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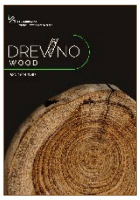

Investigation of Use of Linden (*Tilia tomentosa* Moench.) Wood with UV System Varnish Application IN INDOOR Parquet Flooring

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Linden wood is used in the making of musical instruments, agricultural hand tools, and in the furniture sector. In this study, the changes in glossiness (parallel (//) and perpendicular (⊥) to the fibers at 20°, 60°, and 85°), the pull-off adhesion test, color parameters (CIEL) and pendulum hardness (König method) of two different UV curable varnishes applied to linden (*Tilia tomentosa* Moench.) according to industrial application techniques and exposed to artificial weathering were investigated. According to the research results, while L^*, ΔH^*, and h° decreased with increasing weathering time in both varnish layers, ΔC^*, b^*, ΔE^*, a*, and C^* rose. The pendulum hardness grew for Method B but dwindled for Method A. A decrease was found in the adhesion tests for both varnish methods after artificial weathering. The glossiness was generally reduced due to artificial weathering for all the angles and for both directions, with the exception of 85° in Method A. The variance analysis and homogeneity groups showed that the changes in the adhesion, pendulum hardness, L^*, a^*, h^o, C^*, perpendicular and parallel to the fibers for 60° and 85° were found to be significantly different with artificial weathering for both methods.

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Introduction

Coatings that can be cured with ultraviolet (UV) light have gained great attention and importance in recent years due to their low energy consumption, environmental friendliness, and also fast curing at low temperatures [Decker 1997; Lecamp et al. 1999; Fouassier et al. 2003; Fouassier 1995; Rabek 1997].

Photoinitiators are included in the formulation for UV curing, absorbing UV radiation and producing reactive sites (such as free radicals), which have the ability to initiate the curing process faster, while minimizing involvement in the finishing step [Hoyle and Kinstle 1992].

The properties of a UV-curable varnish depend on its chemical compounds, the type and concentration of photoinitiator, the thickness of the applied layer, and the quantity of UV radiation during the curing step [Dawidowicz et al. 2019].

Surface durability refers to the ability of a material to withstand unwanted changes when exposed to environmental factors during its service life. These changes primarily encompass wear and degradation caused by elements like sunlight, temperature fluctuations, UV radiation, water, pollutants, and oxygen [Feist 1983; Johnson and McIntyre 1996; de la Caba et al. 2007].

The initial signs of chemical degradation on a wood surface are manifested by means of changes in its color. These alterations typically originate from solar radiation, especially the high-energy ultraviolet (UV) spectrum. UV rays can induce photochemical reactions that break chemical bonds in wood and cause depolymerization of cellulosic polymers within the cell wall [Derbyshire and Miller 1981; Feist 1989].

Among all wood polymers, lignin has been reported to be the most sensitive to UV light since its chromophore functional groups are able to absorb a wide spectrum of UV light in the 250-400 nm range [Sadeghifar and Ragauskas 2020].

After extended outdoor service, peeling of the surface coating film will expose the underlying wood and then promote its photochemical degradation [Peng et al. 2020; Corcione and Frigione 2012].

Several physical and mechanical properties are affected, and accelerated testing serves to track the changes in selected properties and to predict life service [de la Caba et al. 2007]. Fufa et al. [2012] reported that 14 days in an artificial weathering chamber results in changes similar to 9 years of outdoor exposure.

The linden (*Tilia tomentosa* Moench.) tree is native to south-western Asia and south eastern Europe, from Hungary and the Balkans to western Turkey and the Marche region in Italy [Conti et al. 2005]. The height of a 10-year-old tree is 4.3-7.8 m and the maximum height is achieved at 10 to 15 years, after which it may slow down [Haralamb 1967]. The fibers from its hard inner bark can be turned into a variety of products such as mats, shoes, and coarse cloth [Elias 1980]. Linden wood is used in a variety of products in the production of casting and hat molds, in musical instruments such as pianos and harps, toys, crates, several types of boards, pencils, and also for the production of cellulose [Aslan 1994].

Some technological properties of linden wood were reported by Aytaskin [2009] like an air-dry density around 460 kg/m^3, bending strength 61.86 N/mm^2, elasticity modulus 6117.76 N/mm^2, compression parallel to the fibers 36.55 N/mm^2, and a thermal conductivity of 0.111 kcal/h·m·°C. The screw holding capacity on a tangential surface was stated to be 19.53 N/mm^2 [Bal et al. 2018].

The aim of this study is to determine the resistance to artificial weathering of coated surfaces by utilizing two different methods of applying UV cured varnishes to linden wood, according to industrial application techniques. The results obtained in this study will allow us to explain the relationship between the varnish types and chemicals used, weathering and linden wood. In addition, it is thought that it will provide important information both for the parquet industry and for linden wood users.

Materials and methods

1. Wood material

Linden (*Tilia tomentosa* Moench.) wood was selected. Wooden timber with dimensions 100 x 10 x 2 cm was purchased from a lumber dealer in Izmir and 30 test samples were prepared. The specimens were selected in a random manner, devoid of knots, cracks, or gaps, possessing uniform fibers, and exhibiting no variation in terms of color or density. The samples were conditioned at 65±3% relative humidity and 20±2°C in accordance with TS ISO 13061-1 [2021].

2. UV cured varnish application

Two different methods, Method A and Method B, were employed to apply UV system parquet varnishes on the surfaces of linden wood. The UV system varnishes were applied by the KPS Parke Factory (Düzce, Turkey) according to industrial application techniques (in line with the manufacturer's recommendations of the varnish chemicals), to the material surfaces as presented in Table 1. The explanations of the chemicals used in this research are presented in detail in the research conducted by Ayata [2019]. The materials with UV curing by Method A and Method B were conditioned until reaching a constant weight according to TS ISO 13061-1 [2021] (relative humidity 65±3% and temperature 20±2°C).

Table 1. Planning of UV cured varnish applications

Method A	Sanding and calibration of machines for 80 to 120 grit sizes
	Clear UV curing hydro primer 10 g/m^2 then drying at 70°C
	UV curtain coating high glossiness → 8 g/m^2
	2 times - UV lamp drying → total 177 mJ/cm^2
	Sanding and calibration of machines for 280 to 320 grit sizes
	Clear mat UV oil → 8 g/m^2
	UV lamp drying → 71 mJ/cm^2
	Clear mat UV oil → 8 g/m^2
	2 times - UV lamp drying → total 314 mJ/cm^2
Method B	Sanding and calibration of machines for 80 to 120 grit sizes
	Clear UV curing hydro primer for 10 g/m^2 then drying at 70°C
	*UV clear curing sealer for 20 g/m^2 then drying at 70°C
	UV clear curing sealer for 10 g/m^2 then drying at 70°C
	UV clear curing sealer for 10 g/m^2 then drying at 170°C
	Sanding and calibration of machines for 280 to 320 grit sizes
	Clear mat UV oil for → 8 g/m^2
	UV lamp drying → total 71 mJ/cm^2
	Clear mat UV oil for → 8 g/m^2
	2 times - UV lamp drying → total 314 mJ/cm^2

3. UV integrator

DIN EN ISO/IEC 17025 [2016] and a UV integrator (Kühnast, Brachttal, Germany) (Fig. 1A) device were used to measure the intensity of the UV lamps in mJ/cm^2 in the varnish application methods as reported in Table 1.

4. Accelerated weathering

Artificial weathering, according to the ISO 4892-3 [2016] standard, 0.76 light intensity with UVB-313 EL lamps (Q-Lab, Westlake, OH, US) for 252 and 504 h and 8 h of UV light at 60°C was carried out by exposure in a QUV weathering tester (Q-Lab, Westlake, OH, US) (Fig. 1B) consisting of a condensation vapor environment at 50°C for 4 h.

5. Measurements of glossiness

The glossiness was determined perpendicular = ⊥ and parallel = // to the fibers at 20°, 60°, and 85° in an ETB-0833 model glossmeter device (Vetus Electronic Technology Co., Ltd., Guangdong, CN), [ISO 2813 1994], (Fig. 1C).

6. Surface adhesion resistance / pull-off adhesion test

The surface adhesion was determined by the pull-off adhesion test in a PosiTest AT-A (automatic) (Defelsko® Corp., S/N AT11802, USA) [ASTM D 4541 1995] (Fig. 1D). 404 Plastik Çelik brand (Çekmeköy/İstanbul, Turkey) fast adhesive (resin and catalyst) was used (Fig. 1E). The surfaces of the materials coated with the UV system varnish were attached to traction rollers with a diameter of 20 mm and left to dry at a normal room temperature of 20°C±2 for 24 h. The surface adhesion values were calculated using Eq. 1.

$$X = (4 \times F) / (\pi \times d^2) \quad (1)$$

where:
d = diameter of draw roll (mm)
F = force at rupture (N)
X = adhesion strength (MPa)

7. Pendulum hardness measurement

The pendulum hardness was determined utilizing the König method (Model 299/300 Erichsen, Hemer, Germany) (Fig. 1F) [ASTM D 4366-95 1984]. The device has two balls with a hardness of 63±3.3 HRC and a diameter of 5±0.0005 mm on the surface of a sample placed on the sample platform [Ayata and Cakicier 2021; Sonmez 1989].

8. Measurements of color parameters

The color parameters were determined by the CIELAB method where L^* is the lightness from 0 = black to 100 = white, a^* represents the green-red axis and b^* the blue-yellow. The values of the aged and unaged samples were measured using a colorimeter (CS-10, China) (Fig. 1G) (CIE D65 light source, 8°/diffused illumination, CIE 10° standard observer) [ASTM D 2244-3 2007], [Ayata and Cakicier 2021].

$$\Delta a^* = [a^*_{\text{UV varnished material weathered}}] - [a^*_{\text{UV varnished material unweathered}}] \quad (2)$$

$$\Delta L^* = [L^*_{\text{UV varnished material weathered}}] - [L^*_{\text{UV varnished material unweathered}}] \quad (3)$$

$$\Delta b^* = [b^*_{\text{UV varnished material weathered}}] - [b^*_{\text{UV varnished material unweathered}}] \quad (4)$$

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta b^*)^2 + (\Delta a^*)^2]^{1/2} \quad (5)$$

$$C^* = [(a^*)^2 + (b^*)^2]^{1/2} \quad (6)$$

$$\Delta C^* = [C^*_{\text{UV varnished material weathered}}] - [C^*_{\text{UV varnished material unweathered}}] \quad (7)$$

$$h^o = \arctan [b^*/a^*] \quad (8)$$

$$\Delta H^* = [(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2]^{1/2} \quad (9)$$

The criteria for color change based on the ΔE^* values, as described by Barański et al. [2017], are provided in Table 2. These ΔE^* values were compared with the values obtained in this study after aging, and the comparative results are presented in Table 5.

Table 2. Color change criteria by Barański et al. [2017]

Color change criteria	►	**ΔE^* value**
Invisible color change	►	$\Delta E^* < 0.2$
Slight change of color	►	$2 > \Delta E^* > 0.2$
Color change visible in high filter	►	$3 > \Delta E^* > 2$
Color change visible with average quality of filter	►	$6 > \Delta E^* > 3$
High color change	►	$12 > \Delta E^* > 6$
Different color	►	$\Delta E^* > 12$

9. Statistical analysis

By using the data obtained from all the tests before and after weathering, the maximum and minimum values, homogeneity groups, mean, analysis of variance and standard deviations were calculated using SPSS software. The test samples consisted of five pieces. A total of 726 measurements were evaluated (pendulum hardness 36 + glossiness 360 + color parameters 300 + adhesion strength 30 = 726).

Fig. 1. UV integrator (A), accelerated weathering machine (B), gloss meter (C), pull-off adhesion tester (D), adhesive glue for surface adhesion test (E), pendulum hardness testing device (F), and colorimeter (G)

Results and discussion

The results of the total color differences are given in Table 3.

Table 3. Δ*a**, Δ*L**, Δ*b**, and Δ*E**

Varnish application technique	Weat-hering time	Δ*C**	Δ*H**	Δ*L**	Δ*a**	Δ*b**	Δ*E**	Results according to Baranski et al. [2017] color change criteria
Method A	252 h	16.09	2.57	-08.31	07.80	14.30	18.29	Δ*E** > 12 different color
	504 h	17.43	2.35	-09.05	08.01	15.66	19.78	
Method B	252 h	17.38	3.16	-08.63	08.06	15.72	19.66	
	504 h	18.79	2.40	-10.75	07.44	17.42	21.78	

It was observed that Δ*E** increased with the weathering time for both methods. It was determined that the Δ*E** values of both the application methods were very close to each other. The highest Δ*E** at 252 and 504 h of weathering was obtained for Method B. A low Δ*E** indicates that the color does not change much or remains identical, while a high Δ*E** means that there was a significant color change [Cui and Matsumura 2019]. It has been reported that lignin is responsible for the total color difference owing to the absorption of light and the formation of free radicals that promote the formation of quinones, which subsequently lead to the discoloration reaction [Obataya et al. 1998]. In addition, according to the scale presented by Barański et al. [2017], the Δ*E** values were in the "*different color*" group. Δ*H** defines the extent of the "hue" change or the difference in "tone" [Robertson 1977; Tolvaj and Faix 1995; Cui and Matsumura 2019]. It is seen that Δ*C** grows while Δ*H** decreases with increasing weathering time in both the varnish application methods. The ΔC^* value of both the varnish layers obtained after weathering were very close to each other.

The variance analysis results between the varnish application method (A) and weathering time (B) fixed factors of the color parameters are presented in Table 4. According to these results, the color tone (b^*) was not significant regarding the application method (A). The weathering time (B) and interaction (AB) were found to be significant for the same parameter. Additionally, for the L^*, a^*, C^*, and h^o parameters, the application method (A), weathering time (B), and interaction (AB) were found to be significant.

Since there was a high significance level for the cross-effects (varnish application method x weathering time), the effect of the varnish application method depends on the level of weathering time, and therefore interpretation of the main effects can be misleading.

Table 4. Analysis of variance data for color parameters

Test	Source	Mean square	Sum of squares	Degrees of freedom	F	α≤0.05
	Application method (A)	74.237	74.237	1	386.022	0.000*
	Weathering time (B)	572.280	1144.560	2	2975.776	0.000*
L^*	Interaction (AB)	4.072	8.144	2	21.175	0.000*
	Error	0.192	10.385	54		
	Total		289054.183	60		
	Application method (A)	58.292	58.292	1	973.119	0.000*
	Weathering time (B)	408.826	817.651	2	6824.840	0.000*
a^*	Interaction (AB)	0.912	1.824	2	15.227	0.000*
	Error	0.060	3.235	54		
	Total		8579.511	60		
	Application method (A)	0.002	0.002	1	0.017	0.896**
	Weathering time (B)	1670.257	3340.515	2	16015.253	0.000*
b^*	Interaction (AB)	4.376	8.751	2	41.956	0.000*
	Error	0.104	5.632	54		
	Total		67924.325	60		
	Application method (A)	155.526	155.526	1	1028.667	0.000*
	Weathering time (B)	162.208	324.417	2	1072.864	0.000*
h^o	Interaction (AB)	2.942	5.884	2	19.458	0.000*
	Error	0.151	8.164	54		
	Total		307243.291	60		
	Application method (A)	5.859	5.859	1	55.278	0.000*
	Weathering time (B)	2033.736	4067.472	2	19186.423	0.000*
C^*	Interaction (AB)	2.930	5.860	2	27.640	0.000*
	Error	0.106	5.724	54		
	Total		76504.614	60		

*: significant, **: insignificant

Table 5. Color parameters before and after weathering

Test	Varnish application technique	Weathering time	N	Mean	Change (%)	Homo-geneity group	Standard deviation	Mini-mum	Maxi-mum
*L**	Method A	Unweathered	10	73.93	-	B	0.44	73.21	74.73
		252 hours	10	65.62	↓11.24	E	0.43	64.99	66.07
		504 hours	10	64.89	↓12.23	F**	0.55	63.79	65.48
	Method B	Unweathered	10	76.83	-	A*	0.19	76.47	77.04
		252 hours	10	68.20	↓11.23	C	0.42	67.59	68.89
		504 hours	10	66.09	↓13.98	D	0.51	64.83	66.66
*a**	Method A	Unweathered	10	7.04	-	D	0.24	6.48	7.34
		252 hours	10	14.84	↑110.80	A	0.23	14.56	15.20
		504 hours	10	15.06	↑113.92	A*	0.27	14.68	15.54
	Method B	Unweathered	10	5.17	-	E**	0.16	4.86	5.43
		252 hours	10	13.24	↑156.09	B	0.34	12.83	13.78
		504 hours	10	12.62	↑144.10	C	0.19	12.39	12.99
*b**	Method A	Unweathered	10	22.82	-	E	0.45	22.23	23.47
		252 hours	10	37.11	↑62.62	D	0.22	36.76	37.60
		504 hours	10	38.47	↑68.58	B	0.23	38.13	38.82
	Method B	Unweathered	10	21.76	-	F**	0.27	21.33	22.24
		252 hours	10	37.48	↑72.24	C	0.30	37.11	37.99
		504 hours	10	39.18	↑80.06	A*	0.39	38.44	39.66
h°	Method A	Unweathered	10	72.85	-	B	0.39	72.57	73.89
		252 hours	10	68.21	↓6.37	F**	0.29	67.69	68.56
		504 hours	10	68.63	↓5.76	E	0.42	67.84	69.16
	Method B	Unweathered	10	76.63	-	A*	0.39	76.24	77.40
		252 hours	10	70.55	↓7.93	D	0.49	69.66	70.99
		504 hours	10	72.15	↓5.85	C	0.31	71.73	72.60
*C**	Method A	Unweathered	10	23.88	-	C	0.49	23.30	24.59
		252 hours	10	39.97	↑67.38	B	0.25	39.55	40.45
		504 hours	10	41.31	↑72.99	A*	0.19	41.02	41.65
	Method B	Unweathered	10	22.37	-	D**	0.28	21.94	22.89
		252 hours	10	39.75	↑77.69	B	0.29	39.38	40.31
		504 hours	10	41.16	↑84.00	A	0.38	40.40	41.60

N: number of measurements, *: highest result, **: lowest result

The homogeneity groups for the color parameters (b^*, C^*, L^*, h^o, and a^*) are shown in Table 5. After weathering, L^* decreased while C^*, a^*, and b^* increased for both the application methods except for a^* between 252 and 504 hours. It can be seen that each set of samples belongs to different homogeneity groups. Soğutlu and Sonmez [2006] reported that an increment in the L^* value is the result of a lighter color, and a decrease is the result of darkening. It can be said that darkening occurs on varnished materials after weathering. The darkening or lightening of the samples is dependent on the initial color of the wood surface as stated before [Esteves et al. 2020]. With the increase in weathering time, h^o declined after 252 hours growing afterwards for 504 hours in both the varnish application methods. On the other hand, h^o dropped compared to the control varnished samples. The control h^o angle of the varnish layers with Method B was higher than that with Method A. After 504 hours of weathering, the increase in the C^* values of the varnish applied by means of Method B was the highest.

The data of the analysis of variance for the pendulum hardness determined according to the König method are given in Table 6. According to Table 6, the varnish application method (A), weathering time (B), and interaction (AB) of the pendulum hardness were significant once again, meaning that the effect of the varnish application method depends on the amount of weathering time.

Table 6. Analysis of variance data for pendulum hardness

Source	**Mean square**	**Sum of squares**	**Degrees of freedom**	**F**	**α≤0.05**
Application method (A)	121.000	121.000	1	8.109	0.008*
Weathering time (B)	93.583	187.167	2	6.271	0.005*
Interaction (AB)	128.583	257.167	2	8.617	0.001*
Error	14.922	447.667	30		
Total		83382.000	36		

*significant

The homogeneity groups for the pendulum hardness are presented in Table 7.

Table 7. Pendulum hardness before and after weathering

Varnish application technique	**Weathering time**	**N**	**Mean**	**Change (%)**	**Homo-geneity group**	**Standard deviation**	**Minimum**	**Maximum**
Method A	Unweathered	6	46.83	-	BC	2.86	43.00	51.00
	252 hours	6	45.17	↓3.54	C	3.92	41.00	49.00
	504 hours	6	46.00	↓1.77	BC	3.58	41.00	49.00
Method B	Unweathered	6	43.33	-	C**	3.08	40.00	48.00
	252 hours	6	50.33	↑16.16	B	5.05	42.00	56.00
	504 hours	6	55.33	↑27.69	A*	4.27	51.00	63.00

N: number of measurements,*: highest result, **: lowest result

According to the homogeneity groups in Table 7, the pendulum hardness did not vary significantly with the weathering time for Method A, while it grew for Method B. Nevertheless, there seems to be a decrease between the initial unweathered samples and the aged ones. It has been reported that after the weathering period, the pendulum hardness of Persian silk wood [Gurleyen 2020], hackberry wood [Ayata et al. 2021b], doussie wood [Gurleyen 2021], apricot wood [Ayata et al. 2021a], and cedar wood [Ayata et al. 2021c] with a UV varnish decreased for Method A and increased for Method B, which is similar to the results obtained for linden wood. It has been reported before that during UV exposure, the film hardens and loses most of its rubbery properties and eventually, stress increases, particularly on the surface of the film layer [Gregorovich et al. 2001; Bartolomeo et al. 2001].

The damage caused by photooxidation leads to changes in the chemical compounds along the cross-linking of the cured film layer at the etching time [Gregorovich et al. 2001]. This causes crispiness of the cured film layer [Lee and Kim 2006], which becomes brittle and stress increases, leading to cracking, channeling, and delamination [Nichols et al. 1999].

The data of the analysis of variance for the pull-off adhesion test is given in Table 8. It is seen that the application method (A), weathering time (B), and interaction (AB) of the adhesion strength to the surface were significantly different. Since interaction was significant, the homogeneity groups were determined and presented in Table 9.

Table 8. Analysis of variance data for pull-off adhesion test

Source	Mean square	Sum of squares	Degrees of freedom	F	α≤0.05
Application method (A)	5.470	5.470	1	130.395	0.000*
Weathering time (B)	2.076	4.153	2	49.497	0.000*
Interaction (AB)	0.301	0.602	2	7.175	0.004*
Error	0.042	1.007	24		
Total		69.947	30		

*: significant

The adhesion by the pull-off test decreased for both methods with increasing weathering time analogous to the results reported earlier for Persian silk by Gurleyen [2020], hackberry by Ayata et al. [2021b], doussie by Gurleyen [2021], and lemon by Ayata [2019] wood species treated with similar UV cured varnishes after weathering. Therefore, according to Sow et al. [2011] adhesion depends not only on the porosity of the wood but also on the rheological properties of the coating. The reduction in bonding strength can be caused by many factors, such as wood degradation, chemical degradation of the coating, or the migration of extractives to the wood surface affecting the bond line [Clerc et al. 2017; Ayata 2019].

Table 9. Pull-off adhesion test before and after weathering

Varnish application technique	Weathering time	N	Mean (MPa)	Change (%)	Homogeneity group	Standard deviation	Minimum	Maximum
Method A	Unweathered	5	2.51	-	A*	0.14	2.31	2.66
	252 hours	5	1.69	↓32.67	B	0.10	1.60	1.86
	504 hours	5	1.28	↓49.00	C	0.41	0.76	1.89
Method B	Unweathered	5	1.26	-	C	0.04	1.20	1.31
	252 hours	5	0.97	↓23.02	D	0.13	0.85	1.13
	504 hours	5	0.69	↓45.24	E**	0.18	0.42	0.84

N: number of measurements, *: highest result, **: lowest result

The variance analysis data for glossiness are presented in Table 10. According to this data, the application method (A) of the parallel (//) glossiness value at 20º was considered not to be significantly different, while the application method (A), weathering time (B) and interactions (AB) were found to be significant for all the other tests.

The homogeneity groups determined for glossiness are presented in Table 11.

Table 10. Analysis of variance data for glossiness test

Test	Source	Mean square	Sum of squares	Degrees of freedom	F	α≤0.05
//20º	Application method (A)	0.013	0.013	1	0.820	0.369**
	Weathering time (B)	8.910	17.820	2	541.225	0.000*
	Interaction (AB)	2.494	4.987	2	151.461	0.000*
	Error	0.016	0.889	54		
	Total		264.110	60		
//60º	Application method (A)	78.433	78.433	1	2912.905	0.000*
	Weathering time (B)	167.882	335.764	2	6234.964	0.000*
	Interaction (AB)	22.263	44.526	2	826.830	0.000*
	Error	0.027	1.454	54		
	Total		11244.500	60		
//85º	Application method (A)	4560.560	4560.560	1	46092.130	0.000*
	Weathering time (B)	942.310	1884.620	2	9523.629	0.000*
	Interaction (AB)	104.763	209.526	2	1058.808	0.000*
	Error	0.099	5.343	54		
	Total		63757.230	60		
⊥20º	Application method (A)	0.193	0.193	1	11.586	0.001*
	Weathering time (B)	6.405	12.809	2	385.136	0.000*
	Interaction (AB)	0.969	1.937	2	58.249	0.000*
	Error	0.017	0.898	54		
	Total		216.040	60		
⊥60º	Application method (A)	94.000	94.000	1	342.257	0.000*
	Weathering time (B)	63.929	127.857	2	232.766	0.000*
	Interaction (AB)	24.117	48.233	2	87.809	0.000*
	Error	0.275	14.831	54		
	Total		7795.650	60		
⊥85º	Application method (A)	4392.993	4392.993	1	5813.115	0.000*
	Weathering time (B)	478.533	957.066	2	633.229	0.000*
	Interaction (AB)	167.098	334.196	2	221.116	0.000*
	Error	0.756	40.808	54		
	Total		37511.080	60		

* significant, **: insignificant

Table 11. Glossiness before and after weathering

Test	Varnish application	Weathering time	N	Mean	Change (%)	Homo-geneity group	Standard deviation	Mini-mum	Maxi-mum
//20º	Method A	Unweathered	10	3.18	-	A*	0.18	2.90	3.40
		252 hours	10	1.40	↓55.97	E**	0.20	1.30	1.90
		504 hours	10	1.47	↓53.77	E	0.05	1.40	1.50
	Method B	Unweathered	10	2.36	-	B	0.10	2.10	2.40
		252 hours	10	1.94	↓17.80	C	0.10	1.90	2.20
		504 hours	10	1.66	↓29.66	D	0.08	1.60	1.80
//60º	Method A	Unweathered	10	15.03	-	B	0.25	14.70	15.40
		252 hours	10	10.50	↓30.14	E**	0.16	10.30	10.70
		504 hours	10	11.26	↓25.08	D	0.20	11.00	11.70
	Method B	Unweathered	10	18.34	-	A*	0.10	18.20	18.50
		252 hours	10	14.19	↓22.63	C	0.11	14.10	14.40
		504 hours	10	11.12	↓39.37	D	0.10	11.00	11.30
//85º	Method A	Unweathered	10	43.56	-	B	0.20	43.30	43.80
		252 hours	10	45.45	↑04.34	A*	0.63	44.70	46.90
		504 hours	10	29.69	↓31.84	C	0.16	29.40	29.90
	Method B	Unweathered	10	27.18	-	D	0.18	26.90	27.40
		252 hours	10	23.00	↓15.38	E	0.26	22.70	23.40
		504 hours	10	16.21	↓40.36	F**	0.16	16.10	16.60
⊥20º	Method A	Unweathered	10	2.64	-	A*	0.28	2.30	3.10
		252 hours	10	1.23	↓53.41	E**	0.05	1.20	1.30
		504 hours	10	1.44	↓45.45	D	0.08	1.30	1.50
	Method B	Unweathered	10	2.32	-	B	0.06	2.20	2.40
		252 hours	10	1.79	↓22.84	C	0.03	1.70	1.80
		504 hours	10	1.54	↓33.62	D	0.08	1.40	1.70
⊥60º	Method A	Unweathered	10	11.26	-	C	0.96	10.60	13.80
		252 hours	10	8.77	↓22.11	E**	0.41	8.00	9.10
		504 hours	10	9.78	↓13.14	D	0.24	9.60	10.30
	Method B	Unweathered	10	15.13	-	A*	0.42	14.50	15.70
		252 hours	10	12.44	↓17.78	B	0.12	12.30	12.70
		504 hours	10	9.75	↓35.56	D	0.55	9.20	10.90
⊥85º	Method A	Unweathered	10	30.82	-	B	0.77	29.00	31.70
		252 hours	10	38.87	↑26.12	A*	1.05	36.50	40.10
		504 hours	10	25.03	↓18.79	C	0.80	23.70	26.40
	Method B	Unweathered	10	18.07	-	D	1.17	16.10	19.30
		252 hours	10	15.20	↓15.88	E	0.37	14.80	16.10
		504 hours	10	10.11	↓44.05	F**	0.84	9.30	11.80

N: number of measurements, *: highest result, **: lowest result

It was determined that the glossiness of the UV coated materials by Method A, at 85° ⊥ and // to the fibers first increases and then decreases depending on weathering, while the gloss perpendicular and parallel to the fibers dwindles for 20° and 60° along with weathering. In relation to the samples where Method B was applied, the glossiness declined for all the angles and for both directions with weathering. Similarly, it was noted that the gloss of UV cured varnish applied to Persian silk by Gurleyen [2020], mulberry by Cavus [2021], doussie by Gurleyen [2021], hackberry by Ayata et al. [2021b], and lemon tree by Ayata [2019] decrease after weathering. Accelerated weathering is one of the reasons for the changes in brightness. This means that exposure to the weather causes the intensity of reflected light to decrease, while the intensity of neutralized light increases [Seo and Weon 2012].

Conclusions

The variance analysis of the different parameters of the varnish application technique and weathering fixed factors showed that the pendulum hardness, pull-off adhesion, a^*, C^*, L^*, h^o, the glossiness value at 85° and 60° parallel (//) and perpendicular (⊥) to the fiber were considered to be significantly different. However, the interaction between both the fixed factors was also significant.

1. The homogeneity groups revealed that with increasing weathering time for both methods, ΔE^*, ΔC^*, a^*, b^*, and C^* grew, while ΔH^*, L^*, and h^o fell.
2. In the pull-off adhesion tests (MPa), reductions were observed for both the varnishing methods after weathering.
3. Regarding the pendulum hardness tests, while the results decreased for Method A, an increase was observed for Method B.
4. The glossiness generally decreased with weathering for all the angles and for both directions with the exception of 85° in Method A.
5. Linden wood can be used in the parquet flooring industry since its results are similar to other species presented in literature.
6. Further work must be done to determine the resistance of these surfaces to different weathering methods (natural, artificial, salt spray corrosion etc.).

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References

Aslan S. [1994]. Ağaç Dendrolojisi, Odun Anatomisi, Hacettepe Üniversitesi, Beytepe, Ankara, Turkey.

Ayata U. [2019]: Effects of artificial aging on the surface properties of ultraviolet varnish applied to lemonwood (*Citrus limon* (L.) Burm.). Bioresources 14: 8313-8323. DOI: 10.15376/biores.14.4.8313-8323

Ayata U., Cakicier N. [2021]: Determination of pendulum hardness (könig method) values against artificial aging in water-based varnishes applied to some wood species after heat treatment (ThermoWood). Drevno 64: 45-61. DOI: 10.12841/wood.1644-3985.381.06

Ayata U., Cakicier N., Gurleyen L. [2021a]: Determination of the artificial aging performance of the apricot wood applied with UV system parquet varnish used indoors. Furniture and Wooden Material Research Journal 4: 40-50. DOI: 10.33725/mamad.922311

Ayata U., Cakicier N., Gurleyen L. [2021c]: Determination of some surface properties of UV curable varnish-applied cedar wood after artificial aging application. Furniture and Wooden Material Research Journal 4: 145-154. DOI: 10.33725/mamad.1005120

Ayata U., Esteves B., Gurleyen L., Cakicier N., Ferreira J., Domingos I., Turk M. [2021b]. Effect of accelerated ageıng on some surface propertıes of UV-coated hackberry (*Celtis australis* L.) wood parquet. Drevno 64: 17-33. DOI: 10.12841/wood.1644-3985.383.09

Aytaskin A. [2009]: Some technological properties of wood impregnated with various chemical substances, 134 p. M. Sc. Thesis Karabük University, Graduate School of Natural and Applied Sciences, Department of Furniture and Decoration Education, Karabük, Turkey

Bal B.C., Ayata U., Cavus V., Efe F.T. [2018]. Determination of screw holding capacity in walnut, maun, chestnut and lime woods. 5th International Congress on Multidisciplinary Studies 02th-03th November 2018, Antalya, Turkey 1: 383-396

Barański J., Klement I., Vilkovská T., Konopka A. [2017]: High temperature drying process of beech wood (*Fagus sylvatica* L.) with different zones of sapwood and red false heartwood. BioResources 12: 1861-1870. DOI: 10.15376/biores.12.1.1861-1870

Bartolomeo P., Irigoyen M., Aragon E., Frizzi M.A., Perrin F.X. [2001]: Dynamic mechanical analysis and Vickers microhardness correlation for polymer coating UV ageing characterization. Polymer Degradation and Stability 72: 63-68. DOI: 10.1016/S0141-3910(00)00203-2

Cavus V. [2021]: Aging performance of mulberry wood with UV varnish applied and its mechanical properties. BioResources 16: 6791-6798.
DOI: 10.15376/biores.16.4.6791-6798

Clerc G., Brülisauer M., Affolter S., Volkmer T., Pichelin F., Niemz P. [2017]: Characterization of the ageing process of one-component polyurethane moisture curing wood adhesive. International Journal of Adhesion and Adhesives 72: 130-138. DOI: 10.1016/j.ijadhadh.2016.09.008

Conti F., Abate G., Alessandrini A., Blasi C. [2005]: An annotated Checklist of the Italian vascular flora. vol. 1. Roma (Italy): Palombi Editore; pp. 175.

Corcione C.E., Frigione M. [2012]: UV-cured polymer-boehmite nanocomposite as protective coating for wood elements. Progress in Organic Coatings 74: 781-787. DOI: 10.1016/j.porgcoat.2011.06.024

Cui X., Matsumura J. [2019]: Wood surface changes of heat-treated *Cunninghamia lanceolate* following natural aging, Forests, 10: 791.
DOI: 10.3390/f10090791.

Dawidowicz A.L., Typek R., Dybowski M.P., Nowakowski P. [2019]: Does the increase of radiation energy really reduce the risk of photoinitiator migration from polygraphic varnish to packed product? The influence of UV radiation dose on the migration of 4-phenylbenzophenone from polyacrylate varnish in food packaging. Food Packaging and Shelf Life 20: 100308. DOI: 10.1016/j.fpsl.2019.100308

de la Caba K., Guerrero P., del Rio M., Mondragon I. [2007]: Aging behaviour of wood-faced construction materials. Construction and Building Materials 21: 1288-1294. DOI: 10.1016/j.conbuildmat.2006.02.008

Decker C. (1997). in Materials Science and Technology, Processing of Polymers, Vol. 18, p. 615 (Meijer, H. E. H., Editor). Wiley, New York.

Derbyshire H., Miller E.R. [1981]. The Photodegradation of Wood during Solar Irradiation. Part 1: Effects on the Structural Integrity of Thin Wood Strips. Holz Roh Werkst 39: 341-350.

Elias T. [1980]. The Complete Trees of N. America, Field Guide and Natural History, Van Nostrand Reinhold Co., ISBN 0442238622.

Esteves B.M., Herrera R., Santos J., Carvalho L., Nunes L., Ferreira J., Domingos I.J., Cruz-Lopes L. [2020]. Artificial weathering of heat-treated pines from the Iberian Peninsula. BioResources 15: 9642-9655, doi:10.15376/biores.15.4.9642-9655.

Feist W.C. [1983]. Aging and Protection of Wood; American Wood-Preservers Association: Kansas City, MO, USA, 79: 195-205.

Feist W.C. [1989]. Outdoor Wood Aging and Protection, In Archaeological Wood: Properties, Chemistry, and Preservation; Rowell, R.M., Barbour, R.J., Eds.; American Chemical Society: Los Angeles, CA, USA.

Fouassier J.P. [1995]. Photoinitiation, Photopolymerization, and Photocuring, Carl Hanser, Munich.

Fouassier J.P., Allonas X., Burget D. [2003]. Photopolymerization reactions under visible lights: principle, mechanisms and examples of applications. Progress in Organic Coatings 47: 16-36. DOI: 10.1016/S0300-9440(03)00011-0

Fufa S.M., Jelle B.P., Hovde P.J., Rørvik P.M. [2012]. Impregnated wooden claddings and the influence of nanoparticles on the aging performance. Wood Material Science and Engineering 7: 186-195. DOI: 10.1080/17480272.2012.692390.

Gregorovich B.V., Adamsons K., Lin L. [2001]: Scratch and mar and other mechanical properties as a function of chemical structure for automotive refinish coatings. Progress in Organic Coatings 43: 175-187. DOI: 10.1016/S0300-9440(01)00187-4

Gurleyen L. [2020]: Effect of artificial aging on the some surface properties of UV system parquet varnish applied to persian silk (*Albizia julibrissin*) wood. Turkish Journal of Forestry 21: 451-460. DOI: 10.18182/tjf.795597

Gurleyen L. [2021]: Effects of artificial aging on the color, gloss, adhesion, and pendulum hardness of UV system parquet varnish applied to doussie (*Afzelia africana*) wood. BioResources 16: 1616-1627. DOI: 10.15376/biores.16.1.1616-1627

Haralamb A. [1967]: Cultura speciilor forestiere, (Translate it in English), Editura Agro-Silvica, Bucuresti.

Hoyle C.E., Kinstle J.F. [1992]: Radiation curing of polymeric materials, American Chemical Society, USA.

Johnson B., McIntyre R. [1996]: Analysis of test methods for UV durability predictions of polymer coatings. Progress in Organic Coatings 27: 95-106. DOI: 10.1016/0300-9440(94)00525-7

Lecamp L., Youssef B., Bunel C., Lebaudy P. [1999]: Photoinitiated polymerization of a dimethacrylate oligomer: 2. Kinetic studies. Polymer 40: 1403-1409. DOI: 10.1016/S0032-3861(98)00380-2

Lee B.H., Kim H.J. [2006]: Influence of isocyanate type of acrylated urethane oligomer and of additives on aging of UV-cured films. Polymer Degradation and Stability 91: 1025-1035.
DOI: 10.1016/j.polymdegradstab.2005.08.002

Nichols M.E., Gerlock J.L., Smith C.A., Darr C.A. [1999]: The effects of aging on the mechanical performance of automotive paint systems. Progress in Organic Coatings 35: 153-159. DOI: 10.1016/S0300-9440(98)00060-5

Obataya E., Norimoto M., Gril J. [1998]: The effects of adsorbed water on dynamic mechanical properties of wood. Polymer 39: 3059-3064.

Peng Y., Wang Y., Chen P., Wang W., Cao J. [2020]: Enhancing aging resistance of wood by using bark extractives as natural photostabilizers in polyurethane-acrylate coating. Progress in Organic Coatings 145: 105665. DOI: 10.1016/j.porgcoat.2020.105665

Rabek J.F. [1987]: Mechanisms of Photophysical and Photochemical Reactions in Polymers: Theory and Practical Applications, Wiley, New York.

Robertson A.R. [1977]: The CIE 1976 color-difference formulae. Color Research & Application 2: 7-11.

Sadeghifar H., Ragauskas A. [2020]: Lignin as a UV Light Blocker - A Review. Polymers 12: 1134.

Seo T.W., Weon J.I. [2012]. Influence of aging and substrate roughness on the interfacial adhesion of acrylic coating based on an increasing load scratch test. Journal of Materials Science 47: 2234-2240. DOI: 10.1007/s10853-011-6034-2

Sogutlu C., Sonmez A. [2006]: The effect of UV lights on color changes on some local wood processed with differential preservatives. Journal of the Faculty of Engineering and Architecture of Gazi University 21: 151-159

Sonmez A. [1989]: Durability of varnishes used on surfaces of wooden furniture against important physical mechanical and chemical effects. 142 p. Ph D. Thesis Gazi University, Institute of Science and Technology, Ankara, Turkey

Sow C., Riedl B., Blanchet P. [2011]: UV-waterborne polyurethane-acrylate nanocomposite coatings containing alumina and silica nanoparticles for wood: mechanical, optical, and thermal properties assessment. Journal of Coatings Technology and Research 8: 211-221. DOI: 10.1007/s11998-010-9298-6

Tolvaj L., Faix O. [1995]: Artificial ageing of wood monitored by DRIFT spectroscopy and CIE $L^*a^*b^*$ color measurements, I. Effect of UV light. Holzforschung 49: 397-404.

List of standards

ASTM D 2244-3:2007 Standard practice for calculation or color tolerances and color, differences from instrumentally measured color coordinates. ASTM International, West Conshohocken, PA

ASTM D 4366-95:1984 Standard test methods for hardness of organic coatings by pendulum test. ASTM, Philadelphia, PA

ASTM D 4541:1995 Standard test method for pull-off strength of coatings using portable adhesion testers. ASTM International, West Conshohocken, PA

DIN EN ISO/IEC 17025:2016 General requirements for the competence of testing and calibration laboratories. German Institute for Standardization, Berlin, Germany

ISO 2813:1994 Paints and varnishes – determination of specular gloss of non-metallic paint films at 20 degrees, 60 degrees and 85 degrees. International Organization for Standardization, Geneva, Switzerland

ISO 4892-3:2016 Plastics – methods of exposure to laboratory light sources – Part 3: Fluorescent UV lamps. The International Organization for Standardization

TS ISO 13061-1:2021 Physical and mechanical properties of wood - test methods for small clear wood specimens – Part 1: Determination of moisture content for physical and mechanical tests, Turkish Standards Institution, Ankara, Turkey.