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Determination of the color changes against accelerated UV aging of used water based layers on some heat-treated (ThermoWood) wood species

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Abstract

Aim of study: The objective of this study is to investigate the accelerated UV resistance of water-based varnish layers, applied on heat-treated wood (ThermoWood) surfaces.

Area of study: Determination of the relationship between heat-treated, water based varnish, aging and color.

Material and Methods: Wood specimens prepared from Scotch pine (*Pinus sylvestris* L.), Oak (*Quercus petreae* L.) and Oriental beech (*Fagus orientalis* L.) were heat-treated according to ThermoWood method at 190ºC for 2 hours, and at 212ºC for 1 hour and 2 hours. Following the heat treatment, one and two component water-based varnishes were applied to similar layer thicknesses. The finished specimens were exposed to UV-A 340 nm fluorescent lamp in a “QUV accelerated weathering tester” for 144, 288 and 432 hours (ASTM G 154-06, 2006). At the end of each exposure period, red color tone, yellow color tone, lightness and total color difference values were determined according to ASTM-D 2244-3.

Main results: Lightness and total color difference values of the water-based single and double component varnishes increased after the UV aging.

Research highlights: All color parameters had changed due to aging.

Keywords: Heat Treatment, UV Aging, Water-Based Varnish, Color

Isıl işlem (ThermoWood) görmüş bazı odun türlerinde uygulanan su bazlı vernikler katmanlarının UV yaşlandırma etkisine karşı renk değişikliklerinin belirlenmesi

Özet

Çalışmanın amacı: Isıl işlem (ThermoWood) görmüş bazı ağaç türlerinde kullanılan su bazlı vernik katmanlarının hızlandırılmış UV yaşlandırma etkisine karşı renk değişim özelliklerini belirlemektir.

Çalışma alanı: Isıl işlem görmüş, su bazlı vernik, yaşlandırma ve renk arasındaki ilişkinin belirlenmesidir.

Materyal ve Yöntem: Bu amaç ile Sarıçam (*Pinus sylvestris* L.), Sapsız meşe (*Quercus petreae* L.) ve Doğu kayını (*Fagus orientalis* L.) odunlarından hazırlanan deney örnekleri ThermoWood metoduna göre 190ºC’de 2 saat, 212ºC’de 1 saat ve 2 saat süreler ile ısıl işleme tabi tutulmuştur. Daha sonra deney örneklerinin yüzeylerine, tek ve çift bileşenli su bazlı vernikler üretici firmaların önerilerine göre uygulanmış ve UV-A 340 nm florasan lambalarının bulunduğu “QUV accelerated weathering tester” cihazında; 144, 288 ve 432 saat süre boyunca UV etkisine altında (ASTM G 154-06, 2006) yaşlandırmaya maruz bırakılmışlardır. Yaşlandırma sonrasında, kırmızı renk tonu, sarı renk tonu, ışıklılık ve toplam renk farkı değerleri ASTM-D 2244-3 standardına göre belirlenmiştir.

Sonuçlar: Yaşlandırma sonrasında ışıklılık ve toplam renk farkı değerlerinin artış gösterdiği belirlenmiştir.

Araştırma vurguları: Yaşlandırmaya bağlı olarak bütün renk parametreleri değişmiştir.

Anahtar kelimeler: Isıl işlem, UV yaşlandırma, Su-bazlı vernik, Renk

Introduction

Wood is a natural composite material. The protection of wooden materials is necessary. There are many studies on this subject (Kurtoglu, 2000; Bozkurt, Goker & Erdin 1993; Korkut & Kocaefe, 2009; Ayata, 2014). There are many different methods in the literature (impregnation, acetylation, etc.) for the protection of wood materials. These protection methods generally contain chemical substances. A sample of this method, Sogutlu & Sonmez (2006) were reported that discoloration performances of acacia, pear, chestnut, oak and cedar applied shellac varnish, teak oil, and liquid paraffin wax after exposure of UV lights for 72 hours. One of these methods is the heat treatment method. But, temperature and water vapor are used in this method. Today, there are various heat treatment methods. ThermoWood method is one of these methods and is located in our country (Bolu-Gerede, Turkey). Heat-treated material is used in outdoor environment. But heat-treated wood material is exposed to external influences (wind, rain, frost, temperature, etc.). For this, surface protective chemicals (varnish, paint, etc.) can be applied to heat-treated wood materials. The color change in wooden materials has due to various reasons. As an example of this work: it was stated that there was a strong correlation between the value of color lightness for hemicellulose in Oriental beech wood, lignin in pine wood and gluxy in a spruce wood (Gonzalez-Pena & Hale, 2009). Considering total color difference results, it can be seen that these values changed. In another study, the color change in wood after heat treatment was due to the hydrolysis of hemicelluloses (Hillis, 1975). Akkus (2012) reported variation in ΔE^* could be a chemical change that can occur in the main polymers of heat-treated wood. In the case of scots pine wood, it was reported that extractives were more abundant than other species and that oxidation-ending color changed too much with water-based varnishes exhibiting alkali (pH 8-9) (Cakicier, 2007). Another study reported that high energy of sunlight ultraviolet (UV) wave lengths causes deterioration of varnish and paint layers (Feist, 1984).

In this study, color parameters against the aging effect of heat-treated Scotch pine, Oak and Oriental beech wood species (at 190ºC for 2 hours, 212ºC for 1 hour to 2 hours according to ThermoWood method) and water based varnishes (single and double component) applied samples were investigated. These results will help determine the relationship between aging - heat treatment - varnish.

Material and Method

Wood Materials

In this study, Scots pine (*Pinus sylvestris* L.), Oriental beech (*Fagus orientalis* L.) and oak (*Quercus petreae* L.) were chosen. These wood species were chosen because they are widely used species in the furniture and decoration industry in our country (Kazan, 2009). These wood types were taken from factories in Duzce, Turkey by measuring dimensions 510 x 110 x 20 mm fresh according to random selection method. Test specimens were chosen to be equally radial and tangential. Wood samples were kept at a temperature of 20±2°C and a humidity of 65 ± 5% relative humidity until reaching a constant weight, resulting in a moisture uptake of 12% (TS 642, 1997).

Heat Treatment Application

Wood samples were subjected to heat treatment at 190°C for 2 hours and at 212°C for 1 hour and 2 hours according to ThermoWood method (Nova ThermoWood Factory, Bolu-Gerede, Turkey) (Anonymous, 2003). Later, test specimens were sanded 100, 120 and 180 sand in the calibrated sanding machine according to industrial applications. The test specimens were determined as 500 x 100 x 14 mm. Heat-treated samples were kept until they reached constant weight at an average temperature of 20±2°C and a humidity of 65±5% relative humidity (TS 642 1997).

Application of Varnishes

Application of Primer Varnish

Heat-treated lumbers were impregnated as a dip method in a 10 second period according to the company's recommendations. This process was applied twice. AQUACOOL FX 6150 was supplied by DUAL Boya Firm. It has a colorless liner containing coded biocide and lignin preservative. After, waiting for 3 hours at 20°C ambient temperature, the dried varnish film 400 was sanded with water and applied on the second layer after the dusts were cleaned. Later thoroughly dry sanding with sanding pad number 400 and cleaning the dusts, water based single and double component varnish application was performed.

Application of Water Based Single and Double Component Varnishes

In this study, water based single component varnish (AQUACOOL FX 7680/00) and water based double component varnish (AQUACOOL 0820/00) were used. Water based double component varnish application was applied to varnish + AQUACOOL AX 0115 hardener (25%) + water (10%).

Table 1. Application of water-based single and double component varnishes

Water-based single component varnish application	FX 6150 UV protective primer immersion method (Solid matter 19.45%)	1. layer	130 g/m^2	25 g/m^2
		2. layers	70 g/m^2	13 g/m^2
	FX 7680 finish coating method with pistole (Solid matter 43.26%)	1. layer	140 g/m^2	61 g/m^2
		2. layers	140 g/m^2	61 g/m^2
	Total solids			160 g/m^2
Water-based double component varnish application	FX 6150 UV protective primer immersion method (Solid matter 19.45%)	1. layer	130 g/m^2	25 g/m^2
		2. layers	70 g/m^2	13 g/m^2
	FX 0820 2K finish coat method with piston pistole (Solids 37.78%)	1. layer	105 g/m^2	40 g/m^2
		2. layers	105 g/m^2	40 g/m^2
		3. layers	105 g/m^2	40 g/m^2
	Total solids			158 g/m^2

Table 2. Information on applied varnishes

Varnish type	Composition	Density	pH	Solid Matter (%)	Viscosity
FX 6150 UV protective primer	Acrylic resin, biocide and UV protection	1.02	9.2	19±2	11 seconds at 20°C in DIN 4 cabinet
FX 7680 outdoor bright lacquer	Acrylic and aliphatic PU resin	1.05	9.3	42±2	45-55 seconds at 20°C in the cabinet in DIN 6
FX 0820 outdoor bright lacquer 2K	Aliphatic PU dispersion	1.03	8.5	32±2	35-45 seconds at 20°C in cabinet (with AX 015 hardener added) in DIN 4
AX 0115 hardener	Water-soluble aliphatic polyisocyanate	-	-	66-72	-

Following the heat treatment, water-based single and double component varnishes were applied on similar layer thicknesses according to manufacturer recommendations. In the application, a spray gun with a top end capacity of 2.0 mm was used. Varnish applications were applied as industrial surface application with spray gun (a distance of 20-25 cm). The applications were first made perpendicular to fiber, then parallel to fiber. The air pressure in the application was chosen as 2 bars. After the application of primer varnish, the second layer for water based single component varnish and third layer for water based double component varnish were applied (Figure 1).

Figure 1. Application of water-based single and double component varnishes (Ayata, 2014)

Application of UV Weathering Aging

The finished specimens (120x80x14 mm) were exposed to UV-A 340 nm fluorescent lamp in a QUV accelerated weathering tester (Figure 2) for 144, 288 and 432 hours according to ASTM G 154-06 (2006) standard. A total of 72 samples were used.

Figure 2. QUV accelerated weathering tester (Ayata, 2014)

Tests

Determination of Solid Contents

In the study, solids of water based were determined according to ASTM D 1644-01 (2006). The amounts of solids were calculated with the following formula (1, 2 and 3).

$$Km = [(Vu-Cb) / Vu] \times 100 \quad (1)$$
$$Vu = G-D \quad (2)$$
$$Cb = G-E \quad (3)$$

Equality;
Vu = Applied varnish (g)
Cb = Evaporating solvent (g)
Km = Solid matter (%)
G = wet weight (g)
D = Tare (g)
E = dry weight (g)

Determination of Impregnated Retention Ratios

For application of colorless primer varnish (AQUACOOL FX 6150) prepared according to the company's recommendations, a short impregnation dipping method was used and test samples were left in impregnate for 10 seconds for 2 times. Amount of solution and amount of dry matter absorbed by impregnated specimens were calculated according to following formula according to TS 5723, (1988) (Bozkurt, Goker & Erdin, 1993).

$$\text{Retention} = \frac{G \times C}{V} \times 10 \text{ kg/m}^3 \quad (4)$$

Equality;
G = Amount of solution absorbed by sample (m_1-m_0) (g)
M_0 = Weight before impregnation (g)
M_1 = Wet weight after impregnation (g)
C = Solution concentration
V = Volume of wood sample (cm^3)

$$\text{Retention} = \frac{\text{Moes - Moeo}}{\text{Moeo}} \times 100 \quad (5)$$

Equality;
Moes = Full dry weight of sample after impregnation (g)
Moeo = Full dry weight of sample before impregnation (g)
C = Solution concentration (%).

Dry Layer Thicknesses Measurement

In this study, dry layer thicknesses of water-based single and double component varnishes were determined by using PosiTector 200 device (Figure 3) according to ASTM D 6132 (2008) standard. With the film layers with various micron thicknesses, the probe of the calibrated device was printed on top of the gel (DeFelsko brand - Ultrasonic couplant) on wood material. Immediately after the device sent ultrasonic multiple signals, the values for micron thickness were automatically read on screen when scanning.

Figure 3. PosiTector 200 device (Ayata, 2014)

Color Measurement

The color changes of heat-treated and water-based varnishes (single and double component) applied samples were measured by using a Konica Minolta Chroma Meter CR-400 (Figure 4) (light source calibrated as D65, 10^o).

Color parameters were taken using ten replicates of each sample and an average value was reported. The CIELAB system characterized by three parameters, L^*, a^*, and b^* was used. The L^* axis represents the lightness, plus (+) a^* is the red, minus (-) a^* for green, plus (+) b^* for yellow, minus (-) b^* for blue, and L^* varies from 100 (white) to zero (black) (Zhang, Kamdem, & Temiz, 2009). At the end of each exposure period, red color tone, yellow color tone and lightness difference values were determined according to ASTM-D 2244-3 (2007) standard. Total color differences (ΔE^*) were calculated through Equation 6.

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

Figure 4. Konica Minolta Chroma Meter CR-400 (Ayata, 2014)

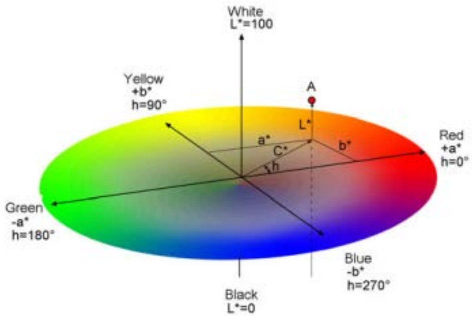

Figure 5. The three-dimensional CIEL*a^*b^* colour space (Johansson, 2005).

Statistical Evaluation

Statistical analysis results were calculated. Total and single comparison tests, variance analysis and LSD (least significant difference) were determined for red color tone, yellow color tone, lightness and total color difference values. Statistical analysis results are tabulated.

Results and Discussion

While the highest solid content was found on water based single component varnish, the lowest solid content was obtained on impregnation colorless filler varnish (Table 3).

Table 3. Solid contents of varnishes

Varnish type	Solid ratio (%)
Impregnation colorless filler varnish (FX 6150 UV)	19.45
Water based single component varnish (FX 7680)	43.26
Water based double component varnish (FX 0820 2K + AX 0115 Hardener)	37.78

Table 4. Dry matter quantities and percent holding ratios of heat-treated wood species according to ThermoWood method

Wood type	Heat treatment	Number of measurement	Dry Matter Quantity (kg/m³)	Hold Ratio (%)
Scots pine	190ºC for 2 hours	3	9.8089	10.34
	212ºC for 1 hour	3	12.2580	11.86
	212ºC for 2 hours	3	12.9515	14.05
Oriental beech	190ºC for 2 hours	3	6.2698	4.09
	212ºC for 1 hour	3	6.8494	4.94
	212ºC for 2 hours	3	7.5817	5.41
Oak	190ºC for 2 hours	3	6.5139	4.57
	212ºC for 1 hour	3	6.6969	5.20
	212ºC for 2 hours	3	6.8342	5.25

Table 5. Layer thickness for varnishes

Heat Treatment	Varnish Type	Number of measurement	Scots pine (µm)	Beech (µm)	Oak (µm)
190ºC for 2 hours	Single	10	139.80	137.00	142.00
	Double	10	155.00	152.00	153.80
212ºC for 1 hour	Single	10	140.80	136.40	147.00
	Double	10	155.40	151.80	156.60
212ºC for 2 hours	Single	10	144.00	139.00	148.60
	Double	10	154.60	152.40	158.20

Table 6. Results of variance analysis on effect of Δa^*, Δb^*, ΔL^* and ΔE^* values on wood type, heat treatment, varnish type and aging period

Test	Variation Source	Degree of Freedom	Sum of squares	Average Square	F Value	$P \leq 0.05$
Red color (Δa^*) tone values	Wood type (A)	2	4776.821	2388.411	6487.0816	0.0000*
	Heat treatment (B)	2	494.405	247.203	671.4190	0.0000*
	Interaction (AB)	4	487.208	121.802	330.8225	0.0000*
	Varnish type (C)	1	0.139	0.139	0.3780	0.1048**
	Interaction (AC)	2	3.484	1.742	4.7308	0.0091*
	Interaction (BC)	2	3.037	1.519	4.1246	0.0166*
	Interaction (ABC)	4	70.604	17.651	47.9415	0.0000*
	Aging period (D)	3	28.302	9.434	25.6237	0.0000*
	Interaction (AD)	6	152.352	25.392	68.9665	0.0000*
	Interaction (BD)	6	57.782	9.630	26.1567	0.0000*
	Interaction (ABD)	12	34.190	2.849	7.7385	0.0000*
	Interaction (CD)	3	0.486	0.162	0.4401	0.1044**
	Interaction (ACD)	6	8.319	1.387	3.7660	0.0011*
	Interaction (BCD)	6	9.929	1.655	4.4946	0.0002*
	Interaction (ABCD)	12	9.961	0.830	2.2546	0.0085*
	Error	648	238.580	0.368		
	Total	719	6375.602			
Yellow color (Δb^*) tone values	Wood type (A)	2	33911.133	16955.567	13775.0690	0.0000*
	Heat treatment (B)	2	7142.748	3571.374	2901.4613	0.0000*
	Interaction (AB)	4	1763.491	440.873	358.1746	0.0000*
	Varnish type (C)	1	5.486	5.486	4.4572	0.0351*
	Interaction (AC)	2	5.726	2.863	2.3259	0.0985**
	Interaction (BC)	2	64.360	32.180	26.1436	0.0000*
	Interaction (ABC)	4	328.411	82.103	66.7021	0.0000*
	Aging period (D)	3	828.258	276.086	224.2982	0.0000*
	Interaction (AD)	6	111.283	18.547	15.0682	0.0000*
	Interaction (BD)	6	127.020	21.170	17.1990	0.0000*
	Interaction (ABD)	12	185.548	15.462	12.5619	0.0000*
	Interaction (CD)	3	38.774	12.925	10.5001	0.0000*
	Interaction (ACD)	6	22.061	3.677	2.9872	0.0069*
	Interaction (BCD)	6	52.437	8.740	7.1002	0.0000*
	Interaction (ABCD)	12	41.327	3.444	2.7979	0.0010*
	Error	648	797.615	1.231		
	Total	719	45425.678			
Lightness (ΔL^*) values	Wood type (A)	2	35297.321	17648.660	33728.2846	0.0000*
	Heat treatment (B)	2	14216.579	7108.290	13584.6242	0.0000*
	Interaction (AB)	4	3072.084	768.021	1467.7620	0.0000*
	Varnish type (C)	1	81.925	81.925	156.5661	0.0000*
	Interaction (AC)	2	14.585	7.292	13.9364	0.0000*
	Interaction (BC)	2	28.514	14.257	27.2467	0.0000*
	Interaction (ABC)	4	248.450	62.113	118.7031	0.0000*

Table 6 (continued)

	Aging period (D)	3	2266.482	755.494	1443.8215	0.0000*
	Interaction (AD)	6	82.123	13.687	26.1574	0.0000*
	Interaction (BD)	6	40.797	6.800	12.9945	0.0000*
	Interaction (ABD)	12	52.996	4.416	8.4401	0.0000*
	Interaction (CD)	3	46.855	15.618	29.8485	0.0000*
	Interaction (ACD)	6	6.407	1.068	2.0409	0.0583**
	Interaction (BCD)	6	36.776	6.129	11.7137	0.0000*
	Interaction (ABCD)	12	46.919	3.910	7.4722	0.0000*
	Error	648	339.072	0.523		
	Total	719	55877.886			
Total color (Δ*E) difference**	**Wood type (A)**	2	63222.572	31611.286	35324.7544	0.0000*
	Heat treatment (B)	2	19899.349	9949.675	11118.4914	0.0000*
	Interaction (AB)	4	4383.929	1095.982	1224.7303	0.0000*
	Varnish type (C)	1	76.265	76.265	85.2237	0.0000*
	Interaction (AC)	2	18.926	9.463	10.5747	0.0000*
	Interaction (BC)	2	71.026	35.513	39.6848	0.0000*
	Interaction (ABC)	4	487.526	121.882	136.1994	0.0000*
	Aging period (D)	3	2730.050	910.017	1016.9190	0.0000*
	Interaction (AD)	6	35.348	5.891	6.5833	0.0000*
	Interaction (BD)	6	22.409	3.735	4.1736	0.0004*
	Interaction (ABD)	12	131.548	10.962	12.2501	0.0000*
	Interaction (CD)	3	65.890	21.963	24.5435	0.0000*
	Interaction (ACD)	6	18.835	3.139	3.5080	0.0020*
	Interaction (BCD)	6	68.082	11.347	12.6800	0.0000*
	Interaction (ABCD)	12	60.618	5.052	5.6449	0.0000*
	Error	648	579.880	0.895		
	Total	719	91872.253			

***:** Significant (α = according to 0.05), **: Insignificant

The amounts of net dry matter and retention increased when increasing heat treatment time and temperature (Table 4).

While the highest dry matter content and retention rate were obtained on Scots pine wood heat-treated at 212ºC for 2 hours, the lowest values were determined on beech heat-treated at 190ºC for 2 hours.

The measurement results of dry film thicknesses of water-based single and double component varnishes are given in Table 5. The highest layer thickness was found oak heat-treated at 212°C for 2 hours and water-based double component varnished samples. But the lowest layer thickness was obtained beech heat-treated at 212°C for 1 hour and water-based single component varnished (Table 5).

Table 7. Single comparison results of wood type - heat treatment - varnish type - aging period for Δ*a**, Δ*b**, Δ*L** and Δ*E** values

Factor		Red color (Δ*a**) tone value X	HG	LSD ±	Factor		Yellow color (Δ*b**) tone value X	HG	LSD ±
Wood type	Scots pine	12.51	A*	0.1087	Wood type	Scots pine	24.46	A*	0.1989
	Beech	9.26	B			Beech	13.68	B	
	Oak	6.20	C			Oak	7.90	C	
Heat Treat-ment	190ºC for 2 hours	10.38	A*	0.1087	Heat Treat-ment	190ºC for 2 hours	19.62	A*	0.1989
	212ºC for 1 hour	9.25	B			212ºC for 1 hour	14.31	B	
	212ºC for 2 hours	8.35	C			212ºC for 2 hours	12.11	C	
Varnish type	Single	26.27	B	0.1627	Varnish type	Single	15.26	B	0.1624
	Double	26.64	A*			Double	15.44	A*	
Aging period	Control	9.19	C	0.1256	Aging period	Control	13.92	C	0.2297
	144 hours	9.08	C			144 hours	14.70	B	
	288 hours	9.58	A*			288 hours	16.36	A	
	432 hours	9.44	B			432 hours	16.41	A*	

Factor		Lightness (Δ*L**) value X	HG	LSD ±	Factor		Total color (Δ*E**) difference X	HG	LSD ±
Wood type	Scots pine	47.53	A*	0.1296	Wood type	Scots pine	54.95	A*	0.1696
	Beech	37.31	B			Beech	40.93	B	
	Oak	30.49	C			Oak	32.20	C	
Heat Treat-ment	190ºC for 2 hours	44.53	A*	0.1296	Heat Treat-ment	190ºC for 2 hours	49.87	A*	0.1696
	212ºC for 1 hour	36.74	B			212ºC for 1 hour	40.77	B	
	212ºC for 2 hours	34.06	C			212ºC for 2 hours	37.43	C	
Varnish type	Single	38.11	B	0.1058	Varnish type	Single	42.37	B	0.1385
	Double	38.78	A*			Double	43.02	A*	
Aging period	Control	35.68	D	0.1497	Aging period	Control	39.77	D	0.1958
	144 hours	38.12	C			144 hours	42.09	C	
	288 hours	39.75	B			288 hours	44.29	B	
	432 hours	40.22	A*			432 hours	44.62	A*	

X: Arithmetic average, *HG*: Homogeneity group, *: Highest value, Control: Unaged

Table 6 shows the results of variance analysis for Δ*L**, Δ*a**, Δ*b** and Δ*E**. According to varnish type (C) and interaction (CD) for Δ*a**, interaction (AC) for Δ*b** and interaction (ACD) for Δ*L** were not significant (Table 6). In addition, all other factors and interactions were significant at Δ*L**, Δ*a**, Δ*b** and Δ*E** values.

Single comparison results of wood type - heat treatment - varnish type - aging period for Δ*a**, Δ*b**, Δ*L** and Δ*E** values are given in Table 7. According to Table 7, for wood type, Scots pine wood was determined highest when Oak wood was found lowest Δ*a**, Δ*b**, Δ*L** and Δ*E** values. At heat treatment level, 190°C for 2 hours were obtained highest while 212°C for 2 hours were found lowest Δ*b**, Δ*a**, Δ*L** and Δ*E** values. For varnish type, double component varnish was determined highest when single component varnish was found lowest Δ*b**, Δ*L** and Δ*E** values. At aging period level, 432 hours were given highest while control (unaged) period was given lowest Δ*L**, Δ*b** and Δ*E** values. While highest Δ*a** value was determined at 288 hours, lowest Δ*a** value was found at 144 hours for aging period level.

Table 8. Total comparison results of wood type - heat treatment - varnish type - aging period for Δ*a**, Δ*b**, Δ*L** and Δ*E** values

Test	Wood type	Heat Treat-ment	Varnish type	N	Control *X*	Control *S*	Control *HG*	144 hours *X*	144 hours *S*	144 hours *HG*	288 hours *X*	288 hours *S*	288 hours *HG*	432 hours *X*	432 hours *S*	432 hours *HG*
Red color (Δa*) tone values (LSD ± 0.5327)	**Scots pine**	**TW_1**	**Single**	**10**	14.13	3.19	A	11.94	0.39	GHIJ	11.97	0.26	FGHIJ	11.09	0.16	KLM
			Double	**10**	12.49	0.47	DEF	11.70	1.10	HIJ	11.53	0.30	IJK	11.07	0.34	KLM
		TW_2	**Single**	**10**	13.45	1.11	B	12.23	0.67	EFGH	11.99	0.25	FGHIJ	11.53	0.17	IJK
			Double	**10**	14.51	0.39	A*	13.11	0.37	BC	12.95	0.29	BCD	13.00	0.37	BCD
		TW_3	**Single**	**10**	12.92	1.04	BCD	11.99	1.21	FGHIJ	12.90	0.32	CD	12.94	0.16	BCD
			Double	**10**	12.65	1.06	CDE	12.27	0.98	EFG	12.96	0.53	BCD	12.87	0.39	CD
	Oriental beech	**TW_1**	**Single**	**10**	11.81	0.93	GHIJ	11.13	3.44	KLM	11.46	0.24	JKL	10.95	0.16	LMN
			Double	**10**	12.01	0.49	FGHI	10.67	0.12	MNO	10.93	0.17	MN	10.31	0.12	O
		TW_2	**Single**	**10**	8.55	0.27	Q	9.69	0.20	P	10.44	0.33	NO	9.56	0.28	P
			Double	**10**	7.87	0.21	STU	8.25	0.54	QRS	9.19	0.28	P	9.47	0.32	P
		TW_3	**Single**	**10**	6.21	0.29	Z	6.89	0.42	WX	7.33	0.51	VW	7.84	0.46	STUV
			Double	**10**	7.35	0.39	UVW	8.09	0.28	QRST	8.27	0.37	QRS	8.05	0.38	QRST
	Oak	**TW_1**	**Single**	**10**	6.84	0.83	WXY	7.31	0.42	VW	8.55	0.43	Q	8.58	0.23	Q
			Double	**10**	7.68	0.39	TUV	7.95	0.25	RST	8.49	0.27	Q	8.42	0.23	QR
		TW_2	**Single**	**10**	4.92	0.49	de	5.40	0.31	bcd	6.53	0.46	XYZ	6.10	0.51	Za
			Double	**10**	4.67	0.34	ef	5.56	0.38	bc	6.35	0.20	YZ	6.57	0.36	XYZ
		TW_3	**Single**	**10**	3.85	0.52	gh	5.09	0.50	bcde	5.58	0.61	ab	6.46	0.23	XYZ
			Double	**10**	3.48	0.59	b	4.23	0.39	fg	5.04	0.63	cde	5.14	0.38	bcde
Yellow color (Δb*) tone values (LSD ± 0.9743)	**Scots pine**	**TW_1**	**Single**	**10**	28.18	0.88	A*	25.71	0.97	DE	27.85	0.77	AB	26.70	0.42	C
			Double	**10**	25.54	0.94	EF	24.74	1.16	FGH	25.37	0.35	EF	25.12	0.48	EFG
		TW_2	**Single**	**10**	25.37	2.17	EF	24.05	1.86	HI	24.99	0.59	EFGH	22.90	0.65	JK
			Double	**10**	25.10	0.53	EFG	24.83	0.18	EFGH	26.59	0.36	CD	26.90	0.51	BC
		TW_3	**Single**	**10**	19.68	2.43	O	20.82	1.42	MN	24.36	0.93	GH	23.31	0.46	IJ
			Double	**10**	18.97	1.71	O	21.63	0.90	LM	24.30	0.76	GH	24.11	0.96	HI
	Oriental beech	**TW_1**	**Single**	**10**	21.55	0.60	LMN	21.32	0.18	LMN	20.69	0.46	MN	22.01	0.29	KL
			Double	**10**	18.99	0.46	O	19.64	0.14	O	20.82	0.36	MN	20.65	0.10	N
		TW_2	**Single**	**10**	8.68	0.44	YZ	12.02	0.54	ST	13.91	1.04	PQ	12.35	0.68	RST
			Double	**10**	8.64	0.44	XYZ	9.49	1.05	UVWX	11.82	0.63	ST	13.21	0.65	QR
		TW_3	**Single**	**10**	6.10	0.52	cde	7.05	0.81	bc	7.97	0.88	YZab	9.21	0.93	VWX
			Double	**10**	8.16	0.88	YZa	10.05	0.82	UV	12.24	1.11	RST	11.70	0.83	T
	Oak	**TW_1**	**Single**	**10**	9.67	1.74	UVW	10.15	0.92	UV	12.53	1.40	RST	12.78	0.41	RS
			Double	**10**	10.36	0.74	U	11.99	0.60	ST	14.02	0.66	PQ	14.44	0.78	P
		TW_2	**Single**	**10**	4.84	0.77	fg	5.78	0.55	def	7.55	0.81	ab	7.35	0.99	ab
			Double	**10**	4.48	0.42	g	5.97	0.67	de	7.75	0.35	Zab	8.92	0.67	WXY
		TW_3	**Single**	**10**	3.37	0.59	hi	5.16	0.81	efg	6.01	0.88	de	7.41	0.47	ab
			Double	**10**	2.89	0.35	i	4.26	0.42	gh	5.71	1.01	def	6.29	0.63	cd
Lightness (ΔL*) values (LSD ± 0.6351)	**Scots pine**	**TW_1**	**Single**	**10**	49.77	1.18	GH	52.22	0.60	D	53.22	0.86	C	55.56	0.67	A*
			Double	**10**	49.01	0.59	IJK	51.52	0.87	E	53.86	0.46	B	55.14	1.17	A
		TW_2	**Single**	**10**	44.81	0.96	O	47.10	1.20	M	49.26	0.69	HIJ	47.50	0.50	LM
			Double	**10**	44.05	0.46	PQ	47.74	0.61	L	50.16	0.75	FG	50.67	0.39	F
		TW_3	**Single**	**10**	38.57	0.90	S	42.22	1.14	R	44.59	1.37	OP	43.57	0.65	Q
			Double	**10**	38.80	0.51	S	42.06	0.35	R	44.65	0.53	OP	44.67	0.79	OP
	Oriental beech	**TW_1**	**Single**	**10**	44.76	1.00	O	47.59	0.17	LM	48.51	0.48	K	49.52	0.28	HI
			Double	**10**	42.04	1.51	R	46.39	0.38	N	48.78	0.59	JK	49.53	0.26	GHI
		TW_2	**Single**	**10**	30.35	0.26	abc	33.95	0.49	W	35.14	0.92	V	34.39	0.71	W
			Double	**10**	30.91	0.61	Za	32.26	0.56	X	33.86	0.54	W	35.39	0.58	V
		TW_3	**Single**	**10**	28.01	0.43	gh	29.69	0.51	de	30.22	0.79	bcd	31.61	0.64	Y
			Double	**10**	30.65	0.80	ab	32.60	0.96	X	35.09	0.84	V	34.27	0.65	W
	Oak	**TW_1**	**Single**	**10**	30.64	1.06	ab	32.41	0.71	X	33.82	1.21	W	34.18	0.46	W
			Double	**10**	32.37	0.51	X	34.40	0.82	W	36.33	0.65	U	37.28	0.80	T
		TW_2	**Single**	**10**	27.24	0.61	i	28.85	0.40	f	29.99	0.47	cd	29.82	0.95	cd
			Double	**10**	27.51	0.27	hi	29.01	0.47	f	30.40	0.29	abc	31.46	0.61	YZ
		TW_3	**Single**	**10**	26.26	0.94	j	28.21	0.76	g	28.52	0.65	fg	29.79	0.42	cd
			Double	**10**	26.55	0.24	j	27.99	0.42	gh	29.11	0.61	ef	29.65	0.56	De

Table 8. (continued)

Total color (ΔE^*) differences (LSD ± 0.8308)	**Scots pine**	**TW_1**	**Single**	**10**	58.99	1.79	DE	59.42	0.90	D	61.25	0.85	BC	62.64	0.62	A*
			Double	**10**	56.66	0.92	F	58.41	1.13	E	60.65	0.43	C	61.60	1.04	B
		TW_2	**Single**	**10**	53.25	1.71	IJ	54.29	1.96	H	56.53	0.73	F	53.98	0.70	HI
			Double	**10**	52.74	0.65	JK	55.39	0.47	G	58.23	0.69	E	58.82	0.53	DE
		TW_3	**Single**	**10**	45.02	1.66	O	48.61	1.16	M	52.42	1.54	K	51.09	0.74	L
			Double	**10**	45.04	1.30	O	48.93	0.54	M	52.47	0.80	JK	52.37	1.05	K
	Oriental beech	**TW_1**	**Single**	**10**	51.07	1.09	L	53.28	0.22	IJ	54.77	0.59	GH	55.29	0.32	G
			Double	**10**	47.67	1.46	N	51.49	0.37	L	54.13	0.66	H	54.64	0.25	GH
		TW_2	**Single**	**10**	32.71	0.41	WX	37.30	0.56	ST	39.21	1.27	QR	37.78	0.92	ST
			Double	**10**	33.07	0.69	VW	34.57	0.95	U	37.02	0.73	T	38.94	0.83	R
		TW_3	**Single**	**10**	29.34	0.51	bcd	31.29	0.76	YZ	32.10	1.08	XY	33.74	0.85	V
			Double	**10**	32.57	1.01	WX	35.07	1.10	U	38.08	1.18	S	37.13	0.87	T
	Oak	**TW_1**	**Single**	**10**	32.81	1.60	WX	34.75	0.91	U	37.08	1.67	T	37.49	0.58	ST
			Double	**10**	34.85	0.72	U	37.29	0.97	ST	39.85	0.87	Q	40.85	1.04	P
		TW_2	**Single**	**10**	28.11	0.73	e	29.92	0.54	ab	31.61	0.71	Y	31.32	1.23	YZ
			Double	**10**	28.27	0.34	e	30.14	0.65	ab	32.01	0.38	XY	33.36	0.82	VW
		TW_3	**Single**	**10**	26.76	1.06	f	28.93	0.96	cde	29.69	0.90	bc	31.38	0.55	YZ
			Double	**10**	26.94	0.29	f	28.53	0.50	de	30.10	0.88	ab	30.75	0.72	Za

X: Arithmetic average, S: Standard deviation, *HG*: Homogeneity group, N: Number of measurement, *: Highest value,
Control: Unaged, TW_1: 190°C for 2 hours, TW_2: 212°C for 1 hour, TW_3: 212°C for 2 hours

Total comparison results of wood type - heat treatment - varnish type - aging period for Δa^*, Δb^*, ΔL^* and ΔE^* values are given in Table 8. According to Table 8, highest Δa^* was found in control (unaged) samples on scots pine specimens varnished with double components varnish and heat-treated at 212ºC for 1 hour when highest Δb^* was found in control (unaged) period of scots pine samples varnished with single component varnish and heat-treated at 190ºC for 2 hours. Highest ΔL^* and ΔE^* values were found at the end of 432 hours weathering period on scots pine specimens varnished with single component varnish and heat-treated at 190ºC for 2 hours (Table 8). When lowest Δb^* and Δa^* values were determined in control period of oak specimens varnished with double component varnish and heat-treated at 212ºC for 2 hours, lowest ΔL^* and ΔE^* were found in control specimens of oak specimens varnished with single component varnish and heat-treated at 212ºC for 2 hours for wood type - heat treatment - varnish type - aging period (Table 8).

Conclusion

In this study, effect of UV weathering on color values of Scotch pine, Oak and Oriental beech wood species heat-treated according to ThermoWood method (190ºC for 2 hours, 212ºC for 1 hour and 2 hours) and water-based varnishes (single and double component) applied were investigated. At the aging period level, for the red color value, 288 hour UV aging samples were given highest, 144 hours UV aging samples were given lowest. A statistical difference was observed between control and 144 hour aging samples and between 288 and 432 hour aging samples. This difference is thought to be caused by the effect of UV-rays on the varnish layer during long aging periods. In addition, the binder resins in the single component varnish formulation may have interfered with the wood extracts. At the aging period level, the yellow color value was highest in the 432 hour UV aging samples and it was lowest in the control samples. Accordingly, it can be said that the aging process was an effect of increasing the yellow color value. At the aging period level, the highest lightness value was determined at 432 hours UV aging samples, lowest lightness was obtained in the lowest control samples. When highest was obtained on pine wood, lowest was found on oak wood at wood species level for yellow color tone, red color tone and lightness values. While highest was determined on heat-treated at 190ºC for 2 hours samples, lowest was found on heat-treated at 212ºC for 2 hours samples at heat treatment level for yellow color tone, red color tone and lightness values. In addition, total color difference value was increased by increasing the aging period. The Feist (1984) study reported that the high energy of sunlight ultraviolet (UV) wave lengths caused deterioration of the varnish and paint layers. In a study done by Payne (1965), it has been reported in the literature that the total color difference values are high in accelerated aging samples.

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