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# ACCELERATED WEATHERING PERFORMANCE OF SCOTS PINE PREIMPREGNATED WITH COPPER BASED CHEMICALS BEFORE VARNISH COATING. PART II: COATED WITH WATER BASED VARNISH

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## ABSTRACT

This study was designed to investigate some surface characteristics such as gloss, color, and surface hardness changes of Scots pine wood preimpregnated with some copper-based chemicals before varnish coating after accelerated weathering. While Adolit KD-5 (AD-KD 5), Wolmanit CX-8 (WCX-8), and Celcure AC-500 (CAC-500) were used as copper-based impregnation chemicals, water-based varnish (WBV) was used as a coating material. Results showed that surface hardness and gloss values of Scots pine were increased after accelerated weathering. Impregnated and WBV coated Scots pine gave better surface characteristics compared to only WBV coated Scots pine. In impregnation chemicals, while AD-KD 5 showed the most appropriate chemical, in terms of surface hardness and total color changes, CAC-500 was found the most valuable chemical in terms of gloss changes after 1000 h accelerated weathering exposure.

KEYWORDS: Scots pine, surface properties, copper-based chemicals, water-based varnish, accelerated weathering.

## INTRODUCTION

Wood is an environmentally friendly and sustainable natural material used for a wide variety of both structural and non-structural applications (Priadi and Hiziroglu 2013, Obata et al. 2005), especially in building and construction applications (Woodard and Milner 2016). Environmental factors such as atmospheric pollutants, oxygen, sunlight, moisture, heat, cold, chemicals, and abrasion by windblown cause an economical loss by shortening the service life of the wood.

Coatings are widely used for protecting wood surfaces against corrosion and environmental degradation as well as biodegradation (Akbarian et al. 2012, Williams et al. 1996) and they can provide wood with desirable aesthetical properties (De Meijer 2001). Impregnation of wood with a compatible preservative chemical and applying a vanish prior to outdoor use has been undertaken to make wood more stable against photochemical degradation, dimensional changes, and biological decomposition (Yalinkilic et al. 1999). Moreover, the surface properties of wood materials can be enhanced easily by impregnating and finishing with various preservatives to provide different performance characteristics for individual applications, such as high hardness, impact resistance, suitable gloss, and chemical resistance (Chang and Lu 2012). Wood treatments such as preservative impregnation and modification techniques can improve the durability of wood on the basis of the intended applications (Kamdem et al. 2002). Increased restrictions on the use of traditional heavy duty wood protectors have allowed copper based formulations to gain wide popularity in the wood preservation industry (Freeman and McIntyre 2008). Impregnation with wood preservatives and then water-based varnish/paint application makes the wood more resistant to photochemical degradation, dimensional changes, and biological organisms and prolongs the life of the treated wood (Yalinkilic et al. 1999, Nejad and Cooper 2011). Turkoglu et al. (2015a) investigated surface hardness and gloss changes of Scots pine (*Pinus sylvestris* L.) and Oriental beech (*Fagus orientalis* L.) wood specimens preimpregnated with copper-based chemicals such as TN-E and adolit-KD 5 (AD-KD 5) before synthetic varnish (SV) and polyurethane varnish (PV) coating after weathering. They found that gloss and surface hardness values of impregnated and varnish coated wood specimens were higher than the only varnish coated wood specimens after weathering. In another study, Turkoglu et al. (2015b) studied the color stability of Scots pine and Oriental beech wood specimens preimpregnated TN-E and AD-KD 5 before synthetic and polyurethane varnishes coating after weathering. They noted that the color stability of impregnated and varnished wood specimens gave better results than untreated and solely varnished wood specimens after natural weathering. The best color stability was obtained from both Oriental beech and Scots pine wood impregnated with TN-E before PV coating. Water-based coatings are increasingly used in the wood industry for their performance, low volatile organic content (VOC) and fast curing properties (Liptakova et al. 2000, Zhu et al. 2016). Today, the role and importance of water-based varnishes used to create the protective layers are great. Because, water-based systems are more environmentally friendly (lower toxic effect, lower volatile organic compound-VOC, and lower solvent content, etc.) than solvent-based systems, the time has become increasingly widespread due to its superior properties and is less common for users it is harmful (Sonmez et al. 2011). Baysal et al. (2014) investigated surface hardness and gloss changes of Scots pine after accelerated weathering. They found accelerated weathering led to an increase in surface hardness and reduced gloss of wood samples treated and varnished. For samples impregnated and not impregnated before and after weather deterioration, PV had a better surface hardness and gloss values. Coating with PV (polyurethane varnish) probably resulted in more color change than coating with SV (synthetic varnish) due to the photolytic degradation processes of polyurethanes. Processing with copper-based formulations before varnishing reduces color variation, possibly delaying lignin depolymerization. Between the wood preservatives, TN-E and CCB pre-treatment before varnishing seemed to have the most promising effect against weather conditions. The use of a combination of copper-based formulations and transparent surface coatings, such as varnish, is believed to promote a longer life for wood. In previous study, we investigated accelerated weathering performance of Scots pine impregnated with copper based chemicals before cellulosic and polyurethane varnishes coating after accelerated weathering. So, in this study, it was aimed to accelerated weathering performance of Scots pine impregnated with copper based chemicals before water-based varnish coating for compare to cellulosic and polyurethane varnish coated Scots pine. In this research, we studied some surface characteristics such as gloss, color, and surface hardness changes of Scots pine wood impregnated with copper- based chemicals before water-based varnish coating after accelerated weathering. AD-KD 5, WCX-8 and Celcure AC-500 (CAC-500) were used as copper-based impregnation chemicals.

## MATERIALS AND METHODS

### Preparation of test specimens and wood preservative solutions

Specimens measuring 6 x 75 x 150 mm (radial by tangential by longitudinal) were machined from air-dried sapwood of Scots pine (*Pinus sylvestris* L.) lumber. Wood surfaces were lightly sanded with 120 grit sandpaper, and then specimens were divided into two groups. The first group comprised non impregnated but varnished specimens, while the second group comprised impregnated and varnished specimens. Nine replicate specimens were used for each treatment. All specimens were conditioned at 20°C and 65% moisture content for 2 weeks before the impregnation procedure. According to technical data sheets of products, AD-KD 5 comprises of didecylpolyoxethylammonium borate, 20.53% copper (II) hydroxydecarbonate and, 8% boric acid. WCX-8 contains of 2.8% bis-(n-cyclohe xyldiazeniumdioxy)-copper, 13.0% copper (II) carbonate hydroxide, and 4.0% boric acid (Anonymous 2007). Celcure AC-500 (CAC-500) comprises of an alkaline copper quaternary system, including 16.63% copper (II) carbonate hydroxide, 4.8% benzalkonium chloride, and 5.0% boric acid (Ozgenc and Yildiz 2014). Aqueous solutions of the wood preservatives with a concentration of 3% were prepared using distilled water at room temperature.

### Impregnation process

The wood specimens were impregnated with 3% aqueous solution of CAC-500, AD-KD 5, and WCX-8 according to the ASTM D1413-07e1 (2007). A vacuum desiccator used for the impregnation process was connected to a vacuum pump through a vacuum trap. The vacuum was applied for 30 min at 760 mm Hg before supplying the solution into the chamber and this was followed by another 30 min at 760 mm Hg diffusion period under vacuum. Nine replications were made for each group. Calculating the amount of preservative impregnation chemicals absorbed by the wood specimens (retention), as kilograms per cubic meter of wood was done using the following Eq. 1:

$$\text{Retention} = [(G \times C)/V] \times 10 \quad (\text{kg}\cdot\text{m}^{-3}) \tag{1}$$

where: $G = (T_2 - T_1)$ - 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 a percentage,
V - the volume of the wood specimen ($cm^3$).

### Coating process

Varnish treatment of wood materials is performed in accordance with ASTM D3023-98 (2017) standard. Wood samples were varnished with a spray gun. With the first varnishing process, the voids on the samples were filled, then the second and the third layers coating were applied. The primary and target coating retention amounts of the samples were determined as

100 g·m$^{-2}$. The retention amounts of the samples were measured consecutively until the target was reached. In this process, it was waited for precipitation of the varnish layer. After the first coating process, specimens were left in ambient conditions for 24 h according to the manufacturer's recommendations. Before the final coating, the test sample surfaces were carefully sanded with a fine sandpaper (220 grit). After the final varnish coating, the samples were conditioned for 3 weeks.

### Surface hardness

The surface hardness of test specimens was performed as the König hardness according to ASTM D 4366–14 (2014). Wood specimens were placed on the panel table, and a pendulum was placed on the panel surface. Then, the pendulum was deflected through 6° and released, at the same time, a stopwatch was started. The time for the amplitude to decrease from 6° to 3° was measured as König hardness.

### Gloss

The gloss test of wood specimens was determined using a gloss meter (BYK Gardner, Micro-TRI-Gloss) according to ASTM D523-14 (2014). The chosen geometry was an incidence angle of 60°.

### Color

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 each accelerated 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, ($\Delta E^*$) was determined for each wood according to ASTM D1536-58T (1964).

### Accelerated weathering

Accelerated weathering test was made in a QUV weathering device equipped with eight UVA 340 lamps according to the principles of the ASTM G154-06 (2006) standard. Specimens were exposed to cycles of 8 h UV light irradiation, followed by condensation for 4 h in the QUV weathering device. The average irradiance was 0.89 W·m$^{-2}$ at maximum intensity ($k_{max}$ = 340 nm). The temperatures in the light irradiation period and in the condensation period were 60 and 50°C, respectively.

## RESULTS AND DISCUSSION

### Gloss

Gloss of wood specimens was measured at a 60° angle of incidence using a gloss meter. The results of gloss for Scots pine before and after accelerated weathering are given in Tab. 1 along with the retention of the Scots pine wood specimens due to the chemical load. The retention values of the Scots pine wood specimens were found to be 14.36, 15.12, and 14.60 kg·m$^{-3}$ for impregnated with AD-KD 5, WCX-8, and CAC-500, respectively.

*Tab. 1: The gloss changes the values of Scots pine before and after the accelerated weathering.*

| Impregnation chemicals and varnish application | Retention (kg·m$^{-3}$) | Before accelerated weathering | Accelerated weathering | | | | | | | | Compare of before and after 1000 hours |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | After 0-250 hours | | After 250-500 hours | | After 500-750 hours | | After 750-1000 hours | | |
| | | | Mean | % | Mean | % | Mean | % | Mean | % | % |
| WBV | - | 12.89 | 12.41 | -3.71 | 12.58 | 1.34 | 12.94 | 2.88 | 13.00 | 0.46 | 0.86 |
| AD KD 5+WBV | 14.36 | 10.98 | 11.88 | 8.20 | 11.41 | -3.93 | 12.57 | 10.13 | 12.60 | 0.27 | 14.78 |
| WCX-8+WBV | 15.12 | 15.66 | 16.80 | 7.31 | 16.10 | -4.17 | 19.32 | 20.00 | 19.99 | 3.47 | 27.69 |
| CAC-500+WBV | 14.60 | 15.09 | 16.23 | 7.58 | 16.41 | 1.10 | 17.77 | 8.26 | 18.20 | 2.44 | 20.62 |

Note: Nine replicates were made for each group.

The gloss values measured before the accelerated weathering test were 12.89, 10.98, 15.66, and 15.09, for WBV, AD-KD 5+WBV, WCX-8+WBV, and CAC-500+WBV treated Scots pine, respectively. Except for AD-KD 5 treatment, other treatment with copper-based formulations caused an increase in the glossiness of Scots pine wood. Turkoglu et al. (2015a) investigated gloss values of Scots pine wood impregnated with some copper-based chemicals before polyurethane and synthetic varnish coating. They found that pre-impregnation with chemicals before PV and SV coating caused to decrease in gloss of Scots pine wood specimens. Because, impregnation with solutions might limit the glossiness up to a point in Scots pine before weathering, probably owing to absorption and dispersion of reflected rays by salt crystals prominent in the large lumens of the vessels in the wide earlywood sections of the grains. Photoactive ions on the wood surface were assumed to cause some loss in the glossiness of varnish-coated wood before weathering (Yalinkilic et al. 1999). In our study, while AD-KD 5 treatment before WBV coating caused to decrease gloss values of Scots pine, WCX-8, and CAC-500 pre-treatment before WBV coating caused to increase gloss values of Scots pine. After the first accelerated period (0-250 hours), except for WBV coated Scots pine, gloss values of all the impregnated and coated wood surfaces were increased. This increase was changed from 7.31 to 8.20%. After the second accelerated period (250-500 h), while gloss values of WBV and CAC-500+WBV treated Scots pine were slightly increased, it decreased for AD KD-5 +WBV and WCX-8+ WBV treated Scots pine. After the third accelerated period (500-750 h), gloss values of impregnated and WBV coated Scots pine increased from 2.88 to 20%. Pre-impregnation before varnish coating cause increase gloss of Scots pine. After the fourth accelerated period (750-1000 h), gloss values of impregnated and coated Scots pine slightly increased from 0.27 to 3.47%. After total exposure time (0-1000 h), gloss values of impregnated and WBV coated Scots pine were increased from 0.86 to 27.69. Preimpregnation before varnish coating caused to increase the gloss of Scots pine. Baysal et al. (2014) reported that accelerated weathering had a slight effect on the glossiness of specimens. Our results showed that the slight increase (0.86%) in the glossiness of WBV coated Scots pine after 1000 h accelerated weathering. However, pre-treatment with copper based chemicals before varnish coating caused to increase Scots pine wood from 14.78 to 27.69 % after 1000 h accelerated weathering exposure. Our results are in good agreement with data Baysal et al. (2014 ).

## Surface hardness

Surface hardness is given in Tab. 2. The surface hardness values measured before the accelerated weathering test were 6.67, 6.00, 6.22, and 6.33 for the WBV, AD-KD 5+WBV, WCX-8+WBV, CAC-500+WBV treated Scots pine, respectively.

*Tab. 2: The surface hardness values of Scots pine before and after the accelerated weathering.*

| Impregnation chemicals and varnish application | Before accelerated weathering | Accelerated weathering (AW) | | | | | | | | Compare of before AW and after 1000 hours AW |
|---|---|---|---|---|---|---|---|---|---|---|
| | | After 0-250 hours AW | | After 250-500 hours AW | | After 500-750 hours AW | | After 750-1000 hours AW | | |
| | | Mean | % | Mean | % | Mean | % | Mean | % | % |
| WBV | 6.67 | 9.44 | 41.67 | 12.33 | 30.59 | 10.44 | -15.32 | 7.22 | -30.85 | 8.33 |
| AD KD 5+WBV | 6.00 | 8.89 | 48.15 | 13.22 | 48.75 | 10.22 | -22.69 | 7.78 | -23.91 | 29.63 |
| WCX-8+WBV | 6.22 | 10.67 | 71.43 | 13.89 | 30.21 | 11.67 | -16.00 | 7.44 | -36.19 | 19.64 |
| CAC-500+WBV | 6.33 | 10.67 | 68.42 | 13.11 | 22.92 | 11.33 | -13.56 | 8.00 | -29.41 | 26.32 |

Note: Nine replicates were made for each group.

Copper-based pre-impregnation before WBV coating resulted in slight decrease in the surface hardness of the Scots pine wood before accelerated weathering exposure. After the first period (0-250 hours), all the impregnated and coated wood surfaces hardened. Surface hardness increases of impregnated and WBV coated Scots pine were higher than only WBV coated Scots pine. After the second period (250-500 h), the surface hardness of Scots pine was increased for all the impregnated and coated wood surfaces. After the third period (500-750 h) and fourth period (750-1000 h), surface hardness values of impregnated and coated Scots pine decreased from 13.56 to 22.69% and 23.96 to 36.19%, respectively. The surface of Scots pine wood specimens hardened after total exposure time (1000 h). For impregnated and WBV coated Scots pine, surface hardness was increased between from 8.33 to 29.63% after 1000 h accelerated weathering. Cakicier et al. (2011) studied the effects of accelerated aging for 432 h on surface hardness of wood materials coated with one and two-component water-based varnish. Accelerated aging may cause some modifications in molecular cohesion, which has a great effect on varnish layer hardness.

The results of the study showed that pre-impregnation with chemicals before WBV varnish coating caused to increase surface hardness after 1000 h accelerated weathering exposure. Remarkable increases of surface hardness of impregnated and coated Scots pine wood specimens were observed than only coated Scots pine. For example, while the surface hardness of WBV coated Scots pine was increased 8.33% after 1000 h accelerated weathering, surface hardness values were increased from 19.64 to 29.63% for impregnated and WBV coated Scots pine. According to our results, while Scots pine wood surface was hardened after first (0-250 h) and second (250-500 h) accelerated weathering periods, it softened after third (500-750 h) and fourth (750-1000 h) accelerated weathering periods. Baysal (2008) determined that synthetic and polyurethane varnishes coating together with CCB impregnation hardened the wood surfaces after 3 months of outdoor weathering. This was because the impregnation materials increased hardness and wood samples had a harder varnish layer (Keskin et al. 2011). Baysal et al. (2014) investigated the surface hardness of Scots pine impregnated with some copper-based chemicals such as with Wolmanit-CB, TN-E and AD-KD 5 before polyurethane varnish coating after accelerated weathering. They found that accelerated weathering caused an increase in the hardness of impregnated and varnished wood specimens. These results were consistent with previous studies (Baysal 2008, Baysal et al. 2014).

## Color

Tab. 3 shows $\Delta L^*$, $\Delta a^*$, $\Delta b^*$, and $\Delta E^*$ values based on the initial color coordinates for each group after 0-250 h, 250-500 h, 500-750 h, and 750-1000 h accelerated weathering exposure.

*Tab. 3: The color changes of Scots pine before and after the accelerated weathering.*

| Impregnation chemicals and varnish | Before accelerated weathering | | | After first period (0-250 hours) | | | | After second period (250-500 hours) | | | | After third period (500-750 hours) | | | | After fourth period (750-1000 hours) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $L_i^*$ | $a_i^*$ | $b_i^*$ | $\Delta L_i^*$ | $\Delta a^*$ | $\Delta b^*$ | $\Delta E^*$ | $\Delta L^*$ | $\Delta a^*$ | $\Delta b^*$ | $\Delta E^*$ | $\Delta L^*$ | $\Delta a^*$ | $\Delta b^*$ | $\Delta E^*$ | $\Delta L^*$ | $\Delta a^*$ | $\Delta b^*$ | $\Delta E^*$ |
| WBV | 69.01 | 7.55 | 27.23 | -6.28 | 3.10 | 2.50 | 7.43 | -1.50 | 0.88 | 1.26 | 2.14 | -1.30 | 0.57 | 0.34 | 1.46 | -1.05 | 0.68 | 0.30 | 1.29 |
| AD KD 5+WBV | 48.77 | 1.35 | 19.38 | 0.94 | 1.63 | 3.34 | 3.83 | 0.37 | 1.03 | 1.31 | 1.71 | -0.44 | 1.12 | 1.08 | 1.62 | -0.50 | 1.22 | 0.57 | 1.43 |
| WCX-8+WBV | 53.67 | 0.63 | 21.42 | -0.72 | 3.40 | 3.23 | 4.75 | -0.77 | 1.67 | 1.22 | 2.21 | -0.84 | 1.23 | 1.35 | 2.01 | -1.17 | 1.43 | 0.38 | 1.89 |
| CAC-500+WBV | 51.12 | 1.75 | 20.58 | 0.17 | 2.57 | 3.04 | 3.98 | 0.15 | 1.04 | 1.81 | 2.10 | -0.52 | 1.09 | 0.97 | 1.55 | -0.57 | 1.13 | 0.73 | 1.46 |

Note: Nine replicates were made for each group.

Also, Fig. 1 demonstrates color changes of impregnated and WBV coated Scots pine before and after each accelerated weathering period.

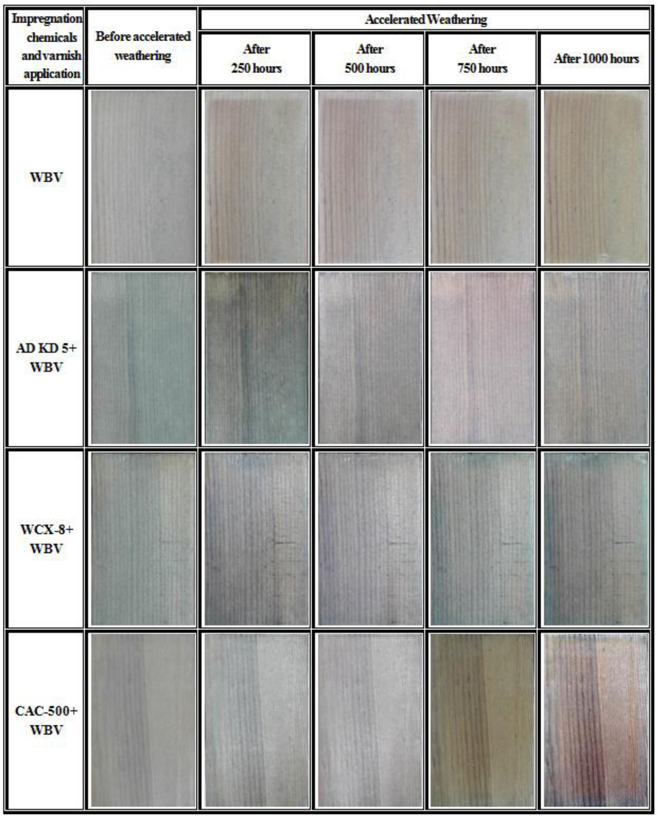


*Fig. 1: The color changes of Scots pine wood specimens before and after the accelerated weathering.*

The L* values measured before the accelerated weathering test were 69.01, 48.77, 53.67, and 51.12 for WBV, AD-KD 5 + WBV, WCX-8 + WBV, and CAC-500 + WBV treated Scots pine wood, respectively. Pre-impregnation with copper-based chamicals caused a decrease in *L** of wood for WBV varnish. Our results showed that *a**, and *b** values of impregnated and coated Scots pine were lower than only coated Scots pine. After the first period (0-250 hours), while *ΔL** values of WBV coated and WCX-8 + WBV treated Scots pine were decreased, it increased for AD-KD 5 + WBV and CAC-500 + WBV treated Scots pine wood. Impregnation with chemicals before varnish coating caused to decrease $\Delta E^*$ values of Scots pine. The positive $\Delta a^*$ and $\Delta b^*$ values indicated that wood specimens maintained reddish and yellowish, respectively. After the second period (250-500 h), while $\Delta L^*$ values of WBV coated and WCX-8 + WBV treated Scots pine were decreased, it increased for AD-KD 5 + WBV and CAC-500 + WBV treated Scots pine wood. The positive $\Delta a^*$ and $\Delta b^*$ values indicated that wood specimens maintained reddish and yellowish, respectively. After the third period (500-750 h), all treatment groups gave negative $\Delta L^*$ values. The positive $\Delta a^*$ and $\Delta b^*$ values indicated that wood specimens maintained reddish and yellowish, respectively. Impregnation with chemicals before both varnish coating caused to increase $\Delta E^*$ values of Scots pine. After a fourth period (750-1000 h), Impregnation with chemicals before varnish coating caused to increase $\Delta E^*$ values of Scots pine. The positive $\Delta a^*$ and $\Delta b^*$ values indicated that wood specimens maintained reddish and yellowish, respectively. The $\Delta L^*$, $\Delta a^*$, $\Delta b^*$, and $\Delta E^*$ values of Scots pine are given in Tab. 4 for total 1000 h accelerated weathering exposure time.

*Tab. 4: The color changes of Scots pine before and after 1000 hours accelerated weathering.*

| Impregnation chemicals and varnish application | Before accelerated weathering | | | After 1000 hours accelerated weathering | | | After 1000 hours accelerated weathering | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $Li^*$ | $a\,i^*$ | $b\,i^*$ | $L^*$ | $a^*$ | $b^*$ | $\Delta L^*$ | $\Delta a^*$ | $\Delta b^*$ | $\Delta E^*$ |
| WBV | 69.01 | 7.55 | 27.23 | 58.88 | 12.78 | 31.63 | -10.13 | 5.22 | 4.39 | 12.22 |
| AD KD 5+WBV | 48.77 | 1.35 | 19.38 | 49.13 | 6.36 | 25.67 | 0.36 | 5.00 | 6.30 | 8.05 |
| WCX-8+WBV | 53.67 | 0.63 | 21.42 | 50.16 | 8.35 | 27.62 | -3.51 | 7.72 | 6.19 | 10.5 |
| CAC-500+WBV | 51.12 | 1.75 | 20.58 | 50.35 | 7.59 | 27.13 | -0.77 | 5.84 | 6.55 | 8.81 |

Note: Nine replicates were made for each group.

After 1000 h total exposure time, except for AD-KD 5 + WBV treated Scots pine, $\Delta L^*$ values for all other treatment groups were decreased from 0.77 to 10.13. Impregnation with chemicals before both varnish coating caused to decrease $\Delta L^*$ and $\Delta E^*$ values of Scots pine. The positive $\Delta a^*$ and $\Delta b^*$ values indicated that wood specimens maintained reddish and yellowish, respectively. Negative lightness stability ($\Delta L^*$) indicates a tendency for the wood surface to turn a dark color after accelerated 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, Petric et al. 2004). $\Delta L^*$ is the most important parameter for describing wood surface quality (Temiz et al. 2005). For each and total exposure time, Scots pine gave positive values of $\Delta a^*$ and $\Delta b^*$ show a tendency for the wood surface reddish and yellowish, respectively.

Our results showed that $\Delta E^*$ values of impregnated and coated Scots pine were lower than only coated Scots pine after the total exposure period. Yalinkilic et al. (1999) investigated the outdoor performance of Scots pine and chestnut wood treated with CCB and applied with polyurethane varnish or alkyd-based synthetic varnish. They reported that CCB impregnation greatly stabilized the surface color. Turkoglu et al. (2015b) investigated the effects of natural weathering on color stability of Scots pine and Oriental beech impregnated with some chemicals (TN-E, AD-KD 5, and CCA) and then coated with PV and SV. They found that the color stability of impregnated and varnished wood specimens gave better results than untreated and solely varnished wood specimens after natural weathering. Baysal et al. (2014) studied the effect of accelerated weathering on the color stability of Scots pine specimens impregnated with some copper-based chemicals such as Wolmanit-CB, TN-E, and AD-KD 5 and coated with synthetic and polyurethane varnishes. They found that color changes of only varnish coated wood surfaces were higher than impregnated and coated wood surfaces after 500 h accelerated weathering exposure. Our results are in good agreement with these researcher's findings. Copper reacting with wood components, results in form of compounds such as copper–cellulose complexes, copper–lignin complexes, and crystalline or amorphous inorganic/organic copper compounds and this situation reduces the effect of the weathering factors on the degradation of the wood surface (Grelier et al. 2000, Temiz et al. 2005). Grelier et al. (2000) also reported that wood ion complexes at the wood surfaces can provide the wood surface with resistance by blocking the reactive sites of photochemical reactions called free phenolic groups. Similar ion complexes might be formed with copper-based formulations and wood components, and these complexes might reduce radials, thereby stabilizing the color of the wood

## CONCLUCIONS

The gloss, color, and surface hardness changes of Scots pine impregnated with copper-based chemicals and coated water-based varnish (WBV) were investigated. Results showed that gloss values of Scots pine were increased after 1000 h accelerated weathering exposure. Pre-impregnation before WBV coating caused to highly increased gloss values of Scots pine. Negative lightness stability ($\Delta L^*$) shows a tendency for the wood surface to turn a dark color after accelerated weathering. Copper impregnation before varnish coating significantly increased $\Delta L^*$ values of Scots pine after accelerated weathering. Our results showed that Scots pine wood gave positive $\Delta a^*$ and $\Delta b^*$ values indicated that wood specimens maintained reddish and yellowish, respectively after each and total accelerated weathering exposure periods and. Total color changes of impregnated and WBV coated Scots pine were lower than only WBV coated Scots pine after 1000 h accelerated weathering. $\Delta E^*$ values were the lowest AD KD-5 impregnated and WBV coated Scots pine. Surface hardness values of impregnated and WBV coated Scots pine were higher than only WBV coated Scots pine. In terms of surface hardness changes after 1000 h accelerated weathering, AD-KD 5 impregnated and WBV coated Scots pine was found the most appropriate treatment.

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