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Characterizing the conservation effect of clear coatings on photodegradation of wood

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Abstract

Photodiscoloration of clear-coated wood may be caused by the yellowing of both clear coating film and underlying wood, or either of them. Wood specimens covered with two types of free polyurethane films with/without light stabilizer were used to simulate the photodiscoloration of clear-coated wood. Percent UV transmission of aromatic polyurethane (PU) films decreased after irradiation, whereas aliphatic polyurethane (PUA) films significantly increased with irradiation time resulting in further photoyellowing of wood beneath the PUA film. A light reflection model was used to elucidate discoloration caused separately by the clear coating film and the underlying wood. After 24 days of light irradiation, clear coating and the underlying wood contributed respectively, 40.70% and 59.30% discoloration of PU-coated specimens, and the corresponding values for PUA-coated specimens were 5.15% and 94.85%. PU film with light stabilizer reduced lignin degradation and generation of carbonyl derivatives in the underlying wood.

Keywords: Wood; Polyurethane coating; Photodiscoloration; Free film; Lightfastness test

1. Introduction

Wood is mainly composed of cellulose, hemicelluloses, lignin, and extractives. It is a favorite indoor and outdoor constructions material because of its abundance, attractive appearance and easy processing. However, unprotected wood is susceptible to discoloration and deterioration that reduce its mechanical and physical properties (Hon, 2001; Pastore et al., 2004; Williams, 2005). Many methods, such as surface coating, chemical modification and impregnation with chemicals or plastics have been found to be able to extend service life of wood (Deka and Saikia, 2000; Gindl et al., 2003; Barnes et al., 2005; Chang and Chang, 2006). Among these methods, surface coating is the most common way to protect wood against degradation and to enhance its distinctive appearance (Hayoz et al., 2003; Buckle et al., 2005). Therefore, characteristics of wood coatings to withstand mechanical or chemical abrasion and to tolerate expansion and contraction of wood are critical to prolong their protective functions (Schwalm et al., 1997).

Polyurethane polymers are considered to be high-quality coatings. In the coating industry, two-component solvent-based polyurethane systems have been widely used because desirable properties can be obtained by adjusting makeup components (Lai and Quinn, 1995; Kim and Pail, 1999). Polyurethane coatings provide not only room temperature cure response, but also excellent abrasion resistance, high strength, hardness, flexibility, adhesion to wood materials, great modulus with elongation at break, and good chemical resistance (Fiori, 1997; Kultys and Pikus, 2001). However, wood coated with clear polyurethane coating is still susceptible to photoyellowing (Sigh et al., 2001). Photodiscoloration is unavoidable even if wood is coated with non-yellowing or durable clear coatings, such as aliphatic polyurethane coatings (Chang and Chou, 1999). Yellowing of both clear coating and underlying wood, or either of them may cause the discoloration.

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In the CIE $L^*a^*b^*$ system, discoloration of a specimen after light irradiation is described by color difference (ΔE^*). However, color difference contributed by clear coating or underlying wood can not be proportioned separately from a single ΔE^* value in the coated wood system.

Objectives of this study were to study photostability properties of coated wood systems and to investigate ways to improve polyurethane-coated wood against photodiscoloration. Photodiscoloration of coated wood was simulated by wood specimens covered with different free polyurethane films with/without a commercial light stabilizer (Tinuvin-1130). A light reflection model based on color factors (tristimulus values) X, Y, and Z was established in order to quantify proportion of discoloration caused by clear coating and underlying wood separately. The model was employed to discuss the efficacy of different clear coating treatments. Chemical changes of wood under different films were also characterized after lightfastness test.

2. Methods

2.1. Wood specimens and formulation of coatings

China fir (*Cunninghamia lanceolata*) wood 50 mm × 75 mm × 10 mm in dimension was used in this study.

Commercial aromatic polyurethane (PU) and aliphatic polyurethane (PUA) (Lignal Co., Germany) with a solid content ca. 51% and 27%, respectively, were used in this study. Also used were PU and PUA containing 2% Tinuvin-1130 (hydroxyphenyl benzotriazole light absorber) based on solid content of the clear coatings, which were respectively labeled as PUS and PUAS.

2.2. Preparation of polyurethane-coated wood and free films

Wood specimens were coated with PU and PUA coatings with or without 2% light stabilizer. The thickness of the wet coatings applied onto wood surfaces was ca. 200 μm. For preparation of free films, wet clear coatings were applied onto glass surfaces at a thickness approximately 200 μm, followed by curing at the ambient temperature and peeling off the cured films for later experiments.

2.3. Lightfastness tests and color measurements

A Q-panel QUV accelerated lightfastness tester with eight UVA-351 lamps was used for accelerated lightfastness test. Specimens were exposed to UVA-351 lamps directly. The temperature of the black panel was 60 ± 2 °C.

The color parameters used in this study were calculated from spectral reflectance curves obtained with a diffuse reflectance UV/Vis spectrophotometer (Jasco V550) equipped with an integrating sphere attachment. The tristimulus values (X, Y, and Z) of the coated wood, free films and wood underneath were calculated from spectral reflectance curves directly. The L^*, a^*, b^*, ΔE^* (color difference) and ΔYI (difference of yellowness index) color parameters were then computed using the CIE (Commission Internationale de l'Eclairage, 1976) $L^*a^*b^*$ equation.

2.4. Models for elucidating discoloration of clear-coated wood samples

In the CIE $L^*a^*b^*$ system discoloration of a specimen after irradiation is described by color difference (ΔE^*). However, discoloration contributed by clear coating and underlying wood cannot be proportioned directly from a single ΔE^* value in coated wood system. In order to do that, wood specimens were covered tightly with dry free coating films using clamps to simulate coated wood. After irradiated at various durations color changes of the free coating films and the underlying wood were measured separately, and the results were used to elucidate photodiscoloration in clear-coated wood. In the CIE $L^*a^*b^*$ system, the tristimulus values for a reflecting sample are calculated by adding the product of the spectral power distribution of the illuminant (Marcus, 1998). A model described below was used to clarify the tristimulus reflected by the coating and wood.

In this model (Fig. 1a) the original tristimulus (X_0, Y_0, Z_0) emitted from light source (D_{65}) is divided into two portions: the partial tristimulus absorbed by free film ($A_{f_1} + A_{f_2} + A_{f_3} + A_{f_4} \ldots$) and the others reflected by standard white board (E_{r_1}). The total reflected tristimulus (E_t) of free film is obtained by UV/Vis spectrometer. Since the absorption of film is not uniform in the visible region, the true absorption of film (film factor, T_f) of X_0, Y_0, Z_0 was calculated by the following equations separately. In this model E_t is a geometric series, and the ratio r_f is expressed below:

$$
\begin{aligned}
E_{t_1} &= (E_0 - E_{r_1}) \times T_f \\
E_{t_2} &= E_{t_1} \times \left(1 - \frac{E_{r_1}}{E_0}\right) \times T_f \\
E_{r_2} &= E_{t_1} \times \frac{E_{r_1}}{E_0} \\
E_{t_3} &= E_{r_2} \times \left(1 - \frac{E_{r_1}}{E_0}\right) \times T_f \\
E_t &= E_{r_1} + E_{t_2} + E_{t_3} + E_{t_4} + \cdots \\
&= E_{r_1} + E_0 \times \left(1 - \frac{E_{r_1}}{E_0}\right)^2 \times T_f^2 + E_0 \\
&\quad \times \left(1 - \frac{E_{r_1}}{E_0}\right)^2 \times T_f^2 \times \frac{E_{r_1}}{E_0} \times \left(1 - \frac{E_{r_1}}{E_0}\right) \\
&\quad + E_0 \times \left(1 - \frac{E_{r_1}}{E_0}\right)^2 \times T_f^2 \times \left(\frac{E_{r_1}}{E_0}\right)^2 \times \left(1 - \frac{E_{r_1}}{E_0}\right)^2 + \cdots \\
r_f &= \frac{E_{r_1}}{E_0} \times \left(1 - \frac{E_{r_1}}{E_0}\right) \qquad (1) \\
E_t &= E_{r_1} + E_0 \times \left(1 - \frac{E_{r_1}}{E_0}\right)^2 \times T_f^2 \times \left(\frac{1}{1 - r_f}\right) \\
\Rightarrow T_f &= \sqrt{\frac{(E_t - E_{r_1}) \times (1 - r_f)}{E_0 \times \left(1 - \frac{E_{r_1}}{E_0}\right)^2}}
\end{aligned}
$$