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COLOUR, GLOSS AND HARDNESS PROPERTIES OF HEAT TREATED WOOD EXPOSED TO ACCELERATED WEATHERING

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Abstract:
Physical, chemical, biological and microscopic properties change in unprotected wooden material that is exposed to weathering conditions and so its structural and some characteristic properties such as colour, gloss and hardness are ruined. The aim of this study is to determine changing of colour, gloss and hardness values of heat treated wood exposed to weathering. For this purpose, Anatolian black pine, calabrian pine, sessile oak and chestnut woods have been used. The experimental samples were subjected to heat under atmospheric pressure at three different temperatures (130, 180 and 230^{0}C) and two different time levels (2 and 8 h). Then, heat treated samples have been exposed to accelerated weathering conditions to two different time levels (120 and 240 h) according to related standards. After the accelerated weathering procedure, changes in the colour, gloss and hardness of the samples have been determined according to related standards. The hardness values of heat-treated wood increased at low heating temperature and time. Aged wood hardness and gloss decreased, compared to the control specimens. Also, results have been compared with values of control samples belonging to each group.

Key words: *thermal treatment; aging; weathering; colour; gloss; hardness.*

INTRODUCTION

The heat treatment of wood is defined as the application of heat to wood in order to bring about a desired improvement in the performance of the material. Heat treatment serves to improve the natural quality properties of the wood, such as dimensional stability and resistance to bio-corrosion and resistance to outdoor weather conditions, biological resistance against fungi and insects, decorative colour variation and equip the wood material with new properties (Gündüz *et al*. 2007, Korkut and Kocaefe 2009).

Increasing environmental pressure has appeared in recent years in many countries, leading to important changes in the field of wood preservation. Heat treatment of wood is an eco- friendly method to modify wood without the use of any toxic chemicals (Kol 2010). Heat-treated timber is used in the construction of building cladding, interior paneling, parquet and plank flooring, park and garden furniture, garden fencing, children's playground equipment, window and window shutters, interior and exterior doors, sauna and sauna elements, interior furniture and musical instruments. Heat-treated timber surfaces naturally tend to age by the effect of sunlight, rain and wind. This condition does not affect the durability of the heat-treated timber but wood surface turns grey after a certain period (Korkut and Kocaefe 2009).

Weathering is the general term used to define the slow degradation of materials exposed to the weather. The degradation mechanism depends on the type of material, but the cause is a combination of factors found in nature: moisture, sunlight, heat/cold, chemicals, abrasion by windblown materials, and biological agents. Weathering is surface degradation of wood that is initiated primarily by solar radiation, but other factors are also important. The wetting and drying of wood through precipitation, diurnal and seasonal changes in relative humidity (RH), abrasion by windblown particulates, temperature changes, atmospheric pollution, oxygen, and human activities such as walking on decks, cleaning surfaces with cleaners and brighteners, sanding, and power washing all contribute to the degradation of wood surfaces (Williams 2005).

Physical, chemical, biological and microscopic properties change in unprotected wooden material that is exposed to weathering conditions. Also, when wood is exposed outdoors, a variety of weathering factors degrades the main structural wood compounds. The factors contributing most to wood degradation by weathering are irradiation (UV) and water. Weathering degradation is defined by colour changes of the wood surface, followed by loss of gloss, roughening and checking. The change of wood colour is explained by the fact that the UV component of sunlight, changes in moisture and temperature as well as that oxidative agents such as oxygen and/or ozone are able to depolymerise lignin and some polysaccharides in the wood cell wall (Temiz *et al*. 2007).

The objective of the present study was to investigate changing of colour, gloss and hardness values of the heat treated wood of Anatolian black pine, calabrian pine, sessile oak and chestnut exposed to weathering. These woods are the most common naturally grown wood species in Turkey.

MATERIALS AND METHODS

The Anatolian black pine (*Pinus nigra* J.F. Arnold subsp. *nigra* var. *caramenica* (Loudon) Rehder), calabrian pine (*Pinus brutia* Ten.), sessile oak (*Quercus petraea* Lieb.) and chestnut (*Castanea sativa* Mill.) trees were randomly selected and 3 stems at 5 meters, with a breast height diameter (DBH) of 30 - 40cm, were obtained from forestlands of the Kastamonu province, Turkey. None of the trees has defects such as spiral grain and cracks. The lumber was cut from the logs in the sawmill, in parallel to grain direction, according to the Turkish standard, TS 4176. Afterwards, the lumbers were air dried until it reached approximately 12% MC. Then, the lumber was planed and cut into small clear specimens for heat treatment in the dimensions of 50×50×50mm. Fifteen specimens for each species were prepared.

Heat treatment

The temperature of the oven was increased to the temperature at which the actual heat treatment occurs. Heat treatment applications were applied in a temperature controlled small heating unit. The treatment started by putting the samples at ambient temperature in the oven, and the period to reach the treatment temperature was about 1 hour for all trials. 3 different temperatures (130, 180 and 230^{o}C) and 2 different durations (2 and 8h) were conducted to the specimens under atmospheric pressure and in the presence of inert (nitrogen) environment. After treatment, the temperature was decreased to room temperature, which took about 24h. The same procedure was conducted for all experiments.

Accelerated weathering

The heat treated wood samples' surface was cut radially in the dimensions of 50×50×10mm for weathering. The outer surface of each of three replicates of each group of wood specimen was exposed for 120 and 240hr. Fig. 1 shows the accelerated weathering test specimens with heat treatment before the experiment.

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pp. 729-738

Fig. 1
Weathering test specimens and accelerated weathering tester.

Then, heat treated samples were exposed to accelerated weathering conditions at two different time levels (120 and 240h) according to ASTM G 154 standard. Although not conclusive, 120 and 240 hours accelerated weathering, in general practice, is that which corresponds to 2.5 and 5 years (Browne 1970, Mallon *et al*. 2002). The accelerated weathering cycle consist of three stages which are UV process (one hour in 60^{o}C and 0.71w/m^2 light intensity), water spray (ten minutes in 20^{o}C) and conditioning (four hours in 50^{o}C), respectively.

After the accelerated weathering procedure, changes in the colour, gloss and hardness of the samples have been determined according to ASTM D 2244-2, EN ISO 2813 and ASTM D 2240 standards, respectively. Results have been compared with the values of control samples belonging to each group.

Measurement of hardness, colour and gloss

To determine change in hardness, colour and gloss, three measurements on each there groups were made. These measurements were on natural (untreated), on heat-treated and on accelerated weathering samples, respectively.

The hardness of the all samples were determined by using Shoremetre-D (Fig. 2a) according to ASTM-D 2240 procedure.

Fig. 2
a - Hardness meter (Mitutoyo Hardmatic-HH-334; b - Colour and gloss meter (Nippon Denshoku-NF999).

Colour and gloss measurements were determined according to ASTM-D 2244-2 and EN ISO 2813 procedures, respectively, by using a colour and gloss meter (Fig. 2b). The ability of samples to reflect light was utilized to determine gloss values. Total colour change (ΔE*); values were calculated using the following formula (ISO 1984, Tunçgenç 2004):

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

RESULTS AND DISCUSSION

The colour became significantly darker with treatment temperature and time compared with the control specimens. This can be explained by increasing the content of lignin depending on the heat treatment temperature and time (Akyildiz *et al*. 2009a, Akyildiz *et al*. 2009b, Ateş *et al*. 2009, Ateş *et al*. 2010).

Table 1 shows the hardness values of heat-treated wood exposed to accelerated weathering. In evaluating the effect of heat treatment among the natural groups, it is noted that, while the hardness value increased at lower heat temperature (130^{o}C and 180^{o}C), it decreased at 230^{o}C and both times (2 and 8 hours) for all wood types (Fig. 3). Similar results were obtained in different studies (Akyildiz *et al*. 2009a, Akyildiz *et al*. 2009b, Ateş *et al*. 2009, Ateş *et al*. 2010).

In investigating the hardness values after accelerated weathering process, it is noted that the hardness values decreased at all groups of species and process compared to each its control groups. So, the hardness of all species was decreased as a function of time in both weathering at 120 hours and 240 hours. The maximum decrease in the hardness was recorded at 240 hours weathering of at 230^{o}C and 2 hours of heat-treatment, and at 120 hours weathering at 230^{o}C and 8 hours of heat-treatment and was 17,2% and 17,0%, respectively. The minimum effect was recorded in the oak group and was 0,3% and 10,8%. Thus, the least reduction in hardness values was of the oak group at 130^{o}C - 2 hours heat-treatment and both 120 and 240 hours weathering (as 0,3%). The hardness of Calabrian pine has been most affected by the weathering process (decreased between 1,9% and 17,2%).

In investigation of the hardness values of weathered natural types, while the maximum decrease was recorded as 10,5% for chestnut, the minimum effect was recorded as 2,1% for black pine. Similar results are given in the literature, that loss of hardness of broad leaved trees is higher than coniferous trees (Karamanoğlu 2012, Örs and Keskin 2001).

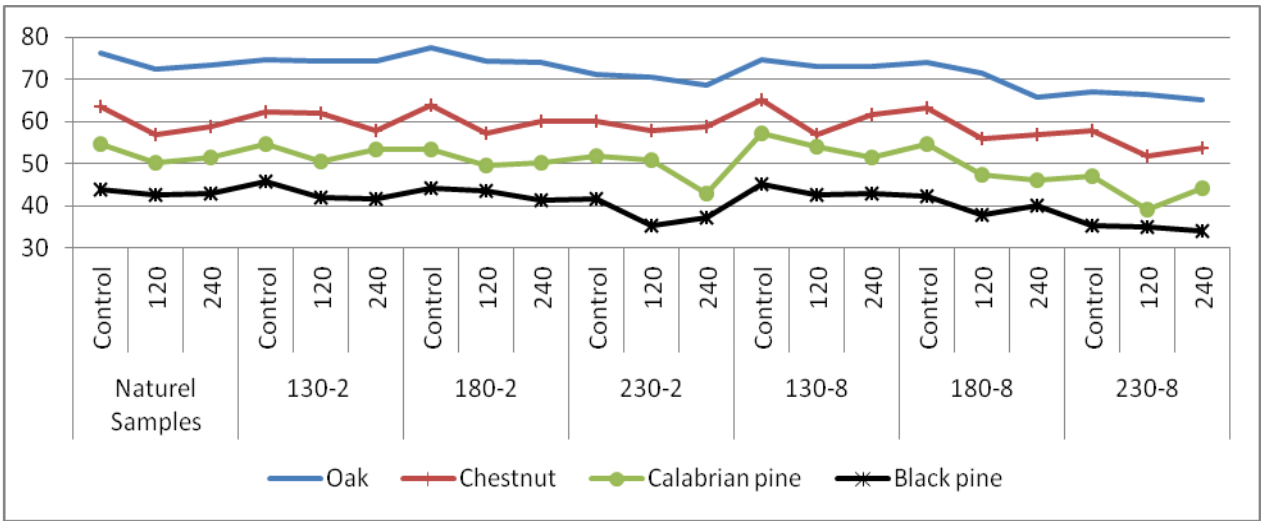

Fig. 3
The hardness values for all measurements.

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pp. 729-738

Table 1

Hardness values of heat-treated wood exposed to accelerated weathering

Species		**Heat treatment temperature & time and Weathering time**																				
		Natural			**130-2**			**180-2**			**230-2**			**130-8**			**180-8**			**230-8**		
		Control	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**
Oak	X_{min}	74,00	70,00	70,50	73,50	73,50	73,00	75,50	73,50	72,50	68,50	69,50	66,50	73,50	72,00	71,50	73,00	70,50	65,00	65,50	64,00	64,50
	X_{max}	78,00	73,50	76,50	75,50	75,00	75,00	78,50	76,00	75,00	73,00	71,50	70,50	75,50	74,00	74,00	75,00	72,50	66,50	69,00	68,00	65,50
	±s	1,67	1,55	2,31	0,79	0,57	0,76	1,17	1,04	1,14	1,78	0,82	1,68	0,76	0,74	0,94	0,74	0,82	0,65	1,29	1,98	0,35
	$\overline{X}$	76,10	72,40	73,30	74,50	74,30	74,20	77,50	74,30	73,90	71,10	70,60	68,70	74,70	73,10	73,00	73,90	71,60	65,90	66,90	66,40	65,00
	Change (%)		-4,9	-3,7	**-2,1**	-0,3	-0,4	**1,8**	-4,1	-4,6	**-6,6**	-0,7	-3,4	**-1,8**	-2,1	-2,3	**-2,9**	-3,1	-10,8	**-12,1**	-0,7	-2,8
Chestnut	X_{min}	62,50	55,50	56,50	61,50	60,00	54,50	63,00	55,00	59,50	58,50	54,50	57,70	64,00	53,00	61,00	62,00	55,50	55,50	56,50	50,00	52,50
	X_{max}	65,50	59,00	60,00	63,50	63,00	60,50	65,00	58,00	62,00	61,00	60,50	59,50	66,50	59,50	62,50	64,50	56,50	59,50	59,00	53,00	54,50
	±s	1,19	1,56	1,35	0,74	1,14	2,22	0,89	1,19	1,08	0,94	2,30	0,67	0,96	2,50	0,67	0,96	0,50	1,58	1,04	1,20	0,84
	$\overline{X}$	63,60	56,90	58,70	62,40	61,90	57,80	63,90	57,10	60,10	60,00	57,90	58,64	65,10	57,00	61,70	63,10	56,00	57,00	57,70	51,70	53,80
	Change (%)		-10,5	-7,7	**-1,9**	-0,8	-7,4	**0,5**	-10,6	-5,9	**-5,7**	-3,5	-2,3	**2,4**	-12,4	-5,2	**-0,8**	-11,3	-9,7	**-9,3**	-10,4	-6,8
Calabrian pine	X_{min}	53,50	49,50	49,50	53,50	50,00	50,50	52,00	48,00	49,00	51,00	50,00	40,50	55,50	53,00	50,00	52,00	45,50	45,00	44,50	38,00	40,50
	X_{max}	55,50	51,00	52,50	55,50	51,50	55,00	55,00	50,50	52,00	52,50	52,50	44,50	59,00	54,50	53,00	55,50	49,00	48,50	49,00	40,50	46,50
	±s	0,89	0,57	1,15	0,89	0,65	1,96	1,10	0,94	1,14	0,57	0,97	1,64	1,43	0,55	1,08	1,54	1,43	1,43	1,67	1,08	2,30
	$\overline{X}$	54,60	50,30	51,30	54,60	50,60	53,20	53,30	49,50	50,10	51,80	50,80	42,90	57,10	53,90	51,60	54,50	47,40	46,10	47,10	39,10	44,10
	Change (%)		-7,9	-6,0	**0,0**	-7,3	-2,6	**-2,4**	-7,1	-6,0	**-5,1**	-1,9	-17,2	**4,6**	-5,6	-9,6	**-0,2**	-13,0	-15,4	**-13,7**	-17,0	-6,4
Black pine	X_{min}	42,50	41,00	42,50	44,50	41,00	41,50	43,50	42,50	40,50	40,50	34,50	35,00	43,00	41,50	41,50	40,00	36,50	39,00	33,50	34,00	33,00
	X_{max}	45,50	44,50	43,50	46,50	42,50	42,50	45,50	44,50	42,00	43,50	35,50	40,00	47,00	43,50	44,50	44,00	39,00	40,50	37,00	36,00	35,00
	±s	1,14	1,54	0,35	0,89	0,67	0,45	0,84	0,74	0,76	1,10	0,42	2,15	1,60	0,79	1,20	1,44	0,89	0,71	1,68	0,76	0,79
	$\overline{X}$	43,90	42,50	43,00	45,60	41,80	41,70	44,30	43,60	41,20	41,70	35,10	37,00	45,10	42,50	42,80	42,20	37,90	40,00	35,20	34,80	34,00
	Change (%)		-3,2	-2,1	**3,9**	-8,3	-8,6	**0,9**	-1,6	-7,0	**-5,0**	-15,8	-11,3	**2,7**	-5,8	-5,1	**-3,9**	-10,2	-5,2	**-19,8**	-1,1	-3,4

$\overline{X}$: average, ±s : standard deviation [grey] *changing between natural control samples and heat-treated control samples*

Table 2

Gloss values of heat-treated wood exposed to accelerated weathering

Species		Heat treatment temperature & time and Weathering time																				
		Natural			**130-2**			**180-2**			**230-2**			**130-8**			**180-8**			**230-8**		
		Control	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**
Oak	X_{min}	25	17	7	20	11	16	17	12	8	5	4	5	20	13	9	7	7	7	6	5	5
	X_{max}	28	19	14	22	15	18	20	16	14	7	5	5	22	16	15	8	8	9	7	5	5
	±s	1,14	0,89	2,95	1,10	1,64	0,84	1,10	1,58	3,03	0,89	0,45	0,00	0,84	1,30	2,24	0,55	0,45	0,89	0,45	0,0	0,0
	$\overline{X}$	26,40	18,40	11,80	21,20	13,20	17,20	18,20	14,00	10,20	5,60	4,80	5,00	21,20	13,80	12,00	7,60	7,20	8,40	6,20	5,00	5,00
	Change (%)		-30,3	-55,3	**-19,7**	-37,7	-18,9	**-31,1**	-23,1	-44,0	**-78,8**	-14,3	-10,7	**-19,7**	-34,9	-43,4	**-71,2**	-5,3	10,5	**-76,5**	-19,4	-19,4
Chestnut	X_{min}	26	17	17	32	17	21	17	11	20	6	6	7	23	14	24	8	9	8	5	5	6
	X_{max}	30	19	23	35	21	24	18	13	27	7	9	9	28	17	27	9	10	11	6	6	6
	±s	1,58	1,10	2,30	1,14	1,87	1,14	0,55	0,71	2,77	0,55	1,30	1,00	1,92	1,64	1,52	0,55	0,55	1,30	0,55	0,55	0,00
	$\overline{X}$	28,00	17,80	19,40	33,40	19,00	22,60	17,40	12,00	23,20	6,40	6,80	8,00	26,20	15,20	25,60	8,40	9,40	9,80	5,60	5,40	6,00
	Change (%)		-36,4	-30,7	**19,3**	-43,1	-32,3	**-37,9**	-31,0	33,3	**-77,1**	6,3	25,0	**-6,4**	-42,0	-2,3	**-70,0**	11,9	16,7	**-80,0**	-3,6	7,1
Calabrian pine	X_{min}	31	23	15	27	23	19	21	21	19	7	6	7	28	19	23	7	9	10	7	5	5
	X_{max}	35	28	23	34	25	21	24	22	23	7	7	8	30	20	24	8	10	12	7	5	6
	±s	1,52	2,17	3,39	2,77	0,84	0,71	1,22	0,55	1,58	0,00	0,55	0,55	1,00	0,45	0,55	0,45	0,45	1,10	0,00	0,00	0,55
	$\overline{X}$	32,60	25,20	18,00	31,20	23,80	20,00	22,00	21,60	21,00	7,00	6,40	7,60	29,00	19,80	23,60	7,80	9,20	11,20	7,00	5,00	5,60
	Change (%)		-22,7	-44,8	**-4,3**	-23,7	-35,9	**-32,5**	-1,8	-4,5	**-78,5**	-8,6	8,6	**-11,0**	-31,7	-18,6	**-76,1**	17,9	43,6	**-78,5**	-28,6	-20,0
Black pine	X_{min}	42	23	25	36	24	25	24	19	23	6	7	7	40	23	27	11	13	17	4	5	5
	X_{max}	48	24	27	39	25	28	29	22	25	8	8	10	43	24	29	13	15	20	6	6	7
	±s	2,17	0,45	0,84	1,30	0,45	1,22	2,07	1,22	0,89	1,00	0,55	1,30	1,14	0,45	0,84	0,84	0,84	1,14	0,89	0,45	1,00
	$\overline{X}$	44,80	23,80	25,80	37,20	24,20	26,00	26,60	21,00	24,40	7,00	7,40	8,80	41,40	23,80	27,80	11,80	13,80	18,60	5,60	5,20	6,00
	Change (%)		-46,9	-42,4	**-17,0**	-34,9	-30,1	**-40,6**	-21,1	-8,3	**-84,4**	5,7	25,7	**-7,6**	-42,5	-32,9	**-73,7**	16,9	57,6	**-87,5**	-7,1	7,1

$\overline{X}$: average, ±s : standard deviation, [grey box] changing between natural control samples and heat-treated control samples

Gloss values after accelerated weathering were given Table 2 and Fig. 4. As shown in this table, the gloss values decreased after accelerated weathering in natural wood species. The reason for this is explained by cracks, with physical and biological degradation occurring on the wood surfaces (Christy *et al*. 2005, Karamanoğlu 2012, Bucur 2011). Similar results for reduction in gloss after weathering were reported by Gorman and Feist (1989) and Bozkurt and Erdin (2000).

In heat-treated wood specimens, the gloss values depending on accelerated weathering have been neither decreased nor increased regularly. While for all wood types the gloss values decreased for both accelerated weathering times in four of the groups of heat-treated wood (130°C - 2 hours, 130°C - 8 hours, 180°C - 2 hours and 230°C - 8 hours) both decrease and increase were recorded in the other groups (Figure 4). This result can be explained by the sub-surface being exposed in the weathering, with washing of the surface destroying by the effect of heat treatment.

The gloss values of heating and weathering control specimens decreased compared to the natural control specimens. This can be explained by the darkening of colour, which occurred in the heat-treatment process (Akyildiz *et al*. 2009a, Akyildiz *et al*. 2009b, Ateş *et al.* 2009, Ateş *et al*. 2010). From this result, the maximum decrease in gloss has been obtained for black pine's control specimen for 230°C - 8 hours as 87,5%.

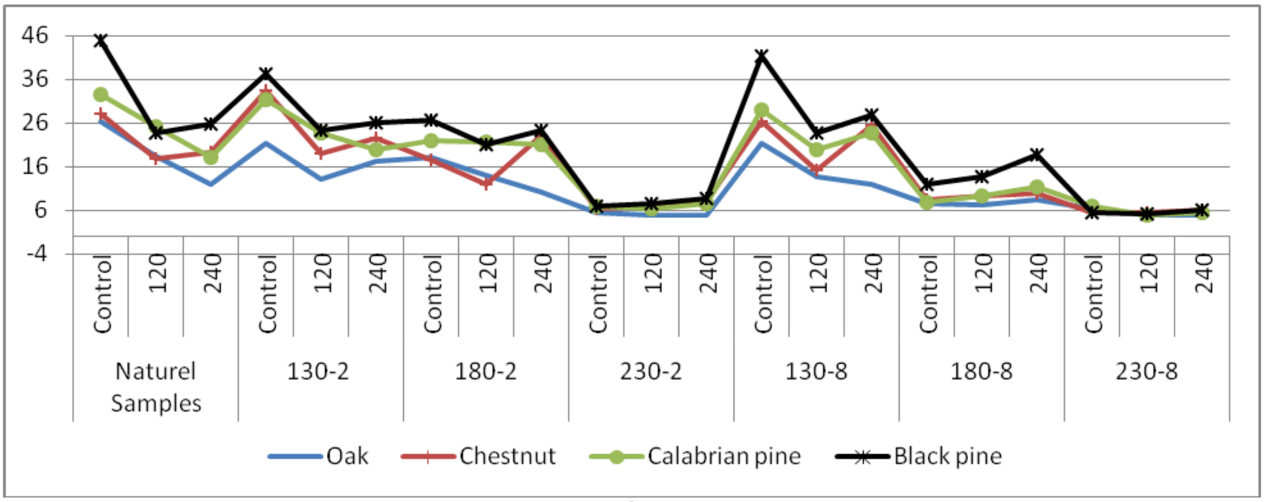

Fig. 4
The gloss values for all measurements.

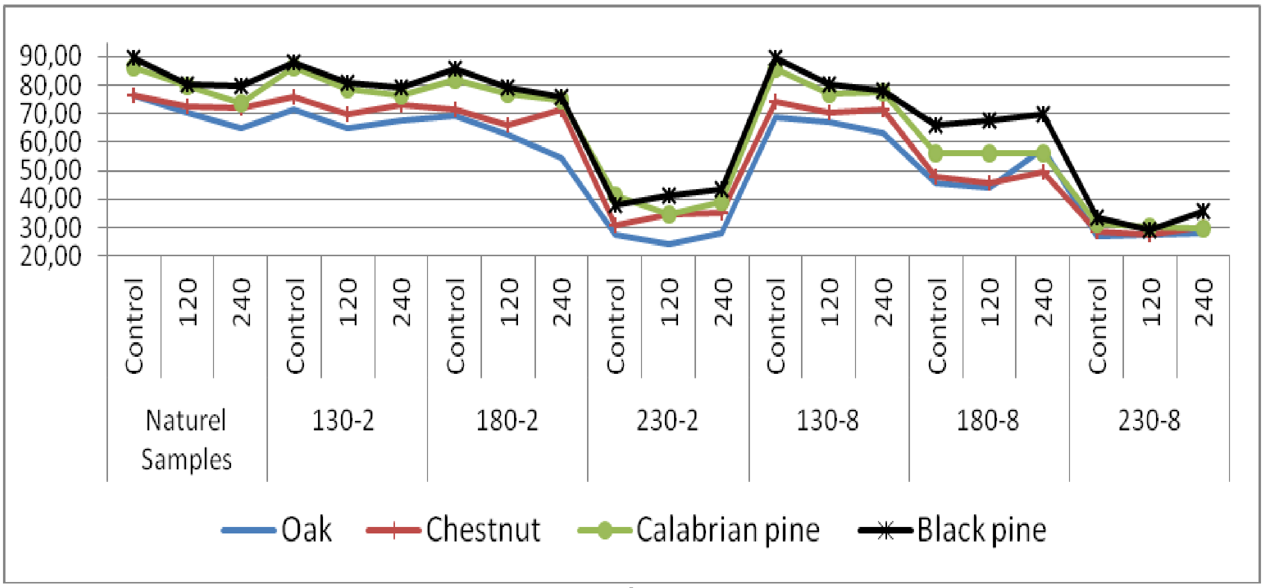

Fig. 5
The colour values for all measurements.

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pp. 729-738

Table 3

Total colour change values of heat-treated wood exposed to accelerated weathering

Species		Heat treatment temperature & time and Weathering time																				
		Natural			**130-2**			**180-2**			**230-2**			**130-8**			**180-8**			**230-8**		
		Control	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**	**Control**	**120**	**240**
Oak	X_{min}	75,89	69,88	60,26	70,26	60,46	64,00	67,90	60,96	51,45	26,94	24,26	27,01	67,35	65,59	61,22	44,44	41,69	54,21	26,28	25,55	26,84
	X_{max}	76,68	71,12	69,15	71,60	66,00	69,02	70,32	65,23	59,19	29,46	24,71	28,82	69,73	67,89	64,45	47,24	45,51	61,95	29,44	29,28	28,71
	±s	0,35	0,46	3,38	0,57	2,40	2,13	1,07	1,53	3,24	1,03	0,18	0,68	1,07	1,13	1,32	1,03	1,61	2,82	1,33	1,80	0,84
	$\overline{X}$	76,15	70,60	65,10	71,22	64,75	67,44	69,05	62,90	54,58	27,81	24,42	27,83	68,87	66,93	63,30	45,92	43,79	57,68	27,10	27,45	27,84
	Change (%)		-7,3	-14,5	**-6,5**	-9,1	-5,3	**-9,3**	-8,9	-21,0	**-63,5**	-12,2	0,1	**-9,6**	-2,8	-8,1	**-39,7**	-4,6	25,6	**-64,4**	1,3	2,7
Chestnut	X_{min}	75,43	71,65	71,06	74,66	69,03	72,93	70,84	64,97	70,83	30,20	32,68	34,18	73,38	69,25	70,49	45,33	44,61	46,74	28,30	27,23	29,26
	X_{max}	77,45	73,24	72,77	77,51	71,11	74,05	72,54	67,41	72,70	31,89	35,64	36,60	75,26	70,92	73,11	50,12	46,09	50,95	29,13	28,28	31,09
	±s	0,80	0,62	0,67	1,11	0,76	0,46	0,72	0,87	0,83	0,83	1,14	0,91	0,94	0,69	1,10	1,74	0,66	1,68	0,33	0,42	0,76
	$\overline{X}$	76,45	72,59	71,80	75,85	69,97	73,35	71,45	66,04	71,62	30,91	34,49	35,27	74,40	70,36	71,59	48,00	45,40	49,50	28,74	27,82	30,30
	Change (%)		-5,0	-6,1	**-0,8**	-10,8	-6,4	**-6,5**	-7,6	0,2	**-59,6**	11,6	14,1	**-2,7**	-5,4	-3,8	**-37,2**	-5,4	3,1	**-62,4**	-3,2	5,4
Calabrian pine	X_{min}	84,93	78,05	72,80	85,16	77,76	75,56	76,91	72,91	74,25	40,11	32,76	38,64	84,87	76,59	76,69	53,84	54,77	55,21	29,92	30,17	27,63
	X_{max}	87,45	81,49	74,90	87,29	79,39	77,96	84,19	78,18	75,36	42,54	37,66	39,98	88,13	77,63	79,08	57,33	57,76	57,34	32,17	30,97	33,36
	±s	0,99	1,28	0,87	0,94	0,68	0,91	2,89	2,17	0,42	1,00	1,86	0,49	1,33	0,43	0,96	1,34	1,43	1,06	0,93	0,32	2,36
	$\overline{X}$	86,46	79,57	73,63	86,26	78,69	76,61	82,00	76,70	74,96	41,05	34,80	39,27	85,98	76,89	77,59	55,95	56,11	56,14	31,54	30,45	29,50
	Change (%)		-8,0	-14,8	**-0,2**	-9,9	-12,3	**-5,2**	-6,5	-8,6	**-52,5**	-15,2	-4,3	**-0,6**	-10,6	-9,8	**-35,3**	0,3	0,3	**-63,5**	-3,4	-6,5
Black pine	X_{min}	89,05	79,66	77,83	87,16	80,00	77,48	85,36	78,68	74,99	36,25	38,78	41,19	88,49	79,38	77,16	64,18	65,92	68,76	32,28	27,29	35,12
	X_{max}	90,29	80,49	80,54	88,60	80,97	80,71	86,18	79,62	77,44	39,63	45,78	47,29	90,23	81,40	79,34	67,71	69,49	71,11	35,52	31,34	37,52
	±s	0,48	0,38	1,09	0,55	0,41	1,23	0,32	0,36	1,00	1,49	2,86	2,37	0,71	0,79	1,01	1,30	1,68	1,06	1,45	1,65	0,96
	$\overline{X}$	89,78	80,10	79,74	87,90	80,55	79,27	85,83	79,23	76,04	37,72	41,33	43,60	89,61	80,03	78,26	65,71	67,73	69,98	33,49	28,94	35,87
	Change (%)		-10,8	-11,2	**-2,1**	-8,4	-9,8	**-4,4**	-7,7	-11,4	**-58,0**	9,6	15,6	**-0,2**	-11,4	-13,3	**-26,8**	3,1	6,5	**-62,7**	-13,6	7,1

$\overline{X}$: average, ±s : standard deviation, [grey box] changing between natural control samples and heat-treated control samples

Total colour change values of accelerated weathering wood are given in Table 3. As shown in table 3, all the colour values, in general, decreased with increasing heat treatment temperature and time except for three groups (180°C - 8 hours, 230°C - 2 hours and 230°C - 8 hours) and so the colour became significantly darker compared with control samples. The results for these three groups can be explained by washing of the surface, in the weathering, destroying the effect of higher temperature and time of heat treatment (Fig. 5).

In natural wood species after accelerated weathering, the maximum darkening occurred for calabrian pine, for which the total colour change is 14,8%. The minimum colour change has been obtained, for chestnut at 120 hour weathering, as 5%.

Decrease in total colour change indicates darkening in the wood samples. The occurrence of total colour change for calabrian pine and black pine were explained by the different chemical composition rates of wood types (Karamanoğlu 2012). A decrease in ΔL indicates a darkening of the wood surfaces as lignin molecules are degraded into quinones by the combination of UV light, oxygen and water, while a progressive rise in ΔL corresponds to the whitening of the wood surface, as the dark coloured quinones are washed away exposing more white coloured cellulose molecules on the surface. Discolouration of wood is caused by changes in the carbonyl group of conjugated ketones, aldehydes and quinines resulting from modification of lignin and other wood components (Nzokou 2011). Also, Temiz *et al.* (2004) emphasized that, as the photodegedration of wood and the colour change of wood are affected by quinones at the surface, coniferous trees degraded faster than broad-leafed trees

The colour values of heat-treated control specimens decreased compared to the natural control specimens. Korkut and Kocaefe (2009) reported that the colour of wood became darker after heat treatment because of the oxidative and hydrolytic reactions of colour occurring during the heat-treatment.

CONCLUSION

Consequently, weathering differences between natural wood and heat-treated wood was not great for hardness, colour and gloss.

According to the experimental results, as shown in the Tables and Figures, while the hardness values for heat-treated wood increased at low heating temperature and time, they decreased with higher temperature and time. The hardness values for all species, after accelerated weathering, decreased compared to the control specimens. After weathering, the colour became darker and the gloss decreased, compared with their control samples. However, after long term weathering, the gloss and colour values increased for heat-treated wood exposed high temperature and time.

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