WOOD RESEARCH
59 (4): 2014
605-616

SURFACE CHARACTERISTICS OF WOOD TREATED WITH NEW GENERATION PRESERVATIVES AFTER ARTIFICIAL WEATHERING

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(Received April 2013)

ABSTRACT

Wood samples treated with new generation preservatives (ammoniacal copper quat (Celcure AC 500), micronized copper quat (MCQ)) and traditional preservatives (didecyldimethylammonium chloride (DDAC), and copper (II) sulfate pentahyrate ($Cu(II)SO_4.5H_2O$)) have been studied in accelerated weathering experiments. Changes to the surface of the all weathered samples were characterized by colour change and surface roughness measurements. The results show that the treatment with new generation preservatives (Celcure AC 500 and MCQ) provided less colour change than that of traditional preservatives (DDAC and $Cu(II)SO_4.5H_2O$) after an artificial weathering test. The least amount of colour change was found on the surface of Celcure AC 500 treated wood samples after 672 hour exposure time. The wood samples treated with copper-containing new generation preservatives were cured to surface roughness in accelerated weathering experiments. The surface values of pine and spruce wood samples treated with DDAC increased more than that of untreated samples after the accelerated weathering test.

KEYWORDS: Copper-based wood preservatives; accelerated weathering; colour change; surface roughness.

INTRODUCTION

Weathering is the process by which wooden surfaces are broken down and easily eroded by elements such as sunlight, water and wind. Some definitions of weathering have been made by various authorities (Williams and Feist 1999; Evans 2009). William and Feist 1999 defined weathering as an aging process which causes surface degradation of wood when it exposed outdoors. They also expressed that weathering is first manifested by a change in the colour of the wood, and this phenomenon is followed by a loosening of wood fibres and gradual erosion of the wooden surface (Williams and Feist 1999). Anderson et al. described the colour change mechanism of wood in artificial and natural weathering. They emphasized that the combination of light and water is very important in the weathering process, which is essentially a free-radical driven series of reactions (Anderson et al. 1991).

Several approaches have been developed to prevent the photodegradation of wooden surfaces during outdoor weathering. One of the approaches considered is the application of clear-coating, which is thought to be the easiest and most common method. It was shown that photostabilization of wooden surfaces plays an important role in enhancing the exterior performance of clear coatings (Dawson et al. 2008). Saha et al. 2011 showed that the coating thickness decreases with increasing weathering time and a tissue deformation beneath the coating surface takes place during weathering (Saha et al. 2011). UV resistant water-borne nanocomposites coatings based on an industrial formulation of an acrylic latex stain were tested for exterior uses of wood. The uniform dispersion of the nanoparticles is thought to be responsible for improving protection against photodegradation initiated by UV light (Cristea et al. 2010). Several solvent- and water-borne exterior wood coatings were tested for artificial weathering performance. It was found that solvent-borne coatings performed well, but some water-borne coatings also showed good performance. On the other hand, water-borne finishes are thought to be better positions at the expense of solvent-borne systems (Bulcke et al. 2008). According to an article by Saha et al. (2011) the acrylic polyurethane coating contained bark extract is the most effective and performed better than the industrial coating.

The other approach considered for enhancement of weathering resistance is wood modification systems. However, very few of these systems are pronounced to able to protect wood from weathering (Evans 2009). Evans et al. (2002) stated that esterification of wood to high weight gains with the aromatic acid chloride, benzoyl chloride, is effective at photostabilising lignin, the component of wood that is most susceptible to photodegradation. Sahin and Mantanis (2001) reported that the largest improvements against discolouration were observed with European pine, fir, Bosnian pine, chestnut and cherry, modified by a new nanoparticulate treatment. Hansmann et al. (2006) found that wood surfaces modified by melamine formaldehyde resin were well preserved after simulated long term weathering and showed advantages compared to untreated control samples regarding discolouration and crack formation. Recent work on weathering of copper-amine treated wood has shown that copper ethanolamine retarded the surface lignin degradation during weathering (Zhang et al. 2009). Temiz et al. (2006) reported that silicon treated wood samples showed less colour change than untreated ones; however, the least colour change was obtained with acetylated and heat-treated samples. On the other hand, high loading of wax to wood is pronounced to reduce or slow down weathering (Lesar et al. 2011).

Water-borne preservatives protect wood against weathering, apart from (confused meaning: but not against or and also against?) fungi and insects. Several studies have been done on the relation between weathering performance and preservative treatment. Jin et al. (1991) suggested that AACs (alkylammonium compounds), especially didecyldimethyl ammonium chloride (DDAC) made the lignin more prone to UV degradation and thus enhanced the surface degradation of wood. Copper wood preservatives have been shown to improve the photostabilization of wood, which may be explained by retarding the formation of carbonyl groups and reducing delignification during weathering (Temiz et al. 2005). Temiz et al. (2007) demonstrated that forming complexes between chromium and guaiacyl units of lignin retarded the total colour change in wood treated with CCA (chromated copper arsenate) and linseed oil. Chromium-copper-boron (CCB) treatment is suggested to stabilize the surface colour of varnish-coated wood panels after outdoor exposure for nine months (Yalınkılıç et al. 1999). According to an article by Humar et al. (2011) it has been shown that copper-ethanolamine based wood preservatives influence certain characteristics of water-borne acrylic coatings applied to wooden substrates. In the study which for the first time evaluates the performance of semitransparent stains on preservative-treated wood it was reported that water-based coatings performed as well as solvent-based coatings on Cu-amine-treated wood (Nejad and Cooper 2011). *Pinus radiata* surfaces delignified by two treatments, peracetic acid and preweathering, were clear-coated by either polyurethane or an acrylic varnish. After three years of exterior exposure, it was observed that both delignification treatments resulted in clear-coated boards with very similar exposure ratings (Dawson et al. 2008).

Not much data exists on artificial weathering performance of new generation wood preservative-treated wood. This study examines the artificial weathering performance of four water-borne wood preservatives in pine, spruce and beech wood samples. Artificial weathering was assessed based on colour change and surface roughness.

MATERIAL AND METHODS

Wood samples and treatment process

The study samples of Scots pine (*Pinus sylvestris* L.), oriental spruce (*Picea orientalis* L.) and oriental beech (*Fagus orietalis* L.) were 20 mm thick, 76 mm wide, 150 mm long. The samples were planed and conditioned at a relative humidity of 65 % and temperature of 20°C.

The wood preservatives and formulations tested in the study were:

1. DDAC: Didecyldimethylammonium chloride
2. Celcure AC 500: Copper carbonate hydroxide, benzalkonium chloride and boric acid
3. MCQ: Micronized copper quat
4. $Cu(II)SO_4.5H_2O$: Copper (II) sulfate pentahyrate.

The samples were treated using the full-cell method without final vacuum in a treatment chamber. The initial vacuum of 700 mmHg for 15 minutes, and then a pressure of 7 bar for the next 30 minutes were applied. Four replicates were used for each treatment group. The wood samples were then removed from the solution, wiped lightly to remove solution from the wood surface, and weighed (a precision of 0.01 g) to determine gross retentions for each treating solution and sample (AWPA U1-09 2009). The retention for each treatment solution was calculated using the following Eq. (1):

$$R= G\times CV\times 10 \qquad (kg.m^{-3}) \qquad (1)$$

where: G – the amount in grams of treating solution absorbed by the sample,
C – the amount in grams of preservative in 100 g of the treating solution,
V – the volume of sample in cm^{-3}.

The end grains, sides and backs of samples were sealed, using a 2K-epoxy resin coating before accelerated weathering test, and then the samples were dried for a period of at least 48 h at 23°C temperature and 50 % relative humidity.

Accelerated weathering test (QUV-Spray)

Artificial weathering was performed in a QUV/spray accelerated weathering tester (Q-Panel Lab Products, Cleveland, USA), equipped with UVA 340 lamps and the temperature in the chamber was approximately 50°C. The weathering experiment was carried out by cycles of UV-light irradiation for 2 hours, followed by a water spray for 18 minutes in an accelerated weathering test cycle chamber during 28 days (672 h) (ASTM G 53-96 1996). Tab. 1 displays the code of wood samples prepared for each variation in the work.

Tab. 1: The wood samples prepared for each variation.

Code	Applied methods	Amount
Control	Untreated control samples	4
AK	Beech wood treated with Celcure AC 500	4
CK	Beech wood treated with $Cu(II)SO_4.5H_2O$	4
DK	Beech wood treated with DDAC	4
MK	Beech wood treated with MCQ	4
AL	Spruce wood treated with Celcure AC 500	4
CL	Spruce wood treated with $Cu(II)SO_4.5H_2O$	4
DL	Spruce wood treated with DDAC	4
ML	Spruce wood treated with MCQ	4
AS	Pine wood treated with Celcure AC 500	4
CS	Pine wood treated with $Cu(II)SO_4.5H_2O$	4
DS	Pine wood treated with DDAC	4
MS	Pine wood treated with MCQ	4

Colour measurements

Colour measurements were performed with a Konica Minolta CM-600d instrument (Canada). The reflection spectrum was acquired from a measuring area of 8 mm in the 400–700 nm wavelength range; five measurements at precisely defined points on the weathered surfaces of each sample were carried out periodically. Thus, colour changes during weathering were always monitored on the same spot of wood. The CIE (Commission Internationale de l'Eclairage) colour parameters: L* (lightness), a* (along the X axis red (+) to green (–) and b* (along the Y axis yellow (+) to blue (–) were calculated using the Konica Minolta Colour Data Software CM-S100w SpectraMagic™ NX Lite (ISO 7724-2 1984), from which the colour differences ΔE* were calculated according to the Eq. (2):

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

Measurements were always performed at the end of an UV irradiation step to provide consistent specimen conditions during colour measurements. Five replicates were used for each sample to evaluate colour change.

Surface roughness

A Mitutoyo Surfest SJ-301 instrument was employed for surface roughness measurements. The R_a, R_{max} and R_z roughness parameters were measured to evaluate surface roughness of unweathered and weathered (treated and untreated) samples' surfaces according to DIN 4768 2013. R_a is the arithmetic mean of the absolute values of the profile departures within the reference length, R_{max} is maximum two point height of profile and R_z is the arithmetic mean of the 10-point height of irregularities (DIN 4768 2013). The cut-off length was 2.5 mm, sampling length was 12.5 mm and detector tip radius was 5 μm in the surface roughness measurements.

RESULTS AND DISCUSSION

Colour measurements

The average retentions of DDAC, Celcure AC 500, MCQ and $Cu(II)SO_4.5H_2O$ applied full cell impregnations are shown in Tab. 2. Oriental spruce (*Picea orientalis* L.) has limited usages in wood preservation because of its difficult impregnability (Yildiz et al. 2012). For that reason, the lowest retention amount was determined in the oriental spruce wood, and it was observed that the retention amount of the samples treated with MCQ substance with a micronized copper property was higher in comparison with other protective substances.

Tab. 2: Retention of wood preservatives.

Wood preservatives (concentration)	Retention ($kg.m^{-3}$)	
	Oriental beech	Oriental spruce
Celcure AC 500 (1.25 %)	7.1 (0.32)*	2.1 (0.06)
$Cu(II)SO_4.5H_2O$ (1.25 %)	6.1 (0.24)	2.6 (0.02)
DDAC (1.25 %)	7.0 (0.42)	1.9 (0.04)
MCQ (1.25 %)	7.5 (0.51)	2.5 (0.07)

*Values in parentheses are standard deviations.

The colour changes of beech, spruce and pine wood samples are shown in Tab. 2. Positive values of ΔL* indicate that the test samples are lighter than the standard, whereas negative values indicate that the test samples are darker. The negative values of lightness (ΔL*) indicate that the surfaces of the samples were getting darker at the beginning of the artificial weathering (Tab. 3). However, the treated test samples showed a colour similar to the majority of control samples. Only the spruce wood samples showed higher lightness (ΔL*) values at the end of the QUV test thus indicating that the wood surface becomes lighter (Tab. 3). Similar results were obtained from other previous studies. Zhang et al. (2009) reported that the lightness of untreated and 0.25 % copper-methanolamine treated wood samples decreased during the first 100 h weathering, and that these samples regained their lightness after another 100 h weathering test. Temiz et al. (2005) carried out experiments with pine wood samples treated with new generation water-borne preservatives and subjected to artificial weathering. These authors observed distinct changes in brightness and colour during the first 200 h weathering test. However, the lightness factor (ΔL*) showed an increasing trend with prolonged exposure time. On the other hand, compared to the control wood samples, all treatments caused an increase in the lightness stability (ΔL*) values with increasing exposure times accelerated test cycle for each wood sample. Zhang et al. (2009) stated that the rate of change in lightness is less in the wood samples treated with higher copper content. In our study, the constant rate in lightness values of Celcure AC 500 and

MCQ could be attributed to its higher copper content unlike in the other solutions.

As known, positive values of Δa* indicate a tendency of wood surface to reddish, while negative values mean a tendency to greenish. Positive values of Δb* indicate an increment of yellow colour, and negative values an increase in blue colour (Jin et al. 1991).

As seen in Tab. 3, the Δa* and Δb* values in all variations of the control and test samples changed in a positive manner. When looking at the sample group of beech wood, Δa* and Δb* values, except the control samples, demonstrated change by increasing in the first 336 hours in a positive manner and later decreasing up to 672 hours. While the Δa* value was decreased in the oriental spruce and the Δb* value was increased, the exact opposite situation in the samples of Scots pine woods was observed.

In general, the treatment with modern and old-generation wood preservation materials in three wood types preserved the surface colour quality against weathering conditions. After the accelerated weathering test was performed for 672 hours, the lowest colour change value (ΔE*) was observed in oriental beech test samples treated with new-generation wood preservation materials (Celcure AC 500 and MCQ) containing copper. The lowest influence in preserving the coating colour stability was seen in coatings on the wood samples treated with DDAC. Also in wood coatings where the treatment process was applied for preservation against the weathering test, the colour change value (ΔE*) increased faster in the first 168 hours before visibly slowing. Many studies in the literature report the colour changing with time in the same way (Temiz et al. 2007; Evans et al. 2002; Zhang et al. 2009)

Generally, the least colour change (ΔE*) for all species was observed on MCQ and ACQ treated wood samples. ACQ and MCQ treatments for all species slowed down photodegradation by retarding the formation of carbonyl groups. The light resistance of Celcure AC 500 and MCQ treated wood may result from Cu (II) chelating with functional groups in wood. These chelates can photo-stabilize wood and retard the formation of carbonyl groups. Colour differences between Celcure AC 500 and MCQ may be partly attributed to different fixation mechanisms. In contrast to soluble copper-based wood preservative systems such $Cu(II)SO_4.5H_2O$, wherein Cu–2 ions are believed to chemically "fix" in wood after treatment, the micronized copper preservative particles with polymeric dispersant molecules attached to the particle surface are carried into the wood through vacuum/pressure impregnation and physically deposited into the wood structure. After treatment, the micronized particles are believed to "fix" onto the wood through strong adhesion between the polymeric dispersants and wood fibre by similar mechanisms as occur in wood coating applications (Jin et al. 1991; Freeman and McIntyre 2008).

These findings agree with the literature reporting that copper containing treatments provided better protection colour changes than untreated samples. Copper with wood components form complexes capable of reducing the degradation of the wood surface. This can cause relatively important modification of the roughness and/or the lightness of the wood surface. The colour change is supposed to effects of carbonyl group of conjugated ketones, aldehydes and quinines resulting from the modification of lignin and other related compounds (Castellan and Davidson 1994; Grelier 2000).

Tab. 3: Colour change parameters of wood species exposed to accelerated weathering test.

Samples	336h After 2nd week	672h After 4th week						
	ΔL	Δa	Δb	ΔE	ΔL	Δa	Δb	ΔE
Oriental beech	AK	-9.4(1.0) *	0.9(2.3)	3.3(4.1)	10.3(4.7)	-9.9(1.6)	2.2(0.3)	6.5(2.1)
	CK	-9.9(1.7)	0.8(0.8)	3.4(1.0)	10.6(1.2)	-11.0(1.6)	1.6(0.7)	6.4(0.4)
	DK	-10.2(3.7)	2.3(1.5)	4.0(3.4)	11.2(2.9)	-11.9(3.5)	3.3(0.2)	6.2(0.9)
	MK	-4.9(1.4)	4.8(0.6)	7.0(1.6)	10.4(1.9)	-11.5(3.2)	2.7(0.2)	4.7(1.3)
	Control	-15.5(2.0)	2.5(0.9)	6.7(0.4)	17.1(1.3)	-17.2(6.0)	2.2(1.3)	5.0(3.7)
Oriental spruce	AL	-9.2(3.2)	4.6(0.8)	12.3(2.3)	16.1(2.3)	-11.4(2.5)	6.1(1.2)	12.1(1.9)
	CL	-14.4(4.5)	4.4(1.5)	6.7(1.6)	16.5(5.9)	-13.2(4.8)	4.4(2.3)	12.7(4.1)
	DL	-13.1(0.7)	4.8(0.3)	14.2(0.9)	19.8(1.1)	-14.9(1.3)	5.7(0.4)	13.1(0.7)
	ML	-15.5(1.3)	4.9(0.4)	8.3(0.7)	18.2(1.0)	-13.3(1.5)	5.1(1.3)	14.1(1.9)
	Control	-22.5(0.8)	7.2(0.7)	9.1(1.1)	25.4(0.4)	-18.8(1.4)	6.3(0.9)	16.3(1.0)
Scots pine	AS	-14.5(2.2)	4.0(0.4)	4.0(2.3)	15.7(1.7)	-13.1(2.1)	4.2(2.2)	9.2(3.4)
	CS	-14.7(3.9)	5.1(2.4)	4.9(2.1)	16.6(4.1)	-12.9(2.5)	5.5(2.5)	10.9(3.2)
	DS	-12.0(1.6)	4.5(2.1)	12.2(2.7)	17.8(1.4)	-14.5(1.9)	5.6(0.6)	10.5(2.3)
	MS	-12.8(2.2)	7.2(1.6)	7.4(2.7)	16.5(1.5)	-11.1(2.5)	6.3(2.1)	11.2(3.9)
	Control	-7.7(1.0)	6.2(0.8)	15.2(1.3)	24.8(1.0)	-24.3(0.6)	9.1(0.8)	10.2(1.6)

*Values in parentheses are standard deviations.

The colour changes (ΔE^*) of untreated and treated samples dependent on the QUV exposure time for beech, spruce and pine are presented in Figs. 1–3. It is clear that both test and control wood samples showed rapid colour changes during the first 336 h of the artificial weathering test. ΔE varied from 0 to almost 25 units. Colour change of all treated wood samples was less than that of untreated wood samples. The highest ΔE^* was observed on the spruce treated with DDAC and copper sulfate, while the lowest was on beech samples treated with Celcure AC 500 and MCQ. Different wood species showed different colour changes. The colour stability of untreated beech samples was better than that of untreated Scots pine and spruce samples. The amounts of the main components of wood, lignin, carbohydrates and cellulose, change according to the type of food. As for the UV absorption effect of wood, the colour stabilities of oriental beech, Scots pine and oriental spruce are different, because UV absorption capacity of lignin is 80–90 %, carbohydrates 5–20 % and extractives 2 % (Temiz et al. 2004; Williams 2005). Another cause could be in extractives removal in pine because this species bleeds resin containing water-soluble phenolic or polyphenolic compounds (Ozgenc et al. 2012). Thus, the result of colour change on pine and spruce wood photo stabilization differs from beech wood which does not contain any resin. This sentence is blurred and redundant.

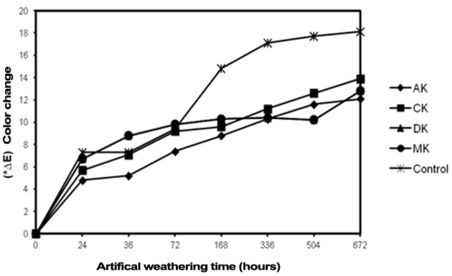

Fig.1: Colour change of untreated beech (Fagus orientalis) samples treated with different wood preservatives during accelerated weathering with QUV (672 hours).

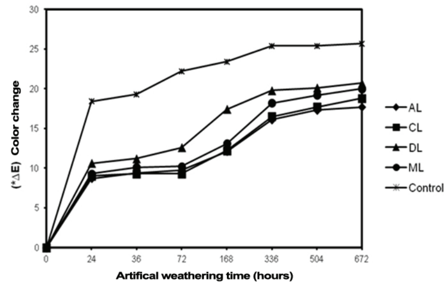

Fig.2: Colour change of untreated spruce (Picea orientalis) samples treated with different wood preservatives during accelerated weathering with QUV (672 hours).

Low retention values were obtained in treatment of oriental spruce samples with preservative materials in comparison with the Scots pine and oriental beech woods. Poorly structured sentence (unclear). As showed in Fig. 2, the colour stabilization of the test samples after accelerated weathering test for 672 hours was higher in comparison with the control samples, despite coating preservation with lower retention value. What was preserved with what?

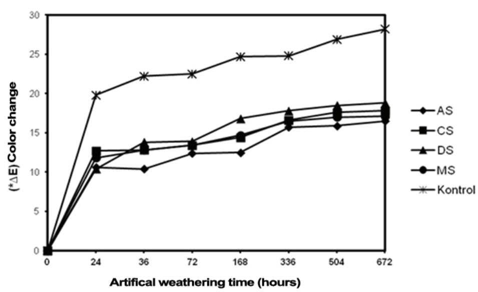

Fig. 3: Colour change of treated with different wood preservatives and untreated pine (Pinus sylvestris) samples during accelerated weathering with QUV (672 hours)

Surface roughness

The surface roughness of beech, spruce and pine wood is shown in Tab. 4. Using the water systems helps in removing and washing solubilized degradation products from the wood surface. Water causes removing and loosening of fibres and particles produced during the UV irradiation (Kamdem and Grelier 2002). As seen in Tab. 3, the surface roughness values (R_a, R_{max} and R_z) of treated and untreated samples changed after weathering exposure. The wood surfaces exposed UV irradiation and water spray contain several checks, splits and cracks. The surface roughness values (R_a and R_z) of treated and untreated wood samples are listed in Tab. 4.

Both untreated control and DDAC-treated samples reached a similar degree of oxidation because DDAC-treatment accelerated the delignification; however, Cu-based preservatives are capable of retarding the delignification. The results showed that the surface values of wood samples treated with Celcure AC 500, MCQ and Cu(II)$SO_4.5H_2O$ were lower than the untreated control and the DDAC-treated samples for pine and spruce after weathering exposure.

The sentence´s structure is not unambiguous. What is compared with what? Generally the surface values of all wood treated with copper-containing preservatives decreased over the irradiation time (Temiz et al. 2005). In the beech wood samples, the surface roughness of test samples treated with all preservatives was better than the control samples.

Tab. 4: The surface roughness of beech, pine and spruce wood samples.

	Before weathering				After weathering	
Species	**Samples**	**R_a**	**R_{max}**	**R_z**	**R_a**	**R_{max}**
Beech	AK	9.2 (1.6)*	76.9 (7.9)	68.2 (6.4)	11.1 (4.6)	104.2 (25.5)
	DK	9.8 (2.0)	80.0 (10.4)	67.4 (9.4)	19.3 (1.5)	112.8 (17.2)
	CK	9.3 (0.9)	77.2 (12.0)	62.0 (6.3)	11.6 (1.7)	102.2 (20.3)
	MK	8.4 (1.5)	79.3 (19.5)	65.7 (11.6)	11.3 (2.9)	81.0 (17.4)
	Control	6.3 (1.7)	56.1 (11.4)	41.8 (7.5)	18.9 (2.7)	127.1 (21.6)
Pine	AS	9.2 (1.7)	86.1 (22.5)	62.1 (10.7)	12.6 (2.5)	100.6 (23.7)
	DS	9.8 (2.1)	86.7 (23.7)	61.2 (13.7)	18.5 (0.3)	110.2 (8.4)
	CS	9.5 (1.6)	86.5 (12.3)	72.8 (10.0)	13.6 (2.2)	101.4 (33.9)
	MS	9.4 (1.5)	78.8 (12.5)	61.6 (10.1)	13.2 (2.2)	101.1 (10.9)
	Control	5.4 (0.9)	51.4 (13.6)	38.9 (9.1)	14.6 (3.1)	106.1 (21.9)
Spruce	AL	9.3 (3.5)	86.2 (29.4)	71.5 (19.9)	13.8 (2.2)	105.1 (19.8)
	DL	9.2 (2.1)	84.9 (17.4)	79.6 (9.1)	19.3 (6.8)	148.8 (31.1)
	CL	9.9 (3.4)	91.7 (21.4)	67.1 (15.4)	12.9 (4.8)	96.3 (29.3)
	ML	9.8 (1.3)	89.5 (26.7)	65.8 (7.9)	13.2 (6.5)	102.9 (37.4)
	Control	7.4 (1.4)	71.2 (15.3)	52.4 (5.8)	15.8 (5.4)	113.5 (30.7)

*Values in parentheses are standard deviations.

When looking at the data before the accelerated weathering test in Tab. 4, a marked difference is seen between the values of surface roughness of the control and test samples. The roughness of wood is a complex phenomenon because wood is an anisotropic and heterogeneous material. Several factors, such as anatomical differences, growing characteristics, machining properties of wood, pre-treatments (e.g. steaming, drying, etc.) applied to wood before machining, and copper-wood interactions after impregnation should be considered in the evaluation of the surface roughness of wood (Aydin and Colakoglu 2003).

CONCLUSIONS

All treatment methods showed lower colour changes compared to the untreated specimens after 672 h artificial weathering. The most effective treatment for stabilizing wood colour was treatment with new generation preservatives (Celcure AC 500 and MCQ). Different wood species manifested colour stability in artificial weathering experiments. Colour change of untreated beech samples was less than that of untreated pine and spruce samples. During the weathering time, the surface roughness values of wood treated with copper-based preservatives were reduced for all wood species. Compared to the untreated wood samples, treatment with all preservatives, except for DDAC, decreased surface roughness after the artificial weathering test.

The answer to these questions may be a good guide for optimizing conditions to develop a high-performing working protection system. In the current work, the comparison of wood treatments with Cu-based preservatives is expected to help the determination of performance of clear-coated woods to date by a considerable margin in the future. Blurred sentence

ACKNOWLEDGMENT

The authors would like to ackowledge the Karadeniz Technical University, Research Fund (Project No: 2009.113.002.1), in Turkey for providing the support.

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