CHEMICAL TREATMENT TO IMPROVE WOOD FINISHING

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ABSTRACT

Black poplar (*Populus nigra* L.) boards were treated with different chemicals including sodium hydroxide, aluminum chloride, and ammonium chloride in aqueous solution; finished with commercial grade varnish; and exposed outdoors for one year to study the stability of the finishing after treatment. The appearance of the boards before and after a one-year exposure was found to be related to the type of chemical used. In the case of NaOH solution, the increase of the treatment temperature from 21°C to 70°C improved the penetration of NaOH solution and subsequently the distribution of finish material in the wood. The absorption, penetration depth, and finishing of wood were markedly better with aqueous solutions of NaOH, compared to $AlCl_3$, NH_4Cl, and water. The pretreatment of boards with the different chemicals decreased the photochemical discoloration of finished boards to the lowest limit after they were exposed to natural sunlight for one year.

Keywords: black poplar (*Populus nigra*), finishing.

INTRODUCTION

Wood is susceptible to weathering and photo-oxidative degradation due to sunlight and moisture, which cause photochemical oxidative degradation of wood. Sunlight raises the temperature and thus increases the chemical reaction rate with the gases present in the atmosphere, especially oxygen. This leads to photochemical degradation of wood surface, resulting in color changes as a result of chemical changes in the wood components. The change in the wood color with sunlight is due to chemical breakdown (photo-oxidation) of lignin and wood extractives (Hon and Feist 1980a). All wood components including cellulose, hemicelluloses, lignin, and extractives are susceptible to photochemical degradation (Gellerstedt and Petterson 1977). Fortunately, ultraviolet light penetrates the surface layer of wood to a depth of no more than 75 mm (Hon and Ifju 1978). Consequently, the interaction of wood and UV light is essentially a surface reaction, in which free radical intermediates generated by light play a major role in surface deterioration and discoloration (Hon and Feist 1980b; Hon 1981; Kalnins 1966).

Fluctuations of temperature, caused by the day and night cycle including insolation, cause physical stress (expansion and contraction) and result in cracking of the wood surfaces. Water also causes the paint to blister and peel; and it promotes the growth of mold on the cracked surface layer. The intimate contact of dew with the wood surface may promote other reactions leading to changes in the appearance of the wood surface.

The principal functions of wood finishes are to protect the wood surface against photochemical deterioration and to maintain appearance. However, wood surfaces can be stabilized against deterioration using a variety of chemical treatments (Chang et al. 1982; Feist and Williams 1991; Feist 1987). Paint and other coatings can protect wood against sunlight deterioration by blocking degradative UV light from reaching the surface. The duration depends on the wood properties, including, *inter alia,* moisture content; density; texture; resin and oil content; annual ring orientation; natural defects in the wood; the nature and quality of the finish used; application technique and pretreatments; and weather conditions (Banove 1973).

Black poplar is distributed widely in many regions of Iraq. It is grown in private and government plantations, which facilitates the availability of the wood to local markets. However, use of the wood is limited due to lack of information on its technical properties. The development of improved surface finishing extends the scope for the utilization of poplar wood. Good finishing of poplar wood is difficult.

This study examined the effectiveness of various inorganic treatments of the wood surface to protect against photodegradation as well as the performance of finishes applied on these treated surfaces. The treating variables, including the type of inorganic chemicals and the concentrations and treatment temperature of NaOH, were investigated to determine their effect on finish penetration and coloration of the wood surfaces. The evaluation of the treatment variables was based on their effect on performance and coloration of wood surfaces.

MATERIALS AND METHODS

Four trees of black poplar (*Populus nigra* L.) of the same age from one site and location were selected to prepare the boards for this study. A one-meter-long log was cut from each tree at the same height (80 cm above ground). The logs were quarter-sawn, and 28 boards were prepared from each log to produce 112 boards from four logs for this study.

Smoothly planed vertical-grain sapwood specimens of 0.6 × 7.0 × 25.0 cm in size, air-dried to 10% moisture content, were immersed in the following aqueous solutions:

1. Water.
2. Aqueous sodium hydroxide (NaOH of 1% and 2% by weight).
3. Aqueous aluminium chloride ($AlCl_3$ of 2% by weight).
4. Aqueous ammonium chloride (NH_4Cl of 5% by weight).

The solution temperatures were controlled in a water bath. The solution completely covered the boards to ensure an even distribution of absorption at temperatures of 45°C and 70°C. The immersion times ranged from 1 to 4 h. To study the effect of concentration, NaOH was used at two concentrations (1% and 2%) at a temperature of 70°C. To study the effect of the temperature change on board finishing, the temperature was changed from 21°C to 45°C and 21°C to 70°C using a solution of 1% NaOH. The immersion times for these experiments also ranged from 1 to 4 h. In view of the ready availability of NaOH, the trials focused mainly on the use of this chemical. It was used at low concentrations of 1% and 2% to avoid unfavorable degradative side reactions of NaOH with wood components.

At the end of treatment, the boards were taken out of the solution, and the amount of chemical absorption was determined by weighing before and after treatment. The treated boards were subsequently air-dried in the laboratory to a moisture content of approximately 10%. A micrometer was used to measure the penetration depth of the chemicals in the wood, after the boards were sliced. The slicing process was to remove the colored portion using a lab-scale bandsaw, and measuring the board thickness after using the micrometer. The penetrated thickness was identified using commercial stable dyes. The thickness of the boards before slicing and after slicing was measured, and the sliced portions were measured also. Multiple readings at different locations of the boards and of the sliced portions were taken in the interest of accuracy.

The boards were finished with commercial

TABLE 1. *The effect of chemicals and concentrations on wood absorption (based on weight difference) at 70°C.*

Treatment Time hours	Absorption of applied solution				
	H_2O %	1% NaOH %	2% NaOH %	2% $AlCl_3$ %	5% NH_4Cl %
1	44.51	38.01	61.81	29.49	24.69
2	45.71	89.18	86.34	52.49	56.20
3	59.36	103.08	95.04	61.70	74.52
4	82.90	140.82	121.42	61.73	90.08

TABLE 2. *The effect of chemicals and concentrations on finish penetration (mm) at 70°C.*

Time Treatment hours	H_2O mm	1% NaOH mm	2% NaOH mm	2% $AlCl_3$ mm	5% NH_4Cl mm
1	1.29	1.67	1.15	1.10	1.13
2	1.31	1.76	1.35	1.25	1.14
3	1.43	1.88	1.63	1.31	1.21
4	1.50	2.07	1.67	1.34	1.29

grade spirit varnish. Finishing was carried out in three stages: 1) cleaning and sanding of the surface; 2) applying the varnish with a soft brush, followed by 2 h of drying; and 3) applying varnish for the second time in the same quantities and direction. The laboratory temperature ranged from 21–23°C. The colors of the finished boards were recorded using Munsell Color Chart match (Munsell Color Chart 1954) based on the hue, value notation, and chroma. The depth of finish penetration was determined by direct measurements and confirmed by slicing (as before). The finished boards were left in the open-air for one year to study the stability of the finishing. The treated boards were horizontally arranged with the finished surface facing the sunlight on a table for more uniform exposure to the sunlight. The treated specimens were protected only from direct rainfall during the rainy season, which extended from December to March. The annual rainfall was approximately 30 cm. To protect against direct rainfall, a transparent plastic cover was fitted at a distance of 1 meter away from the top to maximize sun exposure. After one year of exposure, the colors of the boards were determined, on the same basis as before using Munsell Color Chart match.

A statistical analysis was carried out (analysis of variance, ANOVA) and the variance determined for all the variables in the trials—namely, chemical solutions, different treatment temperatures only in case of NaOH solution, and the two concentrations of NaOH. The effects of the applied chemicals on absorption and penetration depth are noted in the tables. Each of the numbers in the tables represents an average of two (duplicate) observations.

RESULTS AND DISCUSSION

Chemicals and absorption

As shown in Table 1, the effect of the chemicals on absorption varied, especially after 1 and 2 hours of treatment at 70°C. The absorption of NaOH (1% and 2%) was higher than that of the other chemicals. The 5% ammonium chloride and water showed a similar level of absorption, while 2% $AlCl_3$ had the lowest absorption average of all the chemicals tested.

The difference in absorption between these chemicals is due to the different abilities of the chemicals to swell the wood and penetrate its structure, and is related to the formation of new bonds with wood components (cellulose, hemicelluloses, lignin, and extractives) (Rowell 1984). In addition, the applied chemicals had different effects on the hydrogen bonding within and between wood components.

Chemicals and finish penetration

Penetration depth of chemicals inside wood is an indication of chemical changes in the functional groups caused by the applied chemicals. As shown in Table 2, the penetration depth was 1.10–2.07 mm for different chemical solutions including water at 70°C. The solution containing NaOH (1% and 2%) penetrated the wood more than the others.

The cellulose, hemicelluloses, lignin, and extractives have different functional groups that affect penetration. They also have different physical properties, which lead to nonhomogeneous absorption (Rowell 1984). The ability of the solution containing NaOH to penetrate more than others may be due to its strong electrolyte absorbability, which is higher than that of the other chemicals tested (Mahan and Myers 1987). The penetration depth increased with an increase in immersion time due to the longer contact between the solutions and wood.

Solution concentration and absorption

Table 1 shows that absorption increased with increase of the concentration of NaOH in the solution from 0% (water) to 1% over the period of 1 to 4 h at 70°C. However, at the same temperature, increasing the concentration of NaOH to 2% also increased the absorption at the beginning; then it slowed down after 1 h. The concentration of 1% NaOH solution was higher in absorption than 2% NaOH solution due to the lower concentration and higher distribution of solute, as can be seen from Table 1.

The lower concentration of NaOH solution (1%) was more highly absorbed by the boards, than the higher concentration (2%) as shown in Table 1. Both concentrations indicated the same trend of absorption (the absorption increased with time increase).

Solution concentration and penetration depth

The penetration depth of the varnish decreased with the increase of NaOH concentration in the solutions used compared with water (0% concentration), as shown in Table 2. An increase of NaOH concentration to 2% slowed the penetration over the period of the trial. This may due to the slow movement of the high number of molecules inside the wood structure and also the greater hydrogen bonding between NaOH molecules than with wood components (Abrash and Hardcastle 1981).

Treatment temperature, effect on absorption, and penetration of solution

The results of temperature increase on absorption and penetration depth of 1% NaOH solution are presented in Table 3. This shows that the temperature change has a strong effect on the absorption of 1% NaOH solution. The increase of treatment temperature from 45°C to 70°C increased the penetration depth of 1% NaOH solution. The increase of the absorption and the penetration depth with an increase in temperature may be due to the increase of hydrogen bonds in the structure of wood (between its components), in addition to the breaking of some of the bonds, which gives more free space for movement of the solution.

TABLE 3. *The treatment temperature effect on wood absorption and finish penetration depth of 1% NaOH solution.*

Treatment Time hours	Ambient Temp. °C		45°C		70°C	
	Abs. %	Pen.mm	Abs. %	Pen.mm	Abs. %	Pen.mm
1	18.83	1.25	32.14	1.40	38.01	1.67
2	24.73	1.41	34.35	1.63	89.18	1.76
3	30.18	1.51	59.17	1.73	103.08	1.88
4	34.69	1.65	64.24	1.83	140.82	2.07

The samples subjected to different treatments were checked to determine treatment effect on wood weight, wood degradation, and color. The samples showed no color changes after a one-year exposure to outdoor and due to the application of chemicals, treatment temperature, and concentration changes.

The analysis of variance of the results showed that the use of chemicals is significantly effective (probability < 0.01) on penetration depth at 70°C with different immersion times. Due to the higher penetration of NaOH solution compared to the others, the temperature and the concentration were both changed to maximize the effect on board final finishing. The results of the treatment temperature effect on absorption of 1% NaOH and the concentration of NaOH in the solution were significantly effective at the lower limit (probability < 0.05), as shown in Table 4. This finding supports the idea of using the higher temperature of 45°C or 70°C and also of using a 1% NaOH concentration, which increased the penetration more than did a 2% NaOH concentration.

TABLE 4. *The analysis of variance of the results of wood treatments.*

Source of variance	Degree of freedom	Absorption	Penetration depth
Solution	3	0.039	0.251**
Temperature†	2	0.067*	0.091*
Solution Conc.†	2	0.048	0.153*

* Variation is significant at probability of <0.05.
** Variation is significant at probability of <0.01.
† In the case of NaOH only.

Color stability

Table 5 shows the color difference related to the variables used in this study. The finished boards' color was affected by the chemicals applied at 70°C for different times of immersion. There was a variation in the color of the finished boards related to the temperature when 1% NaOH solution was applied at 21°C, 45°C, and 70°C. The change in the concentration of NaOH solution resulted in a variation of color stability at 70°C for different times of immersion. The color variation could be used as an indication of chemical penetration and distribution inside the wood structure, which affected bonding between these chemicals and wood components or created some new bonding. The treated boards were classified into four groups according to coloration (Table 5). The first line in Table 5 shows the hue, value notation, and chroma, while the second line gives the color. In the case of water (the last group in Table 5), the intensity of the yellowish red is 5 YR 5/6 (based on the Munsell Color Chart) which is different from the group before (NaOH 1% and 2% $AlCl_3$) in the intensity of yellowish red of 5 YR 4/6.

CONCLUSIONS

Poplar boards treated with different chemicals, at various temperatures, and concentrations for different times showed different chemical absorption and penetration depths. NaOH was the most effective in both absorption and penetration. The penetration of NaOH solutions of 1% and 2% concentrations inside the wood improved with an increase in temperature.

TABLE 5. *Board colors before and after one year of treatment related to different variables.*

Color	Solution	Concentration	Tem. °C
2.5 YR* 3/4**	NaOH	1% and 2%	45 and
Dark reddish brown†			70
5YR 3/3	NH_4Cl	5%	70
Dark reddish brown			
5YR 4/6	$AlCl_3$	2%	70
Yellowish red	NaOH	1%	Ambient
5YR 5/6	H_2O	0%	70
Yellowish red			

* 2.5 YR: hue.
** 3/4: value/chroma.
† The color.

Generally NaOH at low concentrations of 1% and 2% can be used to improve the finishing of poplar wood when the wood is treated at a temperature range of 45–70°C for 1–4 h. The results of this experiment showed an improved protection of the finished wood against deterioration. The treatment also resulted in good finished surface appearance, which is difficult to obtain without treatment.

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