Weathering Performance of Mulberry Wood with UV Varnish Applied and Its Mechanical Properties

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Mulberry wood is used in carpentry, fences, turnery, and garden architecture. In this study, various mechanical properties (modulus of rupture, modulus of elasticity, Janka hardness, and screw holding resistance) of mulberry (*Morus alba*) wood and its weathering performance after applying 3- and 5-layer UV system parquet varnishes with different surface applications were investigated. The varnished materials were aged using UV lamps for 252 h and 504 h, and the aged specimens were compared with non-aged specimens. The results of the variance analyses found that all tests were significant. According to the results, it was found that while the yellow color (b^*) tone value, lightness, and glossiness (perpendicular (⊥) and parallel (‖) direction at 20°, 60°, and 85° angles) values decreased for both varnish applications, the pendulum hardness value increased. The adhesion strength (pull-off) test (MPa) to the surface first decreased and then increased.

Keywords: UV system varnish; Glossiness; Color; Surface adhesion resistance; Pendulum hardness

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INTRODUCTION

Ultraviolet (UV) cured coatings are mostly utilized in industrial applications where thermal curing is almost impossible to use (Schwalm 2006). UV-cured varnishes have various benefits, *e.g.*, wide-ranging and easy applications, decreased volatile organic compound emission, excellent mechanical properties, and good optical properties (Schwalm 2006; Blanchard *et al.* 2009).

Generally, UV-cured coatings are primarily applied to heat-sensitive surfaces, *e.g.*, wooden furniture, parquet, or plastic products (Schwalm 2006). In previous studies, various wood species, *e.g.*, iroko, chestnut, limba, sapelli (Ayata and Çavuş 2018), oak (Gurleyen *et al*. 2019), Persian silk (Gurleyen 2020), lemon (Ayata 2019), apricot (Ayata *et al*. 2021), beech (Ayata *et al*. 2017), scotch pine (Gurleyen *et al*. 2017), and doussie (Gurleyen 2021) were studied using UV system varnishes. The UV system varnishes were applied, and various tests, *e.g.*, scratch, color, surface adhesion resistance, gloss, pendulum hardness, *etc.*, were performed on the varnished materials, in addition to aging applications, *e.g.*, thermal, natural, artificial, *etc.*

As stated in past literature, mulberry (*Morus alba*) wood is an important material in fencing, carpentry, turning, and garden architecture; it is valuable since it is durable, hard, and accepts polish (Tekeli 1973). In addition, it is used for making sports equipment, chests, furniture, car wheels, and musical instruments, *e.g.*, reeds, *etc.* (Yaltırık and Efe 1994). In this study, the color, glossiness, pendulum hardness, and adhesion resistance properties of the mulberry wood surfaces varnished with 3 and 5 layers of UV varnish were determined after 252 h and 504 h of aging. In addition, the Janka hardness (tangent, radial, and transverse) values of the mulberry wood, the modulus of rupture, the modulus of elasticity, the screw holding (tangent, radial, and transverse) resistance and the air dry density values were also investigated. According to previous literature, it was found that no research has been done on the application of UV varnish to the top surface to this wood.

EXPERIMENTAL

Wood Material

Mulberry (*Morus alba*) wood samples were obtained from a private lumber company from located in Izmir City, Turkey. The unvarnished color properties of the mulberry wood used in the study were determined as L^*: 60.85, a^*: 8.83, and b^*: 29.17. Wood specimens with the following dimensions were prepared: 50 cm x 10 cm x 2 cm (longitudinal x tangential x radial). Afterwards, air conditioning processes, according to TSE TS standard 2471 (1976), at a temperature of 20 °C ± 2 °C and a relative humidity of 65% ± 3%, were applied to the samples.

Application of the UV System Parquet Varnish

The mulberry wood was cut into samples of 50 cm x 10 cm x 1.7 cm. The UV varnishes (3 layers and 5 layers) were applied to the mulberry samples, according to industrial application methods at the KPS Company (Duzce City, Turkey). The production stages are shown in Table 1. Information about these chemicals is disclosed in the article describing the research conducted by Ayata (2019). The coated samples were conditioned in a special room (at a 12% equilibrium moisture content, a temperature of 20 °C ± 2 °C, and a relative humidity of 65 ± 5%) according to TSE TS standard 2471 (1976). It has been discussed in the literature that the varnish types used give different results with other wood species (Ayata 2019; Ayata *et al*. 2021; Gürleyen 2020, 2021).

Table 1. UV System Parquet Production Stages

3 Layers	5 Layers
Using 80 and 120 numbered sanders on a calibrated sander	
Clear UV curing hydro primer for 10 g/m^2 and drying at 70 °C	
UV curtain coating high gloss for 8 g/m^2	*UV clear curing sealer for 20 g/m^2 and drying at 70 °C
2 times --> UV lamp drying Total (177 mJ/cm^2)	UV clear curing sealer for 10 g/m^2 and drying at 70 °C
	UV clear curing sealer for 10 g/m^2 and drying at 170 °C
Using 280 and 320 numbered sanders on a calibrated sander	
Clear mat UV oil for 8 g/m^2	
UV lamp drying (71 mJ/cm^2)	
Clear mat UV oil for 8 g/m^2	
2 times ---> UV lamp drying Total (314 mJ/cm^2)	

Methods

Artificial weathering

Samples varnished with the 3- and 5-layer UV system were exposed to a QUV weathering tester (Q-Lab, Westlake, OH), using ISO standard 4892-3 (2016) (a 15 min water spray, at a light intensity of 0.67, a temperature of 50 °C, and 8 h of ultraviolet light from UVA-340 lamps) for either 252 h or 504 h.

Determination of the pendulum hardness and surface adhesion strength

The pendulum hardness (PH) was determined using a Konig device (Pendulum Damping Tester, Model 299/300 Erichsen, Hemer, Germany), according to ASTM standard D 4366 (1995). The surface adhesion strength was measured according to ASTM D standard 4541 (1995) using a PosiTest AT-A pull-off adhesion tester (automatic) (DeFelsko Corporation, Ogdensburg, NY) for the aged and unaged mulberry wood samples varnished with the 3- and 5-layer UV system (10 cm x 10 cm x 1.7 cm). A room with an adhesion resistance temperature of 20 °C was also set. Cylinders (a 20 mm diameter) and 404 fast plastic steel glue (2.4.6-tris -dimethylaminomethyl phenol) (404 Kimya ve Sanayi Ticaret A.S., Istanbul, Turkey) used. The coated samples were air-dried for 24 h, after which the glue residue was removed with a cutter. The adhesion X (MPa) was determined using Eq. 1,

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

where d is the diameter of the experiment cylinder (mm), and F is the rupture force (N) (Ayata 2019).

Determination of the glossiness and color measurement

An ETB-0833 gloss meter (Vetus Elec. Tech. Co., Ltd., Hefei, China) was used for glossiness measurements according to ISO standard 2813 (1994). The measurements were taken in the parallel and perpendicular direction at 20°, 60°, and 85° angles. A CS-10 (CHN Spec., Hangzhou City, China) colorimeter with a 8°/diffused illumination, a CIE D65 light source, and a CIE 10° standard observer was used to determine the b^* (yellow color tone), a^* (red color tone), and L^* (lightness), according to ASTM standard D 2244-07 (2007). The CIELAB system is defined as follows: The L^* axis represents lightness (from 100 white to 0 black), b^* is the yellow (+) to blue (-) tone, and a^* is the red (+) to green (-) tone (Ayata 2019). The total color difference was determined using Eq. 2 through Eq. 5,

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

$$\Delta b^* = b^*_{\text{weathered UV varnish coated}} - b^*_{\text{unweathered UV varnish coated}} \quad (3)$$

$$\Delta L^* = L^*_{\text{weathered UV varnish coated}} - L^*_{\text{unweathered UV varnish coated}} \quad (4)$$

$$\Delta a^* = a^*_{\text{weathered UV varnish coated}} - a^*_{\text{unweathered UV varnish coated}} \quad (5)$$

Determination of the mechanical properties

The tests to determine the mechanical properties were performed according to TSE TS standard 2474 (1976) for the modulus of rupture (MOR) (N/mm^2) (a sample size of 2 cm x 2 cm x 36 cm with 10 total samples), TSE TS standard 2478 (1976) for the modulus of elasticity (MOE) (N/mm^2), TSE TS standard 2477 (1976) for the impact bending strength (IBS) (kgm/cm^2) (a sample size of 2 cm x 2 cm x 30 cm with 10 total samples), TSE TS standard 2479 (1976) for the static hardness (JH) (N/mm^2) (a sample size of 5 cm x 5 cm x 5 cm with 15 total samples), and TSE TS EN standard 13446 (2005) for the screw holding resistance (SHR) (N/mm^2) (a sample size of 5 cm x 5 cm x 5 cm with 15 total samples). For the screw holding resistance, the front hole diameter was 2.5 mm, the screw diameter was 4 mm, the screw length was 50 mm, and the screw penetration depth was 20 mm. The distance between the supports was set at 30 in for the bending resistance and 24 cm for the shock resistance. During the bending resistance and shock resistance test, the force was applied to the radial surface.

Statistical analysis

In the study, the average values, maximum and minimum values, and standard deviations of the variance analysis were calculated with the SPSS 17 program using the data tests. The obtained results are presented in Tables 2 and 3. In addition, a total of 1305 measurements (color 360 plus gloss 720 plus adhesion 30 plus pendulum hardness 60 plus mechanical tests 135 equals 1305) were taken in the study.

RESULTS AND DISCUSSION

In Table 2, JH, MOR, MOE, IBS, SHR, and air dry density values of mulberry tree, as obtained in the present work, are given in the first column of data. The air dry density was 659.19 kg/m^3, the MOR was 116.06 N/mm^2, the MOE was 9603.60 N/mm^2, the IBS was 0.313 kgm/cm^2, the JH was 67.81 N/mm^2, 64.38 N/mm^2, and 81.29 N/mm^2 in the tangent, radial, and transverse direction, respectively, and the SHR was 39.99 N/mm^2, 40.00 N/mm^2, and 39.16 N/mm^2 in the tangent, radial and transverse direction, respectively.

Table 2. Mechanical Properties of Mulberry Wood and Various Other Species

Test Name		Mulberry	Bitter Orange	Maple	Fragrant Juniper
Air dry density (kg/m^3)		659.19	868.00	574.00	-
MOR (N/mm^2)		116.06	134.70	78.00	93.80
MOE (N/mm^2)		9603.60	8988.00	6808.00	6701.50
IBS (kgm/cm^2)		0.313	0.683	0.217	0.280
JH (N/mm^2)	Tangent	67.81	-	-	45.70
	Radial	64.38	-	-	43.80
	Transverse	81.29	-	-	62.00
SHR (N/mm^2)	Tangent	39.99	55.80	35.10	-
	Radial	40.00	57.70	33.10	-
	Transverse	39.16	52.60	40.90	-
		In this study	Çavuş (2020a)	Efe (2020)	Çavuş (2020b)

The results for the total color (Δ*a**, Δ*L**, Δ*b**, and Δ*E**) differences and the SPSS results of the color parameters (*L**, *b**, and *a**), glossiness values parallel to the fibers at 20°, 60°, and 85° angles, the PH, and the surface adhesion resistance of the samples varnished with 3- and 5-layer UV applications before and after undergoing weathering are presented in Table 3. After the weathering effect was applied, the samples varnished with 3- and 5-layer UV applications, no cracks, blisters, *etc.* were observed. When Table 3 was examined, it was found that the *b** and *L** 3- and 5-layers values decreased as the aging time increased, while the *a** 3- and 5-layers values increased at the end of the 252 h aging process but decreased by the end of 504 h aging process. As stated in previous studies, a decrease in the *L** value means a darkening of the color tone and an increase in the *L** value may mean that the color is lighter (Söğütlü and Sönmez 2006). In this study, the decrease in the *L** values of the samples varnished with UV 3- and 5-layers applications showed that darkening occurred after aging. When focused on the glossiness values, the glossiness measurement values parallel to the fibers at 20° and 60° angles were greater than the measurement values perpendicular to the fibers. In addition, the glossiness values of the samples varnished with a UV 5-layer application were found to be higher than the glossiness values from the UV 3-layer application.

Table 3. Statistical Data for All Tests

Varnish Type	Weathering Period	N	Lightness (L^*)				N	Red Color (a^*) Tone		
			Mean	*HG*	*SS*			Mean	*HG*	*SS*
3 layers	Control	20	65.26	A*	0.75		20	10.14	E**	0.18
	252 h	20	37.49	D	0.83		20	19.50	A*	0.53
	504 h	20	32.16	E**	0.52		20	16.04	C	0.43
5 layers	Control	20	58.55	B	1.07		20	11.48	D	0.50
	252 h	20	42.71	C	0.43		20	16.34	B	0.27
	504 h	20	37.59	D	0.64		20	16.31	B	0.40
Varnish Type	**Weathering Period**	**N**	**Yellow Color (b^*) Tone**				**N**	**Pendulum Hardness**		
			Mean	*HG*	*SS*			Mean	*HG*	*SS*
3 layers	Control	20	43.39	A*	0.70		10	70.60	E**	7.50
	252 h	20	25.26	C	1.09		10	78.60	D	9.12
	504 h	20	12.74	E**	0.55		10	78.00	D	3.97
5 layers	Control	20	39.92	B	0.55		10	95.70	C	6.04
	252 h	20	24.50	D	0.35		10	113.50	B	5.48
	504 h	20	15.14	E	0.60		10	125.80	A*	10.72
Varnish Type	**Weathering Period**	**N**	**Total Color Differences**				**N**	**Adhesion (MPa)**		
			ΔL^*	Δa^*	Δb^*	ΔE^*		Mean	*HG*	*SS*
3 layers	Control	20	-	-	-	-	5	2.004	C	0.22
	252 h	20	-27.77	9.36	-18.13	34.46	5	1.750	D	0.14
	504 h	20	-33.10	5.90	-30.65	45.50	5	2.734	A*	0.31
5 layers	Control	20	-	-	-	-	5	2.260	B	0.19
	252 h	20	-15.84	4.86	-15.42	22.63	5	0.956	E**	0.09
	504 h	20	-20.96	4.83	-24.78	32.81	5	1.672	D	0.13
Varnish Type	**Weathering Period**	**N**	**Glossiness ‖ 20°**				**N**	**Glossiness ⊥ 20°**		
			Mean	*HG*	*SS*			Mean	*HG*	*SS*
3 layers	Control	20	0.68	C	0.08		20	0.60	C	0.00
	252 h	20	0.13	E	0.07		20	0.10	E	0.00
	504 h	20	0.10	E**	0.00		20	0.06	F*	0.05
5 layers	Control	20	2.42	A*	0.04		20	2.40	A*	0.00
	252 h	20	1.24	B	0.23		20	1.10	B	0.02
	504 h	20	0.35	D	0.10		20	0.30	D	0.00
Varnish Type	**Weathering Period**	**N**	**Glossiness ‖ 60°**				**N**	**Glossiness ⊥ 60°**		
			Mean	*HG*	*SS*			Mean	*HG*	*SS*
3 layers	Control	20	5.06	C	0.16		20	4.33	C	0.13
	252 h	20	1.66	E	0.08		20	1.67	E	0.07
	504 h	20	1.15	F**	0.08		20	0.88	F**	0.04
5 layers	Control	20	18.93	A*	0.17		20	16.37	A*	0.11
	252 h	20	11.27	B	0.08		20	10.31	B	0.15
	504 h	20	3.45	D	0.18		20	3.33	D	0.05
Varnish Type	**Weathering Period**	**N**	**Glossiness ‖ 85°**				**N**	**Glossiness ⊥ 85°**		
			Mean	*HG*	*SS*			Mean	*HG*	*SS*
3 layers	Control	20	8.32	D	0.43		20	3.04	D	0.42
	252 h	20	3.64	E	0.28		20	1.34	E	0.11
	504 h	20	1.40	F**	0.11		20	0.36	F**	0.22
5 layers	Control	20	27.89	A*	0.91		20	20.16	A*	0.33
	252 h	20	24.02	B	0.37		20	16.86	B	0.37
	504 h	20	12.47	C	0.43		20	7.14	C	0.28

Note: HG: Homogeneity Group, N: Measurements of number, SS: Standard deviation,
* Highest value, and ** Lowest value

The glossiness values of the samples varnished with UV 3- and 5-layer applications decreased as the aging time increased. According to the hardness results, it was determined that the PH value increased as the aging time increased in the samples varnished with a UV 5-layer application. It was observed that the samples varnished with a UV 3-layer application first increased after 252 h of aging and then decreased after 504 h of aging. During the PH test, the results of the samples vanished with UV 3- and 5-layer applications after 504 h of aging were found to be higher than the control samples. It was reported by Gurleyen (2020, 2021) that the PH values increased, and the adhesion resistance values to the surface decreased after 504 h of aging in the wood species that had a UV 5-layer varnish system applied. In addition, in the same studies, the PH of samples varnished with a UV 5-layer application for were higher than the test samples varnished with a UV 3-layer application. As stated in previous studies, the adhesion strength to the surface of samples varnished with UV 3-and 5-layer applications, before weathering, were 5.720 MPa and 5.840 MPa, respectively, for lemon (Ayata 2019), 3.128 MPa and 3.212 MPa, respectively, for Persian silk (Gurleyen 2020), 2.910 MPa and 2.532 MPa, respectively, for doussie wood (Gurleyen 2021), and 2.004 MPa and 2.260 MPa for this study. According to these results, it was seen that the adhesion strength values of mulberry wood were low when compared to lemon, Persian silk, and doussie wood. In previous studies, the adhesion resistance values decreased during the first period of aging and increased during the last period for the UV 5-layer samples (Ayata 2019; Gurleyen 2020, 2021). Ayata (2019) reported that the reduction in adhesion strength may be due to multiple factors, *e.g.*, wood deterioration, chemical degradation of the coating, and transport of extracts to the wood surface, which affects the bonding line. According to Clerc *et al*. (2017), the decrease in adhesion resistance can often be caused by the deterioration of wood rather than the chemical degradation of the adhesive, depending on weather conditions. According to the total color difference results, the ΔE^* values of the samples varnished with a UV 3-layer system were greater than the samples varnished with a UV 5-layer system. In addition, it was observed that the ΔE^* values of both varnish types increased as the aging time increased. There was a contrasting situation in the aged UV varnished samples applied by Gurleyen (2021, 2020). In this case, it can be said that the different results from the studies originated from different anatomical features of the woods. In addition, it was reported that the different results were obtained due to the different contents of the UV system filling chemicals used in Gurleyen (2021).

CONCLUSIONS

1. The variance analysis results were significant for all the factors that were considered.
2. In the control samples varnished with a UV 5-layer application, the surface adhesion strength, the pendulum hardness (PH), the parallel (‖) and perpendicular (⊥) glossiness values at 20°, 60°, and 85° angles, and the a^* values were greater than the values of the samples varnished with a UV 3-layer application.
3. At the end of 504 h of aging, it was found that there was an increase in the PH of 31.45% in the samples varnished with a UV 5-layer application and 10.48% in the samples varnished with a UV 3-layer application. These results showed that a 5-layer application was suitable for applications where good stiffness is required, *e.g.*, flooring.

4. The gloss values of the samples varnished with UV 3- and 5-layer applications perpendicular and parallel to the fibers at 20°, 60°, and 85° angles decreased as the aging time increased.

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