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Full Length Research Paper

Effects of heating treatment on some of the physical properties of varnish layers applied on various wood species

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The aim of the current study is to determine the effects of different heat treatment and varnish combination applications on some of the physical properties of wood materials sampled from limba (*Terminalia superba*), iroko (*Chlorophora excelsa*), ash (*Fraxinus excelsior* L.) and Anatolian chestnut (*Castenea sativa* Mill.) species. The heat treatment was applied at two levels (150 and 180°C) for both 3 and 6 h period. Once heat treatment was conducted, four types of varnish layers (cellulose lacquer, synthetic varnish, polyurethane varnish and water based varnish) were applied to the materials. After the treatments application, color, brightness and surface roughness of varnish film layers of the treated woods were measured. The effects of heat treatment and varnish combination applications on the earlier mentioned variables were analyzed according to the study design (factorial design with 4 (species) x 2 (heat) x 2 (duration) x 4 (varnish) = 64 experimental units). For significant analysis of variance (ANOVA) , Duncan mean separation test was performed to separate the interaction combinations. Results of the study indicated that surface roughness increased on wood samples for all four wood species treated with cellulose lacquer and synthetic varnish and across all heating treatments. However, surface roughness decreased for all wood species depending on heating temperature and time. As such, the value of brightness also decreased for all four wood species across all the treatment combinations. The results obtained from the upper surface of the enforcement process are thought to contribute to the national economy.

Key words: Heating treatment, cellulose lacquer varnish, synthetic varnish, polyurethane varnish, water based varnish, surface roughness, brightness, color changes.

INTRODUCTION

Timber is an essential element used for decoration and as a building material in both indoor and outdoor substances. Thus, durability, capacity and natural looks of the used materials should be protected in a long-run for both indoor and outdoor conditions. For this reason, a trial has been made to modify some of the wood properties by thermal processing techniques since the 1990's.

However, results of the studies have indicated that heat treatment alone is not an adequate prevention action to protect the materials for varying conditions. On the other hand, application of surface coating and/or protective lacquer coating on heat-treated materials provided long-term protection for the wooden materials against decaying and deterioration of natural looks.

The fact that the wooden material has many specific advantages made it attractive in many application areas. Color and texture are also important in wood-type selection, beside mechanical characteristics. However, because wooden materials are organic matters, they cannot resist naturally, the external effects to which they are

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Abbreviations: MC, Moisture contents; **RH,** relative humidity.

made subject for long times. Therefore, wooden materials should be protected by various preservatives (Sogutlu, 2004). Wooden materials should be preserved for improving its durability against outdoor effects. It was reported that the most popular method is to coat outer surfaces of wooden materials with various lacquer layers to preserve them against weathering effects (Highley and Kirk, 1979).

Heating process has been known for centuries in developing wooden materials' strength such that Vikings used the heating process for outdoor structures like fences, 1000 years ago. The first scientific studies on wooden materials' treatment by heating process were executed by Stamm and Hansen (German scientists) in 1930 and White, a scientist from USA in 1940. Bavendam, Runkel and Buro (Germans) continued studying on this matter in the 1950s, while Kollman and Schneider in the 1960s and Rusche and Burmester in the 1970s also conducted a study on this matter (Korkut, 2008). Heat treatment is often applied to improve the dimensional stability of woods. The aim of the heat treatment is to decrease the swelling-shrinkage of wood and therefore, to increase its dimensional stability and biological resistance, permeability and the quality of surface treatments. Additionally, it is aimed at decreasing the equilibrium moisture content. The heat treatment process involves exposing wood to elevated temperatures ranging from 120 to 240°C. Heat-treated wood has been considered as an ecological alternative in impregnated wood materials and it can also be used for several purposes, for example, garden, kitchen furniture, outdoor furniture, sauna elements, building elements, furniture to be used under dry conditions, flooring materials, ceilings, inner and outer bricks, door-window joinery, sun blinds and noise barriers (Korkut and Kocaefe, 2009; Sevim et al., 2008).

Varnish is a transparent, hard, protective finish or film primarily used in wood finishing, but also for other materials. It is traditionally a combination of a drying oil, a resin and a thinner or solvent. Varnish has little or no color. It is transparent and has no added pigment, as opposed to paints or wood stains, which contain pigment and generally range from opaque to translucent (Kurtoğlu, 2000; Sonmez, 2000; Sonmez and Budakçi, 2004; Budakçı et al. 2010). Quick-drying solvent-based lacquers that contain nitrocellulose, a resin obtained from the nitration of cotton and other cellulostic materials, were developed in the early 1920s and extensively used on wooden products, primarily furniture, and on musical instruments and other objects. The preferred method of applying quick-drying lacquers is by spraying, and the development of nitrocellulose lacquers led to the first extensive use of spray guns. Nitrocellulose lacquers produce a very hard yet flexible, durable finish that can be polished to a high sheen. Drawbacks of these lacquers include the hazardous nature of the solvent, which is flammable, volatile and toxic in handling hazards of nitrocellulose in the lacquer manufacturing process (Kurtoğlu, 2000; Sonmez, 2000). Polyurethane varnishes are typically hard, abrasion-resistant and have durable coatings. They are popular for hardwood floors but are considered by some to be difficult or unsuitable for finishing furniture or other detailed pieces. Polyurethanes are comparable in hardness to certain alkyds, but generally form a tougher film. Exterior use of polyurethane varnish may be problematic due to its heightened susceptibility to deterioration through ultra-violet light exposure (Kurtoğlu, 2000).

Synthetic resins are tougher and more resistant to wear, while synthetic varnishes are very highly resistant to scratches, temperature and sweat, but they give serious problems in their repair (Sonmez, 2000). Water-based finishes are actually made up of droplets of solvent-based finish, usually acrylic or polyu-rethane, and a solvent, usually glycol ether, with water functioning as a thinner. Water-based finishes are treated by coalescing, while the droplets of finish move closer together and interlock as the water evaporates. Water-based finishes offer minimal solvent fumes, easy cleanup and good scuff resistance, but they may raise the wood grain and offer only moderate resistance to water, heat and solvents (Sonmez and Budakçi, 2004).

The aim of this study is to examine the effect of heat treatment on some type of wood varnish layers in ash, Anatolian chestnut, limba and iroko wood, having high industrial potential in Turkey.

MATERIALS AND METHODS

For the wood materials, we used four tree species highly preferred by furniture and the other woodwork industries. Two of them, ash (*Fraxinus excelsior* L.) and chestnut (*Castenea sativa* Mill.), are commonly distributed in the western Black Sea region of Turkey (Yildiz et al., 2006; 2007; 2010). The other two species, limba (*Terminalia superba*) and iroko (*Chlorophora excelsa*) are exotic to Turkey.

The heat treatment was applied at two levels (150 and 180°C) for both 3 and 6 h period. Once heat treatment was conducted, four types of varnish layers (cellulose lacquer, synthetic varnish, polyurethane varnish and water based varnish) were applied to the materials (Table 1). Each treatment combinations were repeated 10 times. After the treatments applications, using light reflections, sample brightness was measured with the aid of Elrepho spectrophotometer according to TS 4318 EN ISO 2813 (2002) standards. For the same samples, colors were also measured with the aid of Elrepho spectrophotometer according to ASTM D2244-07e1 (2007) standards (Figure 1).

Color measurements were made using a tritimus photoelectric colorimeter (Elrepho) with a measuring head of 50 mm in diameter. The Elrepho measures the colour with three coordinates in three-dimensional colour space (Figure 2). This system is called CIE L*a*b* and works according to the CIE standard. The part of the coordinate system that is of interest in this work is the first quadrant, that is, positive values of a* and b* (Hunt, 1995). The three measured co-ordinates, L*, a* and b*, were transformed to L*, C* and h co-ordinates and ΔE values, according to the following equations (Temiz et al., 2005).

Table 1. Properties of varnishes used in tests.

Type of varnish	pH	Solid content (%)	Amount applied (g m^{-2})	Number of varnish layer applied	Viscosity (DINCup/4mm)
Water-based (filler)	6.95	26	83	3	18
Water-based (finishing)	8.83	39	75	2	18
Synthetic	8.87	54	83	3	18
Cellulose lacquer (filler)	4.08	29	83	3	18
Cellulose lacquer (finishing)	4.2	26	100	2	18
Polyurethane (filler)	6.55	55	83	2	18
Polyurethane (finishing)	6.25	42	75	1	18

Figure 1. Elrepho-spectrophotometer.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

The L*C*h system was chosen since only one color variable is needed to denote hue, that is, red, green, blue or yellow, and furthermore, this system is easy to refer to our experience of color characteristics such as lightness, saturation and hue. Each color parameter, L*, C*, h and ΔE, was measured for each material, time and temperature. The average color values, standard deviations and 95% confidence intervals (5% significance level), based on t-distribution, were calculated to assume a normal distribution. The lower value of Δ*E** indicates that the color is either not changed or the changes is negligible.

After heat treatment applications had been made in two different temperatures (150 to 180°C) and two durations (3 to 6 h) in a small heating unit controlled with ±1°C sensitively, under atmospheric pressure, treated and untreated samples were conditioned to 12% moisture contents (MC) in a conditioning room at 20 ± 21°C and 65% (±5) relative humidity (RH). Surface roughness of the samples was measured by using a profilometer (Mitutoyo Surftest SJ-301). The surface roughness of the samples was measured with the profile method using a stylus device standard. The measuring speed, pin diameter and pin top angle of the tool were 10 mm/min, 4μm and 90°, respectively. As such, the points of roughness measurement were randomly marked on the surface of the samples. Measurements were made in the direction perpendicular to the fiber of the samples (Figure 3).

Roughness parameter, mean arithmetic deviation of profile (Ra) was commonly used in previous studies to evaluate surface characteristics of wood and wood composites including veneer. Therefore, such parameter which is characterized by ISO 4287 and DIN 4768 were recorded. Thus, roughness values were measured with a sensitivity of 0.5 μm. The length of scanning line (Lt) was 15 mm and the cutoff was λ = 2.5 mm. The measuring force of the scanning arm on the surfaces was 4 mN (0.4 g), and as such, no significant damage was placed on the surface according to Mitutoyo Surftest SJ-301 user manual (Anonymous, 2002). Measurements were performed at room temperature and the pin was calibrated before the tests.

For all parameters, all multiple comparisons were first subjected to an analysis of variance (ANOVA) and significant differences between mean values of control and treated samples were determined using Duncan's multiple range test.

RESULTS AND DISCUSSION

Results of the data indicated that surface roughness increased on wood samples for all four wood species treated with cellulose lacquer and synthetic varnish and across all heating treatments. However, surface roughness were decreased for all wood species treated with polyurethane varnish and water based varnish depending on heating temperature and time (Table 2).

Feller (1994) claims that heating may have more destructive effects when the samples contain moisture. In a medium with moisture, heating may cause thermolysis, thermolitic and pyrolytic destruction. At high temperature, polymers restrain and start hardening. At this level, even the temperature is stabilized when connections start rupturing and layers begin losing materials. Feist (1990) reported that varnishes may increase aesthetics value, protection lifespan of the wood both with and without impregnation. Sonmez et al. (2004) reported that water

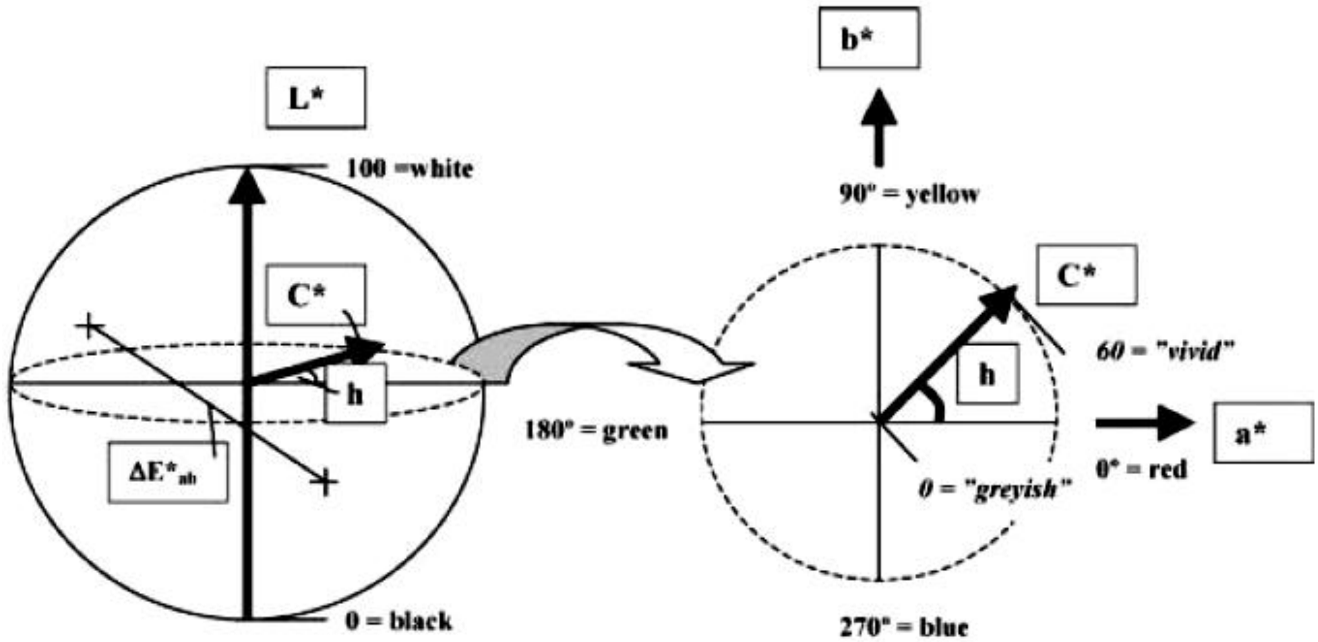

Figure 2. CIE L*a*b* colour space and the transformation to cylindrical colour space L*C*h* (Sundqvist, 2002). To the left: The colour sphere, where the circle of cross section at L* = 50 is given. The colour difference (ΔE) is the distance between two colours (points) within the colour sphere. To the right: Cross section at L* = 50 showing the axis from green to red (a*) and from blue to yellow (b*); the co-ordinates chroma (C*) and hue (h = arctan (b*/a*)) is the hue of a color; 0 or 360° is red, 90 is yellow, 180 is green and 270 is blue. L* is the lightness; 0 = black and 100 = white. C* is the chroma or saturation; 0 represents only greyish colors and 60, for instance, represents very vivid colors (Sundqvist, 2002).

Figure 3. Mitutoyo Surftest SJ-301.

Table 2. Means of surface roughness (Ra)

		Ash	Anatolian chestnut	Limba	Iroko
		Means (µm)			
cellulose lacquer	Control	2.101 ru	2.504 pu	2.378 n	2.009 r
	150/3	3.101 jstu	3.600 ıtu	3.063 g	2.756 mstu
	150/6	3.377 gprstu	3.406 ku	2.442 m	2.791 lstu
	180/3	3.814 bnoprstu	3.851fstu	2.609 k	3.795 drstu
	180/6	3.774 cnoprstu	3.587 jtu	3.232 f	6.298 a
synthetic varnish	Control	2.036 s	0.613 u	1.775 t	1.424 t
	150/3	1.223 u	1.564 t	2.011 r	1.470 s
	150/6	1.595 t	1.593 s	1.725 u	1.121 u
	180/3	2.236 pu	2.220 r	1.884 s	2.669 nstu
	180/6	2.468 nu	3.602 htu	2.280 o	2.848 kstu
polyurethane varnish	Control	3.707 dnoprstu	3.806 gstu	3.439 d	3.737 frstu
	150/3	3.163 ırstu	2.567 nu	2.556 l	2.626 pstu
	150/6	2.738 mtu	3.025 mu	2.760 h	2.991 jstu
	180/3	2.419 ou	3.266 lu	2.693 j	3.566 ırstu
	180/6	2.804 ltu	2.529 ou	2.067 p	2.647 ostu
water-based varnish	Control	7.674 a	7.797 a	5.794 a	4.637 cdefghıjklmnoprstu
	150/3	3.099 kstu	6.155 b efghıjklmnoprstu	2.756 ı	3.734 grstu
	150/6	3.355 hprstu	4.449 erstu	4.740 bcdefghıjklmnoprstu	4.892 bdefghıjklmnoprstu
	180/3	3.562 enoprstu	4.789 dnoprstu	3.297 e	3.764 erstu
	180/6	3.431 fprstu	5.762 cfghıjklmnoprstu	3.638 cstu	3.642 hrstu

Homogenous groups: letters in each column indicate groups that are statistically different according to Duncan's multiple range test at P < 0.05.
Comparisons were between each control and its test.

based varnishes may cause fiber swelling. Therefore, on wood from species with significant density differences among annual rings and soft wood species, surface polishing needs more attentions. Richter et al. (1995) stated that without preparation, paint and varnish impregnations of wood surfaces tend to increase which lead to higher consumptions of these materials. The literature indicates that single or double component water-based varnishes do not have significant effects on surface roughness (Çakicier, 2007).

Value of brightness was also decreased for the four wood species across all the treatment combinations (Table 3). These results are in accordance with the findings of some of the earliest experiments conducted by Sonmez and Budakçi (1999) and Çakicier (2004).

In the literature, brightness has been indicated as the results of heating temperature and heating time. However, Holzhausen et al. (2002) insist that for long-term protection, varnish charecteristics are more important than heating. Values of color differences for ash- and iroko-wood increased depending on heating treatments. As such, the same values for chestnut woods treated with cellulose lacquer and polyurethane varnish decreased, but when the same species of wood treated with water based varnish and synthetic varnish increased, values for color differences were increased. Consequently, color differences for limba wood, receiving water based varnish and cellulose lacquer and heated at 180°C for 6 h, were decreased. The same value for limba wood increased for the other varnish and heating combinations. As such, value of brightness was also decreased for the four wood species across all treatment combinations (Table 4).

Color stability of thermally modified wood is generally better than control samples in accelerated environmental conditions. On the other hand, without protective materials treatment, color may also disappear in outdoor environmental conditions on heated woods too (Syrjanen and Kangas, 2000; Ayadi et al., 2003). Ozalp (2008) found that the pentahydrate added into the varnish increased the toughness and sticking resistance on both wood types (Beech wood and Austrian pine) substantially. However, it also decreased the brightness value of the varnish greatly. Ozalp et al. (2009) found that while the hardness, brightness and resistance of stick were improved for both wooden types which were kept for 2 h

Table 3. Means of brightness.

		Ash	Anatolian chestnut	Limba	Iroko
		Means			
cellulose lacquer	Control	16.842 cfghıjklmnoprstu	11.876 kmnoprstu	26.263 a	7.995 bcdefghıjklmnoprstu
	150/3	22.506 a	23.229 a	19.970 dfghıjklmnoprstu	1.994 j
	150/6	11.543 jklmnoprstu	17.381 eıjklmnoprstu	17.563 fhıjklmnoprstu	2.307 g
	180/3	6.669 moprstu	11.706 lmnoprstu	2.666 mtu	0.848 t
	180/6	1.922 t	7.482 pstu	1.004 t	1.298 r
synthetic varnish	Control	8.378 knoprstu	8.455 orstu	19.094 efghıjklmnoprstu	5.122 cfghıjklmnoprstu
	150/3	16.691 dıjklmnoprstu	16.834 fıjklmnoprstu	17.144 ghıjklmnoprstu	1.412 o
	150/6	7.404 lnoprstu	13.307 jmnoprstu	12.622 lmnoprstu	1.452 n
	180/3	2.240 s	6.459 rstu	1.785 s	0.944 s
	180/6	0.754 u	2.245 u	0.616 u	0.842 u
polyurethane varnish	Control	14.559 gjklmnoprstu	8.759 nrstu	22.924 cdefghıjklmnoprstu	4.081 dghıjklmnoprstu
	150/3	17.869 befghıjklmnoprstu	16.607 gıjklmnoprstu	14.681 jlmnoprstu	2.206 h
	150/6	13.704 ıjklmnoprstu	18.392 dhıjklmnoprstu	15.964 hjklmnoprstu	1.894 l
	180/3	4.980 nprstu	13.637 ıklmnoprstu	2.408 ou	1.609 m
	180/6	2.906 p	4.641 tu	2.074 ru	1.347 p
water-based varnish	Control	14.578 fjklmnoprstu	16.065 hıjklmnoprstu	25.009 bcdefghıjklmnoprstu	8.991a
	150/3	15.160 ejklmnoprstu	20.046 bcdefghıjklmnoprstu	15.822 ıjklmnoprstu	3.905 ehıjklmnoprstu
	150/6	14.489 hjklmnoprstu	18.578 cghıjklmnoprstu	13.948 klmnoprstu	2.922 fstu
	180/3	3.699 ou	9.966 mprstu	2.525 ntu	1.917 k
	180/6	2.722 r	4.732 su	2.256 pu	2.041 ı

Homogenous groups: letters in each column indicate groups that are statistically different according to Duncan's multiple range test at P < 0.05. Comparisons were between each control and its test.

Table 4. Means of total color differences (ΔE)

		Ash	Anatolian chestnut	Limba	Iroko
		Means			
cellulose lacquer	150/3	8.437 l	13.010 ep	8.656 m	21.384 c
	150/6	8.958 k	7.656 o	39.513 hıjklmno	19.021 f
	180/3	19.463 gıjklmnop	6.524 p	62.930 bdefghıjklmno	52.032 abcdefgh
	180/6	34.072 cdefghıjklmnop	9.455 k	2.689 o	55.514 abcdefgh
synthetic varnish	150/3	13.591 ıp	12.445 fp	8.887 l	23.498 b
	150/6	5.903 o	8.339 n	44.399 fıjklmno	19.346 e
	180/3	24.619 fıjklmnop	8.579 l	72.670 a	45.010 abcdefgh
	180/6	55.847 a	24.802 a	9.975 ko	56.100 a
polyurethane varnish	150/3	9.067 j	13.506 dop	7.526 n	12.971 h
	150/6	7.975 m	16.207 cghıjklmnop	41.622 gıjklmno	16.243 g
	180/3	18.976 hıjklmnop	10.453 ı	45.205 eıjklmno	39.933 acdefgh
	180/6	27.975 eghıjklmnop	10.674 h	11.189 jo	43.132 abcdefgh

Table 4. Cont.

	150/3	5.947 n	9.960 j	12.598 ıo	21.029 d
water-based varnish	150/6	5.284 p	8.342 m	57.221 defghıjklmno	27.714 a
	180/3	28.572 dghıjklmnop	11.186 g	59.651 cefghıjklmno	49.807 abcdefgh
	180/6	39.293 bdefghıjklmnop	21.775 bcdefghıjklmnop	8.656 m	52.786 abcdefgh

Homogenous groups: letters in each column indicate groups that are statistically different according to Duncan's multiple range test at $P < 0.05$.
Comparisons were between each control and its test.

in temperatures of 100, 150 and 200°C, they deteriorated in both wooden types kept at 4 and 6 h in the same temperatures. Regarding brightness values, this decreased as temperature and time of the heating process increased for both types of wood. If hardness and sticking resistance are important in the water-based varnish applications, the heating process applied to the wooden material at 100°C and 2 h yielded optimum result. If brightness criterion is important in the processes, the heating process should not be applied to the wood. Ozalp and Korkut (2009) found that the brillianceand resistance of stick were improved for both wooden types which were kept for 2 h in temperatures of 100°C. As such, hardness values of all samples which were processed for 2, 4 and 6 h in 100, 125 and 150°C, respectively, were high. However, with regards to brightness values for Beech wood and Scotch pine samples, the highest values were obtained at 100°C and 2 h after water-based double component varnish applications, while the lowest values were seen at 150°C and 6 h depending on the heating process, heat and time. Various types of water-based lacquers applied on different wood types by various methods have less resistance in hardness, gloss and adherence compared with solvent-base lacquers (Yakin, 2001).

Conclusions

Above 180°C, organic surfaces may start combusting. Besides loosing surface materials, combustion may cause surface roughness. Thus, this temperature threshold should not be exceeded. Since water soluble varnishes may cause fiber swelling, to obtain a surface without roughness preliminary treatments, careful attention should be given to species with higher density differences among annual rings such as chestnuts, oak, etc. and softwood species such as Scots pine, poplar, lime, etc. Since iroko wood contains silicon which prevent surface smoothness, preliminary treatments such as polishing should be implemented carefully for this species. For chestnut wood vessel, cavities should be filled by packing varnish and then polished (Güler, 2010).

Water based varnish may interact with the tannins and as such, could cause darkening. Thus, this type of varnish should be carefully used on woods containing tannins according to customer preference. For future studies, water based solvent varnishes should be experimented with varying temperature, pressure and period for different wood species for both indoor and outdoor usage. Resistance of woods against fungi attack can be compared under different heating and varnish treatments for both outdoor environment and accelerated aging conditions (UV, Xenon-ark and thermal aging, salt spray, etc.).

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