Weathering's Effect on Color and Roughness in Some Heat-treated Wood Species with Modified Water-based Varnish

Ayhan Aytin,[a,*] and Nevzat Çakıcıer [b]

Heat treatment in wood materials and the use of water-based varnishes (WBV) in furniture made from heat-treated wood materials come to the fore in terms of supporting environmentally friendly production in the wood sector. In this study, the total color changes (Δ*E**) and surface roughness (SR) were investigated after heat-treated tree species were exposed to natural and accelerated weathering with and without varnish. In this context, test samples were first divided into two groups. Surface treatment was applied to the samples in the first group by applying modified WBV (A_1) and normal WBV (A_2), and the second group was left unvarnished. Then, one group of the varnished samples was subjected to natural weathering (NAT) for 90 days and the other group was subjected to accelerated weathering (QUV) for 720 h with VAS samples, and then the Δ*E** and SR values of the samples were calculated. The results revealed that Δ*E** was the lowest in the QUV WBV group, and NAT was more effective than QUV in Δ*E**. The highest SR values among all groups were measured in the VAS group, and among the varnished samples, there was no statistical difference between A_1 and A_2 in SR values, except for Rq.

DOI: 10.15376/biores.17.4.6358-6376

Keywords: Total color change; Heat treatment; Weathering; Modified water-based varnish; Surface roughness

*Contact information: a: Interior Design, Department of Design, Duzce Vocational School, Duzce University, Duzce 81100 Turkey; b: Faculty of Forestry, Forest Industrial Engineering Department, Duzce University, Duzce 81100 Turkey; *Corresponding author: ayhanaytin@duzce.edu.tr*

INTRODUCTION

Wood has many advantages, for example, it is natural; environmentally friendly; aesthetic; renewable; reusable; sustainable; and non-waste-forming engineering material. It is easily available as a raw material, has a high durability, and is light and easy to shape by processing (Bozkurt and Erdin 1997; Çolak and Değirmentepe 2020). However, due to the variability in dimensional stability and mostly due to a species with low natural durability, their areas of use can be limited (Ali *et al.* 2021). In contrast, color changes may occur within short periods of use. Today, basic processes, such as drying, impregnation, and surface treatments, are applied to minimize the problems that may arise from the structure of the wood material and that may occur at the place of use (Yalınkılıç *et al.* 2021). However, these processes may be insufficient in many areas where wood materials are used. For this reason, a number of new studies have been conducted to make more rational use of wood. These studies aimed to both eliminate the adverse attributes in the wood material and produce a more useful material. Wood modification is one of the important studies in this context (Tomak and Yıldız 2010). As a result of modification studies, significant improvements have been achieved in some wood-based materials, water exchange in the wood has been reduced with an effective modification process, and dimensional stability has been increased with resistance to rot fungi and external weather conditions. It is known that some successful and useful methods, such as acetylation (Rowell 2004), furfurylation, and dimethylol dihydroxyethylene urea specifically heat treatment (HT) of wood, have been transferred from laboratories to the industry and put on the market since the 1990s, mostly through the academic studies conducted within the scope of wood modification (Demirel and Temiz 2015).

Due to increasing environmental awareness, the demand for materials produced with environmentally friendly production techniques is increasing daily. Heat-treated wood material is a raw material that is produced with an environmentally friendly production technology. The heat treatment technology does not contain environmentally harmful substances in the material structures produced for alternative uses, and can be used in both indoor and outdoor conditions. Its use is becoming increasingly widespread. The amount of energy required for its processing and the CO_2 emissions are lower compared to the energy and CO_2 release required in the processing of alternative materials for similar places of use, which makes heat-treated wood materials attractive in terms of environmental sensitivity (Korkut and Kocaefe 2009; Aytin 2013).

Heat treatment is a physical modification process that causes permanent changes in the chemical structure of polymer compounds in the wood material cell wall. As an environmentally friendly production method, heat treatment improves stability without completely destroying the wood structure (Zivkovic *et al.* 2008; Kačíková *et al.* 2020; Bytner *et al.* 2021) and provides homogeneity and darkening in color (Johansson 2005; Aytin 2013; Gürleyen *et al.* 2018; Torniainen *et al.* 2021) together with resistance to biological degradation (Shukla 2019). When considered industrially, it is possible to cite the main HT methods that provide modification in different physical ways applied in different countries such as the ThermoWood® process (Finland), Plato-Process (Netherlands), Oil-Heat Treatment process (Germany), Rectification process, and Perdure Bois (France) (Torniainen *et al.* 2021).

The main problem with the use of ThermoWood® materials, especially those exposed to external weather conditions, is that the dark color obtained with HT fades after a short time depending on the conditions of use. This situation leads to loss of value in terms of aesthetics (Jirouš-Rajković and Miklečić 2019). It is known that this change in the HT wood material is caused by the outdoor conditions that have a high destructive mechanism on the material. This destruction mechanism affects the protective layer on the surface of HT wood materials. Many factors, such as temperature differences between day and night, dew, snow, air pollution, acid rain caused by industrial chimneys and exhaust gases, humidity, and sunlight (ultraviolet-UV), reduce the resistance of the protective layer and cause color changes (Çakıcıer and Korkut 2009).

The deteriorating effects of factors arising from different environmental conditions necessitate the creation of a protective surface layer on HT wood materials, and varnish is the most widely used material in creating a protective surface layer. Varnish is a transparent solution consisting of two-element systems in which generally solvents are used. Varnishes make the natural color and aesthetic appearance of the wood material more prominent and are used mainly for aesthetic, protection, economic, and cleaning purposes (Kurtoğlu 2000). However, due to the negative effects of the solvent present in varnish on human and environmental health, the use of solvent-containing varnish systems has been reduced in recent years. Organic-based volatile compounds (VOC) are emitted to the atmosphere from the surface of the wood material on which solvent-containing varnish films have been applied, which adversely affects human and environmental health. In addition to environmental sensitivity, human health and other factors has drawn attention to water-based varnish (WBV) systems in recent years, and studies on reducing the use of solvents in varnishes have been accelerated. With the use of some polymers in varnish production, WBV systems have been developed from different synthetic resins, such as alkyds, polyesters, acrylics, and polyurethanes, containing very low levels of VOC. Various studies with WBV have shown that it can provide protection and brightness close to the natural color of the wood material; however, it has been understood that the hardness and adhesion of the surface film of WBV are weaker, and therefore its resistance to mechanical effects is lower than solvent-containing varnishes (Ulay and Budakçı 2015).

Weathering (WEA) simulates the environmental conditions to which materials to be used in areas with different climatic characteristics will be exposed, in natural or laboratory environment, and can imitate degradation. After WEA, the properties of materials arising from their structures are tested and some information about their end-use areas can be obtained (Çakıcıer and Korkut 2009).

With WEA tests, it is possible to have information about the natural structure of the wood material and the properties of the surface protective layers such as color, hardness, adhesion, and surface roughness (SR). A review of the literature shows that in recent years HT wood materials are exposed to natural weathering (NAT) and accelerated weathering (QUV), in varnished/unvarnished state, and color and SR changes have been investigated. A meta-analysis study examining the results of the studies performed so far reported that the results obtained from different studies are both similar to and different from each other (Jirouš-Rajković and Miklečić 2019). For example, Turkay Turkoglu *et al.* (2017) conducted a study with *Fagus orientalis* that the color and SR values obtained after QUV from the HT and polyurethane varnish (PUV) applied samples were better than the samples to which only the varnish had been applied. In another study, Kart *et al.* (2018) exposed Scotch pine and *Fagus orientalis* samples to NAT for 3 months. The samples were applied PUV and cellulosic varnish (CV) after HT. As a result, after HT, HT + PUV varnished Scotch pine and *Fagus orientalis* surfaces had a reddish and yellowish color, while HT + CV varnished surfaces had a reddish and bluish color. They stated that after HT + varnish, ΔE of both wood samples was lower than that of the only varnished control samples. Ayata and Çakıcıer (2017) reported that ΔE* increased after 432 h of QUV in the TM samples to which they applied WBV. Esteves *et al.* (2020) found that the color of TM samples remained approximately constant up to 750 h in the WEA treatment and that the HT initially became more reddish and turned greener and slightly more yellow as the time extended. Aytin *et al.* (2021) stated that WBV with color pigments can be used against color change in outdoor use of HT wood materials. In another study, it was reported that TM samples were better than SR control samples (Aytin *et al.* (2020).

Kropat *et al*. (2020) stated that because there is no need to compare WEA conditions, the most reliable WEA tests are the natural environment tests in which the material will be used. However, WEA time is long in natural environment tests. However, with QUV, whose programs consist of sections simulating the effects of sun rays, temperature differences, humidity condensation, and rain, faster results can be obtained in a short time. The performance of the wood material can be determined quickly with varnish and similar materials used in the surface treatment. In accelerated WEA, the UV effect coming from the sun and reaching the earth is simulated by UV rays with a wavelength of 280 to 400 nm, and two UV rays with different wavelengths (UVA, 315 to 400 nm and UVB, 280 to 315 nm) are included in the WEA device program. Spraying and conditioning can be added to the programs if the usage environment conditions are desired to be more similar (Aytin 2013).

This study investigated the interactions of some wood and surface treatment materials obtained with environmentally friendly production technologies in terms of color and roughness. Within the scope of the study, ThermoWood® test samples prepared from some tree species that grow in Turkey and which have economic use in industry were used. The test samples with normal varnish, water-based varnish (A_1), modified water-based varnish (A_2), and no varnish were subjected to NAT and QUV, and the total color difference and surface roughness change were examined. The study aimed to contribute to environmental awareness, and focused on the opportunities that heat treatment and WBV interaction may create in making more effective use of wood material.

EXPERIMENTAL

Materials

Aspen (*Populus tremula* L.), narrow-leaved ash (*Fraxinus angustifolia* Vahl), and Eastern spruce (*Picea orientalis*) growing naturally in Turkey were used in the study. The trees were selected according to TS 4176 (1984), and the trunks taken from the forest were cut into 60 –mm- thick planks with the sharp cut method as per TS 2470 (1976). Then, the planks were dried to an average of 12% moisture content with the classical drying method, and 20 × 100 × 500 (mm × mm × mm) drafts were prepared from the planks.

Methods

Heat treatment application and creation of a trial pattern

Tree samples prepared with dimensions of 26 mm × 100 mm × 600 mm by giving dimensional tolerances from trial trees were subjected to heat treatment at a temperature of 190 °C for 1 h (TW_1) and 212 °C for 1 h (TW_2) using the ThermoWood® method at the Novawood Forest Products Factory (Gerede/Bolu, Turkey). The ThermoWood® trees obtained were kept in an air-conditione room with control samples at an average temperature of 20 °C ± 2 °C and a relative humidity of 60% ± 5% until they reached a constant weight.

Table 1. Classification of Working Samples and Abbreviations

Wood type (WT)	Abbreviations	Variations	Abbreviations
Aspen (*Populus tremula* L.)	PT	Natural	CON
		190 °C, 1 h	TW_1
		212 °C, 1 h	TW_2
Narrow-leaved ash (*Fraxinus angustifolia* Vahl)	FA	Natural	CON
		190 °C, 1 h	TW_1
		212 °C, 1 h	TW_2
Oriental spruce (*Picea orientalis* L.)	PO	Natural	CON
		190 °C, 1 h	TW_1
		212 °C, 1 h	TW_2

Varnish properties and application

The working samples prepared from TM products that were produced within the scope of the study were divided into two groups as varnished and unvarnished to be subjected to the aging process. After the surfaces of the working samples to be varnished were divided into two with a line in the middle. One side of the surfaces was finished with primer barrier + varnish (AQUACOOLFX1707 Wood color protection barrier (primer) + AQUACOOL AG 4850 Parquet Varnish, given as A_1 in the text), and the other side was treated only with varnish (AQUACOOL AG 4850 Parquet Varnish, given as A_2 in the text). In order to bring the varnish layer thicknesses closer to each other in both groups, the application was completed as four layers for the A_1 group and three layers for the A_2 group. Varnish properties and application principles are presented in Table 2, the varnish was made by Dual Boya (İstanbul, Turkey).

Table 2. Varnish Properties and Application Principles

Varnish Type	Varnish Name	Descriptive Features	Solids Content (%)	Application Method	Number of Applications
A_1	AQUACOOLFX1707 Wood Color Protection Barrier	Two component, water-based wood color protection barrier with "New Generation Acrylic Resin" technology	25	Conventional 1.8 mm airbrush	2
	AQUACOOL AG 4850 Parquet Varnish	Two component, water-based parquet varnish	31	Conventional 1.8 mm airbrush	2
A_2	AQUACOOL AG 4850 Parquet Varnish	Two component, water-based parquet varnish	31	Conventional 1.8 mm airbrush	3

Varnish properties and application

Within the scope of the study, one group of unvarnished and varnished samples was subjected to QUV for 720 h using UVB EL 313 lamps, and the other group of varnished samples was subjected to NAT for 3 months. The principles of the WEA program are presented in Table 3.

Table 3. Weathering Program

QUV (ASTM G154 2006)					NAT
Process	Time (min)	Temperature (°C)	Light Intensity (W/m^2)	Wavelength (nm)	
Ultraviolet (UV)	480	60	0.67	310	Duzce City Center (13.06.2019 to13.09.2019)
Spray	15				
Condensation	225	50			

Determining color values

Measurements were made based on the CIELab color system to determine the color values of the samples. The CIELab color system has three coordinates as L^*, a^*, and b^* calculated from X, Y, and Z tristimulus values and is widely used for this purpose.

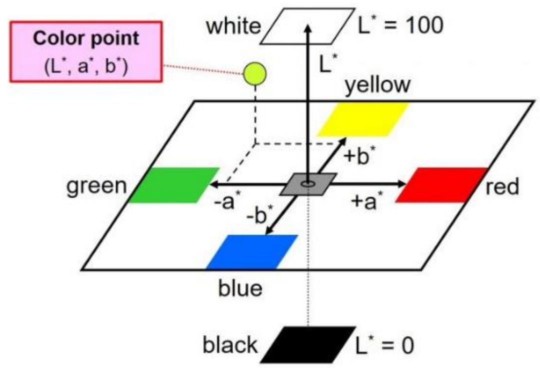


Fig. 1. Determination of *L**, *a**, and *b** values according to CIELab color system (Anonymous 2022a)

The * sign written with letters is used to distinguish CIE formulas from similar formulas in different color systems that have been developed before (Yeşil 2010). In the CIELab system, L^* is on the black-white (L^* = 0 for black, L^* = 100 for white) axis; a^* is on the red-green (positive value red, negative value green) axis; and b^* is on the yellow-blue (positive value yellow, negative value blue) axis. The *L* angle also expresses the color change in the wood. The narrowing of this angle shows that the color of the wood approaches the red color (*a*), and its widening shows that the color of the wood approaches the yellow color (*b*).

For the analysis of color difference, the color values of the samples during and after aging were determined according to the CIELab color system, and the difference between control-start and control-end values was examined.

Color values were determined by Konica Minolta CD-600 color measuring device (Konica Minolta, Inc., Osaka, Japan) in accordance with the ISO 7724-2 (1984) standards, and ΔE^* was calculated according to ISO 7724-3 (1984) with the following formula. Here, Δ indicates the difference and the letter *E* is the initial letter of the German word Empfindung, which means feeling (Yeşil 2010).

ΔE^* is the total color difference in the samples after heat treatment, ΔL^* is the black-white color change, Δa^* is the red-green color change, and Δb^* is the yellow-blue color change.

Surface roughness (SR)

The Mitutoyo surface test measuring device was used for the SR measurements of the samples (Mitutoyo Surftest SJ-301; Mitutoyo Corporation, Kanagawa, Japan). The device measures at a 90º angle to 4 (μm) needle diameter and the longitudinal measuring angle with fiber direction, at a measuring speed of 10 mm/min. To determine the surface roughness values, five measurements were made on each of the working samples. The measurements were made from pre-marked points perpendicular to the fiber direction according to the ISO 4287 (1997) and DIN 4768 (1990) standards. R_a, R_y, R_z, and R_q roughness parameters were determined in the SR measurements of the working samples. Here:

R_a is the average roughness value, which is the arithmetic mean of all values for deviations from the profile mean line along the roughness profile;

R_z is the ten point roughness average value, which is the sum of the average values of the five highest peaks and five deepest dips along the roughness profile;

R_y is the maximum roughness value, which is the sum of the highest peak and the deepest dip according to the mean profile line, along the roughness profile (Çakıcıer 2007).

R_q is the root mean square (RMS) value, which is the root mean square of the sum of the squares of the roughness profile heights (Anonymous 2022b).

Statistical evaluation

The SPSS package program (IBM Corp., SPSS 15.0 for Windows, Armonk, NY, USA) was used for the statistical evaluation of the data. An analysis of variance was used to determine whether the factors were effective for the results obtained, and Duncan's test was used to determine the size of the difference on the factors that were significant. The level of significance was set at $P \leq 0.05$ in the analysis of variance.

RESULTS AND DISCUSSION

Findings on Color Values

Weathering (WEA), heat treatment (HT), and wood type (WT) multiple analysis of variance (MANOVA) results regarding the total color difference are presented in Table 4.

Table 4. Weathering, HT, and WT Variance Analysis Results Regarding the ΔE^*

Source	Type III Sum of Squares (SUM)	df	Mean Square (MS)	F	Sig.	Partial Eta Squared (PES)
WEA	915.873	4	228.968	69.590	0.000	0.607
HT	205.492	2	102.746	31.228	0.000	0.258
WT	92.440	2	46.220	14.048	0.000	0.135
WEA-HT	4838.812	8	604.851	183.83	0.000	0.891
WEA-WT	511.359	8	63.920	19.427	0.000	0.463
HT-WT	943.572	4	235.893	71.695	0.000	0.614
WEA-HT-WT	353.720	16	22.107	6.719	0.000	0.374

Table 5. Weathering, HT, and WT Mean Values for the ΔE^* and Duncan Test Results

WEA				HT				AT		
	N	ΔE^*	Sig.		ΔE^*	Sig.	*N*		ΔE^*	Sig.
A1-QUV-720	45	9.38 (A)	1.000	TW 1	11.9 (A)	0.240	75	PO	12.0 (A)	1.000
VAS-720	45	11.74 (B)	1.000	CON	12.3 (A)	0.240	75	PT	12.8 (B)	1.000
A1-NAT-90-DAY	45	13.91 (C)	0.621	TW 2	14.1 (B)	1.000	75	FA	13.5 (C)	1.000
A2-NAT-90-DAY	45	14.10 (C)	0.621							
A2-QUV-720	45	14.95 (D)	1.000							

According to Table 4 each of, the factors of WEA, HT, and WT had a significant effect on Δ*E** at $p \leq 0.05$, and the interaction between WEA and HT was the factor with a significant effect of 0.891 on Δ*E**. At the same time, when the factors were evaluated separately, it was observed that WEA had the highest effect (0.607), and WT had the lowest effect (0.135). Table 5 presents the Δ*E** mean values and Duncan test results to better understand the effect of WEA, HT, and WT on the Δ*E**.

According to Table 5, the lowest total color change was determined as 9.38 in A_1-QUV-720 samples, and the highest total color change was in A_2-QUV-720 samples with 14.95. It is seen that the lowest Δ*E** was obtained in A_1 varnishes in both NAT and QUV. According to the heat treatment and natural factor comparison, the highest Δ*E** change was obtained in TW_2 working sample. The amount of change in the Δ*E** according to the stages of WEA is given in Fig. 2. The visuals of the working samples after 720 h of QUV and 90 days of NAT are given in Fig. 3.

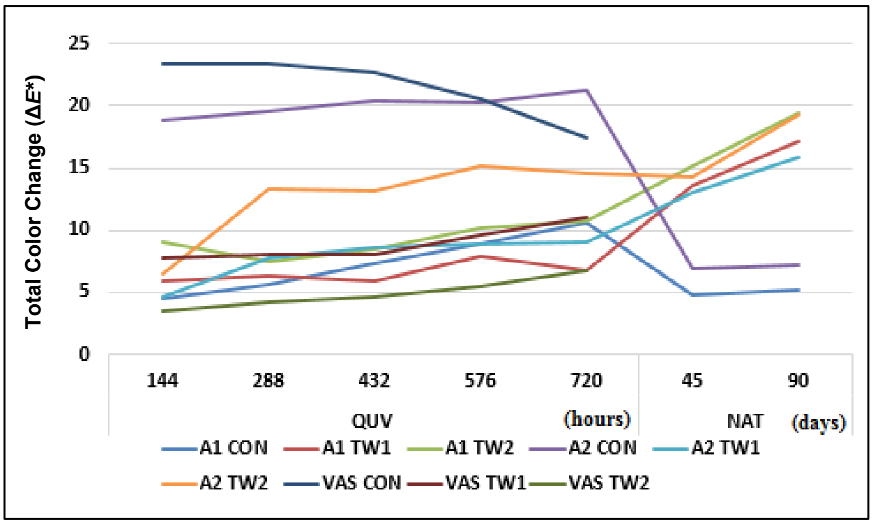


Fig. 2. Average Δ*E** amounts obtained during the stages of the WEA process

The graph in Fig. 2 and the visuals in Fig. 3 reveal that Δ*E** changes across variations in VAS, A_1, and A_2 samples. With WEA, lightening-graying and yellowing mostly occurred in the colors of varnished working samples; lightening-graying is mostly seen in the A_1 group and the surface appearance after WEA was relatively close to the pre-WEA appearance in this group. It is understood that yellowing is seen in the A_2 group. However, in varnished working samples in the A_1 group, PO turned to a whitish-yellowish structure rather than graying in QUV WEA compared to PT and FA, while the color of the same group was close to the initial color in NAT. In contrast, in VAS working samples, it was observed that there was yellowing in CON and lightenings in TW_1 and TW_2 after QUV. On the other hand, it is noteworthy that the yellowing of the surface layers was more intense during the three-month NAT period in the varnished working samples. In addition, as shown in Fig. 2, Δ*E** was seen to be 100% or even higher in heat-treated TW_1 and TW_2 working samples compared to the CON samples. Here, it is also understood that the highest Δ*E** was obtained in the A_2-TW_2 group in QUV-720, and in the A_1-TW_2 and A_2-TW_2 groups in NAT, and therefore, as the color darkness obtained with HT increased, the surface color had less stability against WEA conditions. The changes in the color appearance with NAT were due to the values of *L**, *a**, and *b** parameters, which are the three basic components of the CIELab* color system and are used in the calculation of Δ*E**. Graphs displaying the findings related to color parameters *L**, *a**, and *b** are given in Figs. 4 through 6.

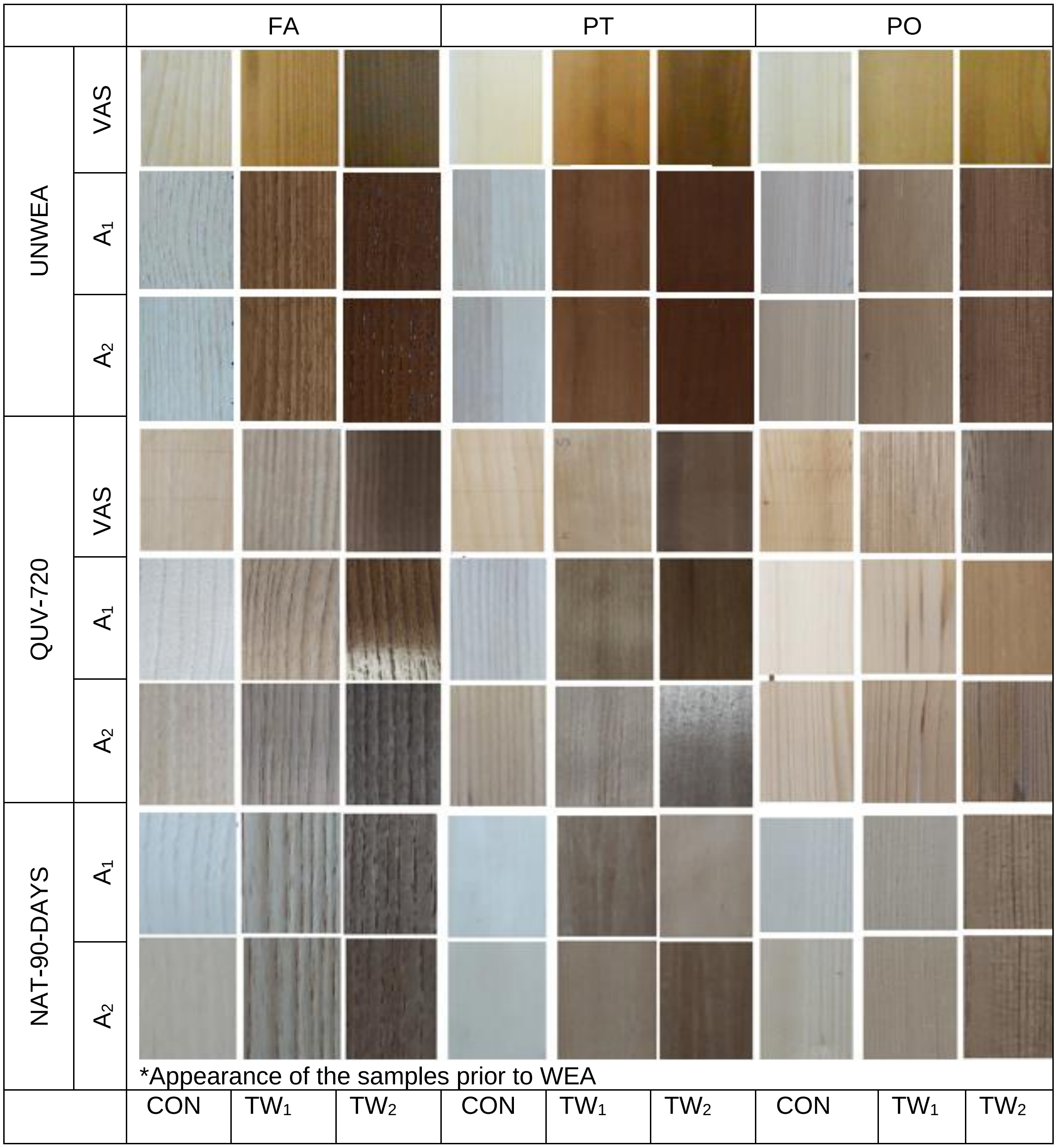
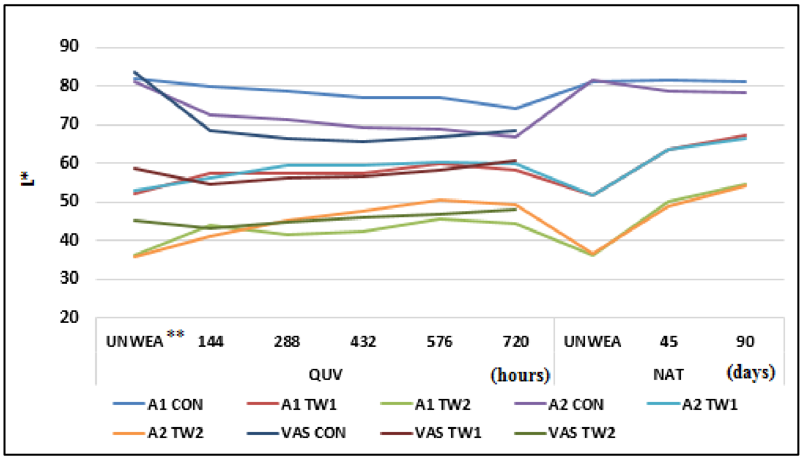


Fig. 3. Appearance of the samples before and after WEA

As shown in Fig. 4, the *L** values of the CON and HT samples, which were exposed to the WEA process as varnished, are different. In unvarnished working samples, *L** first decreases at the beginning of QUV, starts to increase after 144 h WEA, and continues to increase until QUV is over. While the *L** value in the CON group (A_1-CON and A_2-CON) continued to decrease during both QUV and NAT in varnished working samples, it increased from the onset of WEA in the HT groups (A_1-TW_1, A_1-TW_2, A_2-TW_1, and A_2-TW_2). This increase appears to be approximately twice as high in 90-day NAT than in 720-h QUV.



** Represents the values at the beginning of weathering

Fig. 4. *L** amounts obtained from CON and HT variations in the stages of the WEA process

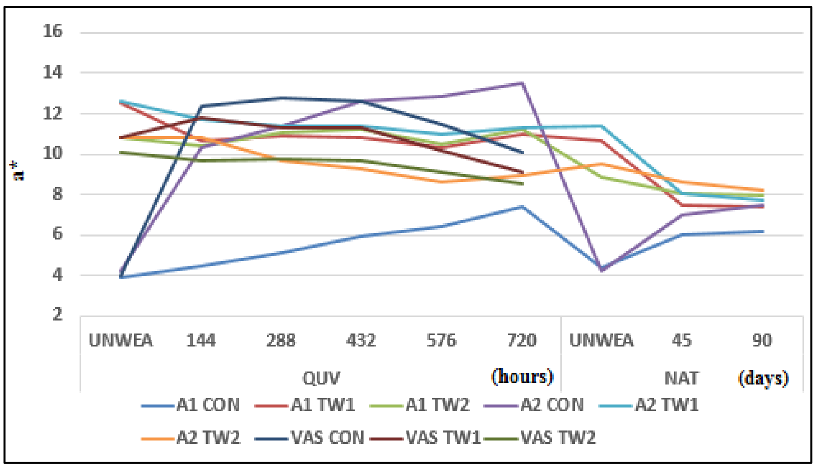


Fig. 5. Red green color (*a**) amounts obtained from CON and HT variations in the stages of the WEA process

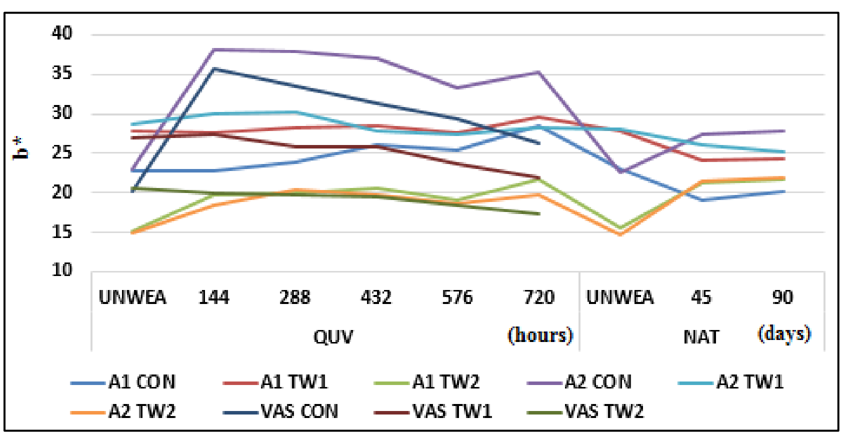


Fig. 6. Yellow-blue color (*b**) values obtained from CON and HT variations in the stages of the WEA process

Although the red-green (a^*) color value of the unvarnished samples increased rapidly in the VAS-CON group in QUV at the beginning (first 144 h), it remained almost the same in the HT groups and decreased approximately 10 to 20% in all three groups until the end of the QUV after 144 h. Although the a^* value increased at the onset of aging in both QUV and NAT in the CON group (A_1-CON and A_2-CON) in varnished working samples (especially evident in the A_2-CON group), it decreased in the HT groups (A_1-TW_1, A_1-TW_2, A_2-TW_1, and A_2-TW_2) from the beginning of aging. The change in the yellow-blue (b^*) color value is almost similar to the change in a^*.

Table 6. Total Color Change, L^*, a^*, and b^* Values Measured at the Beginning and End of the WEA Process

	WT	HT	QUV							NAT						
			UNWEA			720 h			ΔE	UNWEA			90 DAY			ΔE
			L_i	a_i	b_i	L_s	a_s	b_s		L_i	a_i	b_i	L_s	a_s	b_s	
A_1	PT	CO	82.2	3.82	23.5	80.3	5.14	26.4	5.15	82.5	4.10	22.7	85.5	2.66	16.5	6.99
		TW_1	46.2	13.7	25.9	55.9	10.3	28.1	10.5	49.7	13	26.8	66.8	6.27	23.0	18.8
		TW_2	33.1	9.75	11.6	41.6	10.5	19.8	11.9	33.5	9.99	12.2	53.8	7.13	20.2	21.9
	FA	CO	81.6	4.12	20.4	73.7	6.06	25.2	9.43	81.9	4.37	21.6	82	3.74	17.9	3.85
		TW_1	52.5	12.4	27.5	58.9	10.5	28.6	6.82	49.3	12.5	26.6	67.2	6.43	23.1	19.2
		TW_2	34.0	10.0	12.6	43.4	10.5	20.0	12.0	34.3	9.59	12.5	51.5	7.3	18.8	18.4
	PO	CO	81.6	3.73	24.4	69.2	11.0	34.0	17.2	78.8	4.68	24.5	75.3	7.13	25.8	4.55
		TW_1	58.0	11.3	29.7	59.7	11.9	31.9	3.04	55.8	11.9	29.9	68.0	8.01	26.5	13.3
		TW_2	41.7	12.7	21.3	48.8	12.4	25.2	8.27	41.5	12.2	22.0	58.8	9.39	25.9	18.0
A_2	PT	CO	82.4	3.81	22.7	70.0	12.4	35.2	19.6	82.4	4.09	22.2	83.0	4.29	23.2	2.26
		TW_1	47.0	13.8	26.7	60.7	9.22	25.6	14.5	49.9	13.1	27.4	66.2	6.41	23.1	18.1
		TW_2	32.8	10.0	11.6	48.5	7.43	16.3	16.7	33.4	9.99	12.1	51.7	7.78	21.2	20.5
	FA	CO	82.0	4.26	21.5	65.5	12.8	33.6	22.2	82.5	4.09	20.4	78.6	6.07	28.0	8.82
		TW_1	53.0	12.4	28.3	61.2	10.0	26.3	8.88	49.3	12.7	26.8	66.3	7.07	24.4	18.0
		TW_2	33.2	9.85	12.0	48.3	7.86	18.2	16.4	33.4	9.76	11.9	52.0	7.28	19.6	20.3
	PO	CO	79.3	4.72	24.5	65.0	15.3	37,1	21.8	79.1	4.52	24.8	73.0	8.75	32.3	10.6
		TW_1	58.9	11.6	30.7	57.5	14.6	32.5	3.88	55.9	11.8	30.0	66.6	9.36	28.2	11.2
		TW_2	41.8	12.6	20.9	51.6	11.6	24.3	10.4	43.2	12	19.9	58.9	9.56	24.8	16.7
VAS	PT	CO	81.6	4.39	20.6	71.4	10.2	26.6	13.2							
		TW_1	52.5	11.7	26.4	61.4	9.25	24.4	9.64							
		TW_2	41.3	9.21	18.2	44.1	9.00	17.7	3.03							
	FA	CO	86	3.05	18.5	70.5	7.85	23.2	16.9							
		TW_1	55.0	11.5	26.3	62.0	6.66	16.9	12.7							
		TW_2	40.2	9.97	17.5	48.5	7.51	15.5	9.10							
	PO	CO	82.8	4.43	20.9	63.7	12.1	28.9	22.0							
		TW_1	69.0	9.17	27.9	59.3	11.3	24.6	10.7							
		TW_2	54.0	11.0	25.7	51.4	9.10	18.9	8.17							

There are studies in the literature investigating the ΔE^* difference and L^*, a^*, and b^* parameters after HT, varnishing, and WEA. For example, Turkoglu *et al.* (2017) found that QUV of *Fagus orientalis* with polyurethane varnish after HT at 210 °C for 0.5, 1, and 1.5 h caused an increase in L^*, a^*, and b^* values and the value of ΔE^* increased from 11 to 15%. In another study, Baysal *et al.* (2014) investigated ΔE^* and L^*, a^*, and b^* after 500 h of QUV exposure to Scotch pine samples, which were heat-treated at 140, 170, and 200 °C. They revealed that with a value ranging from 1.80 to 15.9, ΔE^* was lower in the heat-treated samples in all HT groups except the samples treated at 140 °C for 2 h. In addition, they found that as HT temperature and time increased, *L** decreased after QUV, *a** and b* color values increased; however, the amount of increase decreased depending on the increase in HT temperature and time. Ayata and Çakıcıer (2017) applied single and double component WBV to the oak, *Fagus orientalis* and Scotch pine working samples. The samples were also subjected to 2 h of heat treatment at 190 °C and 1 and 2 h of heat treatment at 212 °C, and then to QUV up to 432 h, and color change was investigated. The study revealed that after 432 h of QUV, the lowest ΔE^* (30.75) was found in oak with double-component WBV at 2 h of heat treatment at 212 °C, and the highest ΔE^* (62.64) was found in Scotch pine. The study reports that the highest and lowest values of other color parameters (*L**, *a**, and *b**) were 29.79, 55.56; 5.14, 13.00; and 6.29, 26.70, respectively, in double-component WBV. Esteves *et al.* (2020) applied 720 h of QUV and reported that in heat-treated pine species, *L** remained almost the same with minimal changes during the aging period, and the heat-treated products generally turned yellowish at the end of the aging process. In their study with *Abies nordmanniana* and Scotch pine, Kesik *et al.* (2017) exposed water-based varnished and dyed test samples after heat treatment to NAT for one year and investigated ΔE^*. Their study revealed that after NAT, the HT and varnished samples were more stable against color change than the untreated varnished samples.

Findings on surface roughness

The MANOVA results pertaining to the R_a, R_y, R_z, and R_q values across aging, heat treatment, and tree samples are given in Table 7.

Table 7. MANOVA Results For Surface Roughness R_a, R_y, R_z, and R_q Factors

Source	Factor	SUM	df	MS	F	Sig.	PES
WEA	Ra	8701.185	9	966.798	331.978	0.000	0.892
	Ry	739721.908	9	82191.323	42.422	0.000	0.515
	Rz	360736.259	9	40081.807	127.351	0.000	0.761
	Rq	14807.476	9	1645.275	101.217	0.000	0.717
WT-WEA	Ra	229.210	18	12.734	4.373	0.000	0.179
	Ry	20332.663	18	1129.592	0.583	0.912	0.028
	Rz	12187.912	18	677.106	2.151	0.004	0.097
	Rq	592.530	18	32.918	2.025	0.008	0.092
HT-WEA	Ra	169.676	18	9.426	3.237	0.000	0.139
	Ry	42019.305	18	2334.406	1.205	0.254	0.057
	Rz	5537.279	18	307.627	0.977	0.485	0.047
	Rq	314.476	18	17.471	1.075	0.376	0.051
WT-HT-WEA	Ra	202.519	36	5.626	1.932	0.001	0.162
	Ry	80495.543	36	2235.987	1.154	0.256	0.103
	Rz	14591.864	36	405.330	1.288	0.130	0.114
	Rq	669.753	36	18.604	1.145	0.267	0.103

The MANOVA results pertaining to the SR values are given in Table 7, which shows that the WEA process has a significant effect on the SR change at $p \leq 0.05$. The difference is the highest in R_a (0.892) and the lowest in R_y (0.515). To better understand the differences, the averages for the factors of R_a, R_y, *R*z, and R_q belonging to the *b* value, and the Duncan test results are presented in Table 8a, b, and Fig. 7.

Table 8a. Averages for Surface Roughness, R_a, and R_q, and Duncan Test Results

R_a				R_q			
Variation	R_a	HG	Sig.	Variation	R_q	HG	Sig.
A_2-NAT-90-DAY	2.65	A	0.60	A_2-QUV-720	3.95	A	0.158
A_2-QUV-720	2.68	A	0.60	A_2-NAT-90-DAY	4.34	A	0.158
A_2-QUV	3.28	A	0.60	A_2-QUV	4.57	A	0.158
A_2-NAT	3.28	A	0.60	A_2-NAT	4.57	A	0.158
A_1-QUV	3.35	A	0.60	A_1-QUV-720	5.20	AB	0.158 (0.073)
A_1-NAT	3.35	A	0.60	A_1-NAT-90-DAY	5.20	AB	0.158 (0.073)
A_1-QUV-720	3.44	A	0.60	A_1-QUV	5.36	AB	0.158
A_1-NAT-90-DAY	3.44	A	0.60	A_1-NAT	6.87	BC	0.073 (0.248)
VAS	4.79	B	1.000	VAS	7.86	C	0.248
VAS-720	17.90	C	1.000	VAS-720	24.07	D	1.000

Table 8b. Averages for Surface Roughness R_y and R_z and Duncan Test Results

R_y				R_z			
Variation	R_y	HG	Sig.	Variation	R_z	HG	Sig.
A_2-NAT-90-DAY	29.68	A	0.182	A_2-QUV-720	16.24	A	0.109
A_2-QUV-720	26.64	A	0.182	A_2-NAT-90-DAY	16.56	A	0.109
A_2-QUV	31.35	A	0.182	A_2-QUV	18.64	A	0.109
A_2-NAT	31.35	A	0.182	A_2-NAT	18.64	A	0.109
A_1-QUV	41.42	A	0.182	A_1-QUV	21.91	A	0.109
A_1-NAT	41.42	A	0.182	A_1-NAT	22.19	A	0.109
A_1-QUV-720	37.87	A	0.182	A_1-NAT-90-DAY	23.33	A	0.109
A_1-NAT-90-DAY	39.17	A	0.182	A1-QUV-720	23.33	A	0.109
VAS	65.32	B	1.000	VAS	48.35	B	1.000
VAS-720	168.98	C	1.000	VAS-720	112.92	C	1.000

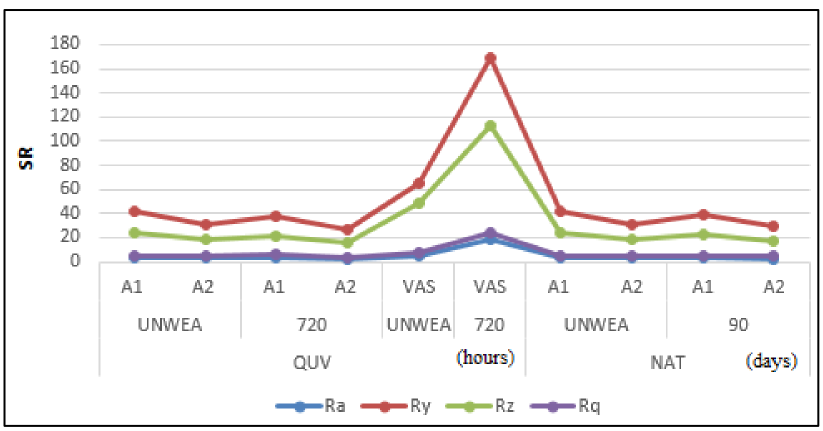


Fig. 7. Amounts of SR obtained from CON and HT variations in the stages of the WEA process

As Tables 8a and 8b show, the highest R_a, R_y, R_z, and R_q values after WEA were in the VAS 720 group as 17.90, 168.98, 112.92, and 24.07, respectively. The lowest R_a and R_y values were 2.65 and 29.68, respectively, in A_2-NAT-90 DAYS group, and the lowest R_z and R_q values were 16.24 and 3.95, respectively, in A_2-QUV-720 group.

According to Table 8, although the values were close to the A_1 and A_2 groups, it is seen that the lowest SR values were obtained in the A_2 varnish group in both QUV and

NAT aging. As expected, the highest values were obtained in the VAS groups. As revealed by the MANOVA results, the high VAS effect related to the surface roughness parameters was due to the differences between the varnished groups and VAS groups in the R_a, R_y, and R_z parameters, and the differences between the varnished groups and the VAS groups in the R_q parameter. The differences can be understood more clearly, especially from the SR values in the R_q parameter. The differences between the varnished groups A_1 and A_2 and the VAS group can be seen clearly in Fig. 7. In contrast, deformations, such as cracking, that can be seen on the sample surfaces during the WEA process were visually checked and illustrated. Although crack formation was not observed on the sample surfaces after 720 h of QUV and three months of NAT in the samples that were treated with varnish, it was seen that capillary cracks started to form along the surface only in TW_1 and TW_2 narrow-leaved ash samples after 432 h of QUV treatment in VAS samples. According to the observations after 532 h of accelerated aging, deformation started in the PT-CON samples, while thin cracks were formed in the areas close to the cross-sections in TW_1 and TW_2. Capillary cracks started to grow in FA samples and the amount of cracks increased; however, the CON-FA samples were still strong without any cracks. It was further observed that the PO-CON samples were still strong without cracks; however, cracks formed along the surface of TW_1 and TW_2. Deformation and crack formation in the unvarnished working samples were slightly more advanced after 720 h of QUV than after 520 h of QUV. The deformations in the form of cracks on the surfaces of VAS samples subjected to HT after QUV are given in Fig. 8.

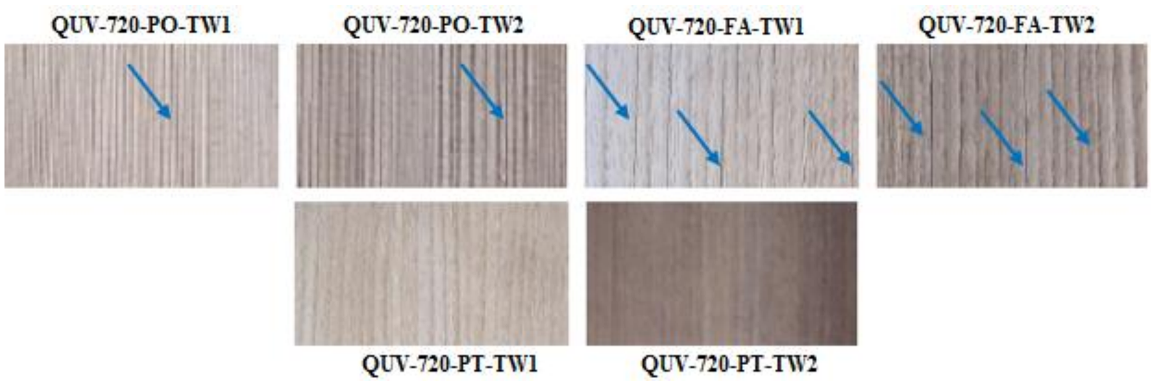


Fig. 8. Cracks on the surfaces of VAS samples subjected to HT after QUV

Yazıcı and Özlüsoylu (2020) investigated the effect of QUV heat-treated Mediterranean laurel (*Laurus nobilis* L.) wood on some surface properties and reported that the heat treatment temperature is effective on SR as the aging time increases, and that the SR increases as the temperature increases. Similarly, Türkoğlu *et al.* (2017) applied polyurethane varnish heat-treated *Fagus orientalis* and reported that the SR values determined after 500 h of QUV (154.35%) were higher compared to the SR values measured before aging (38.71%). Kart *et al.* (2019) investigated the SR change in Scotch pine and *Fagus orientalis* covered with cellulosic varnish (CV) and polyurethane varnish (PUV) after HT and exposed to six months of NAT. They found that SR increased after YAS in both tree species. The study revealed that the smallest R_a (129%) was at 225 °C in the three-hour Scotch pine variation in CV, while highest R_a (350%) was at 205 °C in the one-hour *Fagus orientalis* variation in PUV. The smallest R_z (125%) was at 225 °C in the three-hour *Fagus orientalis* variation in CV, while the highest R_z (370%) was at 205 °C in the one-hour Scotch pine variation in PUV. The smallest R_q (135%) was at 215 °C two-hour variation and at 225 °C three-hour *Fagus orientalis* variation in the CV. The highest R_q (300%) was at 205 °C one-hour *Fagus orientalis* variation in PUV.

The varnish, WT, and HT-based SR values (R_a, R_y, R_z, and R_q) of the ThermoWood® test samples, to which water-based normal (A_1) and modified (A_2) varnish were applied, and the VAS samples are presented in Table 9.

Table 9. WT and NAT-based R_a, R_y, R_z, and R_q Values After WEA

VARNISH	AT	HT	UNWEA				720 h				90 DAY			
			R_a	R_y	R_z	R_q	R_a	R_y	R_z	R_q	R_a	R_y	R_z	R_q
A_1	PT	CON	4.34	30.2	24	5.57	5.58	34.6	27.6	6.94	4.49	38.9	23.8	5.8
		TW1	3.06	27.7	19	4.19	2.15	20.5	15.1	2.95	4.01	33.7	22.8	5.23
		TW2	2.16	16.2	13	2.78	2.34	20	14.4	3.07	3.36	32.2	21	4.67
	FA	CON	3.31	63.4	27.6	7.11	3.54	47.3	23.6	5.79	4.53	74.4	37.5	8.72
		TW1	3.97	68	28.1	7.8	3.97	62.8	29.9	21.5	4.26	54.5	30.5	7.34
		TW2	5.42	76.3	35.9	9.6	6.21	94.8	46.4	12.3	4.29	72.2	31.5	8.96
	PO	CON	3	55	16	3.8	3.61	23.2	17.5	4.44	2.23	14.5	10.7	2.73
		TW1	2.06	13.9	32.4	2.61	2.04	15.9	11	2.74	1.71	11.7	9.21	2.13
		TW2	2.83	22.1	14	3.41	1.59	21.7	11.8	2.15	2.15	20.5	12.8	2.7
A_2	PT	CON	3.9	27.8	20.1	5.15	3.36	23.3	17.9	4.43	2.93	20	14.3	3.74
		TW1	2.12	19.1	14.1	2.92	3.01	21.6	17.2	3.98	2.8	20.7	14.9	3.63
		TW2	4.66	18.3	12.2	2.36	2.18	20.3	14.2	2.95	2.11	16.5	12.9	2.86
	FA	CON	3.99	43.9	27.1	6.73	3.02	38	20.8	4.84	3.32	43.5	25.8	5.98
		TW1	4.29	61.7	31.2	7.63	3.86	49.3	24.6	6.63	2.81	55.4	21.8	6.07
		TW2	4.79	70.1	32.9	9.12	2.74	40.9	19.8	5.04	4.85	74	32.8	10.3
	PO	CON	2.12	18.8	12.4	2.71	2.39	16	11.9	3	2.08	12.7	9.51	2.58
		TW1	1.67	11.3	8.85	2.12	2.06	18.5	11.3	2.71	1.11	10.7	7.27	1.58
		TW2	2.03	11.1	9.03	2.4	1.57	12	8.62	2.02	1.9	12.9	9.84	2.37
VAS	PT	CON	3.55	42.7	34.2	5.01	20.3	149	102	25.3				
		TW1	5.57	64.1	49.2	8.21	24.3	182	158	30.6				
		TW2	4.9	55.9	44.3	6.88	18.3	143	114	23.4				
	FA	CON	4.55	110	53.8	10.2	15.3	193	122	24.5				
		TW1	7.36	126	67.9	14.9	19.9	204	130	29.1				
		TW2	6.8	96.6	57.8	13	14.2	158	109	22.6				
	PO	CON	2.09	20.3	16.2	2.7	16.6	283	92.1	21.3				
		TW1	4.57	33.1	29.1	5.11	14.6	89.5	93.3	18.5				
		TW2	3.78	38.5	29.2	4.9	17.5	118	97.4	22				

As seen in Table 9, the highest SR values were obtained in WEA ThermoWood® samples. The R_a, R_y, R_z, and R_q values determined in VAS samples were approximately four times higher than those in A_1 and A_2 samples both in QUV and NAT. This finding is quite remarkable in terms of emphasizing the importance of the protective top surface treatments to be applied to the furniture surfaces according to the place of use. Among the varnished samples, the smallest R_a, R_q, R_y, and R_z values after WEA were 1.11, 1.58, 10.7, and 7.27 in A_2-NAT-PO-W_1 samples, respectively. In contrast, in the same samples, the highest R_a, R_y, and R_z values were 6.21, 94.8, and 46.4, respectively, in A_1-QUV–FA-TW_2, and the highest R_q value was 21.5 in A_1-QUV-TW_1-FA samples.

CONCLUSIONS

In this study, heat-treated and untreated test samples were divided into two groups. Surface treatment was applied to the samples in the first group by applying modified water-based varnish (A_1) and normal water-based varnish (A_2), and the second group was left unvarnished. The results of the study are presented below. This study aimed to promote environmentally friendly production techniques and materials, and the findings show that modification studies on water-based varnishes can positively affect the surface treatment performance of heat-treated wood materials.

1. The total color difference and surface roughness results obtained after natural and accelerated weathering of heat-treated aspen (*Populus tremula*), Eastern spruce (*Picea orientalis*), and narrow-leaved ash (*Fraxinus angustifolia*) were in the average values category when compared with other varnish types.
2. Modification in water-based varnishes resulted in lower total color difference than normal water-based varnishes.
3. The total color difference values of the accelerated weathering working samples with only heat treatment and the total color difference values of the varnished samples were close to each other, which indicates that the color stability of the wood material modified with transparent varnishes is not yet at a sufficient level. For this reason, to minimize the color change in the surface treatments, the use of color pigments and similar processes can be considered in a way that does not affect the appearance of the wood material much.
4. Aging affected the materials produced under different heat treatment conditions differently, and as the color darkness obtained by heat treatment increased, the total color difference after aging also increased. This indicates that as the heat treatment temperature increases, the color stability shows greater sensitivity in the areas of use.
5. Given the effect of differences in aging, it can be stated that natural weathering conditions have a higher effect on total color difference than accelerated weathering. This is probably due to the high variability of climatic effects in the natural environment. Although the natural environment conditions are made similar in accelerated aging, the periodic effect of the conditions in the form of cycles and their static size throughout the aging process lead to this result. However, in practice, the influential factors are not static, and the effect size of external air conditions, such as temperature, humidity, precipitation, and wind constantly changes.
6. Surface roughness results show that surface treatment is certainly necessary to maintain the surface quality of heat-treated materials. Otherwise, deformations in the form of cracks may occur on the surfaces together with discoloration, which causes deformations to penetrate into the inner parts of the material.
7. As this study reveals, the absence of cracks and similar formations on the surfaces of the varnished samples in both natural and accelerated weathering also reveals the importance of surface treatments.

ACKNOWLEDGMENTS

This work was supported by Dual Boya, İstanbul. The authors thank Dual Boya for their contribution.

REFERENCES CITED

Ali, M. R., Abdullah, U. H., Ashaari, Z., Hamid, N. H., and Hua, L. S. (2021). "Hydrothermal modification of wood: A review," *Polymers* 13(16), article no. 2612. DOI: 10.3390/polym13162612.

Anonymous (2022a). "The CIELAB L*a*b* System – the method to quantify colors of coatings," PROSPECTOR®, (https://knowledge.ulprospector.com/10780/pc-the-cielab-lab-system-the-method-to-quantify-colors-of-coatings/), Accessed 25 March 2022.

Anonymous (2022b). "Yüzey Metrolojisi," Istanbul Teknik Üniversitesi, (https://web.itu.edu.tr/gulmezt/Metroloji/Metroloji%20Bolum%208.pdf), Accessed 25 March 2022).

ASTM G154 (2006). "Standart practice for operating flurescent light apparatus for UV exposure of nonmetallic materials." ASTM International, West Conshohocken, PA, USA.

Ayata, U., and Çakıcıer, N. (2017). "Determination of the color changes against accelerated UV aging of used water based layers on some heat-treated (ThermoWood) wood species," *Kastamonu University Journal of Forestry Faculty* 17(4), 703-714. DOI: 10.17475/kastorman.307003

Aytin, A. (2013). *Effect of High Temperature Treatment on Physical. Mechanic and Technologic Properties of Wild Cherry* (*Cerasus avium* (L.) Monench), Doctoral Dissertation, University of Duzce, Düzce, Turkey.

Aytin, A., Korkut, S., and Çakıcıer, N. (2020). "The effect of accelerated weatherıng on color and surface rougheness in ThermoWood® wıld cherry wood," *Wood Industry and Engineering* 2(2), 70-79.

Aytin, A., Korkut, S., and Çakıcıer, N. (2021). "The effect of different aging conditions on color change of some wood species in ThermoWood® products," *Journal of Bartin Faculty of Forestry* 23(1), 104-118. DOI: 10.24011/barofd.880012

Bytner, O., Laskowska, A., Drożdżek, M., Kozakiewicz, P., and Zawadzki, J. (2021). "Evaluation of the dimensional stability of black poplar wood modified thermally in nitrogen atmosphere," *Materials* 14(6), article no. 1491. DOI: 10.3390/ma14061491

Baysal, E., Değirmentepe, S., and Şimşek, H. (2014). "Some surface properties of thermally modified scots pine after artificial weathering," *Maderas. Ciencia y Tecnología* 16(3), 355-364. DOI: 10.4067/S0718-221X2014005000028

Bozkurt, A. Y., and Erdin, N. (1997). *Wood Technology Textbook*, Istanbul University, İstanbul, Turkey.

Çakıcıer, N. (2007). *Changes Due to Weathering of Surface Finishing Layers of Wood*, Doctoral Thesis, İstanbul University, İstanbul, Turkey.

Çakıcıer, N., and Sevim Korkut, D. (2009). "Aging experiments on coating layers of wood construction materials," *Duzce University Journal of Forestry* 5(1) , 75-90.

Çolak, M., and Değirmentepe, S. (2020). "The use of wood materıals as furniture and building material in interior and outdoor spaces," *Turkish Journal of Nature and*

Science 9(Special Issue), 190-199. DOI: 10.46810/tdfd.789277

Demirel, G. K., and Temiz, A. (2015). “Environmentally friendly modification methods in wood protection,” *Selcuk University Technical Online Journal* 14(1), 1016-1032.

DIN 4768 (1990). “Determination of roughness parameters Ra, Rz, Rmax by means of stylus instruments. terms, measuring conditions,” Deutsches Institut für Normung, Berlin, Germany.

Esteves, B. M., Herrera, R., Santos, J., Carvalho, L., Nunes, L., Ferreira, J., Domingos, I. J., and Cruz-Lopes, L. (2020). "Artificial weathering of heat-treated pines from the Iberian peninsula," *BioResources* 15(4), 9642-9655. DOI: 10.15376/biores.15.4.9642-9655

Gürleyen, L., Esteves, B., Ayata, Ü., Gürleyen, T., and Çınar, H. (2018). “The effects of heat treatment on colour and glossiness of some commercial woods in Turkey,” *Drewno* 61(201), 81-90. DOI: 10.12841/wood.1644-3985.227.03

ISO 4287 (1977). “Geometrical product specifications surface texture profil method terms definitions and surface texture parameters,” International Organization for Standardization, Geneva, Switzerland.

ISO 7724-2 (1984). “Paints and varnishes-colorimetry-part 2: Colour measurement,” International Organization for Standardization, Geneva, Switzerland.

ISO 7724-3 (1984). “Paints and varnishes-colorimetry-part 3: Calculation of colour differences,” International Organization for Standardization, Geneva, Switzerland.

Johansson, D. (2005). *Strength and Colour Response of Solid Wood to Heat Treatment*, Licentiate Thesis,. Luleå Tec Un. Department of Skellefteå Campus, Luleå, Sweden.

Jirouš-Rajković, V., and Miklečić, J. (2019). “Heat-treated wood as a substrate for coatings, weathering of heat-treated wood, and coating performance on heat-treated wood,” *Advances in Materials Science and Engineering* 2019, article ID 8621486. DOI: 10.1155/2019/8621486

Kačíková, D., Kubovský, I., Ulbriková, N., and Kačík, F. (2020). “The impact of thermal treatment on structural changes of teak and iroko wood lignins,” *Applied Sciences* 10(14), Article Number 5021. DOI: 10.3390/app10145021

Kart, S., Baysal, E., Turkoglu, T., Kucuktuvek, M., Peker, H., Altay, C., and Toker, H. (2018). “The effect of natural weatherıng on change in the color of heat-treated and varnıshed Scots pıne and Oriental beech woods,” DSpace@Muğla, Institutional Academic Archive, (https://hdl.handle.net/20.500.12809/1625), Accessed 02 March 2022.

Kart, S., Baysal, E., Kucuktuvek, M., Turkoğlu, T., Toker, H., Altay, Ç., Cibo, C., and Peker, H. (2019). “Some surface characteristics of varnished thermowood after weathering,” *Wood Research* 64(1), 35-48.

Kesik, H. İ., Özkan, O. E., and Öncel, M. (2017). “Characteristics of a protective layer on oil heat-treated scots pine and fir wood,” *BioResources* 12(2), 3067-3075. DOI: 10.15376/biores.12.2.3067-3075

Korkut, S., and Kocaefe, D. (2009). “Effect of heat treatment on wood properties,” *Duzce University Journal of Forestry* 5(2), 11-34.

Kropat, M., Hubbe, M. A., and Laleicke, F. (2020). “Natural, accelerated, and simulated weathering of wood: A review,” *BioResources* 15(4), 9998-10062.

Kurtoğlu, A. (2000). *Wood Material Surface Treatments Textbook*, Volume 1, Istanbul University Faculty of Forestry Publications, University Publication Number: 4262, Faculty Publications: 463, Istanbul University, Istanbul, Turkey.

Rowell, R. M. (2004). “Acetylation of natural fibers to improve performance,” *Molecular*

Crystals and Liquid Crystals 418(1), 153-164. DOI:10.1080/15421400490479244
Shukla, S. R. (2019). "Evaluation of dimensional stability, surface roughness, colour, flexural properties and decay resistance of thermally modified *Acacia auriculiformis*," *Maderas. Ciencia y Tecnología* 21(4), 433-446. DOI: 10.4067/S0718-221X2019005000401
Tomak, E. D., and Yıldız, Ü. C. (2010). "Chemical modification of wood," in: *3rd National Blacksea Forestry Congress*, Vol.4, Artvin, Turkey, pp. 1681-1690.
Torniainen, P., Popescu, C.-M., Jones, D., Scharf, A., and Sandberg, D. (2021). "Correlation of studies between colour, structure and mechanical properties of commercially produced ThermWood® treated norway spruce and scots pine," *Forests* 2(9), article no. 1165. DOI: 10.3390/f12091165
Türkoğlu, T., Kabasakal, Y., Baysal, E., Gunduz, A., Küçüktüvek, M., Bayraktar, D. K., and Peker, H. (2017). "Surface characteristics of heated and varnished oriental beech after accelerated weathering," *Wood Research* 62(6), 961-972.
TS 2470 (1976). "Wood sampling sample trees and long for determination of physical and mechanical properties of wood in homogeneus stands," Turkish Standards Institution, Ankara, Turkey.
TS 4176 (1984). "Wood sampling methods and general requirements for physical and mechanical tests," Turkish Standards Institution, Ankara, Turkey.
Ulay, G., and Budakçı, M. (2015). "Studies carried out in turkey regarding water-based varnishes used on wood surfaces," *Duzce University Journal of Science and Technology* 3(2), 470-480.
Yalınkılıç, A. C., Aksoy, E., Atar, M., and Keskin, H. (2021), "Effect of the bleaching and varnishing process on the collapse time in combustion of wood material, Part 1," *Journal of Polytechnic* 24(2), 637-643. DOI: 10.2339/politeknik.755830
Yazıcı, H., and Özlüsoylu, İ. (2020). "The effect of accelerated weathering on some surface properties of heat-treated sweet bay wood (*Laurus nobilis* L.)," *Turkish Journal of Forestry* 21(4), 468-474. DOI: 10.18182/tjf.809139
Yeşil, Y. (2010). *The Prediction of the Colour Values in the Mélange Fibre Blends by a Newly Developed Algorithm*, Doctoral Thesis, Çukurova University, Adana, Turkey.
Zivkovic, V., Prˇsa, I., Turkulin, H., Sinkovi´c, T., and Jirouˇs-Rajkovi´c, V. (2008). "Dimensional stability of heat-treated wood floorings," *Drvna Industrija* 59(2), 69–73.

Article submitted: March 25, 2022; Peer review completed: June 11, 2022; Revised version received and accepted: September 23, 2022; Published: September 27, 2022.
DOI: 10.15376/biores.17.4.6358-6376