Drewno 2021, Vol. 64, No. 208
DOI: 10.12841/wood.1644-3985.383.09

Ümit Ayata, Bruno Esteves, Levent Gürleyen, Nevzat Çakicier, José Ferreira, Idalina Domingos, Mutlu Türk

EFFECT OF ACCELERATED AGEING ON SOME SURFACE PROPERTIES OF UV-COATED HACKBERRY (*Celtis australis* L.) WOOD PARQUET

The importance of UV-curable coatings is currently increasing. In the parquet industry, where UV systems are applied, it is beneficial to investigate new tree species as potential raw materials. This study was carried out to determine the effect of accelerated ageing on some surface properties of hackberry (Celtis australis L.) wood treated with UV system parquet varnish. UV system parquet varnishes were applied to hackberry wood surfaces in three and five layers, according to the requirements of industrial applications. The varnished surfaces were then exposed to UV rays for 252 and 504 h using UVA-340 lamps in a QUV ageing device. Glossiness, colour parameters, pendulum hardness and adhesion strength (pull-off) (MPa) were determined for the coated samples before and after ageing, and the results for the aged and unaged test samples were compared. Analysis of variance showed that the results were significant for all tests. The results for all tests varied by ageing time.

Keywords: hackberry, UV varnish, ageing, pendulum hardness, colour, glossiness, adhesion

Ümit Ayata✉ (*umitayata@bayburt.edu.tr*), Bayburt University, Faculty of Arts and Design, Department of Interior Architecture and Environmental Design, Bayburt, Turkey; Bruno Esteves (*bruno@estgv.ipv.pt*), Polytechnic Institute of Viseu and Research Center for Natural Resources, Environment and Society (CERNAS) Viseu, Portugal; Levent Gürleyen (*leventgurleyen@hotmail.com*), Golyaka Vocational and Technical Anatolian High School, Duzce, Turkey; Nevzat Çakicier (*nevzatcakicier@duzce.edu.tr*), Duzce University, Faculty of Forestry, Department of Forest Industry Engineering, Duzce, Turkey; José Ferreira (*jvf@estgv.ipv.pt*), Polytechnic Institute of Viseu and Research Center for Natural Resources, Environment and Society (CERNAS) Viseu, Portugal; Idalina Domingos (*ijd@estgv.ipv.pt*), Polytechnic Institute of Viseu and Research Center for Natural Resources, Environment and Society (CERNAS) Viseu, Portugal; Mutlu Türk (*mutluturk@gmail.com*), Efeler-Mesleki Egitim Merkezi, Aydın, Turkey

Introduction

UV system parquet varnishes are an important technical advance in the parquet industry. With the development of technology, the rapid spread of coatings that can dry quickly with UV rays has increased demand in many areas of use. Although domestic and foreign wood species are used in parquet production, it is seen that for many wood species which have an important potential area of application in the furniture sector, their possible use in the UV system parquet industry has not been investigated.

In the literature, there are studies on UV system parquet varnish application using different coatings on different tree species. Various tests were carried out on the varnish layers obtained in these studies, including the determination of colour, glossiness, adhesion strength (pull-off), pendulum hardness, etc. Examples of wood species to which UV coatings have been applied include *Fraxinus mandshurica* Rupr. by Li et al. [2021], *Pinus caribaea* var. *hondurensis* and *Eucalyptus grandis* by de Moura et al. [2013], white oak (*Quercus alba* L.) by Wang et al. [2019], American black walnut (*Juglans nigra* L.), northern red oak (*Quercus rubra*), maple (*Acer pseudoplatanus* L.) and walnut (*Juglans regia* L.) by Ayata et al. [2018a], limba (*Terminalia superba*), sapeli (*Entandophragma cylindricum*), chestnut (*Castanea sativa* Mill.) and iroko (*Chlorophora excelsa*) by Ayata and Çavuş [2018], oak (*Quercus* L.) by Stachowiak-Wencek [2019], Radiata pine (*Pinus radiata*) by Viengkhou et al. [1996], oak, Robinia, toothed oak, elm, walnut, *Pinnate pometia* and *Newtonia* spp. by Zhao et al. [2021], oak (*Quercus petraea* L.) by Gurleyen et al. [2019], Kaygin and Akgun [2008] and Ayata et al. [2016], lemon (*Citrus limon* (L.) Burm.) by Ayata [2019], beech (*Fagus orientalis* Lipsky) by Kaygin and Akgun [2008], Ayata et al. [2017a] and Ayata et al. [2018a; b], Persian silk (*Albizia julibrissin*) by Gurleyen [2020], doussie (*Afzelia africana*) by Gurleyen [2021], sugar maple (*Acer saccharum*) by Vardanyan et al. [2014], rowanberry (*Sorbus* L.) by Gurleyen et al. [2017b], ash (*Fraxinus excelsior*) by Ayata et al. [2017b], Scots pine (*Pinus sylvestris* L.) by Gurleyen et al. [2017a], mulberry (*Morus alba*) by Çavuş [2021], apricot (*Prunus armeniaca* L.) by Ayata et al. [2021a], Taurus cedar (*Cedrus libani* A. Rich) by Ayata et al. [2021b], European ash (*Fraxinus excelsior* L.) by Herrera et al. [2018], and black alder (*Alnus glutinosa* Gaertn. L.) by Salca et al. [2016]. The surface properties of the UV system varnish layers on these wood species were investigated, and positive and negative test results were discussed.

Hackberry (*Celtis australis* L.) trees are naturally present in Turkey, Southern Europe and North Africa. In Turkey, in the North, West, South, and around Hatay city, it grows to between 50 and 1000 metres [Gultekin 2014]. It is a forest tree with a crown diameter of 6-8 m [Çugen 2011] and can grow up to 25 metres. It has edible orange-yellow fruits. It is a plant of the Mediterranean ecosystem. It develops a taproot system, and usually enters the mix of other species in the growing area. It is a durable landscape plant [Gultekin 2014]. It is a tropical to temperate tree [Gaur 1999]. Hackberry wood was determined as cellulose 46.54%, lignin 20.80%, hemicellulose 20.48%, extractive substances 4.05%, hot water solubility 6.71%, ash 1.42%, fuel index value 1800.73 [Sedai et al. 2016], air-dry density 1.058 g/cm^3, dynamic bending (shock) resistance 1.53 kgm/cm^2, bending resistance 108.10 N/mm^2, elastic modulus 8247.10 N/mm^2, static hardness values for tangent, radial and transverse surfaces 106.80 N/mm^2, 117.40 N/mm^2 and 128.20 N/mm^2, and screw holding capacity values for tangent, radial and transverse surfaces 58.10 N/mm^2, 59.60 N/mm^2 and 55.80 N/mm^2 [Çavuş 2020]. Its wood is used in the production of walking sticks [Usher 1974], in the manufacture of hoops [Gultekin 2014], and in the production of tool and whip handles, glasses, spoons, milk jugs, sports equipment, paddles, canoes, rods, and agricultural equipment. It can be carved and used in car construction and as a general building material [Bhatt and Verma 2002]. Celtis timber has also been reported to be a good source of paper and pulp [Pearson and Brown 1932; Trotter 1944]. In the light of this information, it is notable that there are no existing studies in the literature concerning the application of UV system parquet varnishes to hackberry wood.

In this study, UV system varnishes were applied to hackberry wood according to the requirements of industrial applications. These materials were then aged for 252 and 504 h in an accelerated ageing device. By testing some properties – colour parameters, glossiness, adhesion strength (pull-off), and pendulum hardness – of aged and unaged specimens, it was sought to contribute to the international literature by providing new information about the possible use of this tree species.

Materials and methods

Wood material

Hackberry (*Celtis australis* L.) wood was chosen in the study and was purchased from a commercial timber company in Izmir City, Turkey. The dimensions of the wooden sections provided were 90 cm × 10 cm × 1.8 cm. Later, in accordance with the TS 2471 [1976] standard, 30 test samples were subjected to conditioning in air at a relative humidity of 65 ±3% and a temperature of 20 ±2°C.

UV system parquet varnish application

UV system parquet varnishes, consisting of three and five layers, were applied to hackberry wood surfaces at KPS Company (Duzce City, Turkey) to suit industrial applications. The process of varnish application was carried out at a production line speed of 10 m/min. Information on the stages of implementation is shown in Table 1. Detailed information on the chemicals used in the study is given in the study by Ayata [2019]. The varnished materials were later conditioned in air in accordance with the TS 2471 [1976] standard (temperature 20 ±2°C and relative humidity 65 ±3%) until they reached a constant weight.

Table 1. UV system parquet production stages

3 layers	1→	Sanding and calibrating of machines (80 to 120 grit sizes)
	2→	Clear UV curing hydro primer applied 10 g/m^2 then dried (70°C)
	3→	UV curtain coating high glossiness applied 8 g/m^2
	4→	UV lamp drying (2 times) total (177 mJ/cm^2)
	5→	Sanding and calibrating of machines (280 to 320 grit sizes)
	6→	Clear mat UV oil applied 8 g/m^2
	7→	UV lamp drying (71 mJ/cm^2)
	8→	Clear mat UV oil applied 8 g/m^2
	9→	UV lamp drying (2 times) total (314 mJ/cm^2)
5 layers	1→	Sanding and calibrating of machines (80 to 120 grit sizes)
	2→	Clear UV curing hydro primer applied 10 g/m^2 then dried (70°C)
	3→	*UV clear curing sealer applied 20 g/m^2 then dried (70°C)
	4→	UV clear curing sealer applied 10 g/m^2 then dried (70°C)
	5→	UV clear curing sealer applied 10 g/m^2 then dried (170°C)
	6→	Sanding and calibrating of machines (280 to 320 grit sizes)
	7→	Clear mat UV oil applied 8 g/m^2
	8→	UV lamp drying (71 mJ/cm^2)
	9→	Clear mat UV oil applied 8 g/m^2
	10→	UV lamp drying (2 times) total (314 mJ/cm^2)

Determination of light quality – measuring instrument

In accordance with the DIN EN ISO/IEC 17025 [2016] standard, the UV energies of different light sources used during parquet production were determined using an A UV integrator device (Kühnast, Brachttal, Germany).

Artificial weathering

The ageing process of the samples with three and five layers of UV system parquet varnish was performed in a QUV weathering tester (Q-Lab, Westlake, OH, US) in accordance with the ISO 4892-3 [2016] standard. The ageing device was set to 0.67 light intensity, 15 min water spray, 50 °C temperature, and 8 h ultraviolet exposure with UVA-340 lamps. The ageing periods were 252 and 504 h. No unvarnished sample was tested in this study.

Determination of colour parameters

In accordance with ASTM D 2244-3 [2007], the yellow colour (b^*) tone, lightness (L^*), and red colour (a^*) tone of samples were measured using a CS-10 colorimeter (CHN Spec, China) (Fig. 1B) (CIE 10° standard observer; 8°/diffused illumination CIE D65 light source). The CIELAB system, characterized by the three axes L^*, b^*, and a^*, was used: a^* is the red (+) to green (–) tone; b^* is the yellow (+) to blue (–) tone; and the L^* axis represents lightness, ranging from 100 (white) to zero (black) [Ayata 2019]. Δa^*, Δb^*, ΔL^* and total colour difference (ΔE^*) of 3- and 5-layer UV system varnish were calculated using equations (1) to (4):

$$\Delta a^* = a^* \text{ aged UV coated} - a^* \text{ unaged UV coated} \quad (1)$$

$$\Delta L^* = L^* \text{ aged UV coated} - L^* \text{ unaged UV coated} \quad (2)$$

$$\Delta b^* = b^* \text{ aged UV coated} - b^* \text{ unaged UV coated} \quad (3)$$

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (4)$$

Colour change criteria according to Barański et al. [2017] are given in Table 2. The total colour difference (ΔE^*) values calculated using the formulae are compared with this table.

Table 2. Colour change criteria according to Barański et al. [2017]

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

Determination of glossiness values

In accordance with the ISO 2813 [1994] standard, the glossiness values of the test samples with UV system varnish before and after ageing were obtained in a gloss meter device (ETB-0833 model, Vetus Electronic Technology Co., Ltd., CN) (Fig. 1B) at 20°, 60° and 85°, perpendicular (⊥) and parallel (||) to the fibres.

Adhesion strength (pull-off) test

In accordance with the ASTM D 4541 [1995] standard, a total of 30 measurements were made using a PosiTest AT-A (automatic) pull-off adhesion tester (Defelsko® crop., DeFelsko Corporation, Ogdensburg, NY) (Fig. 1C). The adhesive used was 404 Plastic Steel Brand (resin and catalyst) adhesive

(Çekmeköy/Istanbul, Turkey) (Fig. 5F). The UV system varnished surfaces are 20 mm drawing rollers (Fig. 1D) adhered at normal room temperature of 20 ±2°C and left to dry for 24 h. The adhesion strength was calculated using equation (5) below;

$$X = \frac{4 \cdot F}{\pi \cdot d^2} \tag{5}$$

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

Determination of pendulum hardness

In accordance with the ASTM D 4366-95 [1984] standard, hardness properties of unaged and aged test specimens were determined using a König device (Pendulum Damping Tester, Model 299/300, Erichsen. Hemer, Germany) (Fig. 1E) designed to oscillate with two balls with a hardness of 63 ±3.3 HRC and a diameter of 5 ±0.0005 mm.

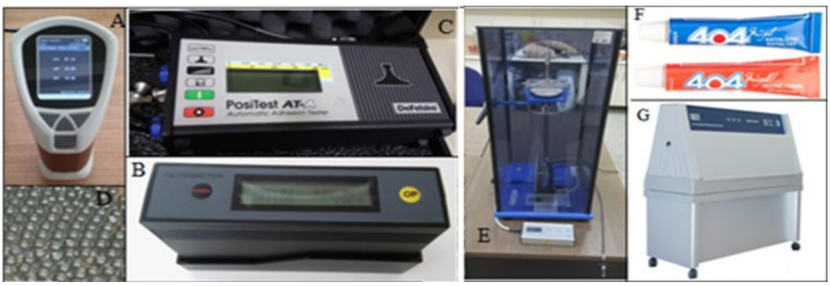

Fig. 1. CS-10 colorimeter (A), gloss meter (B), PosiTest AT pull-off tester (C), Preparing Dolly (D), pendulum hardness (E), 404 Plastic Steel Brand adhesive (F) and QUV weathering tester (G)

Statistical analysis

Test samples consisted of five pieces. Minimum and maximum values, standard deviations, mean, homogeneity groups, and analysis of variance were derived using the SPSS program, with data obtained from colour, glossiness, adhesion strength and pendulum hardness tests before and after weathering. Statistical analysis was performed for a total of 1170 measurements (colour parameters 360 + glossiness values 720 + adhesion strength 30 + pendulum hardness 60 = 1170).

Results and discussion

Analysis of variance results for the colour parameters (L^*, a^* and b^*) are given in Table 3. Significance was confirmed for the results for a^*, b^* and L^*.

Table 3. Analysis of variance results for colour parameters (*L, *a** and *b**)**

Test	Source	Sum of squares	Degrees of freedom	Mean square	F	Sig.
*L**	Varnish Type (A)	68.857	1	68.857	74.297	0.000*
	Weathering Time (B)	347.611	2	173.806	187.538	0.000*
	Interaction (AB)	828.579	2	414.289	447.022	0.000*
	Error	105.652	114	0.927		
	Total	232983.049	120			
	Corrected Total	1350.699	119			
*a**	Varnish Type (A)	95.052	1	95.052	382.209	0.000*
	Weathering Time (B)	73.485	2	36.743	147.744	0.000*
	Interaction (AB)	63.575	2	31.788	127.820	0.000*
	Error	28.351	114	0.249		
	Total	6697.673	120			
	Corrected Total	260.463	119			
*b**	Varnish Type (A)	92.805	1	92.805	156.301	0.000*
	Weathering Time (B)	418.965	2	209.483	352.809	0.000*
	Interaction (AB)	69.192	2	34.596	58.267	0.000*
	Error	67.688	114	0.594		
	Total	42226.743	120			
	Corrected Total	648.651	119			

*Significant if α is less than or equal to 0.05.

SPSS results for the colour parameters are given in Table 4. Among the samples with three layers of varnish, *L** was lowest in the control samples and highest in samples aged for 504 h (*L** increased with increasing ageing time). However, in the case of samples with five layers of varnish, *L** was highest in the control samples, and decreased after ageing. According to Sogutlu and Sonmez [2006], a decrease in *L** indicates "darkening" in colour tone, while an increase indicates "lighter" colour. In this study, the increase in *L** values (from 40 to 49) on ageing in samples with three layers of varnish represents a lighter colour, and the decrease (from 46 to 43) with five layers of varnish represents darkening. For both types of varnish application, the lowest values of *b** and *a** were obtained for the unaged control samples. The highest *a** value was obtained in samples aged for 252 h in the case of three layers of varnish, and in samples aged for 504 h in the case of five layers. The highest *b** value was found in samples aged for 504 h, for both types of varnish application. These results can be assumed to be due to the different contents of chemicals in the two types of varnish used in intermediate coat application.

Table 4. Statistical data for colour parameters (*L, *b** and *a**)**

Test	Varnish type	Weathering period	N	Mean	Homogeneity group	Standard deviation	Mini-mum	Maxi-mum
*L**	3 layers	control	20	40.24	E	0.42	39.44	40.87
		252 h	20	44.69	C	0.89	43.35	45.98
		504 h	20	49.15	A*	0.80	48.06	50.60
	5 layers	control	20	46.13	B	1.22	43.55	48.02
		252 h	20	39.96	E**	1.51	37.49	42.12
		504 h	20	43.43	D	0.44	43.00	44.50
*a**	3 layers	control	20	5.99	E**	0.17	5.76	6.32
		252 h	20	7.05	C	0.71	6.27	9.85
		504 h	20	6.27	E	0.56	5.32	7.88
	5 layers	control	20	6.59	D	0.21	6.29	7.18
		252 h	20	7.96	B	0.65	6.59	8.76
		504 h	20	10.10	A*	0.42	9.27	10.86
*b**	3 layers	control	20	14.30	E**	0.21	13.83	14.65
		252 h	20	19.17	C	0.97	18.36	22.89
		504 h	20	19.73	B	0.67	18.80	21.52
	5 layers	control	20	17.93	D	0.77	16.81	19.30
		252 h	20	19.07	C	1.17	17.05	20.63
		504 h	20	21.48	A*	0.38	20.92	22.61

N: number of measurements, *highest value, **lowest value.

Table 5 shows results for Δa^*, ΔL^*, Δb^* and ΔE^* calculated using the formulae given in the materials and methods section. The results show that ΔE^* in the case of three layers of varnish after ageing for 504 h was higher than the total colour difference in the case of five layers of varnish. The ΔE^* value for samples with three layers of varnish increased with increasing ageing time, but it decreased for samples with five layers (Table 5). When UV system varnish was applied in five layers on Persian silk by Gurleyen [2020] and on doussie by Gurleyen [2021] it was also found that ΔE^* increased with increasing ageing time. In those studies, the ΔE^* values decreased in the case of samples with three varnish layers, although they were found to increase in our study. This can be assumed to be due to the use of different wood types. When the total colour difference (ΔE^*) values of the varnishes are compared with the colour change criteria given in Table 2 according to Barański et al. [2017], it is seen that the results for the three-layer samples satisfy the "high colour change" criterion for both periods of ageing. The results for the five-layer samples satisfy the "high colour change" criterion after 252 hours of ageing, and "colour change visible with average quality of filter" after 504 hours.

Table 5. Δ*a, Δ*L**, Δ*b** and Δ*E** values**

Varnish type	Weathering period	Δ*L**	Δ*a**	Δ*b**	Δ*E**	Colour change criteria [Barański et al. 2017]	
3 layers	252 hours	4.45	1.06	4.87	6.68	12 > Δ*E** > 6	A
	504 hours	8.91	0.28	5.43	10.44	12 > Δ*E** > 6	A
5 layers	252 hours	–6.17	1.37	1.14	6.42	12 > Δ*E** > 6	A
	504 hours	–2.70	3.51	3.55	5.68	6 > Δ*E** > 3	B

A: 12 > ΔE* > 6 (→ High colour change).
B: 6 > ΔE* > 3 (→ Colour change visible with average quality of filter).

Table 6 shows the results of analysis of variance for the glossiness values. They show that for 3- and 5-layer UV system varnish applications, glossiness values at 20°, 60°, and 85° perpendicular and parallel to the fibres were found to be significant.

Table 7 shows the SPSS results for glossiness values at 20°, 60°, and 85° perpendicular and parallel to the fibres.

It was found that the glossiness values at 20°, 60°, and 85° perpendicular and parallel to the fibres, in the case of samples with five layers of UV system varnish, decreased with an increase in ageing time. All glossiness values for samples with five layers were higher than those for samples with three layers. Parallel glossiness values at 60° and 85° were higher than the perpendicular glossiness values. Changes in glossiness during accelerated ageing are strongly correlated with the level of degradation of the surface coating [Cristea et al. 2010]. One of the first wood cell wall polymers to be degraded by UV radiation is lignin, causing bond cleavage of lignin moieties with α-carbonyl, biphenyl or ring-conjugated double bond structures. Lignin absorbs UV radiation across the UV and UV-vis light spectrum. The lignin photodegradation mechanism is complex, with different pathways yielding free phenoxy radicals that lead to chain cleavage and yellowing [Teacă and Bodîrlău 2016].

Table 8 shows the results of analysis of variance for pendulum hardness and adhesion strength. The values for both adhesion strength and pendulum hardness were found to be significant (Table 8).

Table 9 shows SPSS results for pendulum hardness and adhesion strength.

The pendulum hardness values for samples with five layers of UV system varnish were higher than for those with three layers. In addition, pendulum hardness values decreased on ageing in the three-layer case: a reduction of 13.11% was obtained after 252 h of ageing and a reduction of 30.26% after 504 h of ageing, compared with the control. In the five-layer case, the opposite trend was observed (Table 9). It is reported in the literature that surfaces with higher oscillations are hard and those with fewer oscillations have lower hardness [Sonmez 1989]. Cakicier [2007] reported an increase in layer hardness

Table 6. Analysis of variance results for glossiness values

Test	Source	Sum of squares	Degrees of freedom	Mean square	F	Sig.
‖20º	Varnish type (A)	13.534	1	13.534	1198.358	0.000*
	Weathering time (B)	4.273	2	2.137	189.181	0.000*
	Interaction (AB)	5.253	2	2.627	232.567	0.000*
	Error	1.288	114	0.011		
	Total	71.850	120			
	Corrected total	24.348	119			
‖60º	Varnish type (A)	2474.300	1	2474.300	29.389	0.000*
	Weathering time (B)	951.392	2	475.696	5.650	0.005*
	Interaction (AB)	749.985	2	374.993	4.454	0.014*
	Error	9597.921	114	84.192		
	Total	19730.850	120			
	Corrected total	13773.598	119			
‖85º	Varnish type (A)	3882.856	1	3882.856	10670.016	0.000*
	Weathering time (B)	4657.309	2	2328.654	6399.098	0.000*
	Interaction (AB)	1438.763	2	719.382	1976.847	0.000*
	Error	41.485	114	0.364		
	Total	18517.880	120			
	Corrected total	10020.413	119			
⊥20º	Varnish type (A)	17.557	1	17.557	6985.932	0.000*
	Weathering time (B)	6.181	2	3.090	1229.661	0.000*
	Interaction (AB)	8.216	2	4.108	1634.597	0.000*
	Error	0.287	114	0.003		
	Total	77.750	120			
	Corrected total	32.240	119			
⊥60º	Varnish type (A)	1505.633	1	1505.633	28993.517	0.000*
	Weathering time (B)	531.592	2	265.796	5118.349	0.000*
	Interaction (AB)	276.286	2	138.143	2660.176	0.000*
	Error	5.920	114	0.052		
	Total	6106.637	120			
	Corrected total	2319.431	119			
⊥85º	Varnish type (A)	2018.840	1	2018.840	71496.675	0.000*
	Weathering time (B)	1594.741	2	797.371	28238.660	0.000*
	Interaction (AB)	876.751	2	438.376	15524.951	0.000*
	Error	3.219	114	0.028		
	Total	7443.760	120			
	Corrected total	4493.552	119			

*Significant if α is less than or equal to 0.05.

Table 7. Statistical data for glossiness values

Test	Varnish type	Weathering period	N	Mean	Homogeneity group	Standard deviation	Mini-mum	Maxi-mum
‖20°	3 layers	control	20	0.30	E	0.00	0.30	0.30
		252 h	20	0.20	F**	0.00	0.20	0.20
		504 h	20	0.38	D	0.18	0.30	0.90
	5 layers	control	20	1.49	A*	0.09	1.30	1.60
		252 h	20	0.87	B	0.13	0.60	1.00
		504 h	20	0.54	C	0.10	0.40	0.70
‖60°	3 layers	control	20	3.46	B	0.05	3.40	3.50
		252 h	20	1.96	B	0.07	1.80	2.00
		504 h	20	2.10	B	0.02	2.00	2.10
	5 layers	control	20	15.62	A*	0.09	15.50	15.80
		252 h	20	15.02	A	22.47	9.70	110.50
		504 h	20	4.13	B	0.17	3.90	4.40
‖85°	3 layers	control	20	6.79	C	0.13	6.60	7.00
		252 h	20	1.29	E	0.22	0.70	1.40
		504 h	20	0.10	F	0.00	0.10	0.10
	5 layers	control	20	26.26	A*	0.12	26.10	26.50
		252 h	20	13.41	B	0.34	12.90	13.90
		504 h	20	2.65	D	1.41	1.50	5.30
⊥20°	3 layers	control	20	0.21	E	0.08	0.10	0.30
		252 h	20	0.20	E**	0.02	0.10	0.20
		504 h	20	0.30	D	0.02	0.20	0.30
	5 layers	control	20	1.60	A*	0.09	1.40	1.70
		252 h	20	1.00	B	0.00	1.00	1.00
		504 h	20	0.40	C	0.00	0.40	0.40
⊥60°	3 layers	control	20	2.97	D	0.17	2.70	3.20
		252 h	20	1.62	E**	0.19	1.18	1.70
		504 h	20	1.64	E	0.10	1.50	1.80
	5 layers	control	20	13.97	A*	0.41	13.50	14.80
		252 h	20	8.27	B	0.12	8.00	8.50
		504 h	20	5.25	C	0.22	4.80	5.60
⊥85°	3 layers	control	20	2.20	D	0.00	2.20	2.20
		252 h	20	0.23	E	0.22	0.10	0.70
		504 h	20	0.14	E**	0.08	0.10	0.30
	5 layers	control	20	17.91	A*	0.23	17.40	18.20
		252 h	20	5.94	B	0.21	5.60	6.30
		504 h	20	3.34	C	0.13	3.20	3.50

N: number of measurements, *highest value, **lowest value.

Table 8. Analysis of variance results for pendulum hardness and adhesion strength

Test	Source	Sum of squares	Degrees of freedom	Mean square	F	Sig.
Pendulum hardness	Varnish type (A)	22504.067	1	22504.067	406.972	0.000*
	Weathering time (B)	1009.900	2	504.950	9.132	0.000*
	Interaction (AB)	4852.633	2	2426.317	43.878	0.000*
	Error	2986.000	54	55.296		
	Total	441710.000	60			
	Corrected total	31352.600	59			
Adhesion strength	Varnish type (A)	0.222	1	0.222	6.644	0.017*
	Weathering time (B)	5.150	2	2.575	77.110	0.000*
	Interaction (AB)	0.231	2	0.116	3.459	0.048*
	Error	0.801	24	0.033		
	Total	83.077	30			
	Corrected total	6.405	29			

*Significant if α is less than or equal to 0.05.

Table 9. Statistical data for pendulum hardness and surface adhesion strength

Test	Varnish type	Weathering period	N	Mean	Homogeneity group	Standard deviation	Mini-mum	Maxi-mum
Pendulum hardness	3 layers	control	10	71.70	D	8.50	60.00	88.00
		252 h	10	62.30	E	3.86	56.00	69.00
		504 h	10	56.00	E**	5.89	47.00	66.00
	5 layers	control	10	85.00	C	3.86	80.00	93.00
		252 h	10	114.10	A*	8.96	102.00	130.00
		504 h	10	107.10	B	10.71	90.00	121.00
Adhesion strength (MPa)	3 layers	control	5	2.15	A*	0.28	1.86	2.52
		252 h	5	1.46	B	0.15	1.28	1.62
		504 h	5	0.93	C**	0.04	0.88	0.98
	5 layers	control	5	2.14	A	0.29	1.82	2.54
		252 h	5	1.57	B	0.12	1.45	1.75
		504 h	5	1.34	B	0.06	1.27	1.40

N: number of measurements, *highest value, **lowest value.

due to the ageing effect in his study. He stated that the temperature effect, which increases during the ageing process, increases cross-links between varnish molecules, which leads to an increase in the hardness of the polymeric layers. Similar results were obtained after 252 and 504 h with UV system varnish applied (in three and five layers) on apricot by Ayata et al. [2021a], on Persian silk by Gurleyen [2020], and on doussie by Gurleyen [2021]. It is also reported that adhesion strength values decreased after 252 and 504 hours of ageing of samples with three and five layers of UV system varnish: by Ayata et al. [2021a] using apricot, by Gurleyen [2021] using doussie, by Ayata [2019] using lemon, and by Gurleyen [2020] using Persian silk. According to Bilgen [2010], temperature, different wavelengths of sunlight, humidity and UV radiation are influencing factors, and their effect levels may vary according to different times of day and seasonal changes. Their effects cause expansion in the varnish layer, decreasing the adhesion strength between the varnish layer and the sample surface. The results of our study were in line with those reported in the literature. Reduction in adhesion strength may be due to many factors (migration of extractives to the wood surface affecting the bond line, wood degradation, chemical degradation of the coating, etc.) [Ayata 2019]. It has been reported that loss of adhesion strength due to weather conditions is caused by wood deterioration rather than chemical degradation of the adhesive [Clerc et al. 2017].

Conclusions

The results of the study are summarized below:

– Analysis of variance for all tests showed the results to be significant. This highlights the importance of the different types of chemicals used in undercoat applications.
– It was found that glossiness values at 20°, 60°, and 85° perpendicular and parallel to the fibres, adhesion strength, and *L** values decreased, while *a** and *b** values increased, after ageing in samples with five layers of UV system varnish. For samples with three layers of varnish, *L**, *a**, *b**, and glossiness values at 20° perpendicular and parallel to the fibres increased on ageing, while pendulum hardness, adhesion strength and glossiness values at 60° and 85° perpendicular and parallel to the fibres decreased.
– Surfaces with five layers applied were determined to be harder than those with three layers, according to pendulum hardness results.
– Comparing the results of this study with other studies using the same applications of UV system varnish and ageing processes, the fact that the wood species are different has added important information to the existing research results.
– According to the results obtained for both varnish types (3- and 5-layer), it was found that although the top coat applications are the same, different results are obtained after ageing due to the different filling coats.
– It is seen that there are many incomplete studies on hackberry wood in the literature. As a suggestion, it is recommended to apply artificial or natural ageing for this wood type, to determine the relationship between varnish types by applying various varnishes (cellulosic, synthetic, water-based,

acrylic, polyurethane, etc.), and to perform chemical analysis of the wood of this tree.

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Acknowledgements

The authors would like to thank the KPS factory in Duzce City, Turkey for the UV varnish applications.

Submission date: 8.02.2021

Online publication date: 13.12.2021