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Effects of $NaOH/H_2O_2/Na_2SiO_3$ Bleaching Pretreatment Method on Wood Dyeing Properties

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Abstract: Bleaching is a common modification method widely used in the industrialization of wood dyeing. Bleaching can regulate the color of the wood, and it also has great effects on the subsequent wood dyeing properties. In this work, three woods, Ayous, Linden, and Poplar, were processed by using the $NaOH/H_2O_2/Na_2SiO_3$ bleach pretreatment method. Then, the pretreated wood and untreated wood were stained separately by means of water bath dyeing with three dyestuffs: blue anthraquinone and red and yellow double-azo dyestuffs. The study mainly focused on the effect of the bleach pretreatment on the color control and dyeing properties of the wood by analyzing the color difference, staining rate, and final dyeing rate of the dyed wood. The results were as follows: For the color difference, the L* and h* values showed increasing tends, while the a*, b*, and c* values showed decreasing trends. For the staining rate, Ayous reached an equilibrium staining rate at 3~4 h, but for the others, this was not obvious. For the dyeing rate, red and blue Linden veneers and blue Ayous veneers were similar to the unbleached ones, while the final dyeing rate of the other veneers was less than that of the original wood, and the staining rate of the Ayous red and yellow veneer, Linden yellow veneer, and Poplar veneer was less than that of the original wood. The final dyeing rate of the Ayous red and yellow veneers, Linden yellow veneer, and Poplar red, yellow and blue veneers decreased by 4.54%, 2.91%, 5.45%, 10.75%, 2.66%, and 9.55%, respectively. In general, the bleach pretreatment made the staining color of the material surface uniform. The dyeing rate increased due to the increase of the veneers' permeability. Thus, the veneers quickly reached the equilibrium staining rate, but the equilibrium staining rate of some test pieces decreased. This work provides scientific support for the dyeing process.

Keywords: bleaching; wood dyeing; staining properties

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1. Introduction

Forests cover nearly one-third of the Earth's land area and host most of the terrestrial biodiversity. However, despite efforts to curb deforestation and restore degraded lands, the forested area continues to shrink. According to the most recent Global Forest Resources Assessment, the world's total forest area is currently around 460 million ha, occupying 31% of the world's land area, equivalent to 0.52 ha per person [1]. However, the world's timber resources are unevenly distributed geographically, with the tropics containing 45% of the world's forest resources due to the climatic influences. Russia, Brazil, Canada, the United States, and China have more than 54% of the world's forest resources. The overall forestry resources are decreasing year by year, with timber resources becoming more scarce, especially regarding rare and valuable timber [1].

Wood has a high aesthetic value due to its unique macro- and micro-characteristics, and it has been widely used in interior decoration. This has accelerated the scarcity of wood resources. Surface decoration is an important application area of wood and is directly related to the visual characteristics of wood. Currently, the common methods used to modify wood are as follows: varnishing, dyeing, thermal modification, making the wood

transparent, etc. [2–7]. Because wood has a unique grain, varnishing usually enhances the visual appearance of the painted surface of the wood, resulting in a superior color effect. The trees that produce the wood to which the staining modification is applied are mostly fast-growing. This is due to the fact that slow-growing species have a denser texture, making it difficult for the dyes to penetrate, and their wood is usually more expensive.

In wood dyeing, the dye molecules diffuse through a medium into the wood cell wall via the wood's capillary channels and forming a bond with it [8–12]. The process of dyeing wood is in a sense the penetration and adhesion of dye molecules. When different dyes are applied to the wood, they form different bonds with the wood, e.g., direct dyes form hydrogen or van der Waals bonds with the wood, while reactive dyes form covalent bonds with the hydroxyl groups of the wood [13,14]. Wood dyeing makes the wood rich in color and texture. Through the restructuring process, it gives the wood a special texture and better visual and decorative properties. The innovative development of wood modification techniques can improve the quality of fast-growing wood and the efficiency of its production, and this can help supply the demand for wood resources, especially by replacing rare wood [5–7,15,16]. Among the wood modification techniques, bleaching is common, because it can even out the color of the wood and achieve a brighter color than the original wood. Therefore, bleaching is widely used as a pretreatment in the wood dyeing process [17,18]. In comparison, the lacquering process is simple and produces a better result, but it requires more material. Staining is more suitable for woods and uses more common materials, and the stained wood can simulate the texture of rare wood after a certain sequence of steps, giving more possibilities for the application of the wood. There is more room for the development of wood staining process, so that we can broaden the application of stained wood and improve the effect of the staining of the wood.

The wood bleaching process is widely used to prevent wood mildew, to prepare transparent wood, in the paper making process, etc. The bleaching method varies from wood to wood. The wood bleaching methods are mainly divided into oxidative bleaching and reductive bleaching [8–10,19]. Reducing bleaching agents, such as sulfur dioxide, sodium bisulfite, etc., usually work by reducing the pigments in the wood. However, after bleaching, there is the possibility of oxidation, resulting in re-coloring of the wood, leading to a decrease in the whiteness of the wood. Oxidizing bleaching agents, such as sodium hypochlorite, hydrogen peroxide, sodium chlorite, peracetic acid, etc., usually have great stability; thus, they are widely used.

On this basis, $NaOH/H_2O_2/Na_2SiO_3$ was used in this work for the bleach pretreatment of Ayous, Linden, and Poplar, and three dyestuffs were adopted: red and yellow double-azo dye and blue anthraquinone dyestuffs. Large-scale experiments were carried out to analyze the bleaching depth value, staining rate, and microscopic quality of the veneers dyed by means of a constant temperature water bath at 95 °C. The aim was to systematically investigate the positive effect of the $NaOH/H_2O_2/Na_2SiO_3$ bleach pretreatment on the subsequent color regulation and staining rate of the dyed wood. This study is of practical significance for analyzing the properties of the wood for the dying process after the bleach pretreatment, and it provides a basis for color difference control and the long-term development of the wood dyeing industry [20–25].

2. Materials and Methods

2.1. Experimental Materials and Equipment

The experimental flow is shown in Figure 1. Experimental materials: Ayous (*Abachi*), Linden (*Tilia*), Poplar (*Populus* L.). These three species had dimensions of 80 mm (L) × 80 mm (W) × 0.75 mm (T), and their moisture content was controlled between 7% and 12%.



Figure 1. Experimental flow chart [26].

Bleaching solution and dyeing solution: industrial-grade 35% mass fraction of hydrogen peroxide; mass fraction of 37% aqueous sodium silicate, industrial-grade 98% NaOH mass fraction of flakes; red and yellow dyestuffs for acidic double-azo, blue dyestuff for acidic anthraquinone, manufactured by Huzhou Yuanhong Environmental Protection Materials Co., Ltd. (Huzhou, China).

Experimental equipment: (1) magnetically stirred water bath, HH-4J type, Changzhou Langyue Instrument Manufacturing Co., Ltd. (Changzhou, China) it increases the rotation of the stirrer in the beaker by magnetic force to increase the dyeing rate of the wood; (2) one ten-thousandth of a balance, LE204E, Mettler Toledo Technology Co., Ltd., Zurich, Switzerland; (3) electronic balance, JY2002, Shanghai Jingqi Co., Ltd., Shanghai, China; (4) spectrophotometer, PV3, Shanghai Meproda Instruments Co., Ltd., Shanghai, China; (5) colorimeter, NR10QC, Shenzhen Sanenshi Technology Co., Ltd., Shenzhen, China; (6) Xenon light detector, Q-SUN XE-2 XENON TEST CHAMBER, Shanghai Luozhong Technology Development Co., Ltd., Shanghai, China; (7) constant-temperature drying box, DHG-9241A, Shanghai Jinghong Experimental Equipment Co., Ltd., Shanghai, China.

2.2. Test Methods

2.2.1. Bleach Pretreatment

Ten sheets each of three species of Ayous, Linden, and Poplar were taken, and a 4 g/L NaOH aqueous solution was made to pretreat the three species to dissolve the wood surface's extractives. This treatment can also enhance the dyeing rate. The treatment time was 15 min to avoid yellowing and lateral drying of the wood. After pretreatment, the veneer was washed fully in water to avoid residual NaOH on the surface, as this affects the pH of the dye solution when dyeing, thereby affecting the color of the dyed wood.

Industrial-grade hydrogen peroxide with a mass fraction of 35% in an amount of 80 g and 20 g/L of analytically pure sodium silicate per 1000 mL of deionized water comprised the bleaching water solution. The configured bleaching water solution was placed in a magnetically stirred water bath with a temperature setting of 65 °C, and then, the veneers pretreated by NaOH were placed in it for the bleach pretreatment for 6 h. The bleached veneers were fully rinsed with water to wash away the bleaching solution residue on the surface, and then, the veneers were placed in a constant-temperature drying oven to 10%~14% moisture content with a temperature setting of 65 °C.

2.2.2. Dyeing Water Bath Experiment

According to the division into the light, medium, and dark color of the dyed veneers, the weight (1 ± 0.0020 g) of each of the three dyestuffs anda 1 g/L dyeing solution were used. The experimental conditions are shown in Table 1.

Table 1. The experimental conditions.

Materials	Treatment	Dyestuffs	Temperature	Time
Ayous	untreated	red	95 °C	6 h
	bleached	red	95 °C	6 h
	untreated	yellow	95 °C	6 h
	bleached	yellow	95 °C	6 h
	untreated	blue	95 °C	6 h
	bleached	blue	95 °C	6 h
Linden	untreated	red	95 °C	6 h
	bleached	red	95 °C	6 h
	untreated	yellow	95 °C	6 h
	bleached	yellow	95 °C	6 h
	untreated	blue	95 °C	6 h
	bleached	blue	95 °C	6 h
Poplar	untreated	red	95 °C	6 h
	bleached	red	95 °C	6 h
	untreated	yellow	95 °C	6 h
	bleached	yellow	95 °C	6 h
	untreated	blue	95 °C	6 h
	bleached	blue	95 °C	6 h

The beaker with the prepared dyeing solution was placed in a magnetically stirred water bath. The temperature was adjusted to 95 °C, and the treatment was carried out for 30 min. The dyestuff was fully dissolved, and the volume was fixed to 1000 mL. Then, the three kinds of untreated veneers and the three kinds of bleached veneers were placed in the three different dyestuff solutions for dyeing. The temperature was set to 95 °C, and the time was 6 h. After the experiment, they were put into the constant-temperature drying oven and dried to 10%~14% moisture content.

2.3. Test and Analysis

2.3.1. Determination of the Color of the Materials

As shown in Figure 2, the color indices of the Ayous, Linden, and Poplar were measured based on the CIELAB color coordinate system [24,25], including L* (value of lightness and darkness), a* (value of red-green), b* (value of yellow-blue), c* (value of chroma), and h* (value of hue angle). The ΔE^*_{ab} was found, and the color change index was analyzed [26–29].

As displayed in Figure 3, wood is a naturally inhomogeneous material, so six measurement points were selected at equal intervals on the veneer, and the mean values were used as the measurement results.

2.3.2. Dye Spectral Determination and Staining Rate Analysis

The 1 g/L initial solution of the three dyestuffs and was diluted with water in a volumetric flask at 5 mL:250 mL. The cuvette was washed three times. and then. the solution was poured in. The spectra of the dyestuffs were scanned by the spectrophotometer, and the variation of the absorbance of the dyes with the wavelength was measured [30–34]. The wavelength in nm was taken as the abscissa (380~780 nm), and the absorbance Abs was taken as the ordinate (0~1 Abs). The measurements were repeated five time for each 1 nm wavelength, as shown in Figure 4. The wavelength corresponding to the red dyestuff peak

was 503 nm; the wavelength corresponding to the yellow dyestuff peak was 434 nm; the wavelength corresponding to the blue dyestuff peak was 599 nm.

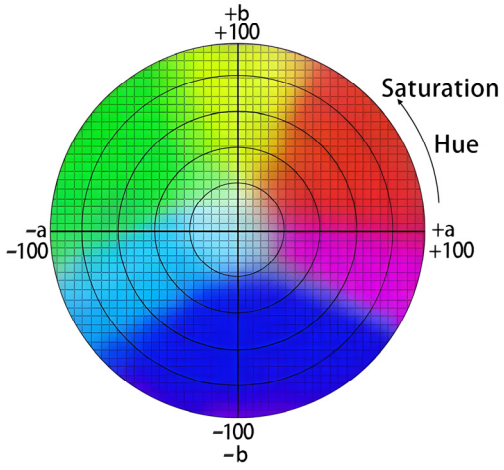


Figure 2. CIELAB color coordinate system [26].

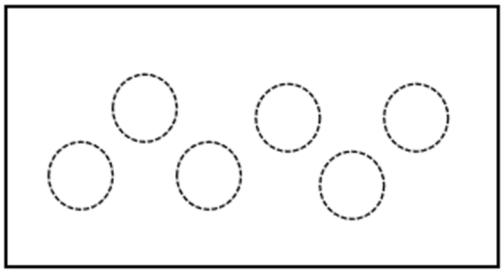


Figure 3. Measurement points.

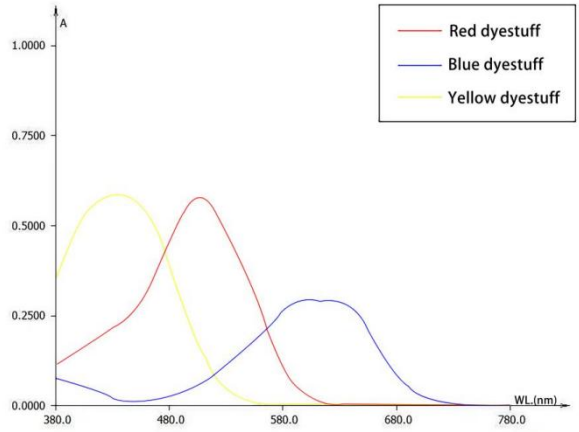


Figure 4. Spectral scan of three dyestuffs.

The remaining dye solution was fixed to 1000 mL per hour, and the wavelength of the dye was set according to the wave peak of the spectrogram. Then, the change of absorbance of the remaining dye solution was tested to compare with the initial absorbance. Since the change of the dyestuffs' concentration was proportional to the change of absorbance at the same wavelength, the change of the dyestuffs' concentration was obtained from the change of the absorbance of the remaining dye solution, so as to obtain the change of the dye staining rate, as shown in Equation (1).

$$\text{Dyeing Vrate} = \frac{A_0 - A_t}{A_0} \times 100\% \quad (1)$$

where A_0—initial absorbance of the dyestuff solution and A_t—remaining absorbance of the dye solution.

2.3.3. Environmental Scanning Electron Microscopy

The environmental scanning electron microscope, a Quanta 200, was used to analyze the microscopic morphology of the untreated and bleached stained veneers at 200×, 400×, and 1000× magnification.

3. Results and Discussions

3.1. Color Analysis

The color of wood is mainly derived from its lignin and extractives and from its absorption and reflection of light sources. The color varies depending on the wavelength of reflection. Otto Nikolaus Witt proposed that the color of organic compounds is due to chromophores in the molecular structure, and the presence of co-chromophores also enhances the role of chromophores [21–25,27]. Thus, wood color is mainly derived from chromophores such as carbon-based ones, benzene rings, vinyl groups, pine aldehyde groups, and lone pairs of electrons such as -OR, -NR2, and -Cl as electron-donating groups in the Π-conjugated system. Furthermore, lignin reacts with aromatic amines, phenolic compounds, and inorganic compounds to produce color. Then, the extractives in the wood are part of the wood coloring, where the polyphenols and pigments also absorb part of the light source [35,36]. The NaOH pretreatment dissolves the extractives on the surface of the wood, and then, the color-emitting groups, color-assisting groups, and coloring-related components in the wood are destroyed by oxidation, reduction, and degradation through the bleaching agent. Therefore, the wood is decolorized. As shown in Table 2, the lightness and darkness L* and h* values of the three substrates increased, and the red and green values a*, yellow and blue values b*, and the color degree value c* decreased.

Table 2. Color depth values of the veneers.

–	–	L*	a*	b*	c*	h*
Ayous	untreated	81.36	8.46	26.52	27.81	72.33
	bleached	92.88	0.20	12.13	12.13	89.15
	Δ	−11.52	8.26	14.39	15.68	−16.82
Linden	untreated	82.63	5.93	23.91	24.63	76.08
	bleached	91.83	−0.19	7.66	7.66	91.41
	Δ	−9.20	6.12	16.25	16.97	−15.33
Poplar	untreated	83.96	5.01	19.31	19.95	75.45
	bleached	89.65	1.42	9.69	9.70	89.41
	Δ	−5.69	3.59	9.62	10.25	−13.96

The effect of wood dyeing is mainly influenced by the color of the wood itself. Under the same dyeing conditions, red, yellow, and blue dyestuffs were used to dye three types of substrates, namely Ayous, Linden, and Poplar. As shown in Table 3, there was variability in the surface color depth values of the finished dyed veneers between veneers with bleach pretreatment and the untreated dyed veneers. By processing the raw data of the color measurement of each dyed veneer in the six groups, it was found that, as wood is an inhomogeneous material, the deviations between the data of the surface color measurement of the dyed veneers with the bleach pretreatment were smaller, and the errors between the raw data of the untreated wood dyed veneers were larger. The phenomenon of the large variability of the surface color depth values of the same veneer also illustrates this characteristic, indicating that the veneers' staining was more uniform after bleaching. This bleach pretreatment can regulate of the color difference of the veneers' surfaces. The dyeing effect was more uniform, so that a greater intended dyeing effect can be achieved.

Table 3. Color depth values of the dyed veneers.

–	–	–	L*	a*	b*	c*	h*
Ayous	red	untreated	44.27	44.71	14.61	47.03	18.09
		bleached	50.03	44.59	8.96	45.48	11.36
	yellow	untreated	67.17	24.62	64.41	68.95	69.08
		bleached	74.15	42.40	66.63	64.47	71.52
	blue	untreated	42.88	−8.06	−22.19	23.61	250.04
		bleached	52.65	−13.24	−21.19	24.98	238.00
Linden	red	untreated	41.04	42.05	16.27	45.08	21.16
		bleached	49.24	42.41	8.77	43.31	11.68
	yellow	untreated	64.63	25.31	63.37	68.23	68.23
		bleached	74.53	19.13	57.49	60.58	71.62
	blue	untreated	35.02	−5.17	−20.04	20.69	255.52
		bleached	50.55	−8.17	−26.54	27.77	252.90
Poplar	red	untreated	43.63	39.11	9.56	40.26	13.73
		bleached	45.65	43.36	9.81	44.45	12.75
	yellow	untreated	65.55	19.06	50.60	54.08	69.36
		bleached	71.27	23.37	64.07	68.20	70.00
	blue	untreated	45.77	−10.68	−18.09	21.11	238.90
		bleached	50.15	−8.90	−25.40	26.91	250.70

3.2. Analysis of Dyeing Rate

The dyeing rate of wood is affected by many factors, including the dyeing conditions, substrates, dyestuffs, etc. Under the same dyeing conditions, the dyeing rate of different dyestuffs on different substrates shows variability. The hydrophilic groups of dye molecules, such as sulfonic acid groups, were dissolved in an aqueous environment under the thermodynamic force of the high temperature to form hydrated ions or hydrated molecules, which, along with the diffusion of the aqueous solution, settled on the wood through the network of pores formed by the grain pores and ducts of the three substrates [37,38]. The dyeing was mainly the result of the migration of the liquid into the wood. From the perspective of the mass flow, the movement of the liquid was along the pore network in the wood structure under the action of a static pressure gradient or capillary pressure gradient, whose driving force can be considered that of the momentum gradient density. Diffusion is mainly divided into that of the gases and the bound water in the cell wall. The dyeing solution entered the wood channel with the aqueous solution. After diffusion through the wood cell wall, the dyeing solution settled on the fiber surface to dye the wood.

Three structurally different dyestuffs were used to stain the three different substrates. The dyeing rates are shown in Figures 5–7. Figure 5 shows the three woods stained with red double-azo dyes. The Ayous and Poplar logs had higher staining rates than the bleached ones, but the Linden had less variability in the staining rates before and after bleaching. Figure 6 shows the staining of the three woods with yellow double-azo dyes. Comparing Figures 5 and 6, it is found that the untreated Poplar wood showed a higher adsorption of the red dye. The Linden wood showed a higher adsorption of the yellow dye, and this was significantly higher than the other woods. Figure 7 shows the blue anthraquinone dyes on the three woods. The bleached Linden had a slightly higher staining rate than the untreated basswood, and the Ayous and Poplar both had a lower staining rate than the original wood. A comparison of Figures 5–7 reveals that there was variability in the adsorption of the different dyes by the same species of wood, with the yellow dye having a significantly lower staining rate than the other dyes. The dyestuff was also an important factor affecting the dyeing effect on the wood. From these three figures, it can be found that the dyeing rate increased continuously with time, and the dyeing rate increased rapidly in

the first 2 h, then slowed down gradually. The equilibrium of the dyeing rate of the Ayous was reached around 5 h, while the dyeing velocities of the Linden and Poplar continued to increase within 6 h, which indicates that the dye adsorption capacity of the Linden and Poplar was higher than that of the Ayous. Under the same dyeing conditions, the dyeing rate of the Ayous was the lowest, and the dyeing rate of the Poplar was the highest among the three materials in terms of the substrate and the dyestuff; the overall dyeing rate of the yellow dyestuff was the lowest.

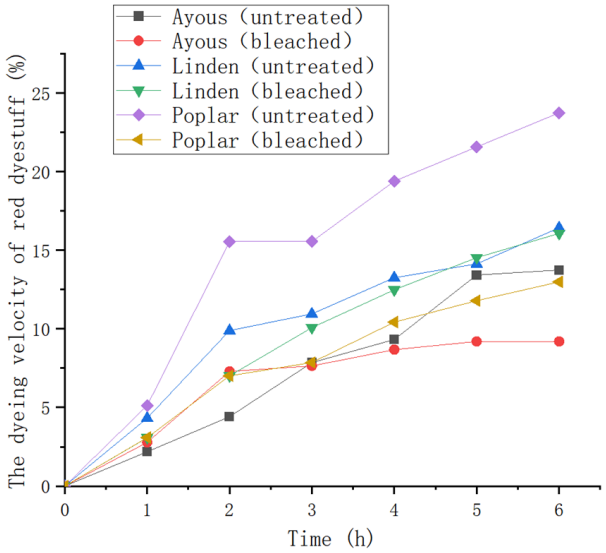


Figure 5. Dyeing rate of red dyestuff.

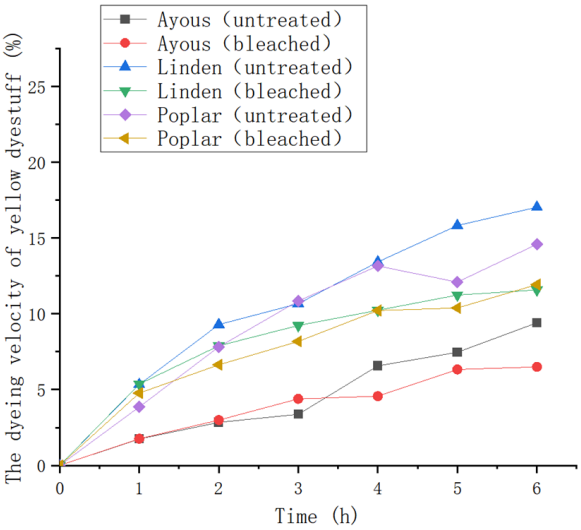


Figure 6. Dyeing rate of yellow dyestuff.

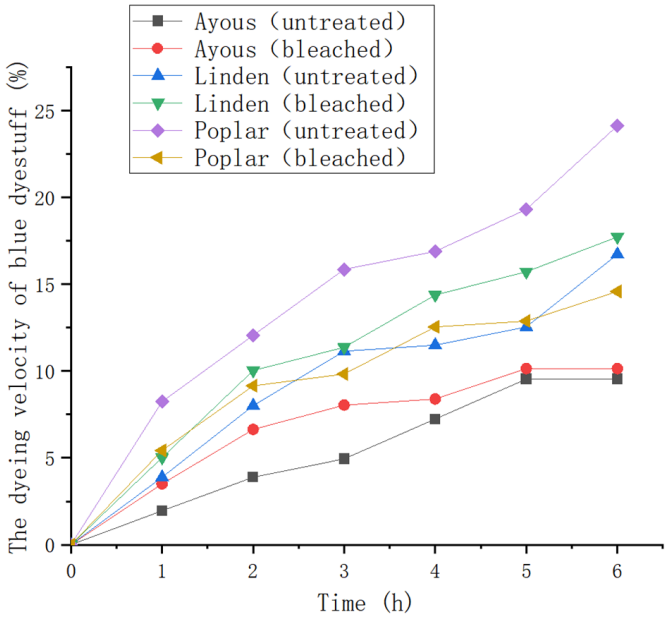


Figure 7. Dyeing rate of blue dyestuff.

The final dyeing rates of the red and blue Linden veneer tended to be similar to the untreated dyed veneers, while the final dyeing rates of the other veneers were less than those of the untreated dyed veneers. The final dyeing velocities of the red and yellow Ayous veneers, yellow Linden veneer, and red, yellow, and blue Poplar veneers decreased by 4.54%, 2.91%, 5.45%, 10.75%, 2.66%, and 9.55%, respectively. This indicates that the dye adsorption capacity of the untreated veneers was higher than that of the dyed veneers with the bleach pretreatment. The bleach pretreatment damaged the wood structure to some extent, and the wood degraded, such that the dye molecules could attach better, resulting in a generally lower final staining rate for the bleached veneers than that of the untreated veneers. The final staining velocities of the dyed veneers were slightly higher than that of the bleach-pretreated dyed veneers. Therefore, there is a correlation between the staining rate of the wood and the species, the dye, the staining time, and the bleach pretreatment.

3.3. Micro-Analysis

Bleach treatment is a pretreatment process for wood dyeing. By degrading the color-forming groups in the lignin and removing the extractives of the surface, it opens up the ducts and pores, which are important transport tissues of the wood. Due to the facilitation of the diffusion of the dye molecules, staining is widely applied to broadleaf timber.

The staining rate of the bleached veneers was better than that of the untreated veneers, but the final staining rate was lower than that of the untreated wood. Based on the SEM results shown in Figures 8 and 9, the bleach pretreatment had a greater effect on the microscopic surface morphology of the veneers. After the bleach pretreatment, the surface extractives were almost removed from the veneers and some of the ducts and grain pores were broken. The pore size increased, and the hydrated ions or hydrated molecules formed by the dye molecules and water were subjected to less resistance to flow [24,25,27–29]. In Figure 8, the unbleached Ayous wood is smoother at the microscopic level. In comparison, the surface of the bleached Ayous wood in Figure 9 is damaged with wrinkled grain pores and broken ducts. As shown in Figure 10, the wood permeability was enhanced, and the dye molecules were able to settle on the wood faster, even forming a pile-up phenomenon. The dyeing rate was enhanced, and there was an activating effect on the wood's surface.

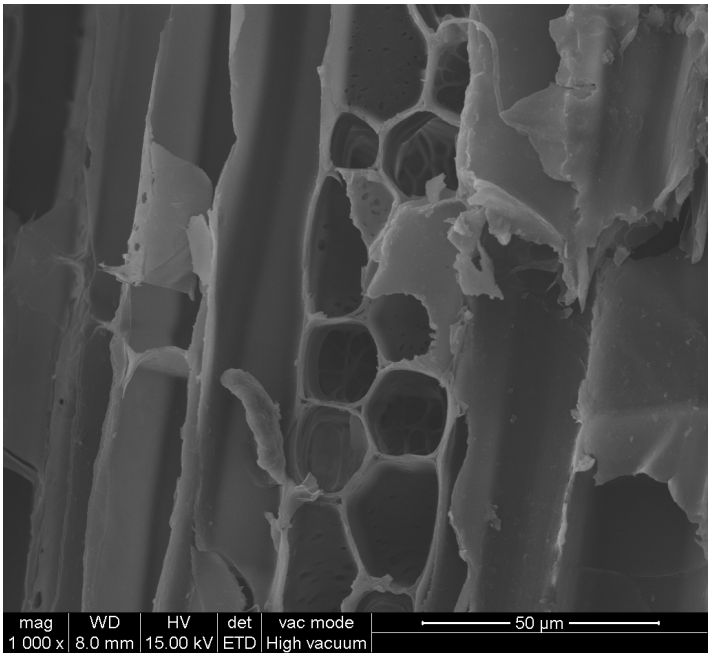


Figure 8. Untreated Ayous.

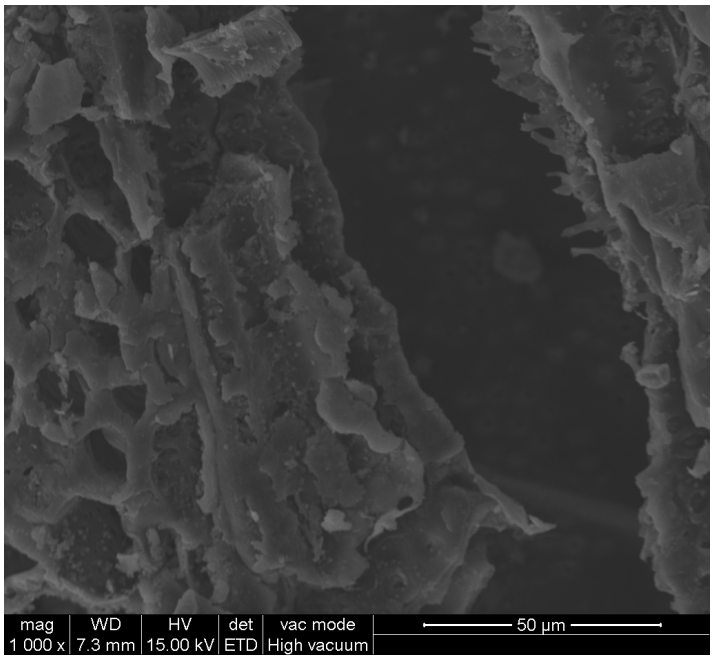


Figure 9. Bleached Ayous.

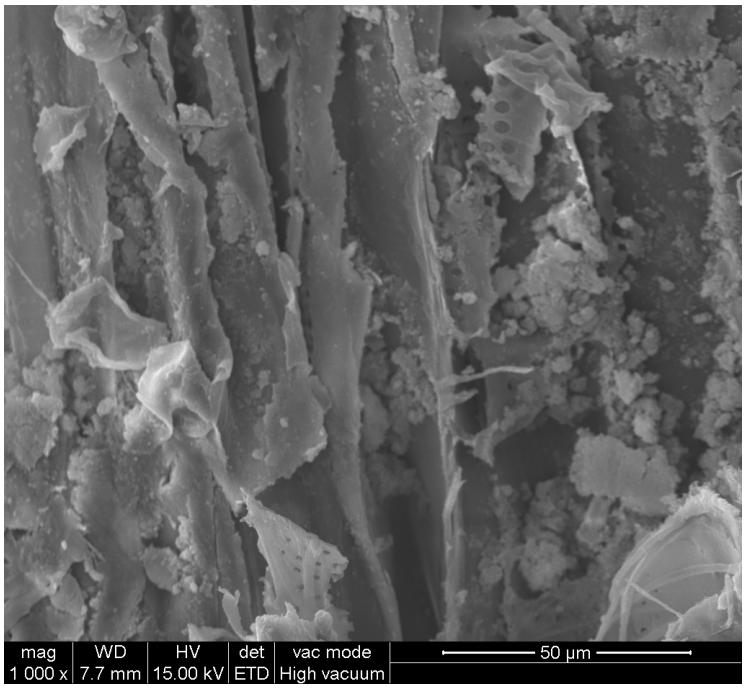


Figure 10. Dye buildup of bleached veneers.

3.4. Discussions

After the bleach pretreatment, the wood color changed and became more uniform, mainly characterized by an increase in the light and dark values, with the a* values close to zero and a decrease in b* and c*. Table 1 reveals that there was variability in the effect of the $NaOH/H_2O_2/Na_2SiO_3$ bleach pretreatment method on the color of the three materials under the same treatment conditions. By comparing the Δ values after bleaching, it was found that the treatment had a greater effect on the color of the Ayous and Linden and a smaller effect on Poplar.

According to Table 2, the L* values of the bleach-pretreated stained veneers were all higher than those of raw wood stained veneers. The a* values were similar when the red dyes were used to stain the Ayous and Linden, and the b* values were similar when the yellow dyes were used to stain the Ayous and Linden. The color variability between the bleach-pretreated stained veneers and the virgin stained veneers was mainly characterized by other values. The color of the bleached veneers was more homogeneous.

In terms of the staining rate, the $NaOH/H_2O_2/Na_2SiO_3$ bleach pretreatment resulted in an increase in the staining rate, and the veneer could reach the equilibrium staining rate much faster. This was due to the improved permeability of the veneer after the bleach pretreatment. However, the bleaching reagent caused some damage and degradation to the veneer. The dye adsorption capacity of the veneer decreased, so the final staining rate of the veneer decreased. Furthermore, it was found by scanning electron microscopy that the $NaOH/H_2O_2/Na_2SiO_3$ bleach-treated Ayous veneer showed the wrinkling and fracture of the ducts. This is also the reason for the change of the staining rate of the wood. Meanwhile, a large amount of dye buildup occurred on the surface of the veneer after the bleach pretreatment.

In this work, the bleaching and dyeing of three types of wood were explored, which were Ayous, Linden, and Poplar. Compared with other works, this work systematically studied the effect of bleaching on the dyeing performance. However, this work also had its limitations. Only three different kinds of wood were selected to analyze the effect of bleaching on the wood's dyeing properties, and the conclusions may not be applicable to all woods. Furthermore, bleach pretreatment still has an impact on other properties of

the dyed veneer, such as light-aging resistance. Therefore, in future research, the dyeing performance and light-aging resistance for different tree species need to be further explored.

4. Conclusions

In this work, the effects of the $NaOH/H_2O_2/Na_2SiO_3$ bleach pretreatment method on the dyeing properties of wood were focused in this work, and the main conclusions are listed as follows:

(1) Bleach pretreatment can regulate the color of finished dyed wood products and achieve the uniformity of wood dyeing.

(2) After the bleach pretreatment, along with the removal of surface extractives and the degradation of the color-emitting groups in the lignin, the ducts and grain pores were damaged, and the pore size increased, which enhanced the permeability and surface activation properties of the wood. This enabled the dye molecules to settle quickly. This led to an increase in the dying rate and a decrease in the final dyeing time.

(3) In the current industrialization of dyed wood, wood can be moderately bleached beforehand, considering the subsequent visual characteristics. Furthermore, the bleach pretreatment method can enhance the dyeing rate and shorten the wood dyeing time; this is beneficial to the long-term development of the wood industry.

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