TEM

The TEM images of free-standing films revealed that for every formulation, aggregates could be observed to varying degrees. Figures 3a and 3b show micrographs of the formulation that contained 1.44 and 2 percent (wt/wt) predispersed ZnO in water, respectively. In both cases, the aggregate size distribution seemed similar ( $\sim 100$  to  $250$  nm). However, the former showed better dispersion, because the distribution of aggregates was more homogeneous. Hence, nanoparticles in this formulation (1.44%, wt/wt) covered a wider area than the formulation that contained 2 percent (wt/wt) ZnO.

Figures 3c and 3d show the 1 and 2 percent (wt/wt) ZnO powder dispersions, respectively. The formulation with 1 percent (wt/wt) nanoparticles showed good dispersion. The presence of few aggregates with small diameter confirms this. In contrast, the formulation with 2 percent (wt/wt) ZnO nanoparticles showed some micrometer-sized aggregates. It is possible that the dispersing agent and mixing process with a high-speed mixer is ineffective when the loading of nanoparticles is higher (Landry et al. 2008b). The dispersion of the 2 percent (wt/wt) ZnO nanoparticle powder is acceptable even though is not as good as that of the 1 percent (wt/wt) formulation. It can be noticed that the size of aggregates does not exceed  $1 \mu\text{m}$  in the formulation containing 2 percent (wt/wt) ZnO powder. The distribution of both 1 and 2 percent (wt/wt) ZnO nanoparticles was homogeneous and covered a wider area of the coating. Compared with predispersed systems, the ZnO powder dispersion was similar at low concentrations and had smaller aggregates. An increase in the loading of nanoparticles in the powder system led to the formation of bigger aggregates compared to the predispersed systems at the same concentrations.

Figures 3e and 3f show the 1 and 2 percent (wt/wt) CuO dispersions. This system shows trends similar to those described above for the powder systems (i.e., aggregates with a diameter  $>1 \mu\text{m}$  were observed). The dispersion morphology of the CuO formulations was relatively poor, and the formulation containing 1 percent (wt/wt) CuO nanoparticles was better than that of the 2 percent (wt/wt) formulation. The distribution of CuO nanoparticles in both formulations was heterogeneous; large areas of coating did not have nanoparticles, especially the formulation containing 1 percent (wt/wt) nanoparticles. In comparison with the ZnO powder, CuO-based formulations had poor dispersion morphology. The use of another dispersing agent that is more effective with the CuO nanoparticles needs to be tested.

The TEM images showed that the concentration of nanoparticles in the formulations influenced the dispersion morphology. The predispersed system dispersed better at high concentrations than the other systems. Despite the presence of aggregates, all nanoparticles may still be able to absorb UV radiation.

### Color stability

Color measurements were used to assess the performance of the UV absorbers on wood. Effectively stabilized coated wood surfaces should have the lowest variation from the

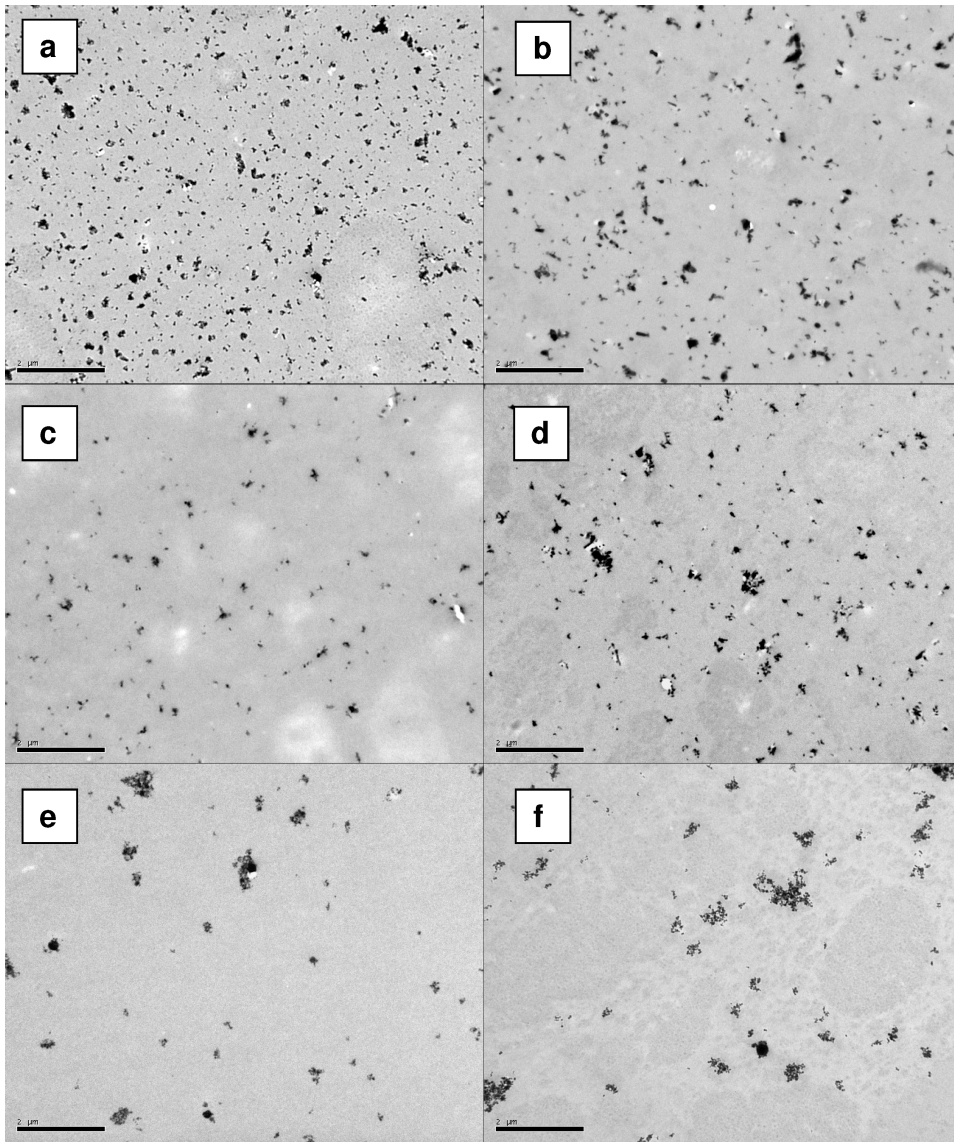


Figure 3.—Transmission electron microscopy images of formulation prepared (by weight) with (a) 1.44 percent ZnO predispersed nanoparticles, (b) 2 percent ZnO predispersed nanoparticles, (c) 1 percent ZnO powdered nanoparticles, (d) 2 percent ZnO powdered nanoparticles, (e) 1 percent CuO powdered nanoparticles, and (f) 2 percent CuO powdered nanoparticles. Bar = 2  $\mu\text{m}$ .

initial value, so the overall variation should tend to zero for high-performance formulations. This study focused on wood color stabilization. The addition of nanoparticles may affect other film properties (Shi et al. 2009), but these are not examined in this work.

Photoinduced discoloration occurred after only 24 hours of exposure. This phenomenon is explained by the degradation of lignin and the formation of unsaturated aromatic compounds. For all color components, all formulations showed the most color variation in the first 175 hours of exposure; afterward, smaller variation occurred.

Figure 4 shows the variation of the  $L^*$  color component ( $\Delta L^*$ ) as a function of exposure time for the different formulations. The 2 percent (wt/wt) ZnO predispersed in water was the best additive at restricting changes in  $L^*$ . The organic UV absorbers were also effective for the first 168 hours of irradiation, but the 2 percent (wt/wt) ZnO predispersed in water performed better thereafter. Changes

in  $L^*$  for the formulations containing ZnO powder were similar at both concentrations (1% and 2%, wt/wt); these were more efficient than CuO nanocomposite coatings obtained with the same dispersion method. In addition, the ZnO nanoparticles in powder formulations were better than the treatments with 1.44 percent (wt/wt) nanoparticles predispersed in water. The formulation with 1.44 percent (wt/wt) ZnO predispersed in water had better dispersion morphology than the formulation containing 2 percent (wt/wt) ZnO predispersed in water, as mentioned above. Nevertheless, it was still inferior at restricting changes in  $L^*$ . CuO nanoparticles were the least effective of all the systems, but the 2 percent (wt/wt) loading performed better than the 1 percent (wt/wt) loading. All formulations containing a UV absorber showed better performance than the formulation without UV absorber after 400 hours of UV irradiation.

Similarly, all the formulations containing a UV absorber were better than the control at restricting changes in  $a^*$ , as

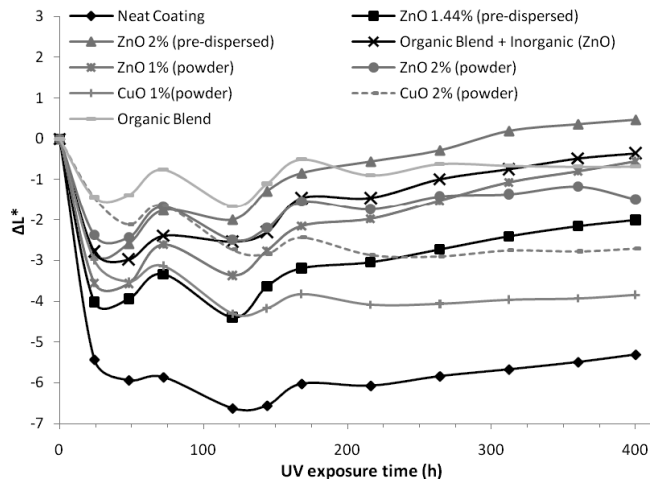


Figure 4.—Variation of  $\Delta L^*$  color component as function of irradiation time (hours) in an accelerated aging apparatus for the outdoor-use clear coatings with different ultraviolet absorbers on wood.

shown in Figure 5. The best protection was obtained with 1.44 percent (wt/wt) ZnO pre-dispersed in water, followed by the 1 percent (wt/wt) ZnO powder. The two formulations containing 2 percent (wt/wt) ZnO nanoparticles (powder and pre-dispersed) had different effects on the  $a^*$  parameter. In the coating containing the powder, the color varied toward red (+), whereas in the coating formulation made with the pre-dispersed ZnO nanoparticles, the color varied toward the green (-). The pre-dispersed nanoparticles could contain additives or grafted molecules that absorbed red color from wood, which might explain this finding.

The blend of organic and inorganic absorbers did not show synergy in protecting  $a^*$ . Actually, all coating formulations containing ZnO performed better or similarly during UV exposure than the formulations containing the blend of inorganic/organic UV absorbers. The formulation containing the blend of inorganic and organic UV absorbers

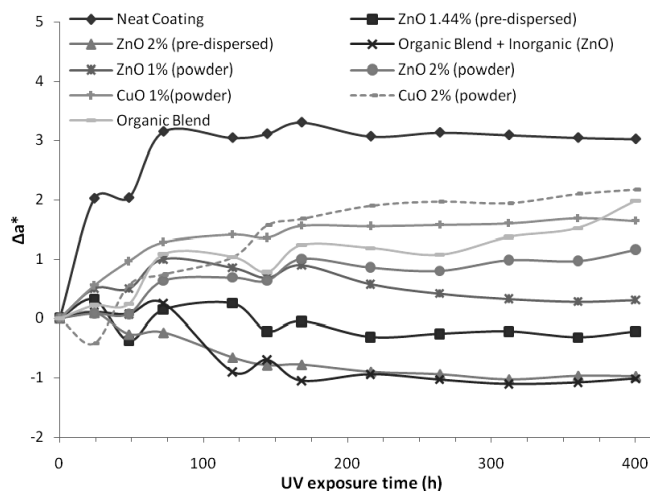


Figure 5.—Variation of  $\Delta a^*$  color component as function of irradiation time (hours) in an accelerated aging apparatus for the outdoor-use clear coatings with different ultraviolet absorbers on wood.

was less effective in restricting changes in  $a^*$  than formulations containing ZnO nanoparticles. However, the organic UV absorbers were more effective than the CuO nanoparticles. Once again, the coating formulations with CuO were the least effective in protecting wood against discoloration, but the formulation containing 1 percent (wt/wt) CuO was better than the formulation containing 2 percent (wt/wt) CuO.

Figure 6 shows the variation of  $\Delta b^*$  as function of time of UV irradiation for all formulations in the study. Again, all coatings formulated with UV absorbers performed better than the control. The inorganic UV absorbers like ZnO (2% [wt/wt] pre-dispersed) and CuO (1% and 2% [wt/wt] powder) were effective at reducing color changes during exposure. The formulation containing 2 percent (wt/wt) CuO nanoparticles performed better than the formulation containing 1 percent (wt/wt) CuO. So, the concentration of nanoparticles plays a role in the protection of wood surface against photodegradation. In fact, for similar dispersion morphologies, within the limit of the study, formulations containing higher concentrations of inorganic additives were better at protecting wood from photodiscoloration. However, for different dispersion morphologies, the best UV protection was obtained with nanoparticles that were better dispersed. The results for  $b^*$  show that organic UV absorbers mixed with ZnO nanoparticles acted synergistically. The photo-protection of the formulations containing organic UV absorbers and that of 2 percent (wt/wt) ZnO powder was similar up to 360 hours of exposure; afterward, the coating containing organic UV absorbers became the worst.

In summary, color components analysis demonstrated that the ZnO nanoparticles were better at restricting color changes in clear-coated wood than CuO nanoparticles and organic UV absorbers. Pre-dispersed systems performed better than powder systems. The pre-dispersed systems had superior dispersion morphology compared with powder systems. Therefore, it can be concluded that a positive relationship exists between dispersion and color stability, as noted by Landry et al. (2010). In addition, the concentration of nanoparticles influenced their effectiveness if the

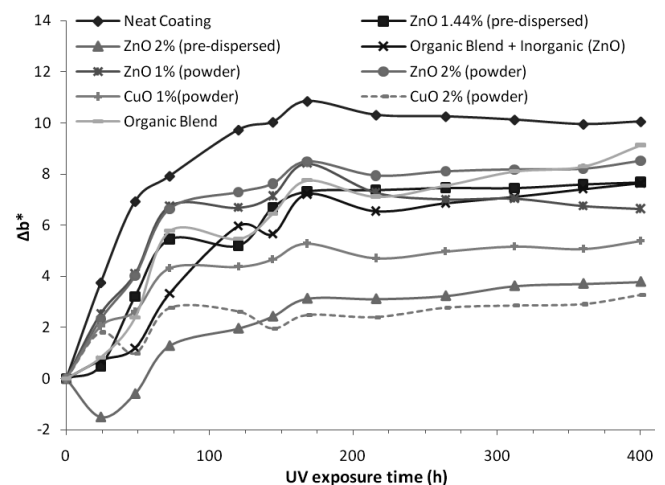


Figure 6.—Variation of  $\Delta b^*$  color component as function of irradiation time (hours) in an accelerated aging apparatus for the outdoor-use clear coatings with different ultraviolet absorbers on wood.

dispersion morphology between two different concentrations was similar. Within the limit of this study, a positive correlation exists between concentration of particles and color stability, but aggregation of particles is detrimental to color stability. The organic absorbers used alone in coatings were less effective than ZnO nanoparticles, but if both were mixed, a synergistic effect was obtained with some color parameters. The CuO nanoparticles do not appear to be suitable UV absorbers for wood clear coatings, because they were less effective than other additives at restricting changes in  $\Delta L^*$  and  $\Delta a^*$  and changed the color of the coating (resulting in a brown, translucent finish). Hence, they are better suited as pigments and as wood preservatives (Evans et al. 2008, Matsunaga et al. 2009).

## Gloss measurement

Addition of UV absorbers into clear coatings can cause a change in the gloss of the coatings (Malshe and Elango 2004), so gloss measurements were performed on all formulations. The effect of UV radiation on gloss was also examined, as shown in Figure 7. The same five samples used for the color stability measurement were used for gloss measurements. The pre-dispersed systems and the formulations containing 1 percent (wt/wt) ZnO and 2 percent (wt/wt) CuO powder increased the gloss of the coating. The mix of inorganic and organic UV absorber acted synergistically, because they produced the greatest increase in gloss. Otherwise, the addition of organic UV absorbers decreased the gloss of coatings. The addition of 2 percent (wt/wt) ZnO powder did not significantly change the gloss of the coating, possibly because this formulation had poorer dispersion morphology compared to the other ZnO nanoparticle systems. The addition of 1 percent (wt/wt) CuO nanoparticles reduced gloss. In general, all additives had an initial effect on gloss, but unlike color measurements, no change was found with UV exposure.

## Conclusions

In this study, waterborne polyurethane-acrylate nanocomposite clear coatings were prepared and applied to wood. Coated samples were exposed to artificial accelerated weathering. Comparison of different UV absorbers was done. TEM analysis showed that the formulation with the

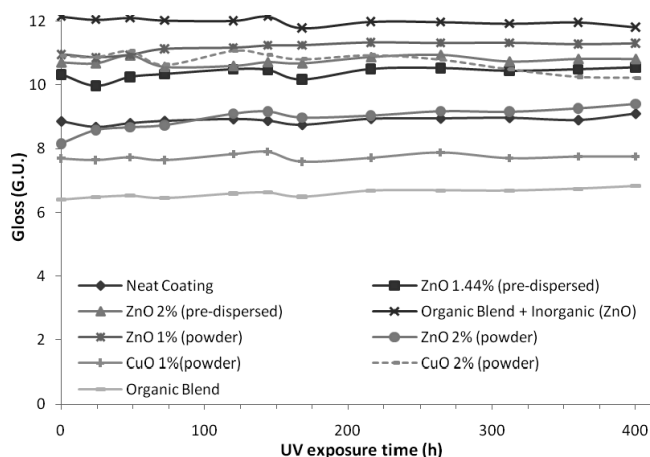


Figure 7.—Gloss as function of irradiation time (hours) in an accelerated aging apparatus for the outdoor-use clear coatings with different ultraviolet absorbers on wood.

best dispersion was the one with 1.44 percent (wt/wt) ZnO nanoparticles pre-dispersed in water. The most effective coating formulation at protecting wood from photodegradation was the one with 2 percent (wt/wt) ZnO nanoparticles pre-dispersed in water. Then, ZnO nanoparticles were better than CuO nanoparticles as additives intended to reduce the discoloration of clear-coated wood exposed outdoors. A blend of inorganic and organic UV absorbers showed synergistic effects on the gloss of coatings. Further work should examine the effects of water on the degradation of stabilized polyurethane films during artificial weathering to complement the current study.

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