WOOD RESEARCH
62 (5): 2017
737-750

WEATHERING PROPERTIES OF SCOTS PINE TREATED WITH SOME CHEMICALS

Ergun Baysal
Mugla Sitki Kocman University, Faculty of Technology, Department of Wood Science and Technology
Kotekli, Turkey

Turkay Turkoglu
Mugla Sitki Kocman University, Koycegiz Vocational School, Department of Forestry
Mugla, Turkey

Erdogan Gavcar
Mugla Sitki Kocman University Department of Business Administration, Fethiye Business Faculty
Mugla Turkey

Hilmi Toker, Ahmet Gunduz
Mugla Sitki Kocman University, Faculty of Technology, Department of Wood Science and Technology
Kotekli, Turkey

Mustafa Kucuktuvek
Gazi University Faculty of Industrial Arts Education, Department of Industrial Technology
Ankara, Turkey

Huseyin Peker
Department of Forest Industry Engineering, Artvin Coruh University Faculty of Forestryartvin, Department of Forest Industry Engineering
Artvin, Turkey

Dursun Kemal Bayraktar
Department of Interior Design, Trabzonvocational and Technical High School The Ministry of Education
Trabzon, Turkey

(Received February 2017)

ABSTRACT

This study was aimed to investigate the gloss, surface hardness, surface roughness, and color changes of Scots pine that was treated with some chemicals after six months of weathering exposure. Chromated copper boron (CCB), vacsol aqua, and imersol aqua were used as the impregnation chemicals. Scots pine wood specimens were impregnated with 3% aqueous solutions of the chemicals according to ASTM standards.The results showed that while chemical treatment caused a decrease in surface hardness, gloss, and lightness of wood specimens, it increased the surface roughness of the wood before weathering. While the gloss values of all treated Scots pine specimens increased after weathering, the gloss loss was observed for the untreated specimen after weathering. All of the treated and untreated Scots pine wood surfaces were softened after weathering. The chemical treatment caused a decrease of surface roughness of wood after weathering. While in terms of the gloss, surface hardness, and surface roughness changes, the vacsol aqua-treated pine specimens gave the best results. The CCB-treated Scots pine showed the best color stability after weathering.

KEYWORDS: Scots pine, impregnation, gloss, surface hardness, surface roughness, color.

INTRODUCTION

Weathering is the process by which wooden surfaces are damaged by elements such as sunlight, water, and wind. Various experts have made some definitions of weathering (Williams and Feist 1999, Evans 2009). The main factor that causes the greatest changes in the surface properties of wood during outdoor exposure is sunlight (Tolvaj et al. 2011). Because lignin is one of the main chemical components of wood, this aromatic polymer, strongly absorbs sunlight (Jebrane et al. 2009), which causes depolymerization of the lignin macrostructure. The yellowing, browning, and/or graying of wood surfaces indicate the modification of lignin when wood is exposed to outdoor conditions (Grelier et al. 2000). Photochemical degradation is manifested by an initial color change, followed by the loosening of wood fibers. Rain washes the degraded woody materials from the surface, which causes dimensional changes, and also accelerates the surface erosion (Kamdem and Grelier 2002). Hong and Chan (1985) determined that the discoloration of wood exposed to sunlight was due to the modification of the chromophoric groups of wood lignin, which absorb ultraviolet-light (UV) in the range of 300 nm to 400 nm. Changes in the chemical, physical, and optical properties of wood lead to discoloration, loss of gloss, roughening of surface, and are also accompanied by the alteration of mechanical properties of the three main wood components (Denes and Young 1999). Although, not generally classified as a wood finish, the preservatives protect against weathering (in addition to decay), and a large quantity of preservative-treated wood is exposed to outdoors without any additional finish (Feist 1987). Treatment with wood preservativesespecially formulated with chromium and/or copper compounds improves the durability ofwood surfaces against UV irradiation and weathering factors (Temiz et al. 2005). Waterborne preservatives including chromate copper arsenic (CCA), copper-azole, ammoniac copper aresenate (ACZA), and amine/ammoniac copper quat are commercially used to treated wood at a specific retention and penetration to extend the service life of wood (Grelieret al. 2000).To limit the photodegradation of wood using some copper containing chemicals (Jinet al. 1991, Cornfield et al. 1994, Zhang and Kamdem 2000,Temiz et al. 2005, Ozgenc et al. 2012, Baysal et al. 2016, Ustun et al. 2016), treatment with inorganic salts particularly hexavalent chromium compounds (Feist 1979, Feist and Williams 1991, Evans et al. 1992, Yalinkilic et al. 1999, Baysal 2012) were investigated. The most effective method of preventing the photodegradation of wood involves a treatment with dilute aqueous solutions of inorganic salts, particularly hexavalent chromium compounds. The application of chromium trioxide to wood surfaces prevents lignin degradation during natural weathering (Evans et al. 1992, Kiguchi and Evans 1998). Feist and Williams (1991) reported that the application of small amounts of chromium salts on the wood surface greatly decreases weathering (erosion) of the wood caused by UV-light catalyzed degradation. Pizzi (1980) found that the beneficial effects of chromium were attributed to the formation of complexes between the chromium and guaiacyl units of lignin. Baysalet al. (2016) investigated the color and surface roughness of bamboo (*Phyllostachys bambusoides*) and Scots pine (*Pinus sylvestris*) specimens impregnated with some chemicals during accelerated weathering from 168 h to 672 h. They found that chromated copper boron (CCB) seemed to be the most effective wood preservative for hindering color change and ensuring smooth surfaces after accelerated weathering. Ustun et al. (2016) reported that some of the copper containing chemicals that treated Scots pine wood specimens showed better color stability compared to untreated pine after weathering. Health concerns about the use of hexavalent chromium have discouraged the commercial development of this concept (Kiguchi and Evans 1998). Therefore, weathering aspects of treated wood with new wood preservatives developed a practical importance (Temiz et al. 2007). In this study, CCB was expected to protect the wood surface against weathering. Moreover, as chromium, copper, and boron containing chemicals, it enhances the biological resistance of wood coincidentally. Imersol aqua and vacsol aqua as water-based chemicals were also used for comparison with CCB. Therefore some surface characteristics, such as surface hardness, surface roughness, gloss, and color changes of Scots pine treated with CCB, vacsol aqua and imersol aqua, after 6 months of weathering were studied. The weathering was performed in Mugla, which is in the Southern Aegean Region of Turkey.

MATERIALS AND METHODS

Preparation of test specimens and chemicals

The wood specimens of dimensions 10 x 100 x 150 mm were prepared from air-dried sapwood of Scots pine (*Pinus sylvestris* L.). The wood specimens were obtained from Yucel Wood Products, Mugla located in the southwest region of Turkey. Vacsol aqua was a water-based formulation containing biodegradable organic biocides and it did not contain any metal-based biocides (Tomak et al. 2013). Little information about the vacsol aqua and imersol aqua was available due to them being patented wood preservatives by the manufacturer (Hemel Wood Production Inc., Istanbul, Turkey). It has been reported that the water-based imersol aqua contained 0.5% tebuconazole, 0.5% propiconazole, 1% 3-iodo-2-propynl-butyl carbonate, and 0.5% cypermethrin (Keskin et al. 2009). The CCB contained approximately 28% $CuSO_4.5H_2O$, 48% $K_2Cr_2O_7$, and 24% H_3BO_3.

Impregnation process

Wood specimens were treated with a 3% aqueous solution of chemicals according to ASTM D1413-07e1 (2007). The retentions of chemicals were calculated from the Eq. 1,

$$Retention\left(\frac{kg}{m^3}\right)=\frac{G\ x\ C}{V}\ x\ 10 \qquad (1)$$

where: G - $(T_2 - T_1)$ that represents the grams of treatment solution absorbed by the wood specimens,

T_1 - the weight of the wood specimens before impregnation,
T_2 - the weight of the wood specimens after impregnation,
C - concentration as percentage,
V - the volume of the wood specimen in cm^3.

Surface hardness test

The surface hardness of wood specimens was measured as the Konig hardness according to ASTM D 4366-14 (2013). Wood specimens were placed on a panel table, and a pendulum was placed on the panel surface. Then, the pendulum was deflected through 6° and released, simultaneously, a stopwatch was started. The time for the amplitude to decrease from 6° to 3° was measured as the Konig hardness.

Gloss test

The gloss test of wood specimens was determined using a Micro-TRI-Gloss (BYK Gardner, Silver Spring, MD, USA) according to ASTM D523-14 (2013). The chosen geometry was from an incidence angle of 60°. Results were based on a specular gloss value of 100, which related to the perfect condition under identical illumination and viewing conditions of a highly polished, plane, and black glass surface.

Surface roughness test

The Mitutoyo Surftest SJ-301 (Mitutoyo Corporation, Tokyo, Japan) instrument was employed for the surface roughness measurements according to DIN 4768 (1990). There are three roughness parameters, which are the mean arithmetic deviation of profile (*Ra*), mean peak-to-valley height (*Rz*), and root mean square (*Rq*). The *Ra* is the average distance from the profile to the mean line over the length of assessment. The parameter *Rz* can be calculated from the peak-to-valley values of five equal lengths within the profile, and *Rq* is the square root of the arithmetic mean of the squares of profile deviations from the mean line (Mummery 1993).

Color test

The color parameters L^*, a^*, and b^* were determined by the CIEL*a*b* method. The L^* axis represents the lightness, whereas a* and b^* are the chromaticity coordinates. The $+a^*$ and $-a^*$ parameters represent the colors red and green, respectively. The $+b^*$ parameter represents yellow, whereas $-b^*$ represents blue. The L^* value can vary from 100 (white) to zero (black) (Zhang 2003). The colors of the specimens were measured by a colorimeter (X-Rite SP Series Spectrophotometer, X-ride Pantone, MI, USA) before and after weathering. The measuring spot was adjusted to be equal or not more than one-third of the distance from the center of this area to the receptor field stops. The color difference, (ΔE^*) was determined for each wood according to ASTM D1536-58T (1964). The color changes were calculated using Eqs. 2 to 5,

$$\Delta a^* = a_f^* - a_i^* \tag{2}$$

$$\Delta b^* = b_f^* - b_i^* \tag{3}$$

$$\Delta L^* = Lf^* - Li^* \tag{4}$$

$$(\Delta E^*) = [(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2]^{1/2} \tag{5}$$

Where Δa*, Δb*, and ΔL* represent the changes between the initial and final interval values.

Weathering exposure

Wood specimens were prepared for weathering exposure according to ASTM D7787 (2013). The specimens were exposed to weathering conditions from March to September in 2016. The weathering site was situated at Mugla Sitki Kocman University (37° 09´ N and 28° 22´ E, 670 m above sea level) in Mugla, a Southern Aegean region of Turkey. The weather conditions of Mugla during weathering are given in Tab. 1 (Meteorological Data 2016).

Tab. 1: Details of the climate condition of Mugla city during weathering.

Months	March	April	May	June	July	August
Average temperature (°C)	9.6	15.9	16.7	24.8	28.0	27.6
Highest temperature (°C)	22.1	30.0	30.2	39.9	39.0	39.5
Lowest temperature (°C)	-0.5	8.6	6.1	10.5	18.0	17.1
Sunbathing time per month (h)	4.6	8.1	7.0	10.2	10.4	8.6
Number of rainy days	15	6	11	5	2	2
Total rainfall per month ($kg \cdot m^{-2}$)	178.5	31.4	92.8	4.8	46.6	3.4
Moisture content (%)	69	57	62	45	41	46

The exposure rack was positioned so that the exposed specimens were at a 45° angle facing south. Wood specimens were set outside for weathering exposure according to ASTM G7/G7M-13 (2013). The exposure period was 6 months. Gloss, surface hardness, surface roughness, and color measurements were made on the exposed surfaces of the wood specimens before and after weathering.

RESULTS AND DISCUSSION

Gloss change

The gloss of Scots pine was measured at a 60° angle of incidence using a gloss meter. The gloss values of Scots pine before and after weathering are given in Tab. 2, along with the retention values of the wood specimens. Retention values were 13.36 $kg \cdot m^{-3}$, 13.01 $kg \cdot m^{-3}$, and 15.60 $kg \cdot m^{-3}$ for vacsol aqua, CCB, and imersol aqua impregnated pine specimens, respectively.

Tab. 2: Gloss values of specimens before and after weathering.

Impregnation	Retention	Before weathering		After weathering		
		Mean	SD*	Mean	SD*	Change (%)
Control	-	4.32	1.17	4.13	0.43	-4.40
Vacsol aqua	13.36	2.84	0.35	4.54	0.67	59,86
CCB	13.01	1.76	0.25	2.04	0.28	15.91
Imersol aqua	15.60	2.32	0.17	3.00	0.31	29.31

*SD: Standard deviation

Note: Ten replicates were made for each treatment group.

Before weathering, the gloss value of the untreated (control) Scots pine wood specimen was higher than that of the impregnated pine wood specimens. It can be explained that the impregnation process with the solutions might have limited the glossiness to a definite point before weathering, possibly due to the absorption and dispersion of the reflected rays by salt crystals prominent in the large lumens of the vessel in the wide early wood sections of the grains. The presence of a photoactive ion on the wood surface was assumed to cause the same losses in glossiness before weathering (Yalinkilic et al. 1999). While the highest gloss value observed was 4.32 for the untreated (control) Scots pine specimens, the gloss values of all of the other impregnated pine samples were between 1.76 and 2.84 before weathering. Baysal (2012) studied the gloss changes of CCA-treated Scots pine wood. The researcher found that the CCA treatment resulted in decreased glossiness of Scots pine. In another study, Ustun et al. (2016) investigated the gloss changes of copper containing chemically treated Scots pine. They found that the chemical treatment caused a decreased gloss of Scots pine. Ozdemir et al. (2015) reported that water-based wood preservatives increased the surface porosity and decreased gloss values of wood. The results obtained in this study were compatible with these researchers' findings. Weathering conditions caused some gloss loss of Scots pine wood. Abrasion on the wood surfaces, along with erosion, also caused gloss degradation (Yalinkilic et al. 1999). A preservative impregnation enhanced the gloss of Scots pine wood after weathering to some extent. For example, while the gloss of untreated pine decreased 4.40% after natural weathering, the gloss values of treated Scots pine increased from 15.91% to 59.86% after weathering. The light absorption of chemicals may be the reason for this observation (Baysal et al. 2016). These results are consistent with the studies of Baysal (2012), Ustun et al. (2016), and Baysal et al. (2016) on the effects of preservative treatment on the glossiness of wood after weathering. The test results showed that with the Scots pine gloss values after weathering, vacsol aqua-treated Scots pine gave the best results. Therefore, while gloss loss was observed for the untreated Scots pine after natural weathering, the gloss values of treated Scots pine increased after weathering.

Surface hardness change

The surface hardness values of Scots pine wood specimens impregnated with vacsol aqua, imersol aqua, and CCB before and after weathering are given in Tab. 3.

Tab. 3: Surface hardness of specimens before and after weathering.

Impregnation	Before weathering		After weathering		
	Mean	SD*	Mean	SD*	Change (%)
Control	18.20	3.74	13.10	2.92	-28.02
Vacsol aqua	12.70	2.65	12.56	2.74	-1.10
CCB	14.00	2.31	13.80	2.35	-1.43
Imersol aqua	15.20	2.78	12.30	2.26	-19.08

*SD: Standard deviation

Note: Ten replicates were made for each treatment group.

The surface hardness value measured before weathering testing was 18.20 for the untreated (control) specimen. The lowest surface hardness value was calculated as 12.70 for the Scots pine wood before weathering for the specimens impregnated with vacsol aqua. The surface hardness test results showed that the preservative impregnation resulted in a decreased surface hardness of the Scots pine wood before weathering. Similar results were recorded by Baysal (2012) and Ustun et al. (2016), who also studied the effects of a preservative treatment on surface hardness values. Weathering conditions softened the untreated Scots pine wood to some extent. Yalinkilic et al. (1999), Baysal (2008), and Turkoglu et al. (2015) also studied the surface hardness values of some weathered wood species. They found that weathering softened the wood surfaces and caused decreased surface hardness values of the wood specimens. Surface hardness values after weathering were in good agreement with the aforementioned studies. The combined effect of moisture, UV light, and temperature could destroy the lignocellulosic network of the wood. Therefore, the degradation products became water-soluble and were leached out resulting in erosion of the wood surface (Meijer 2001). According to the test results, the preservative impregnation improved the hardness of the Scots pine wood after weathering to some extent. While the surface hardness of untreated pine wood decreased 28.02% after weathering, the surface hardness of the preservative-treated Scots pine decreased from 1.10% to 19.08% after weathering exposure. Baysal (2012) studied the surface hardness values of Scots pine wood after accelerated weathering. This study showed that the surface hardness values of CCA-treated Scots pine were higher than that of untreated wood specimens after accelerated weathering. The results of this study are in good agreement with the data from Baysal (2012). Therefore, while preservative impregnation before weathering caused decreased surface hardness of Scots pine, it caused increased surface hardness of Scots pine compared to untreated pine after natural weathering. In terms of surface hardness changes, the vacsol aqua-treated Scots pine gave the best results after weathering.

Surface roughness change

Surface roughness parameters, such as *Ra, Rz,* and *Rq* values of weathered Scots pine wood, are given in Tab. 4.

Tab. 4: Surface roughness of specimens before and after weathering.

Impregnation	Before weathering			After weathering			Differences (%)		
	Ra	*Rz*	*Rq*	*Ra*	*Rz*	*Rq*	*Ra*	*Rz*	*Rq*
Control	2.49	15.25	3.12	3.10	19.33	3.93	24.50	26.75	25.96
Vacsol aqua	4.03	21.12	5.04	3.13	18.50	3.99	-22.33	-12.41	-20.83
CCB	3.69	22.56	4.65	3.38	19.85	4.24	-8.40	-12.01	-8.82
Imersol aqua	3.85	22.99	4.80	3.3	20.24	4.19	-14.29	-11.96	-12.71

Note: Ten replicates were made for each treatment group.

The untreated Scots pine (control) specimen had average *Ra, Rz*, and *Rq* values of 2.49, 15.25, and 3.12, respectively, before weathering. Surface hardness test results showed that the surface roughness of untreated Scots pine wood were higher than the treated Scots pine wood before weathering. This result was compatible with other researchers' findings, which studied the effects of some preservative-treated wood species on the surface roughness of wood (Maldas and Kamdem 1998, Ayrilmis et al. 2006, Baysal et al. 2014 and 2016, Ustun et al. 2016). This increase in surface roughness is very important for many applications of solid wood. Wooden materials with rough surfaces require more sanding processes compared to materials with smooth surfaces, which lead to decreased thickness of the material and, therefore, increased losses due to the sanding process (Dundar et al. 2008). Weathering increased the surface roughness of untreated Scots pine. The increase in *Ra, Rz*, and *Rq* values were 24.50%, 26.75%, and 25.96%, respectively for untreated Scots pine after natural weathering. Turkulin et al. (2004) mentioned that light ir radiation mostly degraded the middle lamella, which is between two cell walls and holds the cells together. This degradation increases the roughness of the wood surface (Tolvaj et al. 2014). Kerber et al. (2016) also reported that in addition to the leaching of lignin degraded by natural weathering reactions, the increase in the roughness of the wood is also related to the sudden changes of humidity (absorption and desorption of the humidity) causing the presence of superficial cracks. However, the surface roughness of all treated Scots pine decreased after weathering. Upon impregnation with chemicals, vacsol aqua-treated Scots pine gave the best results, in terms of decreased surface roughness after weathering. The *Ra, Rz*, and *Rq* decreased 22.33%, 12.41%, and 20.83%, respectively for vacsol aqua-treated Scots pine after weathering. Ozgenc and Yildiz (2014) investigated the surface roughness of some wood species treated with copper-containing new generation preservatives. They found that during the weathering time, the surface roughness values of wood treated with copper-based preservatives reduced for all wood species. Compared to the untreated wood specimens, the treatment with all preservatives, except for didecyldimethylammonium chloride (DDAC), decreased the surface roughness after the artificial weathering test. Temiz et al. (2005) determined that the surface roughness values of CCA-treated Scots pine were lower than that of untreated Scots pine after accelerated weathering. The surface roughness test results in this study were also similar to the results of Ozgenc and Yildiz (2014) and Temiz et al. (2005).

Color change

The L^*, a^*, b^*, and ΔE^*values of preservative-treated Scots pine specimens after weathering are given in Tab. 5.

Tab. 5: Color changes of specimens before and after weathering.

Impregnation	Before weathering			After weathering			Color change			Color difference
	Li*	ai*	bi*	Lf*	af*	bf*	ΔL	Δa	Δb	ΔE
Control	73.55	7.25	24.92	56.01	6.81	17.77	-17.54	-0.44	-7.15	18.95
Vacsol aqua	70.35	6.81	24.81	60.33	7.09	19.40	-10.02	0.28	-5.41	11.39
CCB	45.94	4.83	21.54	47.22	2.2	20.30	1.28	-2.63	-1.24	3.18
Imersol aqua	59.77	3.70	25.66	53.93	8.73	22.49	-5.84	5.03	-3.17	8.34

Note: Ten replicates were made for each treatment group

Before weathering, while the L^* value of the untreated Scots pine wood specimen was 73.55, the L^* values of impregnated pine wood specimens were changed from 45.94 to 70.35. The decrease in the L^* value of wood specimens indicated that the specimens became darker after the preservative treatment. These results were compatible with that of Baysal (2012), Ustun et al. (2016), and Simsek and Baysal (2012) on the effects of some impregnation chemicals on color changes of wood. The lowest values of ΔL^*, which is the most sensitive parameter of the wood surface quality, were observed for the untreated Scots pine after weathering. The negative lightness stability (ΔL^*) values for untreated- and treated- Scots pine specimens occurred after weathering, except for the CCB impregnated Scots pine. Therefore, generally the wood surface became rougher and darker after natural weathering. The darkening of Scots pine might have been due to the degradation of lignin and other non-cellulosic polysaccharides (Hon and Chang 1985, Grelier et al. 2000, Petricet al. 2004). Preservative-treated Scots pine experienced less change in the lightness than the untreated pine specimens in this study. It may have been due to the fact that the preservative impregnation improved the stabilization of wood color in the visible region through a reduction in the lignin degradation that resulted from UV light (Grelier et al. 2000). While ΔL^* of untreated Scots pine was -17.54, it changed from -10.02 to 1.28 for treated Scots pine after weathering. Baysal (2012) investigated the lightness change of CCA-treated Scots pine after accelerated weathering. They found that CCA-treated Scots pine caused less change in the lightness than the untreated Scots pine. Moreover, higher concentration levels of

CCA resulted in lower ΔL^* values of pine after accelerated weathering. In a similar study, Ustun et al. (2016) studied the ΔL^* values of copper based chemically treated Scots pine after 6 months of weathering. They found that ΔL^* values of preservative-treated pine were much lower than the untreated Scots pine after 6 months of weathering. Grelier et al. (2000) studied the ΔL^* value of copper-amine-treated maritime pine (*Pinus pinaster*) wood after 24 h of UV irradiation. They found that while ΔL^* value of copper-amine-treated wood showed a positive ΔL^* value, the untreated wood gave a negative ΔL^* value after exposure. The experimental results were compatible with the aforementioned studies. The positive values of Δa^* indicated the tendency of the wood surface to become redder and negative values represented a less red wood surface after weathering. According to the results, while untreated and CCB-treated Scots pine wood surfaces became less reddish, the vacsol aqua- and imersol aqua-treated pine wood surfaces tended to be less green after weathering. Negative Δb^* values indicated that untreated and treated Scots pine woodsurfaces showed a tendency of becoming more blue after weathering. The Δb^* values changed from -1.24 to -5.41 for treated Scots pine after weathering. The total color change (ΔE^*) values of treated Scots pine wood specimens were less thanthat of untreated pine wood specimens. While (ΔE^*) of untreated pine was 18.95, it changed from 3.18 to 11.39 after weathering. Color change values showed that the best color stability was obtained with CCB-treated Scots pine after weathering. Baysal et al. (2016) investigated the color stability of bamboo wood impregnated with some copper containing chemicals after accelerated weathering. They found that the best preservative for bamboo seemed to be CCB against color changes after accelerated weathering. The chromium and copper in the CCB formulation might create a synergistic effect to retard the surface degradation during weathering. Sell et al. (1974) studied outdoor performance of CCB-treated Obeche, red beech, spruce, and fir wood as a surface treatment. High resistances of CCB-coated wood against weathering have been attributed to the protective effect of Cr-Cu-salt solutions on the wood surface. This can be attributed to the formation of complexes between the chromium and guaiacyl units of lignin (Pizzi 1980, Liu 1997, Zhang and Kamdem 2000). Also, the photostabilization of wood via copper treatments may be explained by retardation of the carbonyl groups formation and reduced delignification after weathering (Temiz et al. 2005).Therefore, the preservative-treated Scots pine exhibited better color stability than that of untreated Scots pine after weathering. With a chemically impregnated treatment, the CCB-treated Scots pine gave the best color stability after weathering.

CONCLUSIONS

Preservative treatment caused gloss loss and softened Scots pine wood'surface before weathering. Moreover, the lightness values of the preservative-treated Scots pine were lower than that of untreated Scots pine. However, the treated Scots pine showed better surface characteristics than untreated Scots pine after weathering. While gloss loss was observed for untreated Scots pine after weathering, the gloss values of all treated Scots pine were increased after weathering, especially that of vacsol aqua-treated pine. Untreated and treated Scots pine wood surfaces were softened after weathering. However, the surface hardness losses of the treated Scots pine were lower than that of untreated Scots pine after weathering. While the surface roughness values of untreated Scots pine increased after weathering, the surface roughness of treated Scots pine decreased. Vacsol aqua gave the best results in terms of surface roughness and surface hardness changes of Scots pine after weathering. Except for the CCB-treated Scots pine, all of the weathered and all-treated and untreated Scots pine wood specimens indicated darker tonality.

The total color changes of untreated Scots pine wood were higher than treated Scots pine after weathering. The CCB was the most effective chemical for the color stabilization of Scots pine after weathering.

ACKNOWLEDGMENTS

Ergun Baysal proposed the research framework and wrote the paper with substantial contributions of Turkay Turkoglu. Erdogan Gavcar and Huseyin Peker contributed to data processing and the interpretation of results. Preparation of wood material, suppyling with chemicals and surface tests of specimens were made by Hilmi Toker, Ahmet Gunduz, Mustafa Kucuktuvek and Dursun Kemal Bayraktar.

REFERENCES

1. ASTM D1536-58., 1964: Tentative method of test color difference using the colormaster differential colorimeter.
2. ASTM D4366-14., 2013: Standard test methods for hardness of organic coatings by pendulum damping tests.
3. ASTM D523-14., 2013: Standard test method for specular gloss.
4. ASTM D7787/D7787M-13., 2013: Standard practice for selecting wood substrates for weathering evaluations of architectural coatings.
5. ASTM G7/G7M-13., 2013: Standard practice for atmospheric environmental exposure testing of nonmetallic materials.
6. Ayrilmis, N., Korkut, S., Tanritanir, E., Winandy, J. E., Hiziroglu, S., 2006: Effect of various fire retardants on surface roughness of plywood, Building and Environment 41(7): 887-892.
7. Baysal, E., 2012: Surface characteristics of CCA treated Scots pine after accelerated weathering, Wood Research 57(3): 375-382.
8. Baysal, E., Tomak, E. D., Topaloglu, E., Pesman, E., 2016: Surface properties of bamboo and Scots pine impregnated with boron and copper based wood preservatives after accelerated weathering, Maderas. Ciencia y Tecnología 18(2): 253-264.
9. Cornfield, J.A., Hale, M., Fellis, G., 1994: A comparison of analytical and visual techniques used for assessment of weathering properties of chromium and copper azole treated timber. In: International Research Group on Wood Preservation. IRG/WP/20023.
10. De Meijer, M., 2001: Review on the durability of exterior wood coatings with reduced VOC-content, Progress in Organic Coatings 43(4): 217-225.
11. Denes, A.R., Young, R.A., 1999: Reduction of weathering degradation of wood through plasma-polymer coating, Holzforschung 53(6): 632–640.
12. DIN 4768, 1990: Determination of values of surface roughness parameters Ra, Rz, Rmax using electrical contact (stylus) instruments, concepts and measuring conditions.
13. Dundar, T., As, N., Korkut, S., Unsal, O., 2008: The effect of boiling time on the surface roughness of rotary-cut veneers from oriental beech (*Fagus orientalis* L.), Journal of Materials Processing Technology 199(1): 119-123.

14. Evans, P.D., Michell, A. J., Schmalzl, K.J., 1992: Studies of the degradation and protection of wood surfaces, Wood Science and Technology 26(2): 151-163.
15. Evans, P.D., 2009: Review of the weathering and photostability of modified wood, Wood Material Science and Engineering 1(2): 2-13.
16. Feist, W.C. 1979: Protection of wood surfaces with chromium trioxide. Res. Pap. FPL 339. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.
17. Feist, W.C. 1987: Finishing of wood. In: Wood Handbook: Wood as an Engineering Material. Agric. Handb. 72. Rev. Chapter 16. USDA Forest Serv., Forest Products Lab., Madison, Wisconsin.
18. Feist, W.C., Williams, R.S., 1991: Weathering durability of chromium-treated Southern pine, Forest Products Journal 41(1): 8-14.
19. Grelier, S., Castellan, A., Kamdem, D.P., 2000: Photo-protection of copper amine treated wood, Wood and Fiber Science 32(2): 196-202.
20. Hon, D.N.S., Chang, S.T., 1985: Photoprotection of wood surfaces by wood-ion complexes, Wood and Fiber Science 17(1): 92-100.
21. Jebrane, M., Sèbe, G., Cullis, I., Evans, P.D., 2009: Photostabilisation of wood using aromatic vinyl esters. Polymer Degradation and Stability 94(2): 151-157.
22. Jin, L.; Archer, K.; Preston, A. 1991. Surface characteristics of wood treated with various AAC, ACQ and CCA formulations after weathering. In: International Research Group on Wood Preservation. IRG/WP/2369, Kyoto, Japan.
23. Kamdem, D.P., Grelier, S., 2002: Surface roughness and color change of copper-amine treated red maple (*Acer rubrum*) exposed to artificial ultraviolet light, Holzforschung 56(5): 473-478.
24. Kerber, P. R., Stangerlin, D. M., Pariz, E., de Melo, R. R., de Souza, A. P., Calegari, L. 2016: Colorimetry and surface roughness of three amazonian woods submitted to natural weathering, Nativa 4(5): 303-307.
25. Keskin, H., Atar, M., Izciler, M., 2009: Impacts of impregnation chemicals on combustion properties of the laminated wood materials produced combination of beech and poplar veneers, Construction and Building Materials 23(2): 634-643.
26. Kiguchi, M., Evans, P.D., 1998: Photostabilization of wood surface using a grafted benzophenone UV absorber, Polymer Degradation Stability 61: 33-45.
27. Liu, R., 1997: The influence of didecyldimethylammonium chloride (DDAC) treatment on wood weathering. Ph.D. Thesis, The University of British Colombia, 193 pp.
28. Maldas, D.C., Kamdem, D.P., 1998: Surface characterization of chromated copper arsenate (CCA)-treated red maple, Journal of Adhesion Science and Technology 12(7): 763-772.
29. Mummery, L., 1993: Surface texture analysis. The handbook. Muhlhausen, Germany: Hommelwerke, 106 pp.
30. Ozdemir, T.; Temiz, A.; Aydin, I. 2015: Effect of wood preservatives on surface properties of coated wood, Advances in Materials Science and Engineering, Article ID 631835: Pp 1-6.
31. Ozgenc, O., Hiziroglu, S., Yildiz, U.C., 2012: Weathering properties of wood species treated with different coating applications, BioResources 7(4): 4875-4888.
32. Ozgenc, O., Yildiz, U.C., 2014: Surface characteristics of wood treated with new generation preservatives after artificial weathering, Wood Research 59(4): 605-616.
33. Petric, M., Kricej, B., Humar, H., Pavlic, M., Tomazic, M., 2004: Patination of cherry wood and spruce wood with ethanolamine and surface finishes, Surface Coatings International Part B: Coatings Transactions 87(B3): 95-201.

34. Pizzi, A., 1980: Wood waterproofing and lignin crosslinking by means of chromium trioxide/guajacylunits complexes, Journal of Applied Polymer Science 25(11): 2547-2553.
35. Sell, J., Muster, W.J., Wälchli, O., 1974: Investigations on weathered wood surfaces. Part V: The efficiency of Cr-Cu-B- salt- solutions for surface treatment, Holz als Roh-und Werkstoff 32(2): 45-51.
36. Simsek, H., Baysal, E., 2012: An investigation on colour and gloss changes of wood impregnated with borates, Wood Research 57(2): 271-278.
37. Temiz, A., Yildiz, U.C., Aydin, I., Eikenes, M., Alfredsen, G., Colakoglu, G., 2005: Surface roughness and colour characteristics of wood treated with preservatives after accelerated weathering test, Applied Surface Science 250(1–4): 35-42.
38. Temiz, A., Terziev, N., Eikenes, M., Hafren, J., 2007: Effect of accelerated weathering on surface chemistry of modified wood, Applied Surface Science 253(12): 5355-5362.
39. Tolvaj, L., Persze, L., Albert, L., 2011: Thermal degradation of wood during photodegradation, Journal of Photochemistry and Photobiology, B: Biology 105(1): 90-93.
40. Tolvaj, L., Molnar, Z., Magoss, E., 2014: Measurement of photodegradation-caused roughness of wood using a new optical method, Journal of Photochemistry and Photobiology B: Biology 134: 23-26.
41. Tomak, E.D., Baysal, E., Peker, H., 2012: The effect of some wood preservatives on the thermal degradation of Scots pine, Thermochimica acta 547: 76-82.
42. Turkulin, H., 2004: "SEM methods in surface research on wood" in: COST E 18 Final seminar, (http://virtual.vtt.fi/virtual/proj6/coste18/turkulinpaper.pdf), Paris, France.
43. Turkoglu, T., Baysal, E., Kureli, I., Toker, H., Ergun, M. E., 2015: The effects of natural weathering on hardness and gloss of impregnated and varnished scots pine and oriental beech wood, Wood Research 60(5): 833-844.
44. Ustun, S., Baysal, E., Turkoglu, T., Toker, H., Sacli, C., Peker, H., 2016: Surface characteristics of Scots pine treated with chemicals containing some copper compounds after weathering, Wood Research 61(6): 903-914.
45. Williams, R.S., Feist, W.C., 1999: Water repellents and water-repellent preservatives for wood. Gen. Tech. Rep., FPL-GTR-109, Forest Products Laboratory, WI: U.S. Department of Agriculture, 12 pp.
46. Yalinkilic, M.K., Ilhan, R., Imamura, Y., 1999: Weathering durability of CCB-impregnated wood for clear varnish coatings, Journal of Wood Science 45: 502-514.
47. Zhang J, Kamdem, P.D., 2000: Weathering of copper-amine treated wood. In: Paper presented at the International Research Group on Wood Preservation (IRG 00- 40155) Kona, Hawaii.

Ergun Baysal*
Mugla Sitki Kocman University
Faculty of Technology
Department of Wood Science and Technology
Kotekli, Turkey
Phone: +90 252 211 17 08
Corresponding author:ergun69@yahoo.com

Turkay Turkoglu
Mugla Sitki Kocman University
Koycegiz Vocational School
Department of Forestry
Mugla
Turkey

Erdogan Gavcar
Mugla Sitki Kocman University
Fethiye Business Faculty
Department of Business Administration
48300 Mugla
Turkey

Hilmi Toker, Ahmet Gunduz
Mugla Sitki Kocman University
Faculty of Technology
Department of Wood Science and Technology
Kotekli
Turkey

Mustafa Kucuktuvek
Gazi University Faculty of Industrial Arts Education
Department of Industrial Technology
06500 Ankara
Turkey

Huseyin Peker
Artvin Coruh University
Faculty of Forestry
Department of Forest Industry Engineering
0800 Artvin
Turkey

Dursun Kemal Bayraktar
Department of Interior Design
Trabzonvocational and Technical High School
The Ministry of Education
61040, Trabzon
Turkey