Effects of Artificial Weathering on Some Surface Properties of Anatolian Chestnut (*Castanea* sativa Mill.) Wood Applied with Yacht Varnish

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Anatolian chestnut wood is an industrial material used in various indoor and outdoor applications in Turkey. This study investigated the effects of artificial weathering (times: 144, 288, 432, and 576 h) conditions on color parameters (L^*, ΔL^*, a^*, Δa^*, b^*, Δb^*, ΔE^*, h^o, ΔH^*, C^*, and ΔC^*), glossiness values at 60° in different directions (‖ and ⊥), pendulum hardness (König method) values, and surface adhesion strength (pull-off method, MPa) on the layers of yacht varnishes applied to Anatolian chestnut (*Castanea sativa* Mill.) wood. The results showed that the univariate analysis of variance was significant by obtaining the weathering factor for all tests. While the brightness values perpendicular (⊥) and parallel (‖) to the fibers increased at 144 and 288 h, they decreased at 432 and 576 h. Adhesion strength to the surface decreased 4.35% at the 576th h of weathering. At the end of weathering, a^*, C^*, b^*, and pendulum hardness values increased, while h^o and L^* values decreased compared to un-weathered samples. The Δa^* and ΔE^* values increased with increased weathering time.

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INTRODUCTION

One of the biggest factors in lengthening the life of a wood material is whether a surface treatment has been applied. A top surface treatment is applied to protect the wood against various factors. The biggest factor in the application of top surface treatments to wood material. Before starting the surface treatments, the appropriate tree species must be selected for the place of use (Sönmez 2005). A top surface treatment of the wood surface consists of its coating with selected aniline paints, putty, fillers, varnishes, other paints, enamel paints, oils, and wax polishes. These materials can be coated by brushing, dipping, spraying, turning, grooving, and dropping methods (Hammond *et al*. 1969). There are various types of varnish whose layer properties have been investigated from past to present (Ulay 2018). One of them is yacht varnish. In Özcan (2019), the materials of various yacht varnishes (double component polyurethane, polyurethane satin, glossy synthetic, hard-strength glossy polyurethane, and tung oil-based glossy synthetic) applied to chestnut, teak, iroko, Uludağ fir, Eastern spruce, and sessile oak woods, were exposed to sea water vapor at 50 °C for different durations (6, 24, 60, and 96 h). Aytin *et al*. (2016) determined the surface adhesion resistance tests after 288 h of weathering on wild cherry wood to which glossy alkyd-based yacht varnish was applied. Altiparmak (2017) reported that the glossiness value of chestnut wood with yacht varnish applied was 81.7. Yacht varnish (one-component alkyd-based varnish) was applied to heat-treated/untreated ash and Scotch pine wood species by Şahin Kol *et al*. (2018), and their color properties were determined.

The surface of wood material is exposed to various weathering processes (natural, artificial environment, *etc.*) with or without varnish (Ulay and Çakıcıer 2017; Ulay 2023; Ulay and Ayata 2023). After the weathering period, the changes in the surfaces of the varnish layer are determined by various tests (color, glossiness, scratch, pendulum hardness, whiteness index, adhesion, *etc.*) (Ulay 2018). In the literature, it has been observed that artificial weathering applications are not made with UV-B 313 lamps after the application of yacht varnish to chestnut wood.

The following are some important features of the Anatolian chestnut (*Castanea sativa* Mill.) wood; contents are as follows: lignin 25.3%, ash 0.82%, holocellulose 71.3%; alcohol-benzene solubility 12.5%, alpha cellulose 39.6%, 1% NaOH solubility 31.2%, solubility in cold water 9.86%, solubility in hot water 11.1% (Aytekin 2011), dry density 0.508 g/cm^3, air dry density 0.540 g/cm^3, maximum water amount 157%, volume density value 0.448 g/cm^3 (Ay and Şahin 2002), bending strength 77.6 N/mm^2, modulus of elasticity 7730 N/mm^2, compressive strength parallel to fibers 38.7 N/mm^2 (Aytaşkın 2009), screw holding capacity on the tangential surface 23.0 N/mm^2 (Bal *et al*. 2018), thermal conductivity value 0.114 W/m.K (Çavuş *et al*. 2019), shore D hardness 59.0 HD (Turk and Ayata 2021), and weight loss after 1 year in seawater environment 38.7% (Şen and Yalçın 2010). The weight loss was 0.80% for *Gloeophyllum trabeum*, 2.74% for *Postia placenta*, 0.44% for *Pleurotus ostreatus*, and 8.99% for *Trametes versicolor* (Çolak 2014).

In this study, artificial weathering was applied on the materials on which yacht varnish was applied with a varnish gun on chestnut wood. Afterwards, the results were discussed with various surface tests taken at the end of 0 to 576 h.

EXPERIMENTAL

Obtaining Wood Samples

Anatolian chestnut (*Castanea sativa* Mill.) was selected in this study. Wood materials were obtained by purchasing from a commercial enterprise (Düzce city, Turkey). Care was taken to choose the wood material according to ASTM D7787 / D7787M (2013), without knots, ridges, without growth defects, with smooth fibers, in a mixed form of core and sapwood parts. The test samples were kept for 4 weeks (a relative humidity of 65 ± 5% and a temperature of 20 ± 2 °C) as per the standard TS 642 ISO 554 (1997). Then, to measure the test materials to 7.5 × 32 × 1.5 cm, their thickness was first brought to the specified size in the side take-up machine, and then the width and thickness were determined in four processing machines.

Application of Varnishes

Before the application, after cleaning the floating dust with sandpaper no. 180-220, two layers of filling and two layers of topcoat were applied with the varnishes in accordance with the ASTM D3023-98 (2017). According to company directives (X commercial firm, Istanbul, Turkey), the one component (VP380.77 PU filler varnish) was thinned to 2 units by volume, the two component (HP777.00 hardener) to 1 unit and 1 unit of PU thinner (TP100 PU thinner). The application amount was 130 g/m^2, and the thickness was 30 to 35 μ in 1 layer of dry layer, a total of 2 layers were applied with 1 h intervals.

The amount of solid matter is 46 ± 2% by weight (%), one component is 53 ± 2 and two components are 35 ± 1. Viscosity (25 °C, KU) is 95 to 102 s, density is 1.030 ± 0.03, and 0.970 ± 0.03, respectively. X brand urethane alkyd based glossy synthetic yacht varnish (VS102.00) and synthetic thinner (TS 100) were thinned by 15 to 20% by volume, kept for 6 h between coats, and applied in 2 coats, with 130 g/m^2 per coat, in accordance with the ASTM D3023-98 (2017) and company directives was implemented. The varnish solids were 50% wt%, with viscosity 140 to 160 s at 25 °C (FORD4), density 0.913 ± 0.03 g/cm^3. Synthetic yacht varnish was filled in 2 (cross coats) and after 2 (cross coats) topcoat, the average dry layer thickness was determined as 130 μm.

UV Accelerated Weathering Application

The materials on the chestnut wood with yacht varnish applied were left to dry for four weeks in the air-conditioning room at 20 ± 2 °C temperature and 65 ± 3% relative humidity conditions according to TS 642 ISO 554 (1997). Later, varnished materials were aged according to ISO 16474-1 (2013) standards in the QUV accelerated weathering tester with UV-B 313 EL type fluorescent lamps (Q-Lab Corporation, Westlake, OH, USA). The weathering environment conditions (0.67 light intensity, 15 min. water spray, 4 h UV, and 50 °C ambient temperature cycle) were determined and exposed to weathering for 144, 288, 432, and 576 h. For all test samples exposed to UV accelerated weathering, tests were conducted after sufficient time conditioning after the weathering period.

Test Standards

The glossiness tests were performed using the ISO 2813 (2014) standard, in the ETB-0833 model gloss meter device, at 60° angle perpendicular (⊥) and parallel (∥) to the fibers (Ayata *et al*. 2021a).

Hardness values were determined by pendulum hardness measuring device (Model 299/300 Erichsen, Hemer, Germany) according to ASTM D4366-16 (2021) standard, according to the König method (from 6º to 3º) (Ayata *et al*. 2021b).

The color change of the samples was measured using a CS-10 (CHN Spec, Hangzhou, China) [CIE 10° standard observer; CIE D65 light source, illumination system: 8/d (8°/diffused illumination)] instrument with the CIELAB color system, according to the standard ASTM D2244-23 (2023). Using the results of the color parameters before and after weathering, the total color differences were calculated with the formulas given below, and these calculated results are presented in Table 2 (Ayata *et al*. 2018; Ayata 2019).

$$C^* = [(a^*)^2 + (b^*)^2]^{0.5} \quad (1)$$

$$h^o = \arctan (b^*/a^*) \quad (2)$$

$$\Delta a^* = (a^*_{\text{weathered}} - a^*_{\text{un-weathered}}) \quad (3)$$

$$\Delta L^* = (L^*_{\text{weathered}} - L^*_{\text{un-weathered}}) \quad (4)$$

$$\Delta C^* = (C^*_{\text{weathered}} - C^*_{\text{un-weathered}}) \quad (5)$$

$$\Delta b^* = (b^*_{\text{weathered}} - b^*_{\text{un-weathered}}) \quad (6)$$

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5} \quad (7)$$

$$\Delta H^* = [(\Delta E^*)^2 - (\Delta L^*)^2 - (\Delta C^*)^2]^{0.5} \quad (8)$$

The adhesion strength to the surface was determined in the PosiTest AT-A (automatic) pull-off Adhesion Tester (Defelsko® crop., S/N AT11802, Ogdensburg, NY, USA) according to the ASTM D4541-22 (2022) standard. Plastic steel instant adhesive (resin and catalyst) 404 plastic steel brand (Çekmeköy, İstanbul, Turkey) adhesive was used in the bonding process. The aged and unaged lacquered surfaces were 20 mm diameter dolly, and the drawing rollers were glued at 20 ± 2 °C at normal room temperature and left to dry for 24 h. Adhesion resistance was calculated using Eq. 9 below (where X = Adhesion resistance (MPa), D = Diameter of drawing roller (mm), and F = force at break (Newton):

$$X = [(4F)/(\pi . d^2)] \quad (9)$$

In the study, standard deviations, homogeneity groups, minimum and maximum values, percentage (%) change rates, averages, and univariate analysis of variance were determined with a SPSS program (Sun Microsystems, Inc., Network Circle, Santa Clara, CA, USA).

RESULTS AND DISCUSSION

Table 1 presents the color, pendulum hardness, glossiness, and surface adhesion strength (MPa) results indicated on the yacht varnish layers before and after weathering. In addition, univariate analysis of variance data was also obtained to determine significance for all tests.

Results of Color Parameters

According to these results, as the weathering time increased from 144 to 576 h, the *L** value decreased and *a** increased. After some of the UV rays pass through the outer surface of the varnish, they turn into short-wave UV rays due to reflections and refractions in the varnish film thickness, and they cannot go out of the varnish film surface and continue to be reflected and refracted. As a result, a heat increase occurs on the varnish film surface. It is thought that this increase in light interactions causes darkening by disrupting the structure of lignin on the surface of the tree. Depending on these, it is thought that there is an increase in the *a** parameter (Bilgen 2010). The decrease in *L** went from 17.3% to 32.9% (Table 1). A decrease in *L** indicates a darkening in color tone, and an increase indicates a lightening of the color (Söğütlü and Sönmez 2006; Karamanoğlu and Akyıldız 2013). Based on this sentence, it can be said that darkening was achieved in this study. Although *C** increased towards the end of the weathering time, they shifted to 52.8% in the last weathering application. However, the *C** of the un-weathered samples were determined as 30.0 at the lowest value. The *b** gave the same level of results as *C** with increased weathering time, and *b** increased 65% with weathering. In addition, while h^o increased at 144 and 288 h of decomposition, they decreased at the end of 432 and 576 h (Table 1). Gurleyen (2018) reported that *b** and *a** increased and *L** decreased after 432 h of artificial weathering on synthetic varnish layers applied to white poplar, American ash, white willow, and European alder wood species.

Results of Pendulum Hardness Test

Pendulum hardness values according to the König method increased by 50.1%, 48.9%, 70.3%, and 63.2%, respectively, at the end of 144, 288, 432, and 576 h of weathering compared to the un-weathered samples (Table 1).

Table 1. Color, Surface Adhesion, Glossiness, and Pendulum Hardness Results

Test	Weathering Time	N	Mean	Change (%)	*HG*	Std. Deviation	Minimum	Maximum
Lightness (*L**) Value (Sig. 0.005)	Un-weathered	10	66.12	-	A*	2.10	63.94	70.25
	144 h	10	54.69	↓17.29	B	0.95	53.29	56.03
	288 h	10	52.48	↓20.63	C	0.94	50.59	53.82
	432 h	10	50.14	↓24.17	D	0.76	49.14	51.06
	576 h	10	44.38	↓32.88	E**	2.09	41.85	47.41
Red (a*) Color Tone Value (Sig. 0.005)	Un-weathered	10	12.50	-	E**	0.57	11.69	13.20
	144 h	10	17.98	↑43.84	D	0.38	17.42	18.76
	288 h	10	20.14	↑61.12	C	1.60	17.38	23.83
	432 h	10	22.18	↑77.44	B	2.71	17.43	24.60
	576 h	10	24.82	↑98.56	A*	1.18	21.96	26.08
Yellow (b*) Color Tone Value (Sig. 0.005)	Un-weathered	10	27.29	-	C**	0.94	25.80	29.21
	144 h	10	43.75	↑60.32	A	1.12	41.32	45.32
	288 h	10	45.11	↑65.30	A*	2.09	41.04	47.41
	432 h	10	44.49	↑63.03	A	2.82	37.88	47.41
	576 h	10	38.51	↑41.11	B	3.11	35.52	44.43
Chroma (*C**) Value (Sig. 0.005)	Un-weathered	10	30.02	-	D**	0.96	28.36	32.05
	144 h	10	47.30	↑57.56	BC	1.11	44.92	49.05
	288 h	10	49.41	↑64.59	AB	2.43	44.57	53.07
	432 h	10	49.73	↑65.66	A*	3.64	41.70	53.07
	576 h	10	45.86	↑52.76	C	2.67	43.40	51.34
Hue (h^o) Tone Value (Sig. 0.005)	Un-weathered	10	65.39	-	B	1.04	64.00	67.34
	144 h	10	67.66	↑3.47	A*	0.51	66.90	68.47
	288 h	10	65.96	↑0.87	B	1.16	63.31	67.05
	432 h	10	63.59	↓2.75	C	1.69	61.78	66.23
	576 h	10	57.10	↓12.68	D**	2.48	53.72	59.96
Glossiness in perpendicular (⊥) value (Sig. 0.005)	Un-weathered	10	112.30	-	A	1.64	110.00	115.00
	144 h	10	113.50	↑1.07	A*	1.27	112.00	115.00
	288 h	10	113.00	↑0.62	A	1.70	110.00	115.00
	432 h	10	90.90	↓19.06	B**	1.85	88.00	94.00
	576 h	10	91.40	↓18.61	B	2.32	86.00	94.00
Glossiness in parallel (‖) value (Sig. 0.005)	Un-weathered	10	107.70	-	A	5.33	98.00	113.00
	144 h	10	108.50	↑0.74	A*	4.20	104.00	113.00
	288 h	10	108.30	↑0.56	A	5.14	97.00	114.00
	432 h	10	90.30	↓16.16	B	1.83	86.00	92.00
	576 h	10	84.80	↓21.26	C**	6.76	69.00	91.00
Pendulum Hardness (s) (Sig. 0.005)	Un-weathered	10	60.30	-	C**	1.95	58.00	64.00
	144 h	10	90.50	↑50.08	B	6.11	79.00	98.00
	288 h	10	89.80	↑48.92	B	4.66	82.00	96.00
	432 h	10	102.70	↑70.32	A*	7.62	91.00	112.00
	576 h	10	98.40	↑63.18	A	4.58	90.00	105.00
Surface Adhesion Tester (MPa) (Sig. 0.005)	Un-weathered	10	3.674	-	B	0.65	2.494	4.382
	144 h	10	3.294	↓10.34	B**	0.34	2.901	3.727
	288 h	10	4.618	↑25.69	A*	1.02	3.204	6.160
	432 h	10	3.709	↑0.95	B	0.27	3.369	4.065
	576 h	10	3.514	↓4.35	B	0.43	2.825	4.044

*: Highest result, **: Lowest result, , *HG*: homogeneity group, N: Number of measurements

It was reported by Çakıcıer (2007) that after artificial weathering (288 h), pendulum hardness values increased in two component acrylic modified water-based varnishes applied to chestnut wood, but decreased in one-component water-based varnishes. This situation is thought to occur because of the different resin structures of the varnish types. Çakıcıer (2007) stated in her study that the temperature effect, which increases during the weathering process, increases the cross-links established between the varnish molecules, leading to an increase in the hardness of the polymeric layers. In the study conducted by Baysal *et al*. (2014), the hardness value increased 153% after weathering synthetic varnish layers applied to Scotch pine wood in a QUV device for 500 h. Ulay and Ayata (2023) reported that in chestnut wood covered with polyurethane varnish, the highest oscillation hardness value was obtained in heat-treated and unaged samples (158s), while the lowest hardness value (113s) was obtained in test samples aged with 432 hours UVB lamp and heat-treated.

Yalinkilic *et al*. (1999) reported that pendulum hardness values increased in chestnut and Scotch pine woods treated with synthetic varnishes that were left outside for 9 months, compared to un-weathered samples. The increase in hardness is because of the progressive crosslinking of alkyd segments and subsequent degradation segments upon outdoor exposure (Majumdar *et al*. 1998; Yalinkilic *et al*. 1999).

Results of Adhesion Resistance to the Surface (MPa)

Adhesion results changed after weathering procedures. With the exposure of the yacht varnish layers to the weathering of the UV-B 313 EL lamp, the adhesion resistance to the surface decreased by 10.3% at the end of 144 h of weathering, while it showed an increase of 25.7% at the end of 288 h. At the end of 576 h, a decrease was recorded with a decrease of 4.35% (Table 1). A smoother pasted surface resulted in a greater bonding force (Sanivar and Zorlu 1980). Bilgen (2010) reported in his study that the water on the surface acts as a lens and causes heating on the sample surface, because of the rainwater that remains on the surface until it dries up in the samples kept in outdoor conditions and the sun rays reflecting off the sample surface at a right angle. In addition, Bilgen (2010) stated that as a result of superficial heating, the bonds formed between the varnish molecules and the sample surface weakened, thus reducing the adhesion resistance to the surface. It was reported by Yalinkiliç *et al*. (1999) that the adhesion strength to the surface first decreased at the end of 6 months and increased at the end of the 9^{th} month.

Clerc *et al*. (2017) stated that the loss of bond strength due to weather conditions is mostly due to the degradation of the wood rather than the chemical degradation of the adhesive. It has been stated in the literature that ultraviolet light can pass through them to initiate photochemical reactions on the underlying wood surfaces that cause discoloration and adhesion failure between the coating system and the wood (Hon *et al*. 1985). In addition to the reflection of the rays from the surface at a right angle, the rainwater remaining on the surface until it dries and the water on the surface acting as a lens during this time and heating the sample surface may weaken the molecular bonds of the varnishes and cause a low adhesion resistance to the surface (Bilgen 2010).

Results of Glossiness Values

While the glossiness values perpendicular (⊥) and parallel (║) to the fibers increased in the 144 and 288 h periods of weathering, they decreased at the end of the 432 and 576 h periods (Table 1). It was stated by Yalinkiliç *et al*. (1999) that the glossiness values increased in Scotch pine and chestnut woods that were applied synthetic varnishes that were left outside for 9 months. Gurleyen (2018) reported that after 432 h of artificial weathering performed on synthetic varnished materials applied to American ash, European alder, white poplar, and white willow wood species, the glossiness values perpendicular and parallel to the fibers decrease.

Results for Total Color Differences

The results of the total color differences are shown in Table 2. According to these results, Δ*a** and Δ*E** values increased with increasing weathering time. It can be said that the weathering application with UV-B 313EL lamps causes changes in the layers of yacht varnish. The Δ*C** values expressing saturation difference are clearer than reference, brighter than reference, Δ*a** values are redder than reference, Δ*L** values are darker than reference, and Δ*b** values are more yellow than reference determined. In the literature, it has been reported that there are changes in the varnish layers after accelerated weathering in different wood species that have been applied to various varnishes (water-based, UV system, acrylic, *etc.*) (Çakıcıer 2007; Ayata 2019; Karamanoğlu 2020; Ayata *et al.* 2021a,b).

The study showed compatibility with the literature, which reported that the total color change values are high on the samples that applied accelerated weathering process. In addition, it has been reported that this situation may be caused by free radicals formed because of photochemical reactions under the influence of UV rays, heat, and precipitation (Payne 1965).

Table 2. Results for Total Color Differences

Weathering Time	Δ*L**	Δ*C**	Δ*b**	Δ*a**	Δ*H**	Δ*E**
144 h	-11.43	17.28	16.46	5.48	1.52	20.77
288 h	-13.64	19.40	17.82	7.64	-	23.71
432 h	-15.98	19.71	17.20	9.68	1.03	25.40
576 h	-21.73	15.84	11.22	12.32	5.18	27.39

CONCLUSIONS

1. At the end of the artificial weathering period, h^o and *L** decreased compared to un-weathered samples, while *a**, *b**, *C**, and pendulum hardness values increased.
2. While the adhesion strength to the surface decreased in the first period of weathering, it increased at 288 and 432 h, but decreased 4.35% at the 576^{th} h.
3. The glossiness values perpendicular and parallel to the fibers increased at 144 and 288 h and decreased at 432 and 576 h.
4. Δ*E** values increased with increasing weathering time. After 576 h, Δ*E** increased by 24.17% compared to the 144-h period.

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