Effect of Bleaching on Hardness, Gloss, and Color Change of Weathered Woods

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The aim of this study was to eliminate the problems of hardness, gloss, and color change of some wood materials exposed to weathering conditions using a bleaching procedure to attempt to return the wood material to its natural state. For this, wood samples of Scots pine (*Pinus sylvestris* L.), Eastern beech (*Fagus orientalis* L.), sessile oak (*Quercus petraea* L.), and chestnut (*Castanea sativa* Mill.) were exposed to weathering conditions based on 12 months ASTM D-1641, followed by a bleaching procedure using 18% solutions of S1 (NaOH + H_2O_2), S2 (NaOH + $Ca(OH)_2$), S3 ($KMnO_4$ + $NaHSO_3$ + H_2O_2), S4 ($NaSiO_3$ + H_2O_2), and the commercial product S5 (Cuprinol Decking Restorer- ($H_2C_2O_4$ + $C_2H_4(OH)_2$). The color, gloss, and hardness changes of samples were determined according to ASTM D 2244-2, EN ISO 2813, and ASTM D 2240 standards. As a result, hardness and gloss values of all woods decreased due to weathering conditions and the wood color turned grey due to degradation. When comparing the weathered samples to the bleached samples, the hardness value was found to be highest in pine wood bleached with the S2 solution, and the gloss value was highest in oak wood bleached with the S1 solution. The greatest color change was found in pine, beech, and chestnut samples bleached with the S4 solution and in oak samples bleached with the S1 solution.

Key Words: Wood material; Weathering conditions; Bleaching procedure; Hardness; Gloss; Color

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INTRODUCTION

In recent years, there has been a rapid increase in the application of chemicals to wood materials in order to improve their physical, mechanical, biological, and fire properties (Yalınkılıç *et al* 1999; Şimşek *et al.* 2010), and many different methods have been discovered in the development of protective systems for wood to prevent photodegradation during outdoor weathering. Several approaches have been developed to prevent the photodegradation of wooden surfaces during outdoor weathering (Chang and Chou 2000; Yang *et al.* 2001; Decker *et al.* 2004; Chou *et al.* 2008; Dawson *et al.* 2008; Forsthuber and Grüll 2010; Saha *et al*. 2011; Özgenç *et al*. 2012; Corcione and Frigione 2012; Forsthuber *et al*. 2013; Özgenç *et al.* 2013).

When wood material, either natural or protected, is exposed to weathering conditions or other external effects, it becomes deformed or structurally degraded (Atar 1999; Özçifçi *et al.* 1999; Budakçı and Atar 2001; Yazıcı 2005; Budakçı 2006; Kılıç and Hafızoğlu 2007).

Though wood materials have a natural resistance against external effects, it is not easy to resist the effects of temperature, radiation (ultraviolet, infrared), moisture (rain, snow, humidity, dew), mechanical (wind, sand, dirt), and biological degradation over time (Budakçı 2006; Feist 1983; Kılıç and Hafızoğlu 2007; Sönmez 2005; Williams 2005). Wood materials exposed to environmental conditions of interior and exterior spaces have faced the complicated processes of physical, chemical, and mechanical degradation (Nzokou *et al.* 2011). Following these processes, roughness, cracks, and distortion (structural degradation) affect the surface of the wood through what appears to be the modification of lignin and other compounds and cause color degradation due to changes in surface carbonyl groups and quinones. All these factors diminish the aesthetic quality of the wood material and shorten its expected life (Nzokou *et al.* 2011; Bucur 2011; Lionetto *et al.* 2012).

The primary problems arising from weathering conditions are color degradation of the wood material and a decrease in hardness and gloss (Budakçı 2006). This situation can be partially reduced with technical drying, impregnation, and suitable finishing. (Kurtoğlu 2000; Sönmez 2005; Yazıcı 2005). Also, bleaching, which is used in the restoration of furniture and decorative materials, increases the economic life and has an advantage in the usage (Budakçı 2006; Budakçı and Atar 2001).

The aim of this study is to eliminate the hardness, gloss, and color change problems of different wood materials exposed to weathering conditions using a bleaching procedure to attempt to return the wood material to its original state.

EXPERIMENTAL

Materials

Wood material

In this study, Scots pine (*Pinus sylvestris* L.), Eastern beech (*Fagus orientalis* L.), sessile oak (*Quercus petraea* L.), and Anatolian Chestnut (*Castanea sativa* Mill.) woods were used as the experimental material. First quality sapwood was chosen by random sampling method and cut to 520 mm (length) × 90 mm (width) × 15 mm (thick). A total of 240 specimens were prepared according to a 4 × 6 × 10 experimental design: 10 specimens for each method and wood type, solution groups + control samples, respectively. The samples were straight fibrous, clean without any cracks, and similar in terms of color and density, with their annual rings vertical on the surface (ASTM D 358 2006). Samples were kept in climate chamber until they reached a constant weight with the 20 ± 2 °C temperature and 65 ± 3% relative humidity. At that point, they measured 500 mm (length) × 80 mm (width) × 12 mm (thick). Afterwards, the samples were sanded with 80-grit sandpaper and then by 100-grit sandpaper (TS 2471 1976).

Samples were put in stands arranged facing South at a 45° angle (Fig. 1) and exposed to natural exterior weathering conditions in the city of Düzce, Turkey, for 12 months (between February 01, 2010 and January 31, 2011) according to ASTM D 1641 (2004). The averages of the climatological data are given in Table 1 (TUMAS 2014). Special care given to remove any waste such as grass which could retain water in the soil (Budakçı 2006; Budakçı and Atar 2001; Garlock and Sward 1972; Karamanoğlu 2012; Sönmez and Özen 1996).

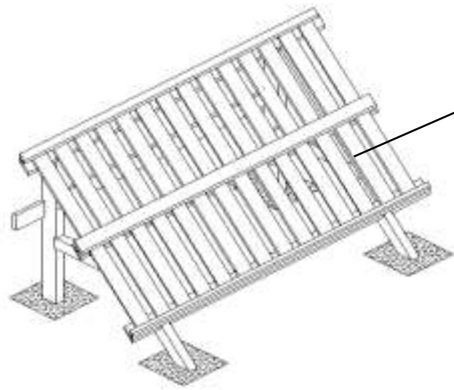

Fig. 1. Test stand used for exposing samples

Table 1. Average of Climatological Data

Date	Temperature (°C)	Moisture content (%)	Rainfall (mm m^{-3})	Pressure (hPa)
Feb. 01, 2010 – Jan. 31, 2011	15.45	75.85	35.37	997.21

Bleaching chemicals

Sodium hydroxide (NaOH), sodium silicate ($NaSiO_3$), calcium hydroxide ($Ca(OH)_2$), hydrogen peroxide (H_2O_2), potassium permanganate ($KMnO_4$), sodium bisulphite ($NaHSO_3$), and the commercial product Cuprinol Decking Restorer ($H_2C_2O_4$ (oxalic acid)+ $C_2H_4(OH)_2$(ethylene glycol)) were used in the bleaching procedure shown in Table 2 as five different solution groups.

Table 2. Solution Groups Used in Bleaching

Solution groups	Chemicals	Neutralizers
S1	$NaOH + H_2O_2$	Acetic acid and distilled water
S2	$NaOH + Ca(OH)_2$	
S3	$KMnO_4 + NaHSO_3 + H_2O_2$	
S4	$NaSiO_3 + H_2O_2$	
S5	Cuprinol Decking Restorer	Distilled water

Chemicals used in the bleaching procedure were prepared as 18% solutions of their weight (mg) and volume (mL) according to Demir (1991).

The prepared solutions were applied with a sponge to the dust-free samples at a rate of 100 ± 10 mL/m^2 parallel to the fibers, followed by a perpendicular application and then a final parallel application. Solutions were applied separately and in order to increase the effect of the first solution, with the second solution application after 2 min. Samples, whose bleaching procedure was completed, were kept at room temperature for 2 days to increase the penetration depth. Following this, they were neutralized with acetic acid and distilled water. Neutralization was applied as two coats with sponge and 2 min intervals. The S5 solution was applied with a brush and neutralized with distilled water per the instructions of the manufacturer. After bleaching procedure, the swollen fibers on all sample surfaces were sanded mildly with the use of a number 220-grit sandpaper.

Methods

Hardness test

The surface hardness of samples was measured by a Hildebrand Durometer HD3000 Shore-D hardness measuring device (Hildebrand 2006) using standards put forth in the ASTM D 2240 (2010). The measuring point applies pressure to a sample on the device tray, and the resistance is recorded on device indicator.

Gloss and color test

The gloss and color change of samples were determined by the use of a BYK-Gardner CC 6801 Spectro-Guide 45/0 device (BYK-Gardner 2008). Using the EN ISO 2813 (1999) standard, a 60° light beam angle was used for gloss measuring.

Color measuring was based on principles found in ASTM D 2244 (2011). Prior to the color measurement, the device was calibrated according to white color a= - 1.00 ± 0.3; b= 0.58 ± 0.3; L= 94.95 ± 0.3.

In the *CIEL*a*b** color system, differences in colors and their locations were determined according to *L**, *a**, *b** color coordinates. Here, symbols are defined as: *L** black-white (for black *L**=0, for white *L**=100); *a** red-green (positive value red, negative value green); *b** yellow-blue (positive value yellow, negative value blue).

In order to determine the effect of the change on color tone, red tone (+a*), yellow tone (+b*), and brightness value (L*) were evaluated separately and the total color change (ΔE*) calculated with formula (1) (Akkuş 2012; Budakçı *et al.* 2010; Karamanoğlu 2012).

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

Statistical analysis

Statistical evaluation of the data were carried out with the statistical software package MSTAT-C, Version 1.42 (https://www.msu.edu/~freed/disks.htm 2014). In the analysis, the values of factors were determined based on an analysis of variance (ANOVA). Factor effects were considered significant with α= 0.05 error rate. According to ANOVA results, the comparisons were made using the critical values obtained from the Duncan test and LSD (Least Significant Difference), and the factors causing the differences were identified. Aged control samples and aged bleached samples were compared. To determine the hardness, gloss, and color differentiation, the first measure has taken place after the samples were exposed to weathering conditions for 12 months and the second after the bleaching procedure on samples which were exposed to weathering conditions for 12 months. Homogeneous groups were classified from A to Z.

RESULTS AND DISCUSSION

Hardness

Analysis of variance results of the hardness value of aged (control) samples and the samples with bleached colors after being aged are given in Table 3. According to analysis of variance table that determines the comparison between control aged samples and the aged samples with bleached colors, type of wood, solution group factor, and interferences of these factors were found to be significant (α=0.05).

Table 3. Analysis of Variance Results of Hardness Value

Factors	Degrees of freedom	Sum of squares	Mean square	*F*-value	Probability α=0.05
Wood type (A)	3	1111.333	370.444	77.6704	0.0000*
Solution Group (B)	5	107.000	21.400	4.4869	0.0007*
Interaction (AB)	15	909.867	60.658	12.7180	0.0000*
Error	216	1030.200	4.769		
Total	239	3158.400			

*Significant difference (α= 0.05)

Comparison of the results of the Duncan test with the use of LSD critical value are provided in Table 4.

Table 4. Comparison Results of Duncan Test of Wood Type-Solution Group

Wood Type	$\bar{x}$	***HG***	***LSD***
Pine	48.10	C	± 0.7859
Beech	52.80	A*	
Oak	53.57	A*	
Chestnut	50.33	B	
Solution Group	$\bar{x}$	***HG***	***LSD***
Aged (Control)	52.10	A*	± 0.9625
S1	51.15	AB	
S2	50.00	C	
S3	50.95	BC	
S4	51.20	AB	
S5	51.80	AB	
Wood type-Solution group Interaction	$\bar{x}$	***HG***	***LSD***
Pine+Aged (Control)	46.90	HI	± 1.925
Pine+S1	48.60	GH	
Pine+S2	50.50	EFG	
Pine+S3	46.90	HI	
Pine+S4	47.50	H	
Pine+S5	48.20	H	
Beech+Aged (Control)	54.70	AB	
Beech +S1	53.50	ABC	
Beech +S2	45.10	**I**	
Beech +S3	53.80	ABC	
Beech +S4	54.40	ABC	
Beech +S5	55.30	**A***	
Oak+Aged (Control)	53.90	ABC	
Oak+S1	54.70	AB	
Oak+S2	53.40	ABC	
Oak+S3	52.30	CDE	
Oak+S4	54.00	ABC	
Oak+S5	53.10	ABC	
Chestnut+Aged (Control)	52.90	BCD	
Chestnut +S1	47.80	H	
Chestnut +S2	51.00	DEF	
Chestnut +S3	50.80	EF	
Chestnut +S4	48.90	FGH	
Chestnut +S5	50.60	EFG	

$\bar{x}$: Average value *HG*: Homogeneous group *: The highest hardness value

According to Table 4 and results of the analysis between the aged control samples and the aged bleached samples, the highest hardness was found in the bleached beech by the S5 solution group and the lowest hardness in the bleached beech by the S2 solution group. It was thought that the content of S5 solution group (oxalic acid) caused an increase in hardness and the NaOH in the S2 solution group a decrease in the hardness of beech wood when compared to its aged form. In the literature, the use of oxalic acid in bleaching procedure was found to form crystal acid particles in the gaps and pores of cells (Sönmez 2005). Also, the type and concentration of chemicals were found to decrease the resistance of the wood according to temperature, duration of effect, and type of wood. Hydrochloric acid, NaOH, and a 2% solution of other acid and bases were found to have no serious effect on the degradation of wood at room temperature. However, together with the increase in concentration, temperature, and duration of effect, degradation is emphasized to increase as well (Örs and Keskin 2001). According to the hardness of aged samples and the effect of all solution groups on hardness of other wood materials, the S2 solution group has shown the greatest increase in the hardness of the pine wood. Here, calcium hydroxide was highly effective. This data was consistent with literature (Budakçı and Atar 2001).

Gloss

Analysis of variance results of gloss value of the aged control samples and the aged bleached samples are provided in Table 5.

Table 5. Analysis of Variance Results of Gloss Value

Factors	Degrees of freedom	Sum of squares	Mean square	*F*-value	Probability α=0.05
Wood type (A)	3	7.908	2.636	34.1984	0.0000*
Solution Group (B)	5	92.911	18.582	241.0901	0.0000*
Interaction (AB)	15	25.893	1.726	22.3957	0.0000*
Error	216	16.648	0.077		
Total	239	143.360			

*Significant difference (α= 0.05)

According to ANOVA table comparing the aged control samples and the aged bleached samples, the type of wood, solution group factor, and the interferences of these factors were found to be significant (α=0.05). Comparison of the Duncan test with the use of LSD critical value are given in Table 6.

In the gloss measurements, the highest value and increase were found in oak wood bleached by the S1 solution (Fig. 2a) and the lowest value in the aged oak and pine wood samples (Fig. 2b, 2c). In the bleaching procedure with the S1 solution group, the increase in gloss was thought to be a result of the reaction of tannin in the structure of oak wood with the bleaching solution.

Sönmez (2005) pointed out that direct use of hydrogen peroxide can cause some staining and spotting on oak wood materials which contain tannin and extractive substances that can be oxidized. To prevent this situation, Sönmez (2005) notes that it is necessary to use hydrogen peroxide with sodium hydroxide. During the oxidation of sodium hydroxide and tannin, tannin's effect is removed and hydrogen peroxide bleaches the wood color.

Table 6. Comparison Results of Duncan Test of Wood Type-Solution Group

Wood Type	$\overline{x}$	***HG***	***LSD***
Pine	2.004	B	
Beech	1.967	B	± 0.09986
Oak	1.858	C	
Chestnut	2.343	A*	
Solution Group	$\overline{x}$	***HG***	***LSD***
Aged (Control)	0.8975	E	
S1	2.657	A*	
S2	2.423	B	± 0.1223
S3	1.961	C	
S4	2.637	A*	
S5	1.682	D	
Wood type-Solution group Interaction	$\overline{x}$	***HG***	***LSD***
Pine+Aged (Control)	0.740	**L**	
Pine+S1	2.518	DE	
Pine+S2	3.065	AB	
Pine+S3	1.647	IJ	
Pine+S4	2.993	AB	
Pine+S5	1.059	K	
Beech+Aged (Control)	1.030	K	
Beech +S1	2.397	DEF	
Beech +S2	2.129	FG	
Beech +S3	2.043	GH	
Beech +S4	2.355	DEF	
Beech +S5	1.846	HI	
Oak+Aged (Control)	0.780	**L**	± 0.2446
Oak+S1	3.125	**A***	
Oak+S2	1.534	J	
Oak+S3	1.797	HI	
Oak+S4	2.387	DEF	
Oak+S5	1.523	J	
Chestnut+Aged (Control)	1.040	K	
Chestnut +S1	2.586	CD	
Chestnut +S2	2.965	AB	
Chestnut +S3	2.358	DEF	
Chestnut +S4	2.811	BC	
Chestnut +S5	2.299	EFG	

$\overline{x}$: Average value *HG*: Homogeneous group *: The highest gloss value

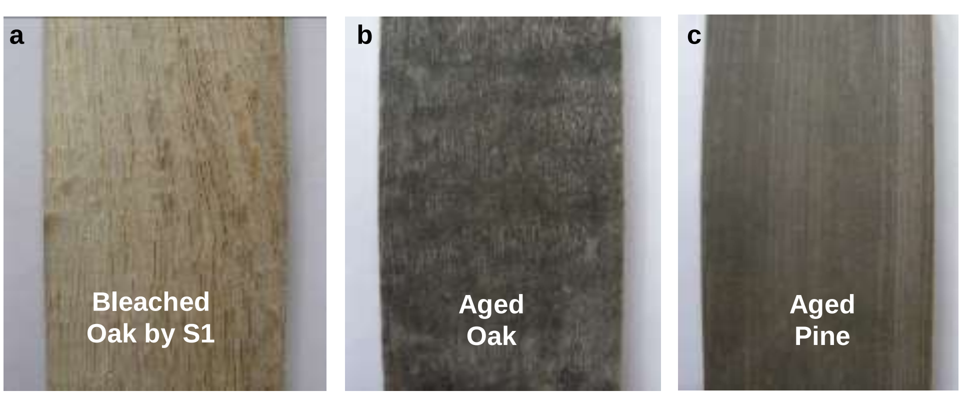

Fig. 2. (a) Oak sample bleached by S1, (b) Aged oak sample, (c) Aged pine sample

Red Color Value (+a)

Analysis of variance results of red color value of the aged control samples and the aged bleached samples are given in Table 7.

Table 7. Analysis of Variance Results of Red Color Value

Factors	Degrees of freedom	Sum of squares	Mean square	*F*-value	Probability α=0.05
Wood type (A)	3	147.118	49.039	238.7481	0.0000*
Solution Group (B)	5	514.924	102.985	501.3814	0.0000*
Interaction (AB)	15	138.148	9.210	44.8384	0.0000*
Error	216	44.367	0.205		
Total	239	844.557			

*Significant difference (α= 0.05)

Table 8. Comparison Results of Duncan Test of Wood Type-Solution Group

Wood Type	$\bar{x}$	***HG***	***LSD***
Pine	4.342	A*	± 0.1629
Beech	3.125	B	
Oak	2.803	C	
Chestnut	2.194	D	
Solution Group	$\bar{x}$	***HG***	***LSD***
Aged (Control)	1.754	C	± 0.1995
S1	3.117	B	
S2	2.942	B	
S3	3.136	B	
S4	1.655	C	
S5	6.091	A*	
Wood type-Solution Interaction	$\bar{x}$	***HG***	***LSD***
Pine+Aged (Control)	1.440	MNO	± 0.3991
Pine+S1	5.301	CD	
Pine+S2	4.302	E	
Pine+S3	4.368	E	
Pine+S4	2.627	HI	
Pine+S5	8.016	**A***	
Beech+Aged (Control)	1.773	KLM	
Beech +S1	3.624	F	
Beech +S2	4.304	E	
Beech +S3	2.151	JK	
Beech +S4	1.928	KL	
Beech +S5	4.967	D	
Oak+Aged (Control)	1.648	LMN	
Oak+S1	2.365	IJ	
Oak+S2	1.904	KL	
Oak+S3	3.135	G	
Oak+S4	1.929	KL	
Oak+S5	5.837	B	
Chestnut+Aged (Control)	2.156	JK	
Chestnut +S1	1.176	O	
Chestnut +S2	1.259	NO	
Chestnut +S3	2.891	GH	
Chestnut +S4	0.1360	**P**	
Chestnut +S5	5.546	BC	

$\bar{x}$: Average value *HG*: Homogeneous group *: The highest red color value

According to the analysis of variance table that compares the aged control samples and the aged bleached samples, the type of wood, solution group factor, and interferences of these factors were found to be meaningful (α=0.05). Comparison of results of the Duncan test with the LSD critical value is provided in Table 8.

The highest red color value was found in bleached pine wood treated with the S5 solution group (Fig. 3a) and the lowest value in bleached chestnut wood treated with the S4 solution group (Fig. 3b). According to aged samples (Fig. 3c, d), the S5 solution increased the red color value in all wood materials with the highest increase in pine wood (Fig. 3a). The acidic form of S5 solution group (oxalic acid + ethyl alcohol) may be the reason for the red color increase.

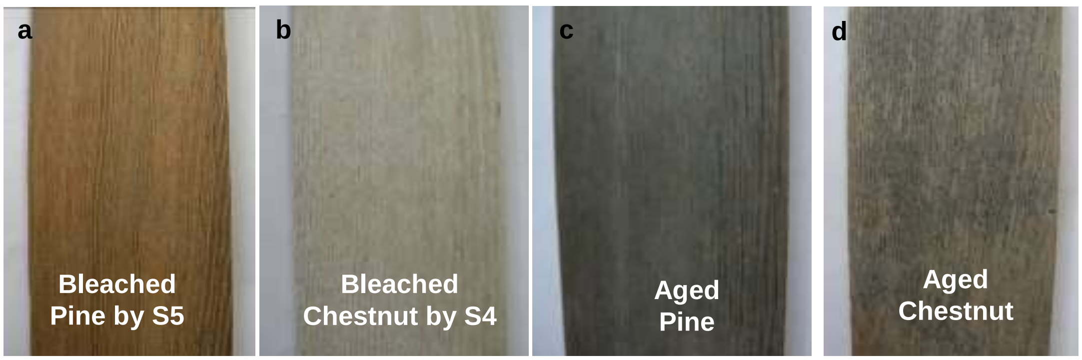

Fig. 3. (a) Pine sample bleached by S5, (b) Chestnut sample bleached by S4, (c) Aged pine sample, (d) Aged chestnut sample

Yellow Color Value (+b)

Analysis of variance results of yellow color value of the aged control samples and the aged bleached samples are given in Table 9.

Table 9. Analysis of Variance Results of Yellow Color Value

Factors	Degrees of freedom	Sum of squares	Mean square	*F*-value	Probability α=0.05
Wood type (A)	3	340.834	113.611	70.0716	0.0000*
Solution Group (B)	5	5007.675	1001.535	617.7123	0.0000*
Interaction (AB)	15	988.702	65.913	40.6531	0.0000*
Error	216	350.214	1.621		
Total	239	6687.425			

*Significant difference (α= 0.05)

According to the analysis of variance table that compares the aged control samples and the aged bleached samples, the type of wood, solution group factor, and interferences of these factors were found to be meaningful (α=0.05). Comparison results of the Duncan test with the LSD critical value are provided in Table 10.

The highest yellow color value was found in the pine wood bleached by the S1 and S5 solution groups (Fig. 4a, b), while the lowest value was present in the aged pine, beech, and oak samples (Fig. 4c, d, e). According to aged control samples, the highest effect of the S1 and S5 solution groups on yellow color value present in the pine materials.

Table 10. Comparison Results of Duncan Test of Wood Type-Solution Group

Wood Type	$\bar{x}$	***HG***	***LSD***
Pine	17.92	A*	± 0.4582
Beech	14.97	C	
Oak	15.56	B	
Chestnut	15.10	BC	
Solution Group	$\bar{x}$	***HG***	***LSD***
Aged (Control)	7.582	F	± 0.5611
S1	20.20	B	
S2	17.56	C	
S3	12.91	E	
S4	16.09	D	
S5	20.97	A*	
Wood type-Solution group Interaction	$\bar{x}$	***HG***	***LSD***
Pine+Aged (Control)	7.076	**K**	± 0.3991
Pine+S1	23.80	**A***	
Pine+S2	21.31	BC	
Pine+S3	11.98	I	
Pine+S4	19.63	DE	
Pine+S5	23.69	**A***	
Beech+Aged (Control)	7.072	**K**	
Beech +S1	20.11	CDE	
Beech +S2	19.20	E	
Beech +S3	9.564	J	
Beech +S4	15.93	G	
Beech +S5	17.95	F	
Oak+Aged (Control)	7.200	**K**	
Oak+S1	21.11	BC	
Oak+S2	13.93	H	
Oak+S3	14.26	H	
Oak+S4	16.18	G	
Oak+S5	20.65	BCD	
Chestnut+Aged (Control)	8.979	J	
Chestnut +S1	15.79	G	
Chestnut +S2	15.81	G	
Chestnut +S3	15.83	G	
Chestnut +S4	12.62	I	
Chestnut +S5	21.60	B	

$\bar{x}$: Average value *HG*: Homogeneous group *: The highest yellow color value

Brightness Value (L)

Analysis of variance results of brightness value of the aged control samples and the aged bleached samples are provided in Table 11.

Table 11. Analysis of Variance Results of Brightness Value

Factors	Degrees of freedom	Sum of squares	Mean square	*F*-value	Probability α=0.05
Wood type (A)	3	2917.420	972.473	217.4243	0.0000*
Solution Group (B)	5	20893.118	4178.624	934.2513	0.0000*
Interaction (AB)	15	2936.459	195.764	43.7686	0.0000*
Error	216	966.103	4.473		
Total	239	27713.099			

*Significant difference (α= 0.05)

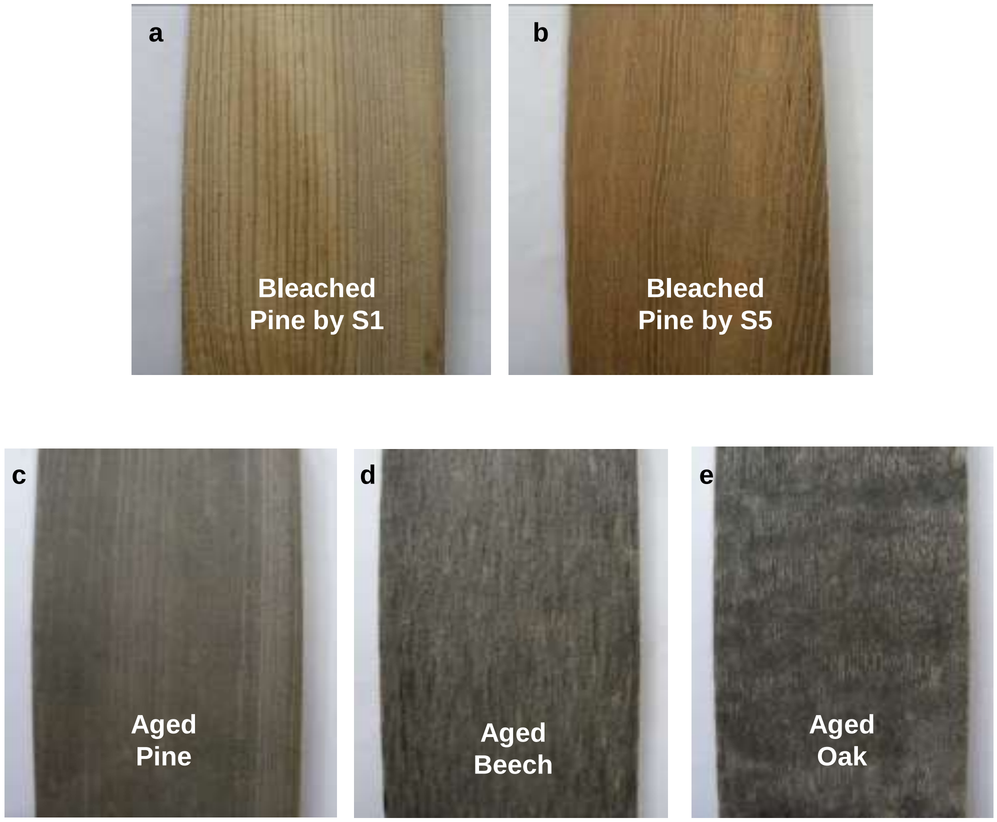

Fig. 4. (a) Pine sample bleached by S1, (b) Pine sample bleached by S5, (c) Aged pine sample, (d) Aged beech sample, (e) Aged oak sample

According to the analysis of variance table that compares the aged control samples and the aged bleached samples, the type of wood, solution group factor, and interferences of these factors were found to be meaningful (α=0.05). Comparison of the results of the Duncan test with the LSD critical value are given in Table 12.

The highest brightness value was found in bleached chestnut wood by the S4 solution group (Fig. 5a) and the lowest in bleached pine wood by the S3 solution group (Fig. 5b). The brightness of aged samples increased in chestnut, pine, and beech woods by the S4 solution group (Fig. 5a, c, d) and in oak wood by the S1 solution group (Fig. 5e).

The S4 solution group showed its best effect on brightness in chestnut wood. When analyzed Table 12, solution groups was increased brightness values and natural values were obtained in all wood type. Specially, according to aged (Fig. 5f) and natural (Fig. 5g) control samples were obtained values above natural values in chestnut. According to aged control samples, the S3 solution group has a decreased effect on brightness of pine wood but an increased effect on other materials.

Total Color Change (ΔE)

Analysis of variance results of total Color Change value of the aged control samples and the aged bleached samples are given in Table 13.

Table 12. Comparison Results of Duncan Test of Wood Type-Solution Group

Wood Type	$\bar{x}$	***HG***	***LSD***
Pine	60.42	D	± 0.7611
Beech	64.17	B	
Oak	62.92	C	
Chestnut	69.93	A*	
Solution Group	$\bar{x}$	***HG***	***LSD***
Aged (Control)	48.66	F	± 0.9321
S1	71.73	B	
S2	68.73	C	
S3	57.82	E	
S4	76.85	A*	
S5	62.38	D	
Wood type-Solution group Interaction	$\bar{x}$	***HG***	***LSD***
Pine+Aged (Control)	48.06	L	± 0.9321
Pine+S1	67.07	G	
Pine+S2	70.17	EF	
Pine+S3	43.25	**N**	
Pine+S4	77.80	B	
Pine+S5	56.17	J	
Beech+Aged (Control)	48.44	L	
Beech +S1	69.31	F	
Beech +S2	65.86	G	
Beech +S3	62.37	H	
Beech +S4	75.44	CD	
Beech +S5	63.63	H	
Oak+Aged (Control)	46.16	M	
Oak+S1	74.04	D	
Oak+S2	63.42	H	
Oak+S3	60.06	I	
Oak+S4	71.54	E	
Oak+S5	62.31	H	
Chestnut+Aged (Control)	52.00	K	
Chestnut +S1	76.49	BC	
Chestnut +S2	75.46	CD	
Chestnut +S3	65.62	G	
Chestnut +S4	82.61	**A***	
Chestnut +S5	67.40	G	

$\bar{x}$: Average value *HG*: Homogeneous group *: The highest brightness value

Table 13. Analysis of Variance Results of Total Color Change Value

Factors	Degrees of freedom	Sum of squares	Mean square	*F*-value	Probability α=0.05
Wood type (A)	3	2351.026	783.675	177.4360	0.0000*
Solution Group (B)	5	23213.637	4642.727	1051.1840	0.0000*
Interaction (AB)	15	2969.901	197.993	44.8287	0.0000*
Error	216	954.000	4.417		
Total	239	29488.563			

*Significant difference (α= 0.05)

Fig. 5. (a) Chestnut sample bleached by S4, (b) Pine sample bleached by S3, (c) Pine sample bleached by S4, (d) Beech sample bleached by S4, (e) Oak sample bleached by S1, (f) Aged chestnut sample, (g) Natural chestnut sample

According to the analysis of variance table that compares the aged control samples and the aged bleached samples, type of wood, solution group factor, and interferences of these factors were found to be meaningful (α=0.05). Comparison of the results of the Duncan test with the LSD critical value are provided in Table 14.

The highest total color change was found in the bleached chestnut wood by S4 solution group (Fig. 5a) and the lowest in the bleached pine wood by S3 solution group (Fig. 5b). According to aged samples, the most color change had occurred in chestnut, pine, and beech woods by S4 solution group (Fig. 5a, c, d) and in oak wood by S1 solution group (Fig. 5e). S3 solution group had negatively caused the color change by degrading the color of pine wood material.

Table 14. Comparison Results of Duncan Test of Wood Type-Solution Group

Wood Type	$\overline{x}$	***HG***	***LSD***
Pine	63.39	D	± 0.7563
Beech	66.10	B	
Oak	64.99	C	
Chestnut	71.70	A*	
Solution Group	$\overline{x}$	***HG***	***LSD***
Aged (Control)	49.31	F	± 0.9263
S1	74.71	B	
S2	71.07	C	
S3	59.41	E	
S4	78.60	A*	
S5	66.18	D	
Wood type-Solution group Interaction	$\overline{x}$	***HG***	***LSD***
Pine+Aged (Control)	48.61	LM	± 1.853
Pine+S1	71.38	E	
Pine+S2	73.47	D	
Pine+S3	45.10	**N**	
Pine+S4	80.29	B	
Pine+S5	61.49	J	
Beech+Aged (Control)	49.00	L	
Beech +S1	72.26	DE	
Beech +S2	68.74	F	
Beech +S3	63.15	IJ	
Beech +S4	77.15	C	
Beech +S5	66.32	GH	
Oak+Aged (Control)	46.78	MN	
Oak+S1	77.07	C	
Oak+S2	64.97	HI	
Oak+S3	61.82	J	
Oak+S4	73.38	D	
Oak+S5	65.91	GH	
Chestnut+Aged (Control)	52.86	K	
Chestnut +S1	78.11	C	
Chestnut +S2	77.11	C	
Chestnut +S3	67.57	FG	
Chestnut +S4	83.57	**A***	
Chestnut +S5	71.01	E	

$\overline{x}$: Average value *HG*: Homogeneous group *: The highest total color change value

CONCLUSIONS

1. Physical changes in wood materials, namely the hardness, gloss, and color changes caused by weathering conditions, can be eliminated by a bleaching procedure.

2. According to the comparison between control samples exposed to weathering conditions for 12 months and test samples that were bleached after exposure to weathering conditions, the hardness value was highest in pine samples bleached by the S2 solution group and the gloss value was highest in oak samples bleached by the S1 solution group.

3. The greatest color change was found in pine, beech, and chestnut samples bleached by the S4 solution group and in oak samples bleached by the S1 solution group.
4. When compared to commercial products, the used solution groups, especially the S4 group, is more advantageous in terms of providing natural color, gloss, and hardness change. Oxalic acid, which is included in commercial products, causes changes in wood products that are exposed to weathering conditions (like garden furniture, woodworking sector, *etc*.) apart from natural color, gloss, and hardness in wooden materials such as oak and chestnut, especially when tannin and extractive substances are present.
5. In the use of equipment (garden furniture, woodworking sector), preference for woods such as oak, chestnut, pine, and beech can minimize the effect and changes in a natural way, thus reducing the need for annual care (color, gloss, and hardness change) in materials that are exposed to weathering conditions.
6. Physical changes (hardness, gloss, and color) in wood materials caused by weathering conditions can be best reduced by the bleaching procedure utilizing the S4 ($NaSiO_3$ + H_2O_2) solution group.

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