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Full Length Research Paper

Effects of QUV accelerated aging on surface hardness, surface roughness, glossiness, and color difference for some wood species

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The surface hardness, surface roughness, glossiness, and color difference were determined for wooden materials produced from three commonly used species - two native of Turkey and one exotic - treated with one- and two-component water-based varnishes and exposed to different amounts of radiation to mimic accelerated aging using a **QUV aging device. One- and two-component water-based varnishes were applied two-and three coats to Scoth pine (*Pinus sylvestris* L.), Iroko (*Chlorophora excelsa*), and Anatolian chestnut (*Castenea sativa* Mill.) woods. Then, the varnish coated materials were exposed to QUV aging devices for 216 and 432 h. Results indicated that the surface hardness and glossiness were decreased for all the three wood species across all the treatment combinations. However, values of surface roughness and color difference were increased for all the three wood species across all the treatment combination.**

Key words: QUV aging, surface hardness, surface roughness, glossiness, color difference, contact information.

INTRODUCTION

Scotch pine (*Pinus sylvestris* L.), Anatolian chestnut (*Castenea sativa* Mill.) and iroko (*Chlorophora excelsa*) are the main species preferred by the outdoor Turkish wood-industry. Iroko (*Chlorophora excelsa)* is a hardwood from tropical Africa. The wood is used for a variety of purposes including boat-building, domestic flooring, and furniture. It is a very durable wood; Iroko does not require regular treatment with oil or varnish when used outdoors (Bozkurt and Erdin, 1998). Scots pine has higher technological properties than most known wood species and high usage potential such as pulp and sawn timber products. It is an important tree species in the forest products industry of Turkey, covering over one milion hectare, making up 5% of the total Turkish forestlands (Anonymous, 2001). Anatolian chestnut *(C. sativa* Mill.) is a tree species of the flowering plant family Fagaceae. They are widely popular in Austria, Turkey, Portugal, France, Hungary, Italy, Slovenia, Slovakia, Serbia, Bosnia, Croatia, and particularly in Corsica. The timber of the species is marketed as chestnut. The wood is of light colour, hard, and strong. It is also used to make furniture, barrels and roof beams notably in southern Europe (Yaltirik and Efe, 2000).

Wood is an organic material used in many construction as well as decorative and aesthetic applications. However, when it is used externally it is exposed to atmospheric agents (mostly solar radiation and rain) that degrade its surface, giving it an “stressed” look. In these conditions, changes in the wood’s superficial layer are due mainly to the breakdown of lignin and of other constituents by photooxidation due to ultraviolet radiation, and its subsequent removal by the action of rain, associated with the loss of water-soluble products. Extended exposure to atmospheric agents leads to a loss in the timber's natural colour, the accumulation of dirt, and also to the eventual growth of fungi on the wood

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surface (Custódio and Eusébio, 2006; Bhat et al., 2010).

Protected wood relies upon the permeability of the water and water vapour through the applied products. The use of coatings with UV absorbers also minimizes the degradation of the wood by ultraviolet radiation. Coatings for exterior millwork such as exterior siding, decks, and doors require distinct performance properties such as excellent light stability, high flexibility, and freeze/thaw cycling properties.

Quantitative ultraviolet (QUV) accelerated weathering testing is a laboratory simulation of the damaging forces of weather for the purposes of predicting the relative durability of materials exposed to outdoor environments. QUV testing takes place in an accelerated weathering chamber, designed to create a highly flexible mix of UV light, temperature, and moisture conditions. The tests are intended to reproduce the damage caused by sunlight, rain, and condensed surface moisture or dew. The chamber subjects the test materials to alternating cycles of light and moisture at controlled elevated temperatures. The moisture includes both condensing humidity, to simulate dew, and water sprays. The light in the chamber is created by specially-designed fluorescent UV bulbs to simulate the effects of sunlight. Although UV radiation actually only comprises about 5% of normal sunlight, the short-wavelength UV light does most of the photochemical damage (Çakicier and Sevim, 2009; Temiz et al., 2005).

The main objective of the study was to determine the surface hardness, surface roughness, glossiness, and color difference of the wooden materials produced from these commonly used two native- and one exotic-species to Turkey treated with one and two component waterbased varnishes and exposed to different amount of radiation to mimic accelerated aging using a QUV aging device.

EXPERIMENTAL

One and two-component water-based varnishes were applied two- and three coats to Scoth pine (*P.sylvestris* L.), Iroko (*C. excelsa*) and Anatolian chestnut (*C. sativa* Mill.) woods. Then, the varnish-coated materials exposed to QUV aging devices for 216 and 432 h.

Two native, Scotch pine (*P. sylvestris* L.) and Anatolian chestnut (*C.sativa* Mill.) one exotic, iroko (*C. excelsa*), species to Turkey were used for wood materials. One- and two-component waterbased varnishes were applied as two and three coats. For the aging treatments the varnish-coated materials were exposed to QUV aging devices for 216 and 432 h. Thus, two types of waterbased varnish at two thickness layers were applied on three different types of woods under two aging period.

Oven-dried wood samples were prepared in 500 × 75 × 18 mm sizes with adequate tolerances. The prepared samples were kept in a conditioning room at an average temperature of 20°C and 60% relative humidity until constant weights were achieved. Except for Scotch pine, all other samples were once sistred then sanded with 80, 100, and 120 sized sandpapers. Then, each of the samples was wetted and subjected to fiber relief treatments. Sanding dust was brushed off with a soft bristle; then compressed air was applied on sample for final cleaning. After cleaning, the samples were treated with lining and filling varnish was applied. Before the aging treatment, moisture content of the samples were determined with a moisture meter as 10% ± 0.5 (TS 2471 1976).

In order to avoid the negative effects of layer performance, mixing ratios and preparation of varnishes were made according to ASTM-D 3023 (1998) standards with the consideration of the recommendations by the manufacturers. Initial viscosities were measured in flow cups with 4 mm diameter at 20 ± 2°C temperature and 60 ± 5% relative humidity in 18 seconds (98 to 100 cp).

One-component and two-component acrylic modified water-based varnishes preferred by industry for their easy applications were used in the experiment. Varnishes produced by different companies (Kimetsan and Akzo-Nobel) were used in two thicknesses. One set of the panels was once varnished with D 17 twice, then D 65 filling varnish was applied three times. The second set of the panels was treated with A1 primer lacquer five times. Then the wet layer thickness of the surface was smothed with 200 µm applicator. A final coat of varnish was applied with 1 to 2 bar (14 to 28 atu) air pressure with the aid of a pistol with 0.7 mm nipple. Pistols were held 20 cm above, perpendicular, and parallel to the sample surface and moved at the same rate during the application (Dyo, 1990). This finishing system build up is commonly used in the industry.

After each application varnished samples were left to dry on the floor at 20°C for 24 h. To eliminate surface roughness, after each varnish application samples were first cleaned with a soft bristle brush, then slightly processed with 600 sized water-sand after each varnish layer. All the exposed surfaces of the samples were coated with varnish to avoid any mositure penetration.

Using an electronic balance with 0.01 sensitivity, each sample was once tared. Then D 45 and A2 topcoat varnishes were applied with a spray gun two- and three times, respectively. To avoid surface roughness, samples were slightly sanded again with 600 sized sandpapers. Then, samples were weighed again and left for three weeks to dry for full-curing.

To ensure complete equilibration with a standard humid air condition, the samples were kept in the laboratory for three weeks at 20 ± 2°C and under 65 ± 5% relative humidity. Then, according to ASTM-D 3924 (1991) protocols the samples were left in a controlled environment at 23 ± 2°C and under 50% ± 5 relative humidity for 16 hours (TS 642, 1997).

The weathering procedure follows ASTM D4587–05 (2010) and ISO 11507 (2007) operation. The UV/condensation cycle is under the environment of 4 h UV at 60°C and 4 h condensation at 50°C, using UVA 340 lamps.

Conditioned samples were subsequently subjected to the König pendulum hardness test to detect the hardness of the varnish coating according to ASTM D 4366-95 (1984). Test panels were placed on the panel table and a pendulum was gently placed on the panel surface. The pendulum was then deflected through 6° and released while simultaneously starting the oscillation counter. The number of oscillations for the amplitude to decrease from 6 to 3° was determined to be the König hardness. Ten replications were conducted on separate specimens for each treatment group.

Rough cut sections for the preparation of test and control samples were cut from the sapwood parts of massif woods with dimensions of 500×100×15 mm. Samples with dimensions of 100×100×10 mm were cut from the sections.

Surface roughness of the samples was measured by using a stylus-type profilometer (Anonymous, 2002). The tracing speed, stylus tip diameter, and tip angle were 10 mm/min, 4 µm, and 90°, respectively. Roughness measurements were taken randomly from the surface of the samples perpendicular to the grain orientation. One roughness parameter, mean arithmetic deviation of profile (Ra), which were commonly used in previous studies, were used to evaluate surface characteristics of the samples (Stombo, 1963). Detailed specifications of these parameters are described in past studies (ISO 4287, 1997). Roughness values were measured with a

Figure 1. Minolta chroma meter CR-231.

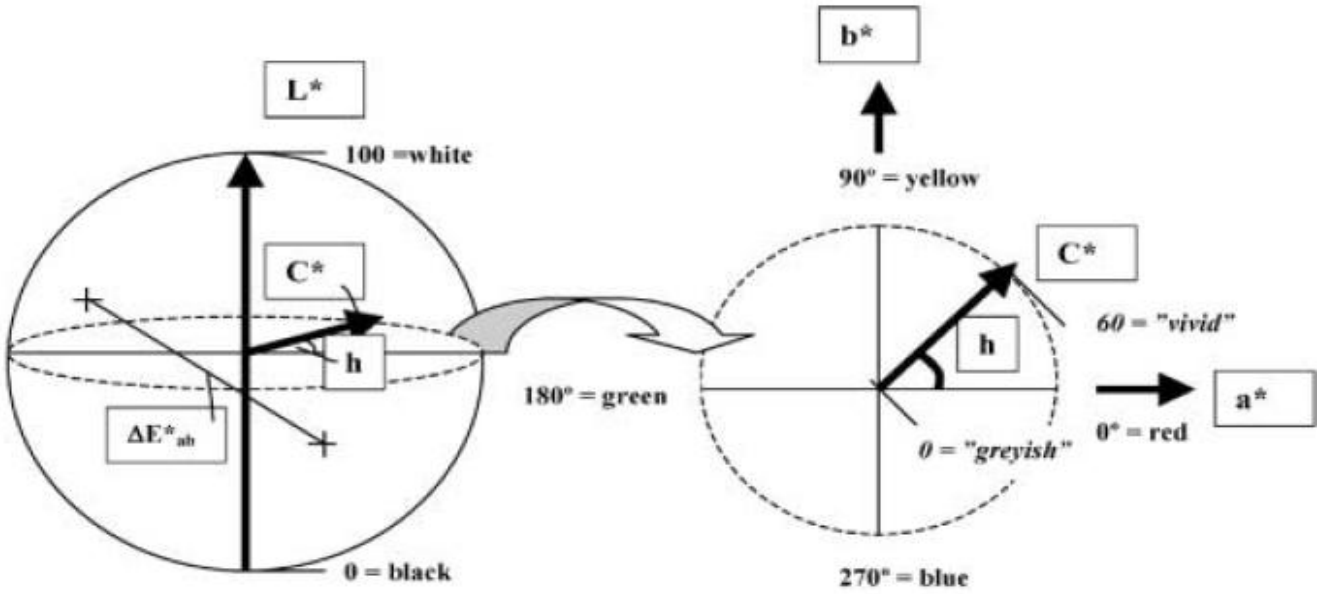

Figure 2. CIE L*a*b* colour space and the transformation to cylindrical colour space L*C*h*.

sensitivity of 0.5 µm. The tracing length (Lt) was 12.5 mm and the cut-off length was λ = 2.5 mm. The measuring force of the stylus on the surfaces was 4 mN (0.4 g), which did not put any significant damage on the surface.

After the treatments applications, using light reflections, sample glossiness values were measured with the aid of a Picogloss 562 MC glossmeter according to TS 4318 EN ISO 2813 (2002) standards. Ten panels for each varnish type and tree species were used in the experiments, and two measurements, that is, parallel and vertical to the fiber, were made on each sample.

Gloss is a measurement of the light reflectance of a varnish surface. In gloss measurement tests, a beam of light is directed toward the test varnish surface at a certain angle from the perpendicular. The percentage of the beam that is reflected at the same angle is measured by a photocell. Two standard angles are used: 60° for general gloss readings; and 85° for sheen readings. Completely specular light reflection (perfect gloss) would be 100%; completely diffuse light reflection (mat or dead flat) would be 0%. The classification of varnishes according to gloss ratings depends on the ability of the surface to bounce back varying amount of light beamed on it, and these readings show the relative reflectability of the coated surface as compared with a smooth, flat mirror.

For the same samples, colors were also measured with the aid of Minolta Chroma Meter CR-231 according to ASTM D2244-07e1 (2007) standards (Figure 1).

Color measurements were made using a tritimus photoelectric colorimeter, Minolta CR-231, with a measuring head 25 mm in diameter. The Minolta CR-231 measures the colour as three coordinates in three-dimensional colour space (Figure 2). This system is called CIE L*a*b* and works according to the CIE Standard. The part of the coordinate system that is of interest in this work is the first quadrant, that is, positive values of a* and b*

(Hunt, 1995).

The left side of Figure 2 illustrates a colour sphere in which the circle of cross section at L*=50 is designated (by a dashed line). The colour difference (∆E) is the distance between two colours (points) within the colour sphere. In the right-hand image, the cross-section at L*=50 shows the axis from green to red (a*) and from blue to yellow (b*), and the co-ordinates chroma (C*) and hue (h=arctan (b*/a*)). A hue value of 0 (or 360) degrees is red, 90 is yellow, 180 is green, and 270 is blue. L* is the lightness; 0=black and 100=white. C* is the chroma or saturation; 0 represents only greyish colors and 60, for instance, represents very vivid colors (Sundqvist, 2002). The three measured co-ordinates, L*, a*, and b*, were transformed to L*, C*, and h co-ordinates and ∆E values, according to the equations below (Temiz et al., 2005):

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

The L*C*h system was chosen since only one color variable is needed to denote hue, that is, red, green, blue or yellow, and furthermore, this system is easy to refer to our experience of color characteristics such as lightness, saturation, and hue. Each color parameter, L*, C*, h, and ∆E, was measured for each material, time, and temperature. The average color values, standard deviations, and 95% confidence intervals (5% significance level), based on t-distribution, were calculated assuming normal distribution. The lower value of ΔE^* indicates that the color either was not changed or the change was not significant.

For all parameters, multiple comparisons were first subjected to an analysis of variance (ANOVA) and significant differences between average values of control and treated samples were determined using Duncan's multiple range test at P value of 0.05 (Kalipsiz 1994).

RESULTS AND DISCUSSION

The statistical data of surface hardness, surface roughness, glossiness, and color difference values are given in Tables 1 to 3.

Values of surface hardness and glossiness were decreased for all the three wood species across all the treatment combinations. However, values of surface roughness and color difference were increased for all the three wood species across all the treatment combinations (Tables 2 and 3). These results are in accordance with the findings of some of the earliest experiments conducted by Temiz et al. (2007).

Values of surface hardness were increased for all the three wood species with application of 3 coats for 432 hours of two-component waterborne varnishes, while surface hardness values of all the three woods coated with one-component waterborne varnishes species were decreased with increasing aging time.

The surface roughness eventually reached a plateau value of about 2.041 µm for Scotch pine, 2.097 µm for iroko, and 2.391 µm for Anatolian chestnut.

The lowest glossiness values (parallel and perpendicular to grain) was 26.42 and 22.57 for iroko wood that had been prepared with 3 coats for 432 h of one-component waterborne varnishes, 24.97 and 22.81 for Scotch pine wood having application of 2 coats for 432 h of one-component waterborne varnishes and 26.03 and 26.60 for Anatolian chestnut wood with the application of 2 coats of one-component waterborne varnishes, respectively.

The highest colour difference (∆E) values was 23.38 for iroko wood to which had been applied 3 coats for 432 h of two-component waterborne varnishes, 31.07 for Scotch pine wood applied in 2 coats for 432 h of two-component waterborne varnishes and 16.45 for Anatolian chestnut wood applied in 3 coats for 432 h of one-component waterborne varnishes, respectively.

The characteristic feature of UV rays is converted to heat energy when they reflected on or absorbed by the surface.

Varnish layer hardness is related to molecular cohesion. The hardness of coatings increases as the coarse molecules getting closer to each other. The large molecules are cured as a result of polymerization reactions and cross-linking between varnish molecules. The direction and intensity of the reaction is a strongly affected by molecular weight and intermolecular cohesion. Exposure to UV rays might cause differentiation in molecular cohesion which cause some increase in surface hardness values due to aging.

Color is determined by the wavelength reflected from the surface of visible light (the range of wavelengths humans can perceive, approximately from 390 to 750 nm) which arrives at the surface. Color is characterized by the wavelength of visible light reflected from the surface. If the color or the color tone is changing at the end of the aging process, this means molecules in the varnish layer in terms of coarseness or geometric shape differs from the original form. Thus the wavelength of visible light and color tone is differs. According to test results, the aging process might change the wavelength of reflected light from the surface which can be attributed the color differentiation.

Budakçı et al. (2010) found that most color change was determined in cellulosic, polyurethane and acrylic varnish layers on the surfaces of Scots pine (*Pinus sylvestris* L.), Eastern beech (*Fagus orientalis* L.) and sessile oak (*Quercus. petraea* L.) wood material. The smallest color change was found in the case of the acrylic varnish. The largest color change due to aging through the hot and cold-check test was observed on the pine wood.

Söğütlü and Sönmez (2006) found that oil, wax, and shellac varnish were not able to protect the acacia (*Robinia pseudoacacia* L.), pear (*Pirus communis* L.), chestnut (*C. sativa* Mill.), oak (*Quercus petrean* Lieble), and cedar (*Cedrus libani* A. Rich) woods against discoloration effects of UV lights. The lowest color changing value obtained by using liquid paraffin wax.

Cakicier (2007) determined that the performance qualities of single and multi-component water-based varnish layers of various thickness applied to yellow pine (*P. sylvestris* L.), Iroko (*C. excelsa*), and Anatolian chestnut (*C. sativa* Mill.) as a result of rapid xenon-arc

Table 1. Statistical data for surface hardness, surface roughness, glossiness and color difference values in Iroko wood.

	Time (h)	Units	Hardness (number of oscillations)	Surface roughness (Ra) (µm)	Glossiness		Colour change values			
					//	⊥	ΔE	ΔL	Δa	Δb
Two-component 2 coats	Control	Avg.	33.7 hk	1.689 ab	65.47 dghıjkl	57.94 cefghıjkl	-	-	-	-
		± s	3.945	0.443	4.673	5.934				
		s^2	15.57	0.196	21.83	35.21				
		V	11.71	26.23	7.137	10.24				
		N	10	10	10	10				
	216	Avg.	34.8 gk	1.757 ab	65.2 eghıjkl	49.56 eghıjkl	19.29 a	14.32	-10.51	-6.872
		± s	3.824	0.67	2.961	1.761	4.825	5.35	1.786	1.315
		s^2	14.62	0.449	8.769	3.1	23.28	28.62	3.188	1.731
		V	10.99	38.15	4.542	3.553	25.02	37.36	-16.99	-19.14
		N	10	10	10	10	10	10	10	10
	432	Avg.	53.3 a	1.603 a	64.55 fghıjkl	45.5 fghıjkl	19.942 a	15.85	-11.02	-4.62
		± s	2.869	0.555	3.121	1.086	4.657	4.638	1.786	1.126
		s^2	8.233	0.308	9.738	1.18	21.683	21.51	3.191	1.267
		V	5.383	34.61	4.834	2.387	23.351	29.26	-16.22	-24.4
		N	10	10	10	10	10	10	10	10
Two-component 3 coats	Control	Avg.	36.2 djk	1.144 b	83.97 a	69.92 a	-	-	-	-
		± s	1.932	0.238	1.318	2.715				
		s^2	3.733	0.057	1.738	7.371				
		V	5.338	20.83	1.57	3.883				
		N	10	10	10	10				
	216	Avg.	30.6 k	1.256 a	81.36 bdefghıjkl	58.26 befghıjkl	21.8 abc	18.63	-9.889	-5.296
		± s	2.366	0.153	1.73	2.079	1.758	1.968	0.436	1.24
		s^2	5.6	0.023	2.994	4.32	3.09	3.874	0.19	1.537
		V	7.733	12.18	2.127	3.568	8.063	10.56	-4.412	-23.41
		N	10	10	10	10	10	10	10	10
	432	Avg.	51 abcdefghıjk	1.526 a	80.46 cdefghıjk	54.29 dfghıjkl	23.38 a	20.61	-10.43	-3.3
		± s	2.582	0.374	1.634	4.611	1.825	2.006	0.38	1.281
		s^2	6.667	0.14	2.669	21.26	3.332	4.024	0.145	1.64
		V	5.063	24.53	2.031	8.493	7.808	9.733	-3.646	-38.8
		N	10	10	10	10	10	10	10	10

Table 1. Contd.

		Avg.	37.6 bghıjk	1.544 a	33.38 hıjkl	29.26 h			
		± s	2.797	0.489	0.745	3.749	-	-	-	-
	Control	s^2	7.822	0.24	0.555	14.05				
		V	7.438	31.7	2.232	12.81				
		N	10	10	10	10				
		Avg.	36.6 cjk	1.478 a	31.13 ıkl	26.58 ı	17.69 c	15.66	-7.909	-1.735
		± s	3.777	0.277	1.898	0.821	1.022	1.04	0.527	1.384
One-component 2 coats	216	s^2	14.27	0.076	3.602	0.674	1.045	1.083	0.278	1.916
		V	10.32	18.72	6.097	3.088	5.78	6.642	-6.668	-79.79
		N	10	10	10	10	10	10	10	10
		Avg.	32.2 j	1.724 ab	30.31 jkl	25.25 j	19.088 a	17.2	-8.103	0.198
		± s	2.658	0.407	1.719	0.756	1.582	1.747	0.603	1.461
	432	s^2	7.067	0.166	2.954	0.572	2.501	3.052	0.364	2.136
		V	8.256	23.63	5.671	2.994	8.286	10.16	-7.447	738.1
		N	10	10	10	10	10	10	10	10
		Avg.	35.5 fjk	1.94 ab	35.7 ghıjkl	32.27 gjkl				
		± s	2.273	0.753	1.233	1.253	-	-	-	-
	Control	s^2	5.167	0.567	1.52	1.569				
		V	6.403	38.81	3.453	3.882				
		N	10	10	10	10				
		Avg.	33.7 ık	2.097 a	27.38 k	22.89 k	19.475 a	18.07	-7.116	1.243
		± s	2.869	0.81	1.274	2.431	1.693	1.649	0.669	0.658
One-component 3 coats	216	s^2	8.233	0.656	1.624	5.908	2.866	2.72	0.448	0.433
		V	8.514	38.64	4.654	10.62	8.693	9.129	-9.404	52.95
		N	10	10	10	10	10	10	10	10
		Avg.	35.9 ejk	1.806 ab	26.42 l	22.57 l	18.27 b	17.03	-6.547	-0.147
		± s	2.685	0.695	0.855	0.999	1.957	1.958	0.649	0.826
	432	s^2	7.211	0.483	0.731	0.998	3.829	3.836	0.421	0.682
		V	7.48	38.49	3.235	4.426	10.71	11.5	-9.914	-5.62
		N	10	10	10	10	10	10	10	10

Number of samples used in each test is 10. Avg. = average; ±s = standard deviation; s^2=variance. V= coefficient of variation. N= number of samples used in each test. Homogenous groups: letters in each column indicate groups that are statistically different according to Duncan's multiple range test at $P < 0.05$. Comparisons were between each control and its test.

Table 2. Statistical data for surface hardness, surface roughness, glossiness and color difference values in Scotch pine wood.

	Time (h)	Units	Hardness (number of oscillations)	Surface roughness (Ra) (µm)	Glossiness		Colour change values			
					//	⊥	ΔE	ΔL	Δa	Δb
Two-component 2 coats	Control	Avg.	26.1 ıjk	1.24 dgh	87.9 cdefghıjkl	80.43 a				
		± s	2.514	0.222	1.165	0.892	-	-	-	-
		s^2	6.322	0.049	1.359	0.796				
		V	9.634	17.94	1.326	1.109				
		N	10	10	10	10				
	216	Avg.	23.2 j	1.252 cgh	86.16 defghıjkl	67.27 cdefghıj	28.77 bdefgh	17.79	-12.07	-19.1
		± s	2.573	0.364	0.906	3.133	1.693	0.776	0.454	1.884
		s^2	6.622	0.133	0.82	9.813	2.865	0.602	0.206	3.55
		V	11.09	29.08	1.051	4.657	5.883	4.361	-3.761	-9.87
		N	10	10	10	10	10	10	10	10
	432	Avg.	39.2 a	1.165 eh	82.97 fghıjkl	63.91 d	31.07 a	20.71	-13.53	-18.7
		± s	2.781	0.281	1.207	2.001	3.817	3.861	0.599	2.029
		s^2	7.733	0.079	1.458	4.005	14.57	14.91	0.359	4.115
		V	7.094	24.13	1.455	3.132	12.29	18.64	-4.429	-10.9
		N	10	10	10	10	10	10	10	10
Two-component 3 coats	Control	Avg.	27.7 hjk	1.568 bcdefgh	88.87 bdefghıjkl	78.6 abcdefghıj				
		± s	1.636	0.331	0.596	4.493	-	-	-	-
		s^2	2.678	0.11	0.356	20.191				
		V	5.908	21.14	0.671	5.717				
		N	10	10	10	10				
	216	Avg.	22.3 k	1.846 abcdefgh	90.49 a	80.02 abcdefghıj	26.58 defgh	9.731	-10.35	-22.4
		± s	2.497	0.418	1.513	1.181	0.916	1.281	0.428	0.701
		s^2	6.233	0.175	2.29	1.395	0.839	1.642	0.183	0.492
		V	11.2	22.64	1.672	1.476	3.446	13.17	-4.13	-3.13
		N	10	10	10	10	10	10	10	10
	432	Avg.	37.4 abcdefghıjk	2.041 a	84.9 efghıjkl	72.33 bcdefghıj	27.22 cefgh	11.47	-11.87	-21.6
		± s	5.661	0.289	1.928	2.498	0.772	1.387	0.303	0.564
		s^2	32.04	0.084	3.718	6.24	0.596	1.925	0.092	0.319
		V	15.14	14.16	2.271	3.454	2.836	12.1	-2.557	-2.61
		N	10	10	10	10	10	10	10	10

Table 2. Contd.

	Control	Avg.	31 chıjk	1.629 acdefgh	28.98 hjkl	28.02 fıj			
		± s	3.742	0.246	2.614	1.696	-	-	-	-
		s^2	14	0.06	6.833	2.877				
		V	12.07	15.09	9.02	6.054				
		N	10	10	10	10				
One-component 2 coats	216	Avg.	30 eıjk	1.892 abcdefgh	25.82 k	23.42 ı	18.4 h	8.292	-6.12	-15.2
		± s	1.826	0.209	0.322	0.278	2.112	0.719	0.427	2.117
		s^2	3.333	0.044	0.104	0.077	4.461	0.517	0.183	4.482
		V	6.086	11.04	1.249	1.187	11.48	8.67	-6.982	-13.9
		N	10	10	10	10	10	10	10	10
	432	Avg.	28.9 gıjk	1.884 abcdefgh	24.97 l	22.81 j	19.98 g	9.39	-7.828	-15.8
		± s	2.767	0.309	0.724	0.559	2	0.926	0.343	2.014
		s^2	7.656	0.096	0.525	0.312	4	0.857	0.118	4.056
		V	9.574	16.41	2.901	2.449	10.01	9.861	-4.387	-12.8
		N	10	10	10	10	10	10	10	10
	Control	Avg.	29.9 fıjk	0.813 h	32.95 ghıjkl	34.73 efghıj				
		± s	2.234	0.119	2.045	2.397	-	-	-	-
		s^2	4.989	0.014	4.183	5.747				
		V	7.47	14.68	6.207	6.903				
		N	10	10	10	10				
One-component 3 coats	216	Avg.	30.5 dıjk	1.034 f	27.76 ıkl	26.17 hıj	22.11 fgh	16.88	-9.516	-10.6
		± s	1.08	0.25	0.652	1.08	1.544	0.931	0.423	1.808
		s^2	1.167	0.062	0.425	1.167	2.383	0.867	0.179	3.27
		V	3.541	24.15	2.348	4.128	6.983	5.518	-4.443	-17.1
		N	10	10	10	10	10	10	10	10
	432	Avg.	32.6 bghıjk	0.939 g	27.34 jkl	26.26 gıj	23.85 egh	18.51	-10.75	-10.4
		± s	2.503	0.276	1.022	1.221	1.578	0.861	0.531	1.758
		s^2	6.267	0.076	1.045	1.492	2.489	0.741	0.282	3.091
		V	7.679	29.33	3.739	4.651	6.616	4.65	-4.938	-16.8
		N	10	10	10	10	10	10	10	10

Number of samples used in each test is 10. Avg. = average; ±s = standard deviation; s^2=variance. V= coefficient of variation. N= number of samples used in each test. Homogenous groups: letters in each column indicate groups that are statistically different according to Duncan's multiple range test at $P < 0.05$.Comparisons were between each control and its test.

Table 3. Statistical data of surface hardness, surface roughness, glossiness and color difference values in Anatolian chestnut wood.

	Time (h)	Units	Hardness (number of oscillations)	Surface roughness (Ra) (µm)	Glossiness		Colour change values			
					//	⊥	ΔE	ΔL	Δa	Δb
		Avg.	29.7 jkl	0.913 j	85.7 abcdefghıj	69.88				
		± s	2.751	0.221	1.274	2.757	-	-	-	-
	Control	s^2	7.567	0.049	1.622	7.602				
		V	9.262	24.21	1.486	3.946				
		N	10	10	10	10				
		Avg.	26.2 kl	1.139 f	70.32 cefghıj	52.91 cdefghıjk	12.67 bg	-7.75	-3.11	-8.94
		± s	1.619	0.339	10.69	1.678	2.399	3.72	0.758	1.854
Two-component 2 coats	216	s^2	2.622	0.115	114.27	2.817	5.753	13.84	0.575	3.438
		V	6.181	29.79	15.201	3.172	18.94	-48.01	-24.4	-20.8
		N	10	10	10	10	110	10	10	10
		Avg.	43.8 a	1.095 g	76.11 bcdefghıj	47.41 efghıjk	10.29 g	-5.88	-3.65	-7.13
		± s	1.932	0.284	2.858	5.765	1.273	2.61	0.705	1.48
	432	s^2	3.733	0.081	8.168	33.23	1.62	6.814	0.497	2.19
		V	4.411	25.95	3.755	12.16	12.38	-44.4	-19.3	-20.8
		N	10	10	10	10	10	10	10	10
		Avg.	33.1 ejkl	0.741 k	86.54 a	69.54 acdefghıjk				
		± s	2.132	0.314	1.289	1.579	-	-	-	-
	Control	s^2	4.544	0.098	1.66	2.494				
		V	6.44	42.37	1.489	2.271				
		N	10	10	10	10				
		Avg.	23.2 l	0.994 ı	70.13 defghıj	48.42 dfghıjk	12.55 cg	1.778	-3.02	-11.7
		± s	1.135	0.421	13.114	2.96	2.12	3.148	0.479	2.195
Two-component 3 coats	216	s^2	1.289	0.177	171.96	8.76	4.493	9.908	0.229	4.82
		V	4.894	42.31	18.699	6.112	16.89	177	-15.8	-18.8
		N	10	10	10	10	10	10	10	10
		Avg.	37.1 bcdefghıjkl	1.059 h	82.73 abcdefghıj	67.34 bcdefghıjk	11.71 f	0.917	-3.42	-10.7
		± s	5.087	0.459	3.576	2.401	2.399	3.094	0.425	2.594
	432	s^2	25.88	0.211	12.79	5.767	5.756	9.571	0.181	6.731
		V	13.71	43.36	4.323	3.566	20.48	337.4	-12.4	-24.2
		N	10	10	10	10	10	10	10	10

Table 3. Contd.

	Control	Avg.	34.7 cghıjkl	1.621 cfghıjk	30.26 h	26.88 ık				
		± s	2.983	0.344	1.799	2.252	-	-	-	-
		s^2	8.9	0.119	3.236	5.073				
		V	8.597	21.25	5.945	8.379				
		N	10	10	10	10				
One-component 2 coats	216	Avg.	31.3 gkl	2.391 a	26.03 j	25.5 j	11.72 e	2.532	-3.07	-10.9
		± s	3.302	0.692	2.872	0.76	0.741	1.721	0.287	0.741
		s^2	10.9	0.478	8.249	0.578	0.549	2.963	0.083	0.548
		V	10.55	28.93	11.03	2.981	6.326	67.98	-9.35	-6.8
		N	10	10	10	10	10	10	10	10
	432	Avg.	32.2 fkl	2.053 acdefghıjk	26.05 ı	23.6 k	11.78 d	2.838	-3.86	-10.7
		± s	2.044	0.558	1.276	1.101	0.763	0.817	0.315	0.843
		s^2	4.178	0.311	1.627	1.211	0.583	0.667	0.099	0.711
		V	6.348	27.18	4.897	4.663	6.479	28.77	-8.16	-7.86
		N	10	10	10	10	10	10	10	10
	Control	Avg.	34 dghıjkl	1.404 ejk	31.28 gıj	26.89 hk				
		± s	2.582	0.259	1.174	2.005	-	-	-	-
		s^2	6.667	0.067	1.377	4.019				
		V	7.594	18.41	3.752	7.455				
		N	10	10	10	10				
One-component 3 coats	216	Avg.	30.9 ıkl	1.856 bdefghıjk	31.91 e	29.57 fhıjk	16.05 abcdefg	12.14	-4.01	-9.61
		± s	2.079	0.578	1.862	1.655	0.974	1.387	0.443	0.832
		s^2	4.322	0.334	3.468	2.738	0.95	1.924	0.196	0.692
		V	6.728	31.16	5.836	5.596	6.071	11.42	-11.1	-8.66
		N	10	10	10	10	10	10	10	10
	432	Avg.	31 hkl	1.446 dıjk	31.46 fıj	28.93 gjk	16.45 a	12.62	-4.65	-9.42
		± s	2.708	0.417	2.273	1.425	1.162	1.312	0.382	0.898
		s^2	7.333	0.174	5.167	2.031	1.351	1.72	0.146	0.806
		V	8.736	28.88	7.225	4.926	7.066	10.39	-8.21	-9.54
		N	10	10	10	10	10	10	10	10

Number of samples used in each test is 10. Avg. = average; ±s = standard deviation; s^2=variance. V= coefficient of variation. N= number of samples used in each test.Homogenous groups: letters in each column indicate groups that are statistically different according to Duncan's multiple range test at $P < 0.05$.Comparisons were between each control and its test.

ageing. The samples exposed to aging process showed increases in their surface sticking resistance and hardness values. Whereas the surface sticking resistance and hardness values of the samples were low before the experiment, as a result of aging process, owing to the continiation of the curing process on the varnish layers, these values were observed to rise. Also, the samples exposed to the aging process showed drastic decreases in their surface roughness, brightness, and color values.

Conclusions

The QUV test data can help in the selection of new coating systems, the improvement of existing materials or the evaluation of changes in formulations.

For the future study, experiments to observe the behaviors of varying applications of water-based wood-treatments and water based varnishes on different wood species should be conducted in different environmental conditions.

We also suggest that the performance of different varnish types under different accelerated aging treatments (UV, Xenon-ark and Thermal aging, Salt spray etc.) should be compared.

Also, resistance of the differently treated wooden materials against fungi attacks should be determined.

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REFERENCES

Anonymous (2001). VIII. Five years development plan. Forestry Private Specialty Commission Report, DPT Publication No:2531, OIK Publication No.547, ISBN:975-19-2555-X, Ankara-Turkey.

Anonymous (2002). Mitutoyo surface roughness tester, Mitutoyo Surftest SJ-301, Product No.99MBB035A1, Series No.178, Mitutoyo Corporation, 20-1, Sakado1-Chome, Takatsu-ku, Kawasaki, Kanag-awa 213-0012, Japan.

ASTM D 4366-95 (1984). Standard test methods for hardness of organic coatings by pendulum test. ASTM, Philadelphia, PA.

ASTM D 3023 (1998). Standard practice for determination of resistance of factory applied coatings on wood products of stain and reagents. American Society for Testing and Materials, USA.

ASTM D2244-07e1 (2007). Standard practice for calculation of color tolerances and color differences from instrumentally measured color coordinates, American Society for Testing and Materials, USA.

ASTM D 3924 (1991). Standard specification for standard environment for conditioning and testing point varnish lacquer and related materials. American Society for Testing and Materials, USA.

ASTM D4587–05 (2010). Standard practice for fluorescent UV-condensation exposures of paint and related coatings. American Society for Testing and Materials, USA.

Bhat IH, Abdul Khalil HPS, Awang KB, Bakare IO, Issam AM (2010). Effect of weathering on physical, mechanical and morphological properties of chemically modified wood materials. Mater. Des., 31(98): 4363-4368.

Bozkurt AY, Erdin N (1998). Important Trees in Trade. Istanbul University Publication No.4024. Faculty of Forestry Publication No.445. ISBN975-404-467- 8.

Budakçı M, Sevim Korkut D, Esen R (2010). The color changes on varnish layers after accelerated aging through the hot and cold-check test. Afr. J. Biotechnol., 9(24): 3595-3602.

Cakicier N (2007). Changes due to weathering of surface finishing layers of wood. Istanbul University, Institute of Science, Ph.D. Thesis, Istanbul-Turkey.

Custódio JEP, Eusébio MI (2006). Waterborne acrylic varnishes durability on wood surfaces for exterior exposure. Progr. Organic Coatings, 56(1): 59-67.

Çakicier N, Sevim Korkut D (2009). Aging experiments on veneer layer of wood construction materials. Duzce University J. For., 5(1): 75-90.

DYO (1990). Püskürtme Tabancası Hareket Etüdü, Teknik Bülten.

Hunt R (1995). Measuring Color. Second edition. (Ellis Horwood series in applied science and industrial technology): Ellis Horwood Limited.

ISO 4287 (1997). Geometrical product specifications (GPS)—Surface texture: Profile method - Terms, definitions, and surface texture parameters, Geneva.

ISO 11507 (2007). Paints and varnishes - Exposure of coatings to artificial weathering-Exposure to fluorescent UV and water, USA.

Kalipsiz A (1994). Statistic methods. Istanbul University Publication No.3835, Faculty of Forestry Publication No. 427, Istanbul University, Istanbul, Turkey. ISBN 975-404-368-X.

Söğütlü C, Sönmez A (2006). The effect of UV lights on color changes on some local wood processed with differential preservatives. J. Fac. Eng. Archit. Gazi Univ., 21(1): 151-159.

Stombo DA (1963). Surface texture measurement. For. Prod. J., 13(6): 299-304.

Sundqvist B (2002). Color response of Scots pine (Pinus sylvestris), Norway spruce (*Picea abies*) and birch (*Betula pubescens*) subjected to heat treatment in capillary. Holz Roh. Werks, 60: 106-114.

Temiz A, Yildiz UC, Aydin I, Eikenes M, Alfredsen G, Çolakoğlu G (2005). Surface roughness and color characteristics of wood treated with preservatives after accelerated weathering test. Appl. Surf. Sci., 250: 35-42.

Temiz A, Terziev N, Eikenes M, Hafren J (2007). Effect of accelerated weathering on surface chemistry of modified wood. Appl. Surf. Sci., 253(12): 5355-5362.

TS 4318 EN ISO 2813 (2002). Paints andvarnishes - Determination of specular gloos of non-metallic paint films at 20, 60 and 85, Turkish Standards Institution, Ankara-Turkey.

TS 642 (1997). Standard atmospheres for conditioning and/or testing: Specifications. Turkish Standards Institution, Ankara-Turkey.

TS 2471 (1976). Wood, determination of moisture content for physical and mechanical tests. Turkish Standards Institution, Ankara-Turkey.

Yaltirik F, Efe A (2000). Dendrology Handbook, Gymnospermae–Angiospermea. University of Istanbul Publication No.4265, Faculty of Forestry Publication No.465, ISBN975–404-594-1.