DYEING OF ACETYLATED WOOD WITH DISPERSE DYES

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Abstract. In this study, fir powder and acetylated fir powder were dyed using a series of disperse dyes under high temperature and pressure and were compared with the dyeing of polyester under the same condition. Acetylated oak and poplar veneer were also dyed as a reference. Unmodified fir powder, acetylated fir powder, and dyed acetylated fir powder were characterized by IR spectra and scanning electron microscope. The effect of pH value and dye concentration on the dyeing properties and fastness was evaluated and compared. Disperse dyes exhibited better dyeability and fastness on acetylated fir powder than on unmodified fir powder. This was because of the differences in the structures of the two fir powders.

Keywords: Wood modification, acetylated wood, wood dyeing, disperse dyes, color shade.

INTRODUCTION

Wood is one of the most abundant lignocellulosic resources on the planet and has long been used for building, fuel, and various other applications. During the past four decades, chemical modification of wood has been intensively studied to increase its compatibility with other substances (Efanov et al 2008; Borysiak 2010; Chang et al 2013), dimensional stability (Rowell and Tillman 1986; Chadlia and Farouk 2010), and resistance to decay (Timar et al 1999; Terzi et al 2011; Papadopoulos 2012). Among the various chemical modifications, acetylation is the most emphatic and widely applied and already has numerous industrial applications.
With the continuous expansion of the applications of acetylated wood, methods to enhance its color are of great interest, but to date, dyeing has been limited to the application of direct, acid, alkali, metal complex, and reactive dyes to untreated wood (Sun et al. 2003; Li and Yu 2005; Kielmann et al. 2014). This is because wood is mainly composed of cellulose, hemicelluloses, and lignin, which contains rich hydrophilic OH groups. Acetylation closes part of the hydroxyl groups on these substances by converting hydrophilic OH groups into larger, more hydrophobic groups and alters the molecular structure of the cell wall components. As a result of this structural alteration, the cell wall itself assumes a permanently swollen state that attracts no or very little water, thus increasing the hydrophobic properties of the material (Mohbby 2008). Consequently, hydrophobic disperse dyes offer the best potential for dyeing acetylated wood. In this study, acetylated and untreated Chinese fir powders were dyed with a series of disperse dyes under high temperature and pressure and the powders were measured to determine dye exhaustion, color shade, color difference, and washing fastness (WF). Samples were observed using IR spectra and scanning electron microscopy (SEM). Acetylated oak and poplar veneers were also dyed with disperse dyes and tested to provide a comparison. This investigation establishes a theoretical foundation for the dyeing of acetylated wood with disperse dyes and demonstrates bright future prospects for the application of disperse dyes to treated wood.

MATERIALS AND METHODS

Materials

All chemical reagents were analytical grade. Disperse dyes used in the dyeing experiments were supplied by Zhejiang Runtu Co. Ltd., Zhejiang, China. Table 1 lists the chemical structure and molecular weight (MW) of the 12 disperse dyes used in this series of studies (He 2004). Chinese fir (Cunninghamia lanceolata [Lambert] Hooker) wood and poplar (Populus tomentosa) veneer were obtained from Hunan, China. Oak (Quercus aliena) veneer was obtained from Jilin, China.

Acetylation of Chinese Fir Powder

Chinese fir powder was ground sufficiently fine to pass through a 20 mesh screen. Prior to use, the powder was extracted in a Soxhlet apparatus with a mixture of toluene–ethanol (1:1, v:v) for 8 h followed by water for an additional 4 h. Then, the powder was oven-dried at 80°C for 20 h and cooled to ambient temperature in a desiccator over phosphorus pentoxide. Acetylation was performed in a standard set of conditions in a three-necked round-bottomed flask equipped with a condenser, thermometer, and mixer. Reagent solutions consisting of 20.0 g dry fir powder, 140 mL acetic anhydride, and 5.0 g Na₂CO₃ were used throughout. The reaction temperature was 120°C for 5 h. The modified materials were filtered out and then rinsed with 100 mL water (70-80°C), 40 mL 50% ethanol, and finally 100 mL water (70-80°C) to remove all nonbonded chemicals. The acetylated wood powder was dried in an oven at 80°C for 24 h.

Acetylated Modification of Oak and Poplar Veneer

This method was also applied to oak veneer and poplar veneer (40 × 20 × 2 mm). The materials were first extracted in a Soxhlet apparatus with a mixture of toluene–ethanol (1:1, v:v) followed by water, and then the acetylation reaction was performed as previously described.

Dyeing Process

Dyeing operations were performed by means of a laboratory-scale dyeing machine (HS-12P; Jingjiang Huatai Co. Ltd., Jiangsu, China) using a process described by Jung et al. (2005) and Woo et al. (2008), a dyebath containing 1.00 g acetylated fir powder in 100 mL H₂O, 0.01 g dispersant MF, 0.1 mL emulsifier OP-10, 1.0 mL 2.0 M HAc-NaAc buffer solution, and
0.005-0.04 g dye. From a starting point of 20°C, the temperature was raised to the set temperature at a rate of 2.0°C-min⁻¹ and then held until completion of the incubation period. In the earliest study, different temperatures were used (80 and 120°C) and thereafter it was decided that 120°C and an incubation period of 0-60 min would be used for all subsequent studies. At the end of dyeing, the dyebath was cooled to 60°C at a gradient of 2.0°C min⁻¹ and the dyed samples were removed from the dyebath. Then the samples were poured out, drained with a Brinell filter bucket, and rinsed twice with 20 mL water. The residue solution was collected for the determination of dye exhaustion as subsequently explained. The samples were dried at 60°C for 24 h, and dyed acetylated fir powder was obtained. The same method was used to dye acetylated oak and poplar veneer.

**Determination of Dye Exhaustion and Color Difference**

Dye uptake was determined as follows: 0.010 g dye was weighed to 50 mL in a beaker, and 1.0 mL buffer solution of HAc-NaAc was added. The solution was then transferred to a 100-mL measuring flask with a constant volume of dimethylformamide (DMF). Then 5.00 mL solution was pipetted to a 50 mL measuring flask with a constant volume of DMF. The absorbance (A₀) of dye standard solution was measured at the wavelength of the maximum absorbance (λ_max) using a UV-VIS spectrophotometer (UV-2100; Shimadzu Corp, Kyoto, Japan).

**Table 1. Chemical structure and molecular weight (MW) of disperse dyes.**

<table>
<thead>
<tr>
<th>Dye</th>
<th>MW</th>
<th>Chemical structure</th>
<th>Dye</th>
<th>MW</th>
<th>Chemical structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>R73</td>
<td>348</td>
<td><img src="image" alt="R73" /></td>
<td>R54</td>
<td>416</td>
<td><img src="image" alt="R54" /></td>
</tr>
<tr>
<td>R145</td>
<td>380</td>
<td><img src="image" alt="R145" /></td>
<td>R177</td>
<td>438</td>
<td><img src="image" alt="R177" /></td>
</tr>
<tr>
<td>R153</td>
<td>404</td>
<td><img src="image" alt="R153" /></td>
<td>R167</td>
<td>506</td>
<td><img src="image" alt="R167" /></td>
</tr>
<tr>
<td>R179</td>
<td>410</td>
<td><img src="image" alt="R179" /></td>
<td>B79</td>
<td>625</td>
<td><img src="image" alt="B79" /></td>
</tr>
<tr>
<td>R152</td>
<td>453</td>
<td><img src="image" alt="R152" /></td>
<td>Y114</td>
<td>408</td>
<td><img src="image" alt="Y114" /></td>
</tr>
<tr>
<td>B148</td>
<td>414</td>
<td><img src="image" alt="B148" /></td>
<td>Y163</td>
<td>417</td>
<td><img src="image" alt="Y163" /></td>
</tr>
</tbody>
</table>
Japan). Simultaneously, 5.00 mL residue solution was pipetted to a 25.00 mL measuring flask with a constant volume of DMF, and the absorbance \((A_1)\) of the solution was measured at \(\lambda_{\text{max}}\). The dye bath exhaustion \((%E)\) was calculated using Eq 1 (Choi et al 2007):

\[
%E = \left(1 - \frac{A_1}{A_0}\right) \times 100
\]

where \(A_0\) and \(A_1\) are absorbance at \(\lambda_{\text{max}}\) of the dye originally in the dyebath and of the residual dye after dyeing.

Color difference \((\Delta E)\) was determined as follows: under pressure of 1771 kPa, 0.200 g dyed acetylated fir powder was pressed into a thin slice with a 20 mm diameter. Similar to dyed polyester fabric prepared under the same condition, three points on each slice surface were measured with a chroma meter (CR-300; Minolta Co. Ltd., Osaka, Japan) according to CIE 1976, \(\Delta E\) for each sample was calculated using Eq 2 (Liu et al 2011), and the average value was taken as the \(\Delta E\) of the dyed sample.

\[
\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}
\]

\[
\Delta L = L_{\text{sample}} - L_{\text{standard}}, \quad \Delta a = a_{\text{sample}} - a_{\text{standard}}
\]

\[
\Delta b = b_{\text{sample}} - b_{\text{standard}}
\]

where \(L\), \(a\), and \(b\) are the color parameters of brightness index, red–green index, and yellow–blue index; and \(\Delta L\), \(\Delta a\), and \(\Delta b\) are the differences between the sample and the standard of the colors, respectively. \(\Delta E\) indicates the total color difference of the sample.

### Determination of Color Fade Rate and Washing Fastness

The color fade rate \((F\%)\) was determined as follows: 0.500 g dyed acetylated fir powder and 50 mL water were added to a stainless steel dyebath and placed in a laboratory-scale dyeing machine (HS-12P). The temperature was raised rapidly to 60°C at a rate of 2.0°C-min\(^{-1}\) and held for 45 min. Then the sample was poured out and drained with a Brinell filter bucket. A total of 10.00 mL residue solution was pipetted to a 25 mL measuring flask with constant volume of DMF, and the absorbance \((A_2)\) of the solution was measured at \(\lambda_{\text{max}}\) by a UV-VIS spectrophotometer. The color fade rate \((F\%)\) and WF were calculated using Eqs 3 and 4:

\[
F(\%) = \frac{A_2}{(A_0 - A_1)} \times 100\%
\]

\[
WF = \frac{1}{F\%} = \frac{(A_0 - A_1/A_2)}{100}
\]

where \(A_2\) is absorbance of the residual dye after washing at \(\lambda_{\text{max}}\).

### RESULTS AND DISCUSSION

#### Effect of pH Value on Dyeing of Acetylated Fir Powder

pH is one of the most important environmental factors influencing not only site dissociation of acetylated powder, but also structural stability of dyes and their color intensity for hydrolysis of cyanoethyl or acetate groups (Mall et al 2005). The effect of pH on dyeing of acetylated powder was studied by varying pH across the range of 3.0-10.0 for three disperse dyes of R153, Y114, and B79. The results are shown in Table 2. The color shade of dyed acetylated fir powder resembles that of dyed polyester fabric with pH range 4-9 for R153, 3-7 for B79, and 3-7 for Y114. Thus, the pH range of the dyeing process was the same for acetylated fir powder and polyester fibers with the same disperse dyes. Because pH of 4.5 was most

<table>
<thead>
<tr>
<th>Dye name</th>
<th>pH = 3</th>
<th>pH = 4</th>
<th>pH = 5</th>
<th>pH = 7</th>
<th>pH = 9</th>
<th>pH = 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>R153</td>
<td>Light red</td>
<td>Red</td>
<td>Red</td>
<td>Red</td>
<td>Red</td>
<td>Blackish red</td>
</tr>
<tr>
<td>B79</td>
<td>Blue</td>
<td>Blue</td>
<td>Blue</td>
<td>Blue</td>
<td>Gray</td>
<td>Light yellow</td>
</tr>
<tr>
<td>Y114</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Yellow</td>
<td>Blackish yellow</td>
<td>Blackish yellow</td>
</tr>
</tbody>
</table>

\(^a\) 1.00 g acetylated fir powder, 0.010 g dyes, 100 mL H\(_2\)O, 120°C, 60 min.
suitable for the dyeing process, the solution was maintained in this range for subsequent dyeing tests.

**Dyeing Rate Curve of Acetylated Fir Powder**

Ten azo disperse dyes were classified into two groups according to cyanoethyl and acetate in their coupling components. During the dyeing process, the concentration of disperse dyes was 1% based on the weight of dye/fiber (owf). The dyeing temperature began at 20°C and rose to 80°C at a rate of 2.0°C min⁻¹. Sample 1 was removed at a dyeing temperature of 80°C. The temperature rose to 120°C at the same rate, and sample 2 was obtained. At a dyeing temperature of 120°C, the dyeing time maintained 30 and 60 min and samples 3 and 4 were obtained, respectively. The dyeing results were illustrated in Figs 1 and 2. In Fig 1, the substituents contained cyanoethyl on the coupling component, excluding the acetate group. In Fig 2, the substituents on the coupling component contained one or two acetate groups, excluding cyanoethyl. At a dyeing temperature of 80°C, the percentage of dye exhaustion (%E) decreased with increase of MW, ie R73 > R145 > R153 > R179 > R152 in Fig 1 and B148 > R54 > R177 > R167 > B79 in Fig 2. This indicates that the smaller the MW of the disperse dye, the faster the diffusion into the acetylated fir powder surface. Compared with the closer MW of disperse dyes, %E of R153 (MW 404, 36.8%) and R179 (MW 410, 23.6%) were lower than that of B148 (MW 414, 53.2%) and R54 (MW 416, 45.6%). The reason is that B148 and R54 contained a strong hydrophilic acetate group, which dissolved relatively easily in water and was compatible with acetylated fir powder. At a dyeing temperature of 120°C, when dyeing time was beyond 60 min, the %E of 10 disperse dyes exceeded 95%. This revealed that the dyeing process was basically complete and adsorption was saturated.

**Effect of Dye Concentration on Dyeing of Acetylated Fir Powder**

To investigate the influence of dye concentration on %E, experiments were performed with dyeing temperature at 120°C for 60 min (Figs 3 and 4). For disperse dyes with a cyanoethyl group in coupling components, %E decreased with the increase of dye concentration across the range of 0.5 and 4%. The decreasing tendency is most obvious for R152. This indicates that the cyanoethyl group was a hydrophobic group and had low compatibility, probably because of its relatively heavy MW and large molecular structural features (Yang and Huda 2003). In contrast, for disperse dyes with acetate groups, %E showed no significant change in the dyeing concentration of 0.5
and 4%. In all cases, the color shade of dyed acetylated fir powder deepened with increased dye concentration.

Comparison Among Dyeing of Polyester Fabric, Fir Powder, and Acetylated Fir Powder

Polyester fabric, fir powder, and acetylated fir powder were dyed with 12 disperse dyes. The color shade, %E and ΔE are illustrated in Table 3 and Figs 5 and 6. The color shade of dyed acetylated fir powder resembled that of dyed polyester fabric and was more brilliant or brighter than that of dyed untreated fir powder. In Fig 5, the %E for dyed acetylated fir powder was higher than that for dyed unmodified fir and dyed polyester fabric under the same dyeing conditions for all dyes. This illustrated that acetylation could decrease the polarity and affinity capacity of fir powder. Thus, acetylated fir powder is more conductive to disperse dyes than unmodified fir powder. Also, the %E of Y163 for dyed acetylated fir powder was 73%, which was much lower than that for other disperse dyes. This may be related to the molecular structural features of Y163 (Yang and Huda 2003). Taking dyed polyester fabric as a reference, the ΔE of dyed acetylated fir powder was smaller than that of dyed unmodified fir powder with these disperse dyes. The ΔE of dyed unmodified fir powder (41.8) or dyed acetylated fir powder (26.4) by Y114 was much bigger than that by other disperse dyes. The reason is that Y114 was naturally pale yellow, whereas the original color of polyester fabric was white, which indicates a large color change for the reference samples.

Washing Fastness Properties

The WF of disperse dyes on acetylated fir powder was determined by the color fade rate (F%), in which lower color fade rate indicated higher WF. Table 4 shows the test results of the color fade rate and WF of 10 disperse dyes on acetylated fir powder. The WF of disperse dyes such as R73, R145, R153, R179, and

Table 3. Color shade of dyed polyester fabric, fir powder, and acetylated fir powder. a

<table>
<thead>
<tr>
<th>Dyes</th>
<th>Polyester fabric</th>
<th>Fir powder</th>
<th>Acetylated fir powder</th>
<th>Dyes</th>
<th>Polyester fabric</th>
<th>Fir powder</th>
<th>Acetylated fir powder</th>
</tr>
</thead>
<tbody>
<tr>
<td>R54</td>
<td>Red</td>
<td>Dark red</td>
<td>Red</td>
<td>R177</td>
<td>Red</td>
<td>Dark red</td>
<td>Red</td>
</tr>
<tr>
<td>R73</td>
<td>Claret</td>
<td>Dark purple</td>
<td>Claret</td>
<td>R179</td>
<td>Rose red</td>
<td>Dark purple</td>
<td>Rose red</td>
</tr>
<tr>
<td>R145</td>
<td>Red</td>
<td>Dark purple</td>
<td>Rose</td>
<td>B79</td>
<td>Navy blue</td>
<td>Dark blue</td>
<td>Navy blue</td>
</tr>
<tr>
<td>R152</td>
<td>Brilliant red</td>
<td>Dark red</td>
<td>Brilliant red</td>
<td>B148</td>
<td>Blue</td>
<td>Dark blue</td>
<td>Deep blue</td>
</tr>
<tr>
<td>R153</td>
<td>Brilliant red</td>
<td>Dark red</td>
<td>Brilliant red</td>
<td>Y114</td>
<td>Bright yellow</td>
<td>Dark yellow</td>
<td>Bright yellow</td>
</tr>
<tr>
<td>R167</td>
<td>Claret</td>
<td>Dark red</td>
<td>Claret</td>
<td>Y163</td>
<td>Orange</td>
<td>Dark orange</td>
<td>Orange</td>
</tr>
</tbody>
</table>

a 1.00 g sample, 0.010 g disperse dye, 100 mL H2O, 0.5 mL HAc-NaAc, 120°C, 60 min.
R152 was in the range 8.3-25.0, whereas the WF of disperse dyes such as B148, R54, R177, R167, and B79 was in the range of 5.6-6.6. This means that the WF of disperse dyes containing a cyanoethyl group was higher than disperse dyes containing an acetate group on the coupling component. As is well known, an acetate group is more hydrophilic than an ethyl or cyanoethyl group. Therefore, disperse dyes with acetate groups were desorbed easily from

![Figure 5. Dye bath exhaustion (%E) of dyeing on polyester fabric, fir powder, and acetylated fir powder.](image)

![Figure 6. Color difference (ΔE) of dyed fir powder and dyed acetylated fir powder.](image)

<table>
<thead>
<tr>
<th>Dyes</th>
<th>R73</th>
<th>R145</th>
<th>R153</th>
<th>R179</th>
<th>R152</th>
<th>B148</th>
<th>R54</th>
<th>R177</th>
<th>R167</th>
<th>B79</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW</td>
<td>348</td>
<td>380</td>
<td>404</td>
<td>410</td>
<td>453</td>
<td>414</td>
<td>416</td>
<td>438</td>
<td>506</td>
<td>625</td>
</tr>
<tr>
<td>Number of acetate group</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Color fade rate (F%)</td>
<td>1.2</td>
<td>0.8</td>
<td>0.6</td>
<td>0.5</td>
<td>0.4</td>
<td>1.8</td>
<td>1.8</td>
<td>1.6</td>
<td>1.8</td>
<td>1.5</td>
</tr>
<tr>
<td>WF</td>
<td>8.3</td>
<td>12.5</td>
<td>16.7</td>
<td>20.0</td>
<td>25.0</td>
<td>5.6</td>
<td>5.6</td>
<td>6.3</td>
<td>5.6</td>
<td>6.6</td>
</tr>
</tbody>
</table>

*a Dyeing condition, 1.00 g acetylated fir powder, 0.010 g disperse dyes, 100 mL H₂O, 0.5 mL HAc-NaAc, 120°C, 60 min.

*b MW, molecular weight; WF, washing fastness.
the powder surface. For disperse dyes with cyanoethyl groups on the coupling component, such as R73, R145, R153, R179, and R152, the WF generally increased with MW. This illustrates that disperse dyes with lower MW might seep more easily into the micropores of acetylated fir powder.

IR Spectra Analysis

IR spectra for the samples were performed in the IR region on a FT-IR spectrometer (Thermo Nicolet Avatar 330; Waltham, MA). About 2 mg of sample material was mixed with 200 mg of spectroscopic grade KBr. The spectra of fir powder, acetylated fir powder, and dyed acetylated fir powder by disperse dye R54 are shown in Fig 7. The spectrum of acetylated fir powder exhibits the decrease of the stretching frequency of the hydroxyl group from 3374 to 3356 cm⁻¹ and the appearance of a strong absorption band at 1747 cm⁻¹ assigned to the carbonyl group of saturated ester. Simultaneously, the spectrum contains two main bands characteristic of acetate base at 1374 and 1235 cm⁻¹. This confirms esterification of hydroxyl groups from fir powder with an acetyl group. Comparison of the spectra of acetylated fir powder (b) and dyed acetylated fir powder (c) reveals significant absorption peaks. No absorption peak at 2251 cm⁻¹ assigned to the cyanoethyl group was observed. This was because of the lower amount of disperse dyes in the dyeing process and indicates that the interaction between disperse dye and fir powder might have involved physical Van der Waals forces.

Scanning Electron Microscope Analysis

Samples of powder were prepared for SEM by being conductively coated with gold, and SEM was operated at 20 kV by sputtering for 15 s. The surface of unmodified, modified, and dyed samples was characterized by SEM (6380LV; JEOL, Tokyo, Japan). Figure 8 shows the typical SEM photographs of the samples. A regular, porous, and compact surface structure is observed in the SEM micrograph of unmodified fir powder (a), and the lumen and microfibrilla cell wall structure (d) is very obvious or complete. When the hydroxyl groups on the cell wall of fir powder were acetylated in the process by the use of acetic anhydride under the release of acetic acid, because of the greater volume of acetyl groups relative to hydroxyl groups, acetylation damaged the intact cell structure (Stamm 1964). This led to the presentation of more cracks and scars in the microfibrillar cell wall of the pit, and the surface

Figure 7. IR spectra of (a) fir powder, (b) acetylated fir powder, and (c) dyed acetylated fir powder.
of the cell wall became rougher with more tiny holes than that of untreated fir powder (b, e), which benefited the adsorption of dye molecules. After the dyeing of acetylated fir powder, apparent changes occurred with a smooth and soft surface structure on the cell wall of tracheids (c, f). This illustrates that the cracks and scars in the microfibrillar cell wall were completely covered by dye molecules, which probably entered the cracks of the microfibrillar cell wall.

**Dyeing of Acetylated Oak Veneer and Acetylated Poplar Veneer with Disperse Dyes**

Taking 40×20×2 mm acetylated oak and poplar veneers as the dyeing objects, Tables 5 and 6 show their dyeing properties in terms of

### Table 5. Color shade, color difference, and dye exhaustion of acetylated oak veneer dyed with six disperse dyes.

<table>
<thead>
<tr>
<th>Dyes</th>
<th>R73</th>
<th>R153</th>
<th>R177</th>
<th>B148</th>
<th>B79</th>
<th>Y114</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW</td>
<td>348</td>
<td>404</td>
<td>438</td>
<td>414</td>
<td>625</td>
<td>408</td>
</tr>
<tr>
<td>%E</td>
<td>70.2</td>
<td>68.3</td>
<td>67.7</td>
<td>66.4</td>
<td>63.4</td>
<td>71.4</td>
</tr>
<tr>
<td>ΔE</td>
<td>8.7</td>
<td>9.0</td>
<td>9.3</td>
<td>9.5</td>
<td>7.3</td>
<td>11.4</td>
</tr>
</tbody>
</table>

*0.5% disperse dye (owf), 100 mL H2O, 1.5 mL HAc-NaAc, 120°C, 60 min.

### Table 6. Color shade, color difference, and dye exhaustion of acetylated poplar veneer dyed with six disperse dyes.

<table>
<thead>
<tr>
<th>Dyes</th>
<th>R73</th>
<th>R153</th>
<th>R177</th>
<th>R167</th>
<th>R152</th>
<th>R54</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW</td>
<td>348</td>
<td>404</td>
<td>438</td>
<td>506</td>
<td>453</td>
<td>416</td>
</tr>
<tr>
<td>%E</td>
<td>76.6</td>
<td>71.3</td>
<td>73.4</td>
<td>72.9</td>
<td>67.7</td>
<td>75.2</td>
</tr>
<tr>
<td>ΔE</td>
<td>9.1</td>
<td>9.6</td>
<td>9.8</td>
<td>8.8</td>
<td>8.5</td>
<td>7.6</td>
</tr>
</tbody>
</table>

*0.5% disperse dye (owf), 100 mL H2O, 1.5 mL HAc-NaAc, 120°C, 60 min.

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Figure 8. Scanning electron micrographs of unmodified fir powder (a, d), acetylated fir powder (b, e), and dyed acetylated fir powder (c, f).
color shade, %E, and ΔE. When Figs 3 and 4 were compared with Tables 5 and 6, the %E of dyed acetylated oak veneer was about 70%, which was obviously lower than that of dyed acetylated fir powder and dyed polyester fabric at the same condition. This occurred because acetylated oak veneer had a finer texture with many hardwood fiber tracheids and relatively few open vessel structures. Therefore, dye molecules had greater difficulty penetrating the acetylated oak veneer and were more likely to remain at the surface layer. Compared with dyed polyester fabric, the color shade of dyed acetylated oak veneer was similar to that of dyed polyester fabric. However, the ΔE of dyed acetylated oak veneer was smaller under the same dyeing conditions. Also, the surface texture had no change. The %E of acetylated poplar veneer was higher than that of acetylated oak veneer. However, the color shades of acetylated oak veneer and acetylated poplar veneer were similar. This is because oak veneer is a hardwood with a dense texture, whereas poplar veneer is soft wood with relatively low density and diffuse porous structure. Key characteristics of the cellular structure of poplars include shorter fibers and smaller cells than many other hardwoods as well as considerable shrinkage (Koubaa et al 1998), which allows more dye molecules to enter the interior when the dyeing temperature reaches 120°C. Consequently, the surface dye concentration of poplar veneer was lower than that of oak veneer. In summary, it is feasible to dye acetylated oak and poplar veneer with disperse dyes. The dyeing process not only achieves the beautiful colors of acetylated wood, but also preserves the textural features, making it highly practical.

CONCLUSIONS

In this study, successful dyeing of fir powder was carried out with a series of disperse dyes after acetylation of the hydroxyl groups in fir powder with acetic anhydride. At the same time, acetylated poplar veneer and oak veneer were dyed with disperse dyes. The pH for dyeing acetylated fir powder was almost the same as that for polyester fiber. Meanwhile, the %E of acetylated fir powder was higher than that of polyester fabric or unmodified fir powder. The color shade of dyed acetylated wood was similar to that of dyed polyester fabric and more brilliant or brighter than that of dyed unmodified fir powder under the same dyeing conditions. Dyed acetylated wood exhibited good WF. Compared with dyed polyester fabric, the ΔE of dyed acetylated fir powder was smaller than that of dyed unmodified fir powder. No obvious absorption peaks appeared in the IR spectra of dyed acetylated fir powder compared with acetylated fir powder. The SEM analysis illustrated that the cracks and scars in the microfibrillar cell walls of acetylated fir powder were completely covered by dye molecules, and the apparent changes occurred for the dyed acetylated fir powder with a smooth, soft surface structure on the cell wall of the tracheids. Also, successful dyeing of acetylated poplar veneer and oak veneer also shows potential in dyeing veneer. This study not only has important theoretical and practical significance in expanding the use of modified wood, but also can improve the value of dyeing modified wood.

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REFERENCES


