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EFFECT OF HEAT TREATMENT ON THE SURFACE OF SELECTED EXOTIC WOOD SPECIES

This study measured the effect of heat treatment according to the ThermoWood method on the colour and glossiness properties of selected exotic wood species. For this purpose, Afrormosia (Pericopsis elata), Doussie (Afzelia bipindensis), Frake (Terminalia superba) and Iroko (Chlorophora excelsa) were heat treated at 212°C for 1 hour and 2 hours using the ThermoWood method in Novawood Factory, Gerede, in Bolu, Turkey. After this process, the glossiness and colour of the untreated wood were tested in comparison with the heat-treated samples. The results show that the colour (L^*, a^* and b^*) and glossiness (parallel and perpendicular to the grain at 20°, 60° and 85° angles) were changed by the treatment. Generally the L^* and glossiness of the surface decreased and the ΔE^* and a^* increased with the intensity of the treatment.

Keywords: colour, exotic wood species, glossiness, heat treatment, ThermoWood

Introduction

Wood modification procedures are now well-established. These processes improve wood properties such as the dimensional stability or durability against several wood-destroying microorganisms, insects or marine borers, depending on the process. Some of these processes have already reached a commercial phase and a few are in full production. According to Militz [2015], the production of modified wood in Europe is estimated at approx. 400 000 m^3. The main proportion is attributed to heat-treated wood with a total of ca 300 000 m^3. This makes heat treatment the most popular wood modification procedure. Of the different heat treatment processes, the most widespread is ThermoWood®, commercialized in two standard treatment classes, Thermo-S and Thermo-D. The first one is a treatment administered at lower temperatures and is intended to

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mainly impart [S]tability, while the second one is administered at higher temperatures and is meant to impart [D]urability. Both treatments are applied to softwoods and hardwoods, although Thermo-D is only applied to hardwoods when a darker colour is needed. Heat treatment has been mentioned earlier in the literature as a good method for changing wood colour, replacing the use of solvent-borne finishes which have seen a reduction in their use mainly in the furniture sector [Fonseca 2004]. The biggest advantages of heat-induced colour change are, firstly, the homogeneity obtained throughout the thickness of the board allowing further machining without compromising the colour of the surface, and secondly the darker colour which masks many blemishes and discolorations, as stated by González-Peña and Hale [2009].

The change in colour following heat treatment has been attributed to numerous factors, all of them linked to chemical changes due to thermal degradation. Sundkvist [2002] and Sehlstedt-Persson [2003] attributed colour changes to the formation of coloured degradation products from hemicelluloses, proposing the change was due to a hydrolysis reaction similar to a Maillard reaction, a familiar process in the food industry, while Sundqvist and Morén [2002] attributed the changes to extractives. Colour changes have also been attributed to oxidation products, such as quinines, that are formed during heat treatment [Tjeerdsma et al. 1998; Mitsui et al. 2001; Bekhta and Niemz 2003; Sehlstedt-Persson 2003]. According to González-Peña and Hale [2009], colour changes are probably more linked to changes in the acid-insoluble lignin than in the carbohydrate fraction.

Glossiness is an important property in furniture production because it influences light reflection from the surface. Changes in glossiness due to heat treatment have been reported in the last few years. Generally, glossiness decreases following heat treatment, which has been found for Scots pine [Aksoy et al. 2011], and wild cherry [Korkut et al. 2013], as well as Anatolian black pine, Calabrian pine, Sessile oak and Chestnut wood [Karamanoglu and Akyildiz 2013]. Bekhta et al. [2014] reported an increase in glossiness when heat treatment is combined with densification, with the increase being attributed to densification rather than to the heat treatment. Glossiness measured along the grain was reported to be higher than that measured across the grain.

Exotic wood species are used to produce high quality furniture but, sometimes, boards from the same species have a very different colour which is disadvantageous. With heat treatment these differences are mitigated. In this research the aim was to investigate the changes in the lightness (L^*), a^* and b^* colour parameters, total colour (ΔE^*) and glossiness (parallel and perpendicular to the grain at 20°, 60° and 85° angles) of selected exotic wood species, such as Afrormosia (*Pericopsis elata*), Doussie (*Afzelia bipindensis*), Frake (*Terminalia superba*) and Iroko (*Chlorophora excelsa*), following heat treatment using the ThermoWood method.

Materials and methods

Afrormosia (*Pericopsis elata*), Doussie (*Afzelia bipindensis*), Frake (*Terminalia superba*) and Iroko (*Chlorophora excelsa*) exotic wood species were obtained from Duzce industrial zone. The dimensions of the samples used for colour and glossiness measurements were 100 mm by 100 mm by 10 mm (longitudinal × tangential × radial). After being cut, the wood samples were conditioned to 12% MC (moisture content) in a climatic chamber at a temperature of 20 ±2°C and 65% (±5) RH (relative humidity) [ISO 554: 1976].

The samples were then treated using the ThermoWood® method in Novawood Factory located in Gerede, Bolu, Turkey. For the ThermoWood process the wood is placed inside an autoclave and heated to a temperature of at least 180°C using steam as shielding gas. The process is divided into three main phases. The first one consists of a temperature increase and high-temperature drying using heat and steam. The kiln temperature is raised rapidly to a level of ca 100°C. The temperature is then increased steadily up to 130°C, during which high-temperature drying takes place and the moisture content of the wood decreases to nearly zero. The second phase is the actual heat treatment where the temperature inside the kiln is increased to between 185°C and 215°C and generally kept at this temperature for 2-3 hours. The exotic wood samples were treated at 212°C for 1 h and 2 h in accordance with the programme used in the factory. After the treatment, the samples were cooled and conditioned to the final moisture content of approximately 4-7% [Anonymous 2003].

The colour of the Afrormosia (*Pericopsis elata*), Doussie (*Afzelia bipindensis*), Frake (*Terminalia superba*) and Iroko (*Chlorophora excelsa*) exotic wood species heat-treated samples and untreated controls were analysed using a spectrophotometer (Datacolour 110, Datacolour Technology Suzhou Co., Ltd., China) with a wavelength resolution of 10 nm, measurement geometry of D/8°, and a D65 standard illuminant. The colour parameters were measured in the centre of the samples using ten replicates for each heat-treated sample and untreated control and an average value was reported. The CIE $L^*a^*b^*$ system was used to describe the colour parameters and changes from untreated to heat-treated wood. This system is characterized by three parameters, L^*, a^*, and b^*. The L^* axis represents lightness varying from 100 (white) to zero (black), $+a^*$ is the red, $-a^*$ green, $+b^*$ yellow and $-b^*$ blue [Zhang et al. 2009]. The corresponding variations ΔL^*, Δa^* and Δb^* with heat treatments were calculated using the untreated control as a reference
($\Delta L^* = L^*_{\text{heat-treated}} - L^*_{\text{ref}}$, $\Delta b^* = b^*_{\text{heat-treated}} - b^*_{\text{ref}}$, $\Delta a^* = a^*_{\text{heat-treated}} - a^*_{\text{ref}}$).

The total colour difference (ΔE^*) between the heat-treated samples and untreated controls was calculated using equation 1.

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

The glossiness, parallel and perpendicular to the grain of all the untreated (control) and heat-treated wood species were analysed using a gloss meter (Novo-Gloss Trio, Rhopoint Instruments Ltd., UK) at 20°, 60° and 85° in accordance with ISO 2813:1994. The SPSS 17 Software Package programme was used for statistical evaluation. A two-way ANOVA with an F-test (Fisher-Snedecor distribution) was used in order to test if the main effects were both significant (wood species and heat treatment), that is, to know if the species and the heat treatment were all equal, and did not interact with each other.

Results and discussion

Table 1 presents the minimum and maximum values, homogeneity groups, averages and standard deviations for the L^*, a^* and b^* values of the untreated and heat-treated wood species. Before the treatment, Frake presented a significantly higher lightness than the other species (80.6), followed by Doussie (58.3), Iroko (57.5) and Afrormosia (54.3). Only Doussie and Iroko were not statistically different from each other. In relation to redness (a^*), the highest value belonged to Doussie, followed by Afrormosia, Iroko and Frake, all considered statistically different. The yellow tone (b^*) was similar for Iroko (26.9), Afrormosia (26.7) and Doussie (26.6), only being statistically different to the value obtained for Frake (24.0).

As expected, the L^* decreased for all of the treated wood samples and the magnitude of the decrease was generally greater for the wood treated for longer time periods, as stated earlier in the literature regarding *Pinus Pinaster* and *Eucalyptus globulus* [Esteves et al. 2007], *Fagus orientalis* [Ayata et al. 2017] and Scots pine [Gurleyen et al. 2017]. Nevertheless, the difference between the untreated and heat-treated wood was much higher than between the samples treated for 1 h and 2 h. The decrease in the L^*, which represents a darkening of the wood surface, was greater for Frake, followed by Iroko, Doussie and Afrormosia. The largest decreases were possibly due to the initial lightness of the samples because Frake (80.62) has a significantly higher lightness than the other species. The final L^* values ranged between 41.5 and 48.5 for Afrormosia and Frake, respectively. This means that the differences between the species were mitigated by the heat treatment since the heat-treated samples had a similar lightness despite being from different species. This is confirmed by the statistical analysis. While all of the control samples had a significantly different lightness compared to each other, this did not happen for the heat-treated wood where the heat-treated (2 h) lightness for Afrormosia and Iroko were not significantly different. The same was true for Doussie and Frake although treated for different time periods. These results are in accordance with the results presented previously for different , such as Spruce [Bekhta and Niemz 2003], Anatolian black pine, Calabrian pine, Sessile oak and Chestnut wood [Karamanoglu and Akyildiz 2013].

Table 1. L^*, a^* and b^* values for untreated and heat treated samples

	Exotic wood species	Durations	Mean	HG	Standard deviation	Minimum	Maximum
L^*	Afrormosia (*Pericopsis elata*)	control	54.29	C	0.85	53.10	55.37
		212°C – 1 h	44.06	F	0.30	43.77	44.76
		212°C – 2 h	41.46	G	1.89	38.53	43.21
	Doussie (*Afzelia bipindensis*)	control	58.26	B	1.66	56.40	60.40
		212°C – 1 h	47.45	E	2.29	44.53	51.05
		212°C – 2 h	44.38	F	1.45	42.55	47.00
	Frake (*Terminalia superba*)	control	80.62	A*	0.74	79.43	81.96
		212°C – 1 h	49.46	D	0.90	48.26	50.85
		212°C – 2 h	48.50	DE	1.15	46.43	49.66
	Iroko (*Chlorophora excelsa*)	control	57.53	B	0.19	57.14	57.79
		212°C – 1 h	42.37	G	1.07	40.31	43.67
		212°C – 2 h	42.47	G	1.00	40.34	43.80
a^*	Afrormosia (*Pericopsis elata*)	control	11.36	F	0.17	11.02	11.59
		212°C – 1 h	11.83	DE	0.22	11.42	12.19
		212°C – 2 h	12.14	CD	0.35	11.69	12.68
	Doussie (*Afzelia bipindensis*)	control	15.67	A*	0.78	14.50	16.57
		212°C – 1 h	13.58	B	0.28	13.05	13.85
		212°C – 2 h	13.85	B	0.41	13.37	14.56
	Frake (*Terminalia superba*)	control	2.28	I	0.21	1.89	2.63
		212°C – 1 h	11.40	F	0.27	10.91	11.79
		212°C – 2 h	10.73	G	0.37	10.15	11.20
	Iroko (*Chlorophora excelsa*)	control	9.00	H	0.23	8.54	9.26
		212°C – 1 h	12.38	C	0.27	11.92	12.77
		212°C – 2 h	11.76	E	0.47	11.24	12.47
b^*	Afrormosia (*Pericopsis elata*)	control	26.68	A	0.66	25.95	27.93
		212°C – 1 h	20.44	E	0.49	19.45	21.03
		212°C – 2 h	19.26	F	1.49	16.88	20.74
	Doussie (*Afzelia bipindensis*)	control	26.51	A	0.43	25.89	27.10
		212°C – 1 h	25.18	B	1.53	22.97	27.15
		212°C – 2 h	23.51	D	1.11	22.01	25.31
	Frake (*Terminalia superba*)	control	23.98	CD	0.48	23.20	24.74
		212°C – 1 h	26.10	A	0.61	25.51	27.30
		212°C – 2 h	24.55	BC	0.52	24.01	25.54
	Iroko (*Chlorophora excelsa*)	control	26.87	A*	0.32	26.34	27.43
		212°C – 1 h	21.09	E	1.49	19.05	22.72
		212°C – 2 h	20.43	E	0.87	19.45	22.25

HG – homogeneous group.
N – number of measurements.

Several studies refer to the reddening of the wood surface due to heat treatment, which means an increase in a^* [Mitsui et al. 2001; Aksoy et al. 2011; Korkut et al. 2013] while other studies mentioned the opposite [Korkut et al. 2013; Guller 2014]. This shows that probably the reddening of the surface depends on the initial wood colour. Most of the species studied, presented an increase in a^*, however, for Doussie there was a small decrease in a^* after the heat treatment. Guller [2014] reported a decrease in a^* in heat-treated *Pinus nigra* which is in accordance with the results found for Doussie. The b^* parameter has often a higher variance, which is the case for the samples presented here. Although most of the samples showed a decrease in b^*, the differences were small and there was even a slight increase for the heat-treated Frake.

The colour changes (ΔL^*, Δa^*, Δb^* and ΔE^*) for the untreated and heat--treated wood at 212°C for 1 hour and 2 hours are shown in table 2. The ΔE^* values in table 2 show that the highest colour changes due to heat treatment were found in Frake, while the smallest colour changes were in Afrormosia and Doussie. The ΔE^* values were strongly influenced by the decrease in lightness which was much larger in Frake. The changes in ΔE^* were considered by González-Peña and Hale [2009] to be associated with the generation of chromophoric groups, mainly of quinone species.

Table 2. Colour changes (ΔL^*, Δa^*, Δb^* and ΔE^*) from untreated to heat-treated woods at 212°C for 1 and 2 h

Exotic wood species	Durations	ΔL^*	Δa^*	Δb^*	ΔE^*
Afrormosia (*Pericopsis elata*)	212°C – 1 h	-10.23	0.47	-6.24	11.99
	212°C – 2 h	-12.83	0.78	-7.42	14.84
Doussie (*Afzelia bipindensis*)	212°C – 1 h	-10.81	-2.09	-0.71	11.03
	212°C – 2 h	-13.88	-1.82	-3.00	14.32
Frake (*Terminalia superba*)	212°C – 1 h	-31.16	9.12	2.12	32.54
	212°C – 2 h	-32.12	8.45	0.57	33.22
Iroko (*Chlorophora excelsa*)	212°C – 1 h	-15.16	3.38	-5.78	16.57
	212°C – 2 h	-15.06	2.76	-6.44	16.61

The analysis of variance for L^*, a^* and b^* is presented in table 3. The results show that the L^*, a^* and b^* values were significantly different for Wood species (A), Heat treatment (B) and Interaction (AB), according to the level of significance ($p < 0.05$). That is, the wood species were not all equal, and neither were the heat treatments. The wood species did not interact with the heat treatment. This means that the heat treatment to impart a darker colour in the wood has to be tailored to each species.

Table 3. Variance analysis for L^*, a^* and b^*

	Factors	Sum of squares	Degree of freedom	Mean square	F number	Level of significance ($p < 0.05$)
L^*	Wood species (A)	3163.426	3	1054.475	653.824	0.000*
	Heat treatment (B)	8368.159	2	4184.079	2594.324	0.000*
	Interaction (AB)	1816.403	6	302.734	187.709	0.000*
	Error	174.181	108	1.613		
	Corrected Total	13522.169	119			
a^*	Wood species (A)	591.018	3	197.006	1427.548	0.000*
	Heat treatment (B)	184.905	2	92.453	669.932	0.000*
	Interaction (AB)	424.770	6	70.795	512.995	0.000*
	Error	14.904	108	0.138		
	Corrected Total	1215.598	119			
b^*	Wood species (A)	196.408	3	65.469	73.833	0.000*
	Heat treatment (B)	347.298	2	173.649	195.831	0.000*
	Interaction (AB)	290.413	6	48.402	54.585	0.000*
	Error	95.767	108	0.887		
	Corrected Total	929.885	119			

*Significant at 95% confidence level.

The perpendicular (⊥) and parallel (||) glossiness at 20°, 60° and 85° angles is shown in table 4. The surface of the untreated Frake samples presented the highest gloss at 20° and 60° (2.72 and 4.30), followed by Doussié, Afrormosia and Iroko. Statistically, Doussié and Afrormosia have a similar gloss. In general, both the parallel (||) and perpendicular (⊥) glossiness decreased following heat treatment and the magnitude of the decrease was generally greater for longer treatment times, apart from in some cases, such as in the case of the perpendicular glossiness for Frake and Iroko at 20°, or Iroko at 60° and 85°. An increase was observed in the glossiness for Doussie between the control and 1 hour sample, while a decrease was noted between the 1 hour and 2 hour samples.

This is in accordance with results presented previously for Frake [Korkut 2012], Scots pine [Aksoy et al. 2011], wild cherry [Korkut et al. 2013], Anatolian black pine, Calabrian pine, Sessile oak and Chestnut wood [Karamanoglu and Akyildiz 2013]. The magnitude of the increase, however, was different for each species. The biggest decrease was found for Frake, followed

Table 4. Perpendicular (⊥) and parallel (||) glossiness at 20°, 60° and 85° angles

Wood species type	Durations		Mean	HG	Std. deviation	Minimum	Maximum		Mean	HG	Std. deviation	Minimum	Maximum
Afrormosia (*Pericopsis elata*)	control	20° ⊥	1.49	B	0.07	1.40	1.60	20° ||	1.20	C	0.12	1.00	1.40
	212°C – 1 h		0.87	E	0.07	0.80	1.00		0.75	F	0.05	0.70	0.80
	212°C – 2 h		0.85	EF	0.07	0.70	0.90		0.69	FG	0.06	0.60	0.80
Doussie (*Afzelia bipindensis*)	control		1.52	B	0.12	1.30	1.70		1.39	B	0.10	1.30	1.60
	212°C – h		1.26	C	0.07	1.10	1.30		1.05	D	0.12	0.80	1.20
	212°C – h		1.04	D	0.07	1.00	1.20		0.91	E	0.06	0.80	1.00
Frake (*Terminalia superba*)	control		2.72	A*	0.09	2.60	2.90		2.47	A*	0.08	2.30	2.60
	212°C – 1 h		1.27	C	0.22	1.00	1.50		1.04	D	0.13	0.90	1.20
	212°C – 2 h		1.30	C	0.12	1.10	1.40		1.06	D	0.12	0.90	1.20
Iroko (*Chlorophora excelsa*)	control		1.30	C	0.08	1.20	1.40		1.21	C	0.06	1.10	1.30
	212°C – 1 h		0.72	G	0.09	0.60	0.80		0.63	G	0.05	0.60	0.70
	212°C – 2 h		0.77	FG	0.12	0.60	0.90		0.74	F	0.11	0.60	0.90
Afrormosia (*Pericopsis elata*)	control	60° ⊥	3.02	C	0.18	2.80	3.30	60° ||	4.40	BC	0.55	3.50	5.10
	212°C – 1 h		2.32	D	0.98	1.60	4.90		2.27	HI	0.37	1.80	2.70
	212°C – 2 h		2.17	D	0.37	1.70	2.60		1.99	I	0.30	1.70	2.50
Doussie (*Afzelia bipindensis*)	control		3.41	BC	0.68	2.40	4.20		4.11	CD	0.68	3.30	4.90
	212°C – 1 h		3.61	B	0.48	3.10	4.40		4.69	B	0.71	3.40	5.40
	212°C – 2 h		3.29	BC	0.19	2.90	3.50		3.68	DE	0.41	2.90	4.20
Frake (*Terminalia superba*)	control		4.30	A*	0.26	4.00	4.90		5.21	A*	0.43	4.60	6.00
	212°C – 1 h		2.45	D	0.46	1.70	2.90		3.12	F	0.76	2.20	4.20
	212°C – 2 h		2.44	D	0.19	2.10	2.70		2.88	FG	0.41	2.30	3.50
Iroko (*Chlorophora excelsa*)	control		2.98	C	0.27	2.40	3.20		3.22	EF	0.42	2.80	3.90
	212°C – 1 h		2.01	D	0.44	1.30	2.50		2.09	HI	0.42	1.50	2.80
	212°C – 2 h		2.08	D	0.65	1.30	3.00		2.51	GH	0.69	1.50	3.30
Afrormosia (*Pericopsis elata*)	control	85° ⊥	1.71	CD	0.17	1.50	2.00	85° ||	8.03	A	1.20	6.30	9.70
	212°C – 1 h		1.40	DE	0.25	1.00	1.80		2.26	E	0.95	1.10	3.50
	212°C – 2 h		1.61	CD	0.21	1.30	1.90		2.06	E	0.59	1.50	3.40
Doussie (*Afzelia bipindensis*)	control		2.64	A	0.33	2.10	3.20		6.89	B	1.50	4.90	9.20
	212°C – 1 h		2.79	A*	0.40	2.30	3.40		8.60	A*	2.24	3.90	11.40
	212°C – 2 h		2.58	A	0.27	2.00	2.90		5.73	C	1.10	3.90	7.50
Frake (*Terminalia superba*)	control		1.44	D	0.11	1.30	1.60		1.84	E	0.27	1.50	2.30
	212°C – 1 h		1.11	E	0.21	0.80	1.30		1.50	E	0.54	0.90	2.30
	212°C – 2 h		1.11	E	0.03	1.10	1.20		1.23	E	0.21	0.90	1.60
Iroko (*Chlorophora excelsa*)	control		2.66	A	0.34	2.20	3.10		4.74	C	1.23	3.20	6.70
	212°C – 1 h		1.87	BC	0.47	1.20	2.40		3.43	D	1.47	2.10	6.30
	212°C – 2 h		2.11	B	0.62	1.30	3.10		4.66	C	1.81	1.80	6.80

HG – homogeneous group. N – number of measurements.

Table 5. Results of the variance analysis for perpendicular (⊥) and parallel (||) glossiness at 20°, 60° and 85°

	Factors	Sum of squares	Degree of freedom	Mean square	F number	Level of significance ($p < 0.05$)
20° ⊥	Wood species (A)	11.956	3	3.985	349.068	0.000*
	Heat treatment (B)	14.932	2	7.466	653.964	0.000*
	Interaction (AB)	4.669	6	0.778	68.163	0.000*
	Error	1.233	108	0.011		
	Corrected Total	32.790	119			
60° ⊥	Wood species (A)	22.585	3	7.528	31.429	0.000*
	Heat treatment (B)	20.920	2	10.460	43.667	0.000*
	Interaction (AB)	12.513	6	2.086	8.706	0.000*
	Error	25.870	108	0.240		
	Corrected Total	81.888	119			
85° ⊥	Wood species (A)	37.762	3	12.587	121.128	0.000*
	Heat treatment (B)	2.315	2	1.157	11.137	0.000*
	Interaction (AB)	2.427	6	0.404	3.892	0.001*
	Error	11.223	108	0.104		
	Corrected Total	53.726	119			
20° ||	Wood species (A)	8.562	3	2.854	335.022	0.000*
	Heat treatment (B)	13.402	2	6.701	786.610	0.000*
	Interation (AB)	4.714	6	0.786	92.227	0.000*
	Error	0.920	108	0.009		
	Corrected Total	27.597	119			
60° ||	Wood species (A)	47.184	3	15.728	55.152	0.000*
	Heat treatment (B)	48.800	2	24.400	85.560	0.000*
	Interation (AB)	30.457	6	5.076	17.800	0.000*
	Error	30.799	108	0.285		
	Corrected Total	157.239	119			
85° ||	Wood species (A)	462.732	3	154.244	99.838	0.000*
	Heat treatment (B)	81.841	2	40.920	26.487	0.000*
	Interation (AB)	202.414	6	33.736	21.836	0.000*
	Error	166.853	108	1.545		
	Corrected Total	913.839	119			

*Significant at 95% confidence level.

by Iroko, probably due to the higher gloss of the untreated samples in the case of Frake. The treatments lasting 1 h and 2 h were not, in most cases, statistically different in relation to the gloss.

On average, the parallel glossiness (along the grain) was higher than the perpendicular glossiness (across the grain), and the differences were greater for higher angles. Similar results were presented by Bekhta et al. [2014]. In most of the cases the decrease in glossiness was higher for the parallel glossiness, meaning that the differences between the parallel and perpendicular glossiness were reduced.

The results of the analysis of variance for the parallel (||) and perpendicular (⊥) glossiness at 20°, 60° and 85° are presented in table 5. The values for the parallel (||) and perpendicular (⊥) glossiness at 20°, 60° and 85ºangles were found to be significant for Wood species (A), Heat treatment (B) and Interaction (AB), according to the level of significance ($p < 0.05$). This means that the wood species and the heat treatments were not all equal in relation to the gloss and that the wood species did not interact with the heat treatment. In relation to the glossiness at an angle of 85°, all the parallel (||) and perpendicular (⊥) glossiness was found to be significant for Wood species (A), Interaction (AB) and Heat treatment (B). The lowest level of significance (0.001) was obtained for Interaction (AB) in the perpendicular (⊥) glossiness at 85°. Nevertheless, this is probably due to the high dispersion of the results at this angle. Once again, these results show that the treatment was different for each species.

Conclusions

Overall, the L^* decreased, representing a darkening of the wood surface. This decrease was greater for Frake, followed by Iroko, Doussie and Afrormosia. Most of the species studied presented an increase of a^*, however, for Doussie there was a small decrease. The greatest changes in colour due to the heat treatment were in Frake, while the smallest colour changes were in Afrormosia and Doussie. Generally, both parallel (||) and perpendicular (⊥) glossiness decreased following the heat treatment and the magnitude of the decrease was greater for longer treatment times. The results show that heat treatment is efficient in changing the colour of wood and that this method can be used to reduce the use of stains by the industry. Statistical analysis has proven that heat treatment to impart a darker colour in wood has to be tailored to each species.

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