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Ayous Wood (*Triplochiton scleroxylon* K. Schum) physical characterisation after three different cycles of heat treatment†

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Abstract: Thermally modified wood has an increasing interest in exteriors due to its longer service life and attractive appearance. This work evaluates the influence of the thermal modification cycle on the physical properties of ayous wood (*Triplochiton scleroxylon* K. Schum). Ayous planks were dried and then thermally treated for 6 hours in a conventional oven at 180 °C, 190 °C, and 215 °C. The samples obtained were characterised for density, basic density, shrinkage and shrinkage anisotropy coefficient, and colour. Data were collected in accordance with the UNI ISO reference standards. The results of this study showed that wood density decreased by 10%, 14%, and 20%; the basic density decreased by 10%, 18%, and 22%; the tangential shrinkage decreased by 17%,29%, and 53%; the radial shrinkage decreased by 6%, 14%, and 50%; and the volumetric shrinkage decreased by 13%, 51%, and 80%; these values are referred, respectively, to 180 °C, 190 °C, and 215 °C modification cycles. Thermo treatment is confirmed an interesting process to enhance wood stability in outdoor use.

Keywords: Wood modification; Thermal modification; Heat treatment; *Triplochiton scleroxylon*; Physical properties; Colour variations

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1. Introduction

Thermal modification is widely considered a key to improving some interesting characteristics of wood as a substitute for toxic chemical compounds, in particular for outdoor uses. This is due to the improvement of the dimensional stability and the natural durability of the material as consequences of the reduction of its hygroscopicity. On the other hand, the process influences the colour of the material, subjected to increasing darkening with increasing temperature and time, and negatively affects its mechanical properties [1,2]. Although the results of natural weathering processes differ from those of artificial weathering tests, they are useful to understand the variation trends. It has been observed that with increasing exposure times to leaching and radiation simulating sunlight, the surface of untreated samples darkens, while heat-treated samples lighten [3]. The thermal modification of wood materials is usually performed in the range of temperatures between 180 °C and 260 °C. With temperatures below 140 °C the changes are very limited, while temperatures higher than 260 °C, produce an intense degradation of the material [4]. The effects of the heat treatment on wood are mainly related to the alteration of the cell wall compounds, in particular of the hemicelluloses. In fact, hemicelluloses are the most hydrophilic and easily degraded compounds of the cell wall. During heat treatment they were transformed into a hydrophobic network within the lignin-carbohydrates-complex which consequent improvement of dimensional stability and hygroscopicity [5]. The thermal modification cycle has a great influence on the material properties. This work aims to evaluate the effect of the treatment temperature on the physical properties of a tropical hardwood.

2. Materials and methods

2.1. Samples preparation

The samples were obtained from untreated ayous wood planks (*Triplochiton scleroxylon* K. Schum) coming from Cameroon. After drying, the planks have been heat treated for 6 hours using a ventilated oven (BINDER series FD) under atmospheric pressure at 180 °C, 190 °C and 215 °C, respectively; after the treatment, each plank was left to cool down slowly for 24 hours. After cooling and equilibration to environmental conditions (20 °C and 60% of relative humidity), the planks were cut to obtain the test samples in accordance with the reference standard ISO 3129 [6].

2.2. Wood density and basic density

The samples used to determine wood density and basic density were 20x20x30 mm. For each treatment cycle, 20 samples were collected, for a total of 60. The moisture content of the test pieces was determined following the reference standard UNI ISO 13061-1 and the test was performed in accordance with the reference standard UNI ISO 13061-2 [7,8].

2.3. Wood shrinkage

To determine the shrinkage of ayous wood, 20x20x30 mm samples were used and the adopted procedure followed the reference standard ISO 13061-13 [9]. For each treatment cycle, 20 samples were collected, for a total of 60. The shrinkage anisotropy factor was obtained as the ratio between tangential and radial shrinkage.

2.4. Colour

The dimension of the samples used for colour characterisation was 50x10x300 mm, and the experimental design was in accordance with the reference standard UNI EN ISO CIE 11664-4 [10]. The points of colour measurement were 17 for each specimen. Two measures were acquired for each point, so that 34 measures were obtained for each specimen. Considering the three thermally modified specimens, 102 colour measurements were taken in total. Average values have been considered for each specimen.

2.5. Statistical analysis

Data were analyzed using Statistica TM version 7.1 (TIBCO Software Inc., Palo Alto, CA, USA). At first, data normality was checked by Kolmogorov-Simonov's test, and homogeneity of variances was checked by Levene's test. The means of parameters were compared by ANOVA and Tuckey test was performed.

3. Results

3.1. Wood density and basic density

The results of these tests are presented in Table 1. Both wood density and basic density showed a greater reduction at higher treatment temperature. These data show a percentage reduction in wood density of 10%, 14%, and 20% and a reduction of 10%, 18%, and 22% in basic density, respectively for the treatment temperatures 180 °C, 190 °C, and 215 °C, if compared to the results obtained in a similar study on untreated ayous wood [11]. The ANOVA test (Figure 1) showed that the treatment temperatures significantly influenced both density (P-value = 0.00003) and basal density (P-value = 0.0001) while the Tukey's test indicated that the 180 °C treatment constituted a separate grouping.

Table 1. Wood density and basic density of heat treated ayous wood

Temperature	Sample N.	Wood density (g/cm³)		Basic density (g/cm³)	
		Mean	St. Dv.	Mean	St. Dv.
180 °C	20	0.40	0.06	0.34	0.05
190 °C	20	0.36	0.01	0.31	0.01
215 °C	20	0.34	0.01	0.29	0.01

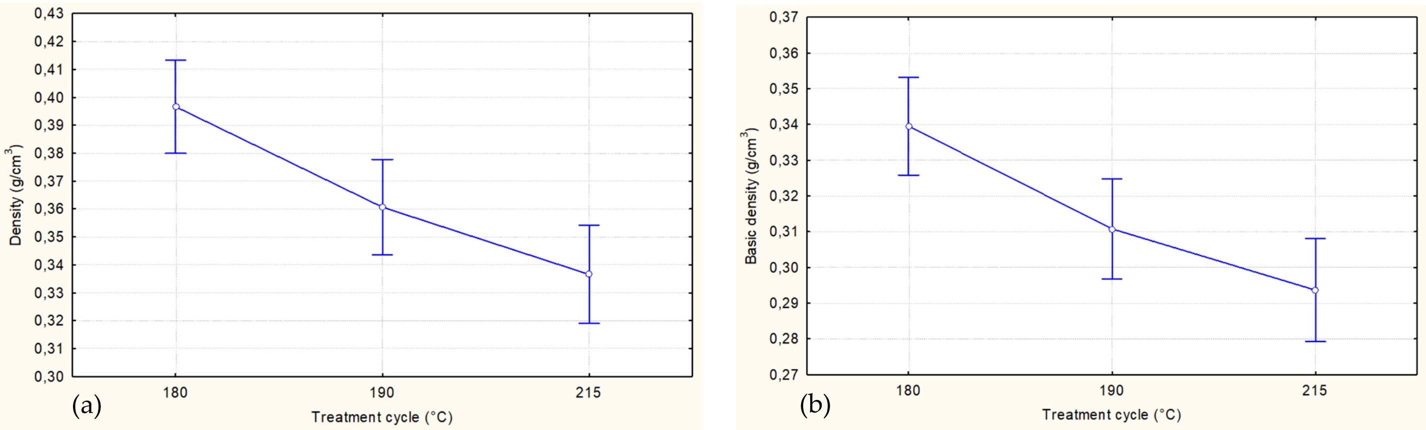

Figure 1. Results of the ANOVA test for density (a) and basic density (b) of ayous wood after three different heat-treatment cycles [P-values: (a) 0.00003; (b) 0.0001]

3.2. Wood shrinkage

Table 2 shows the results obtained for the linear and volumetric shrinkage of heat treated ayous wood for each modification cycle. Compared to the linear and volumetric shrinkage of untreated ayous wood, there is a percentage reduction in radial shrinkage of 6%,14%, and 50%; a reduction of 17%, 29%, and 53% of the tangential shrinkage; and a reduction of 13%, 51%, and 80% in volumetric shrinkage respectively for the temperatures 180 °C, 190 °C, and 215 °C [11].

Table 2. Linear and volumetric shrinkage of heat treated ayous wood

		180 °C		190 °C		215 °C	
	Sample N	Mean	St. Dv.	Mean	St. Dv.	Mean	St. Dv.
Radial (%)	20	2.6	0.5	2.4	0.3	1.4	0.2
Tangential (%)	20	4.1	0.5	3.5	0.2	2.4	0.2
Volumetric (%)	20	6.6	1.0	5.8	0.4	3.7	0.3

3.3. Colour

Table 3 provides an overview of the data from the colour characterisation of heat treated ayous wood subjected to three different thermal modification cycles. The CIELab colour space parameters L*, a*, and b* for each treatment cycle are reported. The L* parameter is the colour lightness, while the a* parameter, when positive, is the red component and the positive b* parameter is the yellow component.

Table 3. CIELab colour coordinates of heat treated ayous wood

	L*		a*		b*	
	Mean	**St.Dv.**	**Mean**	**St.Dv.**	**Mean**	**St.Dv.**
Untreated	73.08	1.23	7.39	0.37	27.88	0.65
180 °C	57.42	1.66	11.44	0.40	27.96	0.78
190 °C	56.03	1.74	11.84	0.35	27.33	0.58
215 °C	39.29	2.39	10.60	0.70	19.53	1.64

The colour differences between untreated and heat treated ayous wood are presented in Table 4. Data about colour of untreated ayous wood are reported in the literature [3]. The observed decrease in L* and b* parameters with higher treatment temperature could be interpreted as a reduction in colour lightness and yellow component of the colour, while the red component increases.

This is due to the darkening caused by heat treatment; overall, these results indicate that at higher treatment temperatures wood darkening increases.

Table 4. Colour differences between untreated and heat treated ayous wood

	ΔL*	**Δa***	**Δb***	**ΔE***
180 °C	-12.79	0.56	3.80	13.35
190 °C	-14.17	0.64	4.20	14.79
215 °C	-30.91	1.29	2.96	31.08

4. Discussion

The observed reduction of wood density results from the effect of the modification cycle on the cell wall components, particularly on hemicelluloses and amorphous regions of cellulose, that are more susceptible to thermal degradation [12]. Furthermore, hemicelluloses are the most hydrophilic among the cell wall components and their thermal degradation results in the reduction of wood hygroscopicity due to less available bonding sites for water molecules [5]. This leads to an increase in dimensional stability, as highlighted from the reported findings about wood shrinkage, that are in line with those obtained by other authors both in studies regarding the general influence of heat treatment on wood properties and about the influence of heat treatment focusing on poplar wood, which is often considered as a substitute of ayous wood [1,12,13]. Moreover, low wood hygroscopicity leads to an improvement of material durability due to the reduction of the effect of water as a degradation factor and its ability to favor biological attacks [12] . Besides, the thermal modification influences the colour of the heat-treated wood. The colour becomes darker with the increase of treatment temperature and time, and this is attributed to the products formed by the degradation of hemicelluloses, to the present extractives, and to the formation of quinones as oxidation products [5,14,15]. Also in this case, the here reported findings are in line with the observations of other authors both regarding the general influence of the thermal modification and about heat-treated poplar wood colour variations [1,12,13].

5. Conclusion

The results reported here provide further evidence about the importance of the thermal modification cycle on the physical properties of heat-treated wood. This study highlights that the thermal modification of wood is an important method to improve some of its physical properties and, in particular, the improvement of the material durability and dimensional stability makes the heat-treated wood suitable for outdoor using with no need for toxic preservative compounds. These findings add substantially to our understanding about the influence of the modification cycle on the physical properties of tropical hardwoods and their possible uses.

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