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THE EFFECTS OF VARNISH AND WEATHERING PROCESSES ON HEATED WILD CHERRY WOOD (*Cerasus avium* (L.) Moench)

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Abstract

The rapid deformation in the appearance features of heat-treated wooden (HT) materials used outdoors is a significant problem in terms of aesthetics and economics. It is seen that the various surface protection treatments applied have not provided a permanent solution to this problem, yet. There is a clear need for more detailed studies to contribute to the problem's solution. In this study, the heat-treated Wild Cherry (*Cerasus avium* (L.) Moench) wood samples were subjected to accelerated (QUV) and natural weathering (NW) in a way that the panels would be at an angle of 45° to the ground plane after varnishing. After that, the features like the thickness of the varnish layer (LT), total color change (ΔE), glossiness (G), and surface roughness average (Ra) were examined before and after the weathering process. The results of the examination showed that LT decreased in heat-treated samples compared to control samples (UT) depending on the lengthening of weathering time; both NW (120 days) and QUV (144 hours) increased first, then decreased (240 days and 288 hours). Glossiness increased by 18% over control samples at 144 hours at QUV, but remained almost the same at 120 days NW; on the other hand, it decreased with increasing duration in both aging. On the other hand, total color change results achieved at NW 120 days were approximately double the results obtained at 144 and 288 hours on QUV, while increased up to 3 times at NW 240 In addition, it was understood that there was no significant difference in Ra according to the current weathering conditions.

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1. Introduction

ThermoWood® is a modified product that can be used in places where dimensional stability and biological degradation are primarily important. At the same time, the color of the wooden material darkens, and the color homogeneity is provided in ThermoWood®. The color change is seen as a gain, especially in hardwood, and provides potential opportunities for new markets (Johansson, 2005).

An industrial-scale heat-treatment process for wood has been developed at VTT in cooperation with the Finnish wood product industry. The ThermoWood® process is licensed to the members of the Finnish Thermowood Association. The ThermoWood process can be divided into three main phases:

Phase 1: Temperature increase and high-temperature drying Using heat and steam, the kiln temperature is raised rapidly to a level of around 100°C. Thereafter, the temperature is increased steadily to 130°C, during which time the high-temperature drying takes place and the moisture content in the wood decreases to nearly zero.

Phase 2: Heat treatment Once high-temperature drying has taken place, the temperature inside the kiln is increased to between 185°C and 215°C. When the target level has been reached, the temperature remains constant for 2–3 hours depending on the end-use application.

Phase 3: Cooling and moisture conditioning, the final stage is to lower the temperature by using water spray systems; when the temperature has reached 80–90°C, re-moisturizing takes place to bring the wood moisture content to a useable level, 4–7% (Web-1).

ThermoWood® process graph main diagram is given in Figure 1.

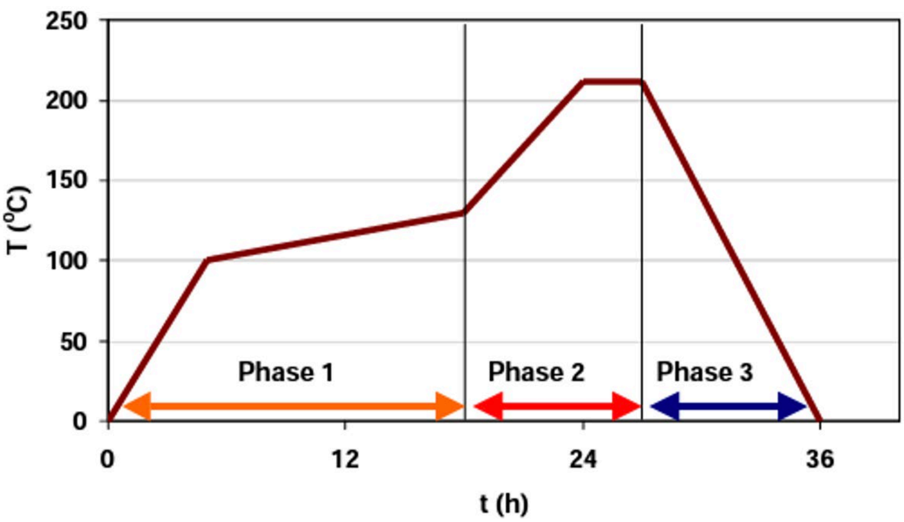

Figure 1: ThermoWood® process graph main diagram (Web-1)

Wooden materials exposed to heat lost their charm because the color of the material, especially in outdoor use, changes over time, and after a while, the dark appearance of the material exposed to direct sunlight is grayed out (Web-1). The color change issue which comes up as an esthetical problem brings about some question marks in the choice of the heat-treated wooden material. Therefore, to avoid the color change in heat-treated wooden material and protect the original color, the coating of the surfaces by applying some top surface treatments like paint/varnish, pigment, and UV protection is a must (Güler, 2010). However, it does not necessarily mean that the varnish layer of the wooden material surfaces that are used in furniture and decoration has a protective - effect. When the aim is to create a protective varnish layer, the possible effects that wood may come across in places where it is used must be taken into consideration and a type of varnish that can endure these effects must be chosen and applied. Besides, regular and timely maintenance and repair must do the varnish layer, and the varnish layer features and user manual to the consumers must be announced (Sönmez, 2000; Çakıcıer, 2007).

The effects of degradation caused by the weathering of the wooden material surface on the protective varnish layer can be determined periodically, by measuring the degradation of the varnish layer in external environmental conditions. However, when the degradation mechanism is left to time, the determination of the natural weathering effects takes many years, the production processes slow down and costs increase. This situation negatively affects the competition process for the varnish and paint manufacturers in the industry. Thanks to artificial weathering techniques, these difficulties in the natural weathering process are eliminated and it is now possible to get faster results (Çakıcıer, 2007). However, in both cases, it must be taken into consideration that the conditions of the usage and testing environments are never identical.

Today, increasing environmental awareness encourages the promotion of more environment-friendly material usage to benefit from wooden material. Choosing water-based varnish to coat the protective layers and wooden material surfaces is important in this regard. The compatible test results obtained from the polyurethane and synthetic varnish that are commonly used in the market and of the water-based varnish tests will bring a remarkable achievement to the field. From this point forth, the Wild Cherry (*Cerasus avium* (L.) Moench) samples were coated with various types of varnish including water-based ones. The color, glossiness, surface roughness, and layer thickness measurements were performed on varnished and heat-treated samples exposed to OUV and NW processes. Because of the fact that the incidence angle of external environmental conditions to the surface of the material can lead to different results, the study samples in NW were treated with a 45 ° contact angle.

2. Materials and Methods

2.1. Material

Wild cherry (*Cerasus avium* (L.) Moench) was used in the study. Trees were selected according to TS 2470 (1976) and were sawn into 60 mm thick timbers before heat treatment. The ThermoWood® (Web-1) was used in heat treatment (Table 1).

Table 1: Variations used in the study

Test samples		**Abbreviation**
Temperature (°)	Time (h)	
Control	-	UT
190	1	HT1
190	2	HT2
212	1	HT3
212	2	HT4

A total of 200 test sample pieces, with 40 pieces for each of 5 different varnish types that were prepared at 10 mm x 78 mm x 150 mm (thickness, width, and length) sizes were waited in the conditioning chamber with 20 ± 2 °C temperature and %65±5 relative humidity until it reached the constant weight according to TS EN 15679 (2010).

2.2. Method

After the test samples were sanded with 80 grits first, then 120, and finally 180, they were varnished. The basic information about the varnish types is given in Table 2.

Table 2: The basic information about the varnish types (VT) used in the study

Company code	**Type of varnish**	**Polymer family(PF)**	**Research code (RC)**
Aquacool FX 7680	One-component water borne(bright)	Water-based acrylic polyurethane based	**WB$_1$**
Aquacool FX 0820	Two-component waterborne(bright)	Water-based polyurethane based	**WB$_2$**
Aquacool FX 7560	One-component water borne(bright)	Water-based acrylic polyurethane based	**WBM**
BV38Z011	One-component (bright)	Alkyd resinous polyurethane based	**PU**
938-9001 Yacht	Bright	Alkyd based	**SYN**

The basic characteristics of varnish types obtained from the market and used in the varnishing process are given in Table 3.

Table 3: The basic characteristics of varnish-type applications

RC	**Viscosity**	**Proper amount. (gr/cm^2)**	**Method**	**Solid content**	**Amount of varnish applied**
WB$_1$	DIN 4 plate, 20°C 11 seconds. → DIN 6 plate 20°C, 45-55 seconds →	65-125 80-150	Dipping 1,8 Paint blaster	19% ± 2 43%±2	FX 6150 primer 2 coats, FX 7680 top coat 2 coats
WB$_2$	DIN 4plate 20°C de 11 seconds → DIN 4 plate 20°C de, 35-45 seconds→	65-125 60-100	Dipping 1,8 Paint blaster	19% ± 32%±2	FX 6150 primer 2 coats FX 0820 2 coats (%20 AX 115 hard and % 10 water supplement)
WBM	DIN 4 plate20°C, 26-33 seconds → DIN 4 plate20°C de 45-55 seconds →	60-80 70-110	Dipping 1,8 Paint blaster	33% ± 2 34%±2	FX 7060-A primer 2 coats FX 7560 top coat 2 coats
PU	DIN 4 plate20°C de 14-16 seconds →	150-200	1,8 Paint blaster	60%±2	Thin single-coat application (hard and 1-1 % 10 Cellulosic thinner) Completely two coats (hard and 1-1 % 10 Cellulosic thinner supplement)
SYN	DIN4 plate 25 ˚C'de 95-100 seconds→	120-150	1,8 Paint blaster	50%±1	Thin single-coat application(% 10 Synthetic thinner supplement) Two coats application (% 10 Synthetic thinner supplement)

The test samples were then divided into four groups; the weathering process was not applied to one group with the purpose of control (UW), two groups were reserved for QUV weathering (144 h and 288 h) and one group was also reserved for natural weathering (120 days-NW120 and 240 days-NW240). The principles of the QUV and NW applications can be seen in Table 4.

Table 4: The principles of the QUV and NW applications

<table>
<tr><th>Group 2</th><th>Group 3</th><th colspan="6">Group 4</th></tr>
<tr><td colspan="2">QUV*</td><td colspan="6">NW</td></tr>
<tr><td>144 hours</td><td>288 hours</td><td colspan="3">120 days (08.05-08.09.2014)</td><td colspan="3">240 days (18.09-18.01.2015)</td></tr>
<tr><td colspan="2" rowspan="3">1. 8 hours UV (313EL UVB)
2. 15 minutes sprinkling
3. 3 hours 45 minutes conditioning</td><td colspan="6">Climate properties(Average values)**</td></tr>
<tr><td>Temperature (°C)</td><td>Relative Humidity (%)</td><td>Rain (mm m^{-3})</td><td>Temperature (°C)</td><td>Relative Humidity (%)</td><td>Rain (mm m^{-3})</td></tr>
<tr><td>23.74</td><td>68.61</td><td>3.00</td><td>10.27</td><td>87.03</td><td>4.22</td></tr>
</table>

*ASTM G 154 (ASTM 2006), **Location-Düzce weather station.

The weathering applications were conducted as two variations at QUV Accelerated Artificial Test (Accelerated Weathering Tester-Model QUV/Spray) device which was produced by Q-LAB company for 144 and 288 hours in line with ASTM G154 (ASTM 2006) standard and NW was applied in Düzce Weather

Station's Garden. Natural weathering was adjusted as two-time variations for 120 (NW120) and 240 days (NW240) and sample holder panels were also adjusted to an angle of 45 ° to the ground plane (Figure 2).

Figure 2: Natural weathering of test samples with an angle of 45°.

In natural weathering, the first measurements were completed within 10 days after 120 days, and then the samples were re-weathering for 240 days.

Measuring the layer thickness (LT)

It was performed with Defelsko Positector 200 B3 according to ASTM D 6132 (ASTM 2008) and ISO 2808 (ISO 2007) standards (Web-2). Defelsko Positector 200 measures the layer thickness of many different surfaces with the ultrasonic method without damaging the surface. The measuring range is between 50-3800 μ and can measure with ± (2 microns + 3% of reading) precision. For measuring, the ultrasonic gel is dropped on the clean-prepared layer surface, and the value on the indicator is read by fixing positector prob on the gel.

Measuring the glossiness value (G)

It was carried out with Erichsen brand Picogloss 562 Mc Gloss Meter according to BS EN ISO 2813 (2002)principles. The gloss meter device that measures at 60±2° was calibrated before each measurement. For daily calibration, the well-polished and smooth black glass with a refractive index of 1,567 whose glossiness was set to 100 for each geometry was used. The measurement was carried out parallel and perpendicular to the fibers from a total of twenty points and average glossiness was calculated by averaging the values that were parallel and vertical to the fibers.

Measuring the color values (*ΔE)**

Color measurement was carried out according to the CIELab color system and the color area where the measurement was carried out is given in Figure 3. In the CIELab system, the differences in colors and their places were determined by L*, a*, b* color coordinates. Here, L * is located on the black-and-white (black, L * = 0, white, L * = 100) axis, a * is located on red – green (positive value is red, negative value is green) axis, and b * is located on the yellow-blue (positive value is yellow; negative value is blue) axis. The "*" sign written with letters is used in order to distinguish the CIE formula from other formulas in different color systems which were developed before (Yeşil, 2010).

The color difference was examined with Konica-Minolta (CR-231) spectrometer which was calibrated as a=4,91; b=3,45; c=6,00, L=324,9 for white according to ISO 7724–2 (ISO 1984) standard. Ten measurements were carried out for each variation according to TS EN 15679 (TS 2010). The red color shade (a*), the yellow color shade (b*), and the color lightness (L*) were examined independently of one another in order to decide which color shade was affected by the change and the total color change (*ΔE**) of the designated color values was calculated by the formula below according to ISO 7724–3 (ISO 1984) (Equation 1);

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

In the equation; ΔL*: Li-Le, Δa*: ai-ae, Δb*: bi-be, i: initial measure, e: final measure

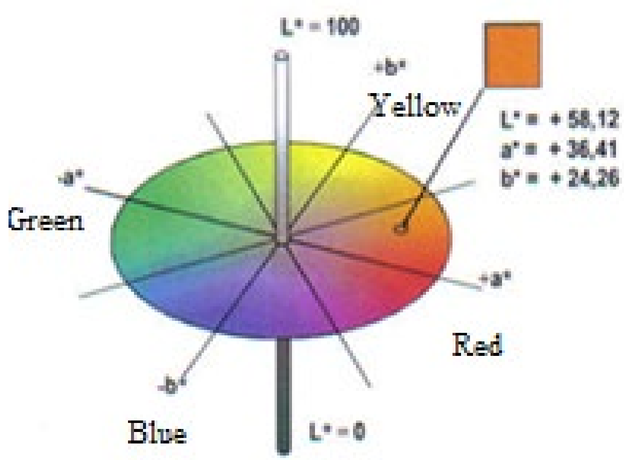

Figure 3: The determination of L*, a* ve b* values according to the CIELab system (Aytin, 2013).

Measuring the surface roughness average (Ra)

It was carried out with a Mitutoyo surface test measuring device (Mitutoyo Surftest SJ-301). The profiles were measured with a device that has a recording stylus in Mitutoyo Surftest SJ-301. The device operates with a 4 (μm) stylus diameter, a vertical angle of 90º to the fiber, and a 10 mm/minute measuring speed.

In determining the surface roughness, a plane whose cutting blade speed was 4500 cycles/minute and 4 panels whose surfaces were smoothened by being grated in the thickness machine were prepared for each variation. The surface roughness of 5 pieces of each panel that were waited at 20±2 °C temperature and %65±5 relative humidity for 1 month was measured from 10 different points for each variation and the measurement was carried out as the determining measurement points would be vertical to the fiber direction. The surface roughness average (Ra) was determined according to ISO 4287 (ISO 1997) and DIN 4768 (DIN 1990).

For all parameters, all multiple comparisons were first subjected to an analysis of variance (Univariate), and significant differences between mean values of control and treated samples were determined using Duncan's multiple range test.

3. Results

3.1. Layer Thickness (LT)

According to the analysis of multi-variance results conducted for layer thickness (LT); it was seen that varnish(V), weathering(W), and wood types(WT) factors and their interactions with one another had significant effects on LT value at the level of $P<0.05$ and there were significant differences between subgroups. It was stated that the significance level of the effects of factors and interactions on LT value was highest (0.810) at VT and lowest (0.068) at WT. The results of the Duncan test were conducted in order to determine the effects of WT, VT, and W factors on LT value given with arithmetic mean (M) and standard error (SE) in Table 5.

Table 5: Average mean(M), standard error (SE), and Duncan test results for layer thickness.

WT	M	VT	M	W	M
UT	88.12 D*	**WB_1**	**110.84 D***	**UW**	90.64 C
HT_1	**82.84 AB**	**WB_2**	101.13 C	**144**	**85.59 B**
HT_2	80.96 A	**SBM**	78.85 B	**288**	**81.80 A**
HT_3	**85.60 C**	**PU**	65.01 A	**NW120**	82.09 A
HT_4	83.85 BC	**SYN**	**65.54 A**	**NW240**	81.24 A
SE	0.905	**-**	0.905	**-**	0.905

(*) Represents the highest G value among all the factors.

3.2. Glossiness (G)

According to multiple variance analysis (MVA) results for the average glossiness; it was seen that there were significant effects of VT, W, and WT factors and their interactions on G value at the level of P<0.05 and there were significant differences among subgroups. Besides, it was stated that the significance level of the effects of each factor and their interactions on G value was the highest at 0.722 in W and the lowest at 0.121 in WT. The results of the Duncan test conducted in order to determine the effects of WT, VT, and W factors on G value are given with M and SE in Table 6.

Tablo 6: Duncan test results, M and SE for average glossiness.

HT	M	VT	M	W	M
UT	76.16 ABC	**WB_1**	**81.83 C**	**UW**	76.291 B
HT_1	**78.86 BC**	**WB_2**	76.37 B	**144**	**90.068 C***
HT_2	79.70 C	**SBM**	77.08 C	**288**	**69.570 A**
HT_3	**73.62 A**	**PU**	80.31 BC	**NW120**	77.856 B
HT_4	74.99 AB	**SYN**	**67.75 A**	**NW240**	69.575 A
SE	1.386	-	1.386	-	1.386

3.3. Total Color Change (*ΔE**)

According to MVA results for the total color change, it was seen that there were significant differences among the subgroups where there were significant effects of VT, W, and WT factors and their interactions on *ΔE** at the level of P<0.05. It was stated that the effects of each factor and their interactions on *ΔE** were highest at 0.853 in W and lowest at 0.068 in VT. The results of the Duncan test conducted in order to determine the effects of tree type, VT, and W factors on *AE** value are given with M and SE in Table 7.

Table 7: Duncan test results, M and SE for ΔE*.

HT	M	VT	M	W	M
UT	**11.967 A***	**WB_1**	14.426 B	**UW**	-
HT_1	13.990 C	**WB_2**	14.634 BC	**144QUV**	8.325 A*
HT_2	12.752 B	**SBM**	15.202 CD	**288QUV**	**7.869 A***
HT_3	16.862 D	**PU**	**15.508 D**	**NW120**	17.502 B
HT_4	**17.446 D**	**SYN**	**13.247 A***	**NW240**	**24.717 B**
SE	0.216	-	0.216	-	0.193

L*, a* ve b* values for heat-treated Wild Cherry (*Cerasus avium* (L.) Moench) wood UW test samples are given in Figures 4a, 4b, and 4c.

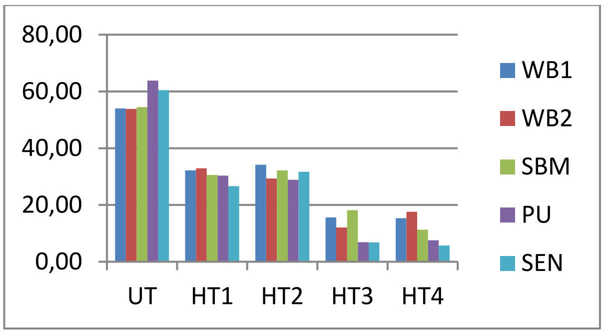

Figure 4a: L* values in UW samples.

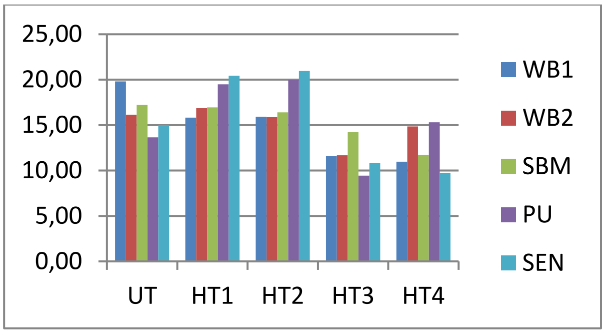

Figure 4b: a* values in UW samples

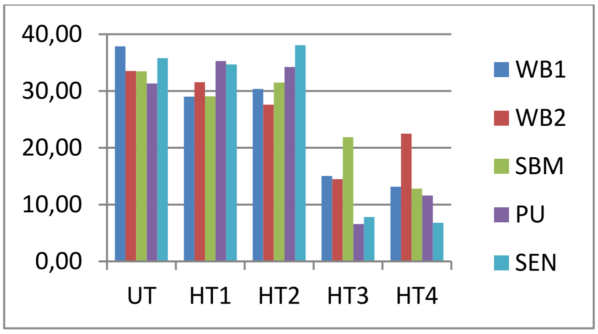

Figure 4c: b* values in UW samples

Figures 3b and 3c show that L* and b* substantially contributed to the change occurring in the color of heat-treated samples. It was understood that the increase in temperature had a significant role when the principles of heat treatment were considered.

According to the color values of test samples measured after QUV and NW weathering applications, it was observed that the color of test samples grayed out in NW while the appearance of samples stayed the same as before UW (Figures 5a and 5b, Figure 6a, 6b, 6c, and 6d).

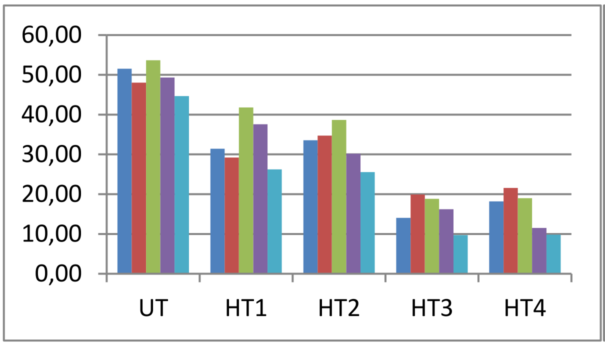

Figure 5a: 288QUV L* values

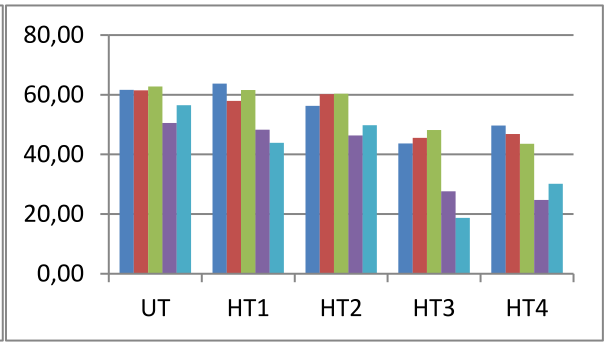

Figure 5b: NW240 L* values

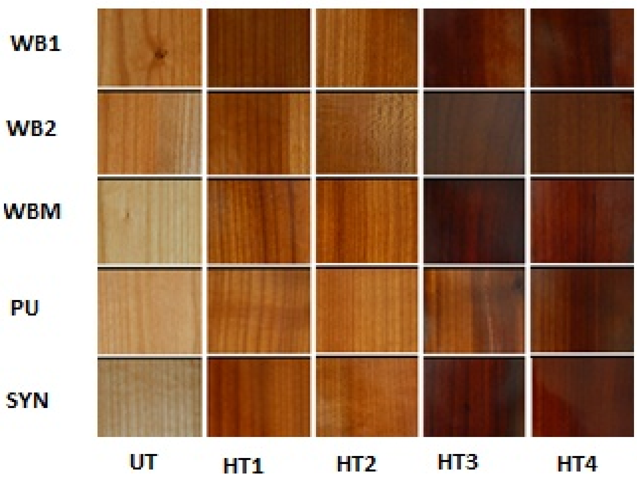

Figure 6a: The appearances in UW samples

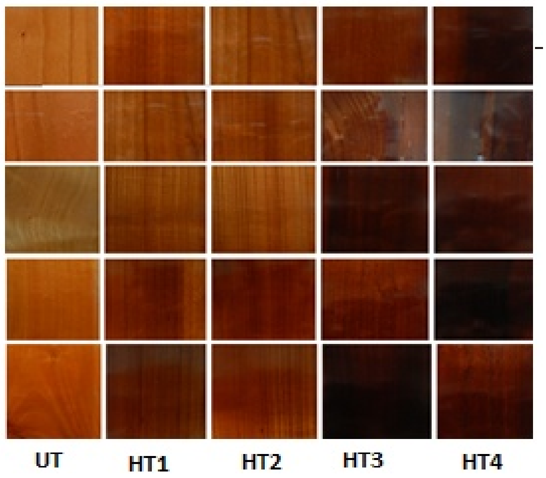

Figure 6b: The appearances after 144QUV

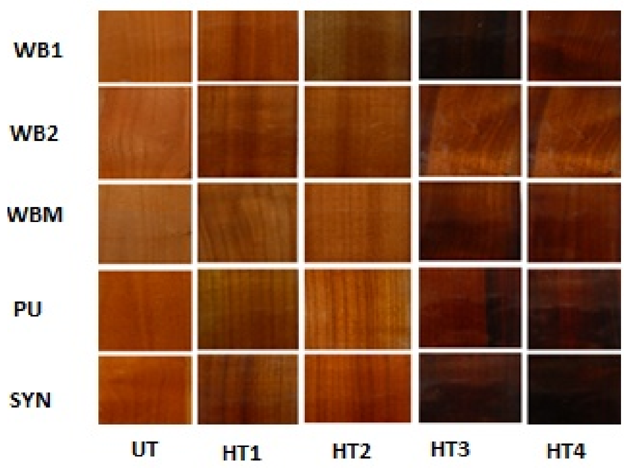

Figure 6c: The appearances after 288QUV

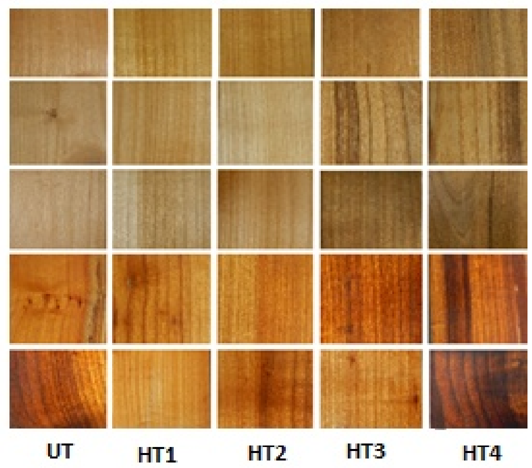

Figure 6d: The appearances after NW120

3.4. Surface roughness (Ra)

Roughness average MVA results showed that W, VT, and WT factors and their interactions had effects on Ra at the level of $P<0.05$ and there were significant differences among subgroups. According to the significance level of each factor and the effects of their interactions on Ra, the biggest effect was determined as (0.520) in W and the smallest effect was also determined as (0.017) in VT. The results of the Duncan test conducted in order to determine the effects of WT, VT, and W factors on Ra are given with M and SE in Table 8.

Tablo 8: Duncan test results, M and SE for average surface roughness.

WT	M	VT	M	W	M
UT	**0.988 A**	**WB$_1$**	0.729 A	**UW**	0.917 A
HT$_1$	0.702 A	**WB$_2$**	0.387 A	**144**	0.770 A
HT$_2$	0.819 A	**SBM**	0.975 AB	**288**	**1.242 A**
HT$_3$	0.881 A	**PU**	**1.056 AB**	**NW120**	**0.884 A**
HT$_4$	**1.375 A**	**SYN**	**1.618 A**	**NW240**	**1.095**
SE	0.261	**-**	0.261	**-**	0.233

4. Discussion

According to Table 5, LT was determined as the highest UT, the lowest HT$_2$ variations in WT; the highest WB1, the lowest PU and SYN in varnishes in VT; the highest 144 hours in QUV, and no difference between NW120 and NW240 in W. It is noted that among the varnish types, water-based varnishes have high LT values, and WB$_1$ with the highest value is 40% higher than SYN with the lowest value. Thus, it can be stated that water-based varnishes are more resistant to QUV and NW conditions.

According to Table 6; G was determined as the highest HT$_1$, the lowest HT$_3$ variations in WT; the highest WB$_1$ in VT, the lowest SEN in varnishes in VT; the highest 144 hours in QUV, the shortest 288 hours in QUV and NW240 variations in W. When the results are examined in terms of wood type and HT, it is seen that the HT temperature is effective in W and there is more gloss loss with W as the temperature increases. On the other hand, among the VT, the G values of the varnishes except SYN are higher and closer to each other. Considering the effect of weathering treatments on G, it can be said that the G values that increased rapidly at the beginning of QUV compared to the UW samples (G was found to be 17.95% more than UW at 144 hours QUV) decreased rapidly in the continuation of the weathering process (G was found to be 8.82% less than UW at 288 hours QUV). On the other hand, G was almost the same as the UW samples in NW120; however, it decreased by approximately 8.80% in NW240 compared to UW. Based on these results, it is noteworthy that the QUV effect on G created using 313EL UVB lamps is higher compared to the NW weathering, and 288 hours of QUV weathering values and NW240 values are close to each other.

Gorman and Feist (1989) stated that brightness and color changes can be easily observed in a short period of time in wood exposed to natural outdoor and artificial UV weathering. They also reported that Douglas fir (*Pseudotsuga menziesii*) and Mahogany (*Swietenia mahogani*) type woods regain the brightness they lost in the first months after the sixth month and a decrease in their brightness is observed in the next six-month period. Güler (2010) investigated the change in gloss values in heat-treated Ash (*Fraxinus excelsior* L.), Anatolian chestnut (*Castenea sativa* Mill.), Limba (*Terminalia superba*) and Iroko (*Chlorophora excelsa*) samples after the application of cellulosic, synthetic, polyurethane, water-based varnish. The study revealed that the gloss values of the samples increased at 150°C and 3 hours of heat treatment in all varnish types and decreased at 150°C and 6 hours of heat treatment and 180°C and 3 and 6 hours of heat treatment. Ayata and Çakıcıer (2017) reported that the gloss value decreased after 432 hours of QUV in some ThermoWood® wood species on which they applied single and double-component water-based varnish. Gündüz *et al*. (2019) investigated the G change over time on WBV-coated surfaces on which they applied 1000 hours of QUV. They found that brightness increased up to about 100% in up to 500 hours, then started to decrease again, and was about 8% higher than the initial value at the end of the QUV.

According to Duncan test results in Table 7; ΔE* was determined as the highest HT_4 in WT, the lowest UT variations, the highest PU and the lowest SYN in VT, the highest NW240, and the lowest 288 QUV in W. When the results are examined in terms of tree species and HT, it is seen that HT temperature has an effect on *ΔE**, and *ΔE** increases as the temperature increases. It is understood that *ΔE** is as high as 45% at HT_4 compared to UT. Considering the effect of weathering treatments on *ΔE**, it can be stated that the effect of natural weathering has a significantly higher effect.

*ΔE** in wooden material was caused because of the changes in color components (color lightness (L*), red color shade (a*), and yellow color shade (b*)) due to both heat treatment and usage. The results of various studies revealed that the color change mainly resulted from L*. Matsuo *et al*. (2010) stated that L* decreased dramatically with heat treatment and *ΔE** changed largely because of this reason. In another study, heat-treated Scotch pine (*Pinus sylvestris* L) and Eastern beech (*Fagus orientalis* L.) woods were varnished with polyurethane and cellulosic varnish, and they were exposed to 3 and 6 hours of natural weathering. As a result, more positive results were obtained in color values (Kart, 2017).

According to Duncan's test results in Table 8, Ra did not change between weathering and heat treatment except VT variations. Kart (2017) stated that after varnishing heat-treated Scotch pine (*Pinus sylvestris* L) and Eastern beech (*Fagus orientalis* L.) woods with polyurethane and cellulosic varnish, they achieved more positive results in the surface roughness values measured following 3 and 6 hours of natural weathering.

5. Conclusion

The heat-treated Wild Cherry (*Cerasus avium* (L.) Moench) wood samples were exposed to QUV and NW with an angle of 45° to the ground plane after varnishing. Based on the findings, significant changes were obtained in total color change while there was no remarkable deformation in glossiness, average surface roughness and layer thickness of test samples. Especially the angle of 45° used in weathering could be said to be effective on the height of total color change. However, in order to reach a final judgment, the results of natural weathering applied with the angle of 5° and 90° should be seen, as well. It was understood that the average glossiness values in both accelerated and natural weathering followed a similar pattern and there were no significant losses in both weatherings.

Accordingly, the fact that there were no significant losses in the properties of the protective film layer of varnish revealed that the development of the varnish content should be focused on in a way that can slow the rapid changes in the color differences. Another result of the study was that there were no significant differences between the varnish types with respect to the properties examined.

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Disclosure Statement

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