environmental sciences proceedings

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Proceedings

Water absorption behaviour and dimensional stability of a thermally modified tropical hardwood (*Triplochiton scleroxylon* K. Schum) †

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Presented at the 2nd International Electronic Conference on Forests, 1 to 15 September 2021; Available online: https://iecf2021.sciforum.net/

Abstract: The thermal modification of wood is well known and widespread as method to improve the dimensional stability and natural durability of this interesting material with biological origin. This work aims to evaluate the effect of a 3 hour at 215 °C thermal modification cycle, carried out with an industrial system with a slight initial vacuum, on some physical properties of ayous wood (*Triplochiton scleroxylon* K. Schum). This research will offer an overview on the dimensional stability and the water absorption behaviour of the material, comparing these properties between untreated and heat-treated ayous wood. To collect the data, the ISO reference standard was adopted. The data here presented highlight the influence of the thermal modification in the reduction of wood hygroscopicity. It has been possible to verify that heat-treated wood shows less swelling and reaches a lower humidity than untreated wood with the same environmental conditions. Therefore, the dimensional stability of the heat-treated wood was also improved, making the material more suitable for outdoor use.

Keywords: absorption behaviour; dimensional stability; heat treatment; thermal modification; hygroscopicity; *Triplochiton scleroxylon*.

Citation: Gennari, E.; Picchio, R.; Lo Monaco, A. Water absorption behaviour and dimensional stability of a thermally modified tropical hardwood (*Triplochiton scleroxylon* K. Schum). *Proceedings* **2021**, *68*, x. https://doi.org/10.3390/xxxxx

Published: date

1. Introduction

Wood is a wide diffused material of biological origin adaptable to many different uses, its versatility is related to some physical and mechanical properties that characterize it. However, the biological origin of wood also leads problems, many of which are related to the effect of water. As a consequence, treatments are often necessary, particularly for outdoor use, to limit the interaction between water molecules and cell wall compounds. Common wood treatments are based on chemical preservatives but, in addition to chemicals, physical methods can also be used, such as thermal modification. The thermal modification of wood is generally carried out at a temperature of 180-260 °C for some hours [1]. The main effect of the modification cycle is related to the partial degradation of the cell wall compounds and the degradation intensity depends on the modification cycle. After the treatment, the wood shows a lower weight, less hygroscopicity, a general reduction of the mechanical properties, and a darker colour [2]. In particular, the variation in wood hygroscopicity is a consequence of the reduction of the bonding sites available for water within the cell wall. This work examines the influence of the heat treatment, carried out with an industrial system with a slight initial vacuum, on the water absorption behavior, wood density, and dimensional stability of a tropical hardwood named ayous (*Triplochiton scleroxylon* K. Schum), which is subject to growing commercial interest.

2. Materials and methods

The samples were collected from untreated and heat-treated ayous (*Triplochiton scleroxylon* K. Schum) planks coming from FSC (Forest Stewardship Council) certified Cameroonian forests. The heat treatment cycle was carried out on ayous planks in an industrial autoclave (Model TVS 6000 WDE Maspell srl, Terni, Italy) at a temperature of 215 °C for three hours and then the planks were left cooling down slowly and equilibrated to normal environment condition (20 °C, 60% RH).

The size of the samples was 20x20x30 mm and, 40 samples for each type were collected for a total of 80 samples. To collect the samples, the ISO 3129 reference standard was adopted [3].

The analysis of the dimensional stability was carried out following the ISO 13061-15 and ISO 13061-16 reference standards, related to linear and volumetric wood swelling [4,5].

The water absorption behavior was studied monitoring the weight increment after a complete drying of the samples using a ventilated oven (103±2 °C for 24+6 h). After 504 hours, when the samples reached the equilibrium moisture content in environmental conditions, they were put in conditioning chamber with 70% of RH. When the equilibrium was reached again, the samples were soaked in distilled water for three days to reach the maximum swollen condition. The applied methodology to determine the moisture content was in accordance with the ISO 13061-1 reference standard [6].

In addition, the density of untreated and heat-treated wood was determined following the ISO 13061-2 reference standard [7].

Statistical analyses were carried out with StatisticaTM version 7.1 (TIBCO Software Inc.).

3. Results

3.1. Dimensional stability

The results of these tests are presented in Table 1. Figure 1, showing the Δ values, highlights the differences in the comparison of linear and volumetric wood swelling between untreated and heat-treated ayous wood.

Table 1. Linear and volumetric swelling of untreated and heat-treated ayous wood.

	Untreated		Heat-treated	
	Mean	**St. Dev.**	**Mean**	**St. Dev.**
α_r (%)	4.2	1.3	1.7	0.5
α_t (%)	5.8	0.9	1.8	0.9
α_v (%)	10.2	1.7	3.5	1.1

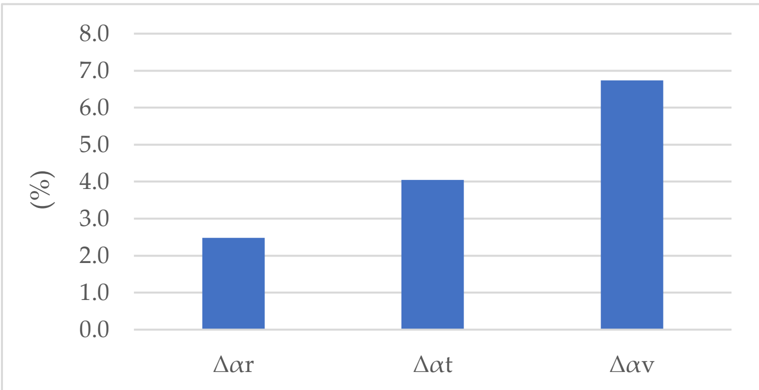

Figure 1. Difference (Δ) between the swelling values before and after the treatment.

3.2 Water absorption behavior

Table 2 shows the Δ values and the related reduction percentage of wood moisture content from the anhydrous condition to the equilibrium exposed to the environmental condition. Figure 2 shows the temporal increase in moisture content of untreated and heat-treated ayous wood.

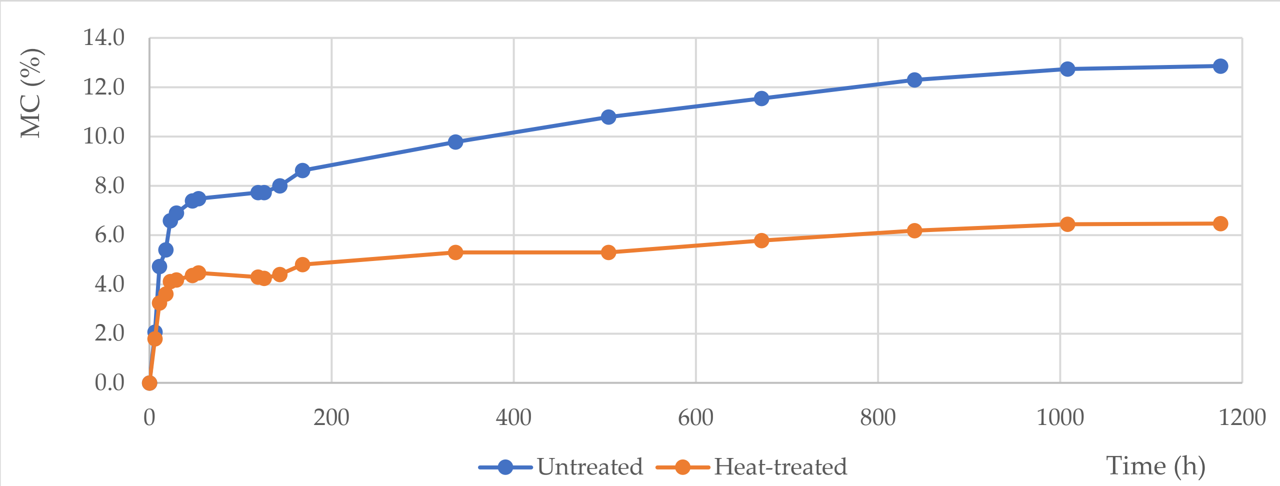

Figure 2. Temporal increase in moisture content of untreated and heat-treated ayous wood. The weight increment was monitored after a complete drying of the samples using a ventilated oven (103±2 °C for 24+6 h). After 504 hours the samples were put in conditioning chamber with 70% of RH.

Table 2. Wood moisture content difference between untreated and heat-treated over time and related reduction percentage.

Time (h)	Δ (%)	Reduction percentage (%)
0	0.0	0
6	0.3	13
11	1.5	31
18	1.8	33
23	2.5	38
30	2.7	39
47	3.0	41
54	3.0	40
119	3.4	44
126	3.5	45
143	3.6	45
168	3.8	44
336	4.5	46
504	5.5	51
672	5.8	50
840	6.1	50
1008	6.3	49
1176	6.4	50

3.3 Wood density

Table 3 shows the difference between untreated and heat-treated ayous wood, both in the anhydrous state and at 12% of moisture content.

Table 3. Density of untreated and heat-treated ayous wood.

	Untreated		Heat-treated	
	Mean	**St. Dev.**	**Mean**	**St. Dev.**
Dry density (g/cm^3)	0.37	0.03	0.32	0.01
Density 12% MC (g/cm^3)	0.41	0.04	0.34	0.01

3.4 Statistical analysis

The results of the statistical analyses performed are shown in Table 4.

Table 4. T-test for independent samples results compared between heat-treated and untreated wood [8].

Parameter	p-value
Density 12% MC	<0.001
Radial shrinkage βr	<0.001
Tangential shrinkage βt	<0.001
Volumetric shrinkage βv	<0.001

4. Discussion

As previously reported, the dimensional stability of the wood results significantly higher after the thermal modification. The linear swelling was reduced from 4.2±1.3% and 5.8±0.9%, respectively for radial and tangential direction of the untreated wood, to 1.7±0.5% and 1.8±0.9%. The percentage reduction is 60% for radial swelling and 69% for tangential swelling. The volumetric swelling was reduced from 10.2±1.7% to 3.5±1.1%; which results in a percentage reduction of 66%.

The thermal modification showed an important influence also on the water absorption behavior. The equilibrium moisture content of the wood exposed to environmental condition with a temperature of 20 °C and 70% of RH was 12.9% and 6.5% respectively for untreated and heat-treated ayous wood. Which results in a percentage reduction of 50%.

Likewise, density is affected by a significant reduction due to heat-treatment. The dry density was reduced from 0.37±0.03 g/cm^3 to 0.32±0.01 g/cm^3. The reduction percentage of the dry density is 16%. Whereas density at 12% of moisture content was reduced from 0.41±0.04 g/cm^3 to 0.34±0.01 g/cm^3, which results in a percentage reduction of 15%.

Similar results of different properties have been reported before in our work on ayous wood subjected to thermal modification, where physical, mechanical, and colorimetric properties were studied [8–10]. Other studies report a difference in swelling behavior between hardwood and softwood, hardwood swell more, assuming a correlation with wood density [11]. There are also hypotheses that the reduction of wood swelling induced from the thermal modification is not only due to the degradation of the hemicelluloses, but also to a structural modification and a chemical change of lignin [12]. Regarding the water absorption dynamic, the results are in line with other studies where a lower reactivity with water was observed after the thermal modification; however, also a greater quantity of soaked water was observed, possibly related to cracks that occur during the heat treatment [13].

The results reported here reinforce the observed improvement of some physical properties of this wood after the thermal modification cycle. Thermal modification makes ayous wood more suitable for outdoor use by decreasing the equilibrium moisture content, as moisture is one of the most important factors related to decay [14]. These results can be a starting point for a better understanding of the natural durability and outdoor performance of this tropical wood based on the application of predictive models, both on raw and heat-treated wood [15-17]. Ayous wood already seems to play an important role in outdoor use and heat treatment may contribute to its widespread use [18].

5. Conclusion

These results emphasize the validity of the thermal modification as alternative method to improve some physical properties of wood, particularly for the improvement of the dimensional stability and the reduction of the hydrophilicity. This work can be helpful to provide a general overview of the heat treatment effects on this tropical hardwood, which it is little studied and is enjoying a growing interest in the market.

Author Contributions: Conceptualization, A.L.M. and R.P.; methodology, A.L.M., E.G.; validation, A.L.M., and E.G.; formal analysis, A.L.M.; investigation, A.L.M., E.G.; resources, A.L.M.; data curation, A.L.M., E.G.; writing—original draft preparation, A.L.M., E.G.; writing—review and editing, A.L.M., E.G., R.P.; visualization, funding acquisition, A.L.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors are grateful to "Vasto Legno spa" who donated the untreated and heat-treated wooden planks used in this project.

Conflicts of Interest: The authors declare no conflict of interest.

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