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Modifications of Physical and Mechanical Characteristics Induced by Heat Treatment: Case Study on Ayous Wood (*Triplochiton sSleroxylon* K. Schum) †

Emiliano Gennari [1], Rodolfo Picchio [1], Damiano Tocci [1] and Angela Lo Monaco [1]*

[1] Department of Agriculture and Forest Sciences (DAFNE), University of Tuscia, Via S. Camillo de Lellis, 01100, Viterbo, Italy emiliano.gennari@unitus.it; r.picchio@unitus.it; tocci@unitus.it; lomonaco@unitus.it.
* Correspondence: lomonaco@unitus.it

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Abstract: Wood is a material of biological origin of fundamental importance for artisan and industrial uses. In outdoor environments it is very attractive, but easily subjected to degradation. A valid alternative to chemical preservatives is the thermal modification. The aim of this study is to evaluate the ayous wood industrially subjected to thermal modification (215 °C), in order to emphasize the influence of heat treatment on selected physical and mechanical characteristics. As a result of the heat treatment, the physical and mechanical properties are generally reduced: the density in natural wood (TQ) was 379 kg/m^3, in heat treated wood (TT) 319 kg/m^3; the basic density in TQ was 327 kg/m^3 in TT 299 kg/m^3; the axial compression strength of TT was reduced by 18,1%; the static bending strength of TT was reduced by 41,4% compared to untreated wood at 10% EMC. In addition, the samples, under the same environmental conditions in the laboratory, reached the equilibrium moisture content of 10% on TQ and 4% on TT.

Keywords: density; basic density; axial compression strength; static bending strength; moisture content

1. Introduction

Ayous wood is obtained from the species *Triplochiton scleroxylon* K Schum, widely diffused in tropical areas of central western Africa with uneven annual rainfall distribution [1,2]. The major exporting Countries are Cameroon, Ghana, Ivory Coast, Niger and Nigeria; for some of them ayous wood export is crucial because it represents the largest portion of total wood export [3]. Appreciation and diffusion for this wood on occidental market is due to the low cost compared to similar species produced in Europe. Important use of ayous wood is for realizing outdoor covering of the buildings, especially in northern and central Europe. Outdoor uses expose wood to the main degradation agents such as UV, moisture and biological attacks [4,5]; and ayous wood is a low durable wood. To improve the durability of material preservatives are generally needed, which can limit the effects caused by wood degradation agents. A valid alternative to chemical preservatives is the thermal modification of wood [6]. Thermo treatment is a physical-chemical alteration realized exposing the wood to high temperature for some hours [7,8]. Thermal modified wood properties are related to the heat treatment cycle; cycles with different temperatures and time of exposure originate materials with different characteristics [9]. Heat treated wood is less hygroscopic due to lower quantity of free polar sites. Other effect of heat treatment is color alteration, that change in darker tones generally more appreciated [10,11], and increased durability [12].

The aim of this study is to evaluate the ayous wood, (*Triplochiton scleroxylon* K. Schum), which was industrially subjected to thermal modification, in order to emphasize the influence of heat treatment at 215 °C on selected physical and mechanical characteristics with a comparison with untreated wood coming from the same area (Cameroon).

2. Materials and methods

The wood comes from a natural forest, it is FSC certified for forest management and chain of custody. Untreated and heat-treated samples were used. The thermal modification was conducted on planks of ayous in an industrial system that used a slight initial vacuum in an autoclave (Maspell WDE Model TVS 6000) and a treatment temperature of 215 °C for three hours.

Untreated as well as modified wood samples were subjected to mechanical tests at the equilibrium moisture content (EMC) of the laboratory conditions. The properties were further calculated at 12% moisture content, when required and possible as indicated in the standards for comparison to the literature. Laboratory tests were conducted following the reference standards UNI ISO 13061-1, UNI ISO 13061-2, ISO 13061-3, ISO 13061-13, UNI EN 1534, UNI ISO 3787 for the tests and UNI ISO 3129 for the sample realization [13-19].

Analyzed physical characteristics were wood density, basic density, linear shrinkages and volumetric shrinkage. Samples dimension was measured with a digital caliper (± 0.01 mm), mass was recorded at a precision scale ±0.001 g. Sample were dried using a ventilated oven to 103 ±2 °C for 24+6 h, according to the reference standard. Demineralized water was used to reach the maximum swelling. Applied formulas to define physical properties were reported in the reference standards [13,14,16,19].

Determined mechanical properties were axial compression strength, static bending strength and Brinell hardness.

For axial compression strength test samples were measured and weighed, then they were put between the steel plates of testing machine. The load was applied such that the sample was broken in 1,5-2 minutes. After the test, samples were weighed and dried in oven to 103°C for 24+6 h to determine moisture content and wood density according with reference standard. Applied formulas are reported in the reference standards [13,14,18,19].For static bending strength test samples length and the median section were measured; the load was applied such that the sample was broken in 1,5-2 minutes. After test, from every samples were cut a piece used to determine wood density and moisture content. Applied formulas are reported in the reference standards [13-15,19].

For Brinell hardness test samples were loaded with 1 kN for 25 seconds; the load was applied such that the maximum load of 1 kN was reached in 15 seconds from the start. The samples were left rest for at least three minutes after load application. Then two diameters of the indentation were measured, one parallel to fiber direction, and the second perpendicular to fiber direction. Applied formulas to define the Brinell hardness are reported in the reference standards [13,17,19].

3. Results and discussion

The selected physical properties of untreated wood are shown in table 1. The obtained results were similar to the values of other authors [20-24].

Table 1. Physical properties of untreated wood (MC= moisture content).

Physical properties	Sample n.	Mean	Standard dev.
Wood density (g/cm^3) (MC 12%)	30	0.39	0.02
Basic density (g/cm^3)	30	0.33	0.02
Radial shrinkage (%)	30	2.76	0.27
Tangential shrinkage (%)	30	5.00	0.28
Volumetric shrinkage (%)	30	7.83	0.42

The selected mechanical properties of untreated wood were presented in table 2. Even the mechanical characteristics, as expected, were similar to those reported in the literature [20,21].

Table 2. Mechanical properties of untreated wood (MC= moisture content).

Mechanical properties	Sample n.	Mean	Standard dev.
Compression strength (MPa) (MC 12%)	35	36.62	1.50
Static bending strength (MPa) (MC 12%)	40	61.07	7.71
Brinell hardness HB (N/mm^2)	73	12.21	2.09

The selected physical properties of thermally treated wood were presented in table 3. Heat-treatment adversely influenced them. In details, wood density was reduced from 0,39 to 0,32 g/cm^3; basic density from 0,33 to 0,30 g/cm^3; volumetric shrinkage from 7,8% of untreated wood to 3,3% of heat-treated wood. The heat treatment performed therefore induced a decrease of these characteristics of 18, 9, and 58% respectively.

Table 3. Physical properties of heat-treated wood (MC= moisture content).

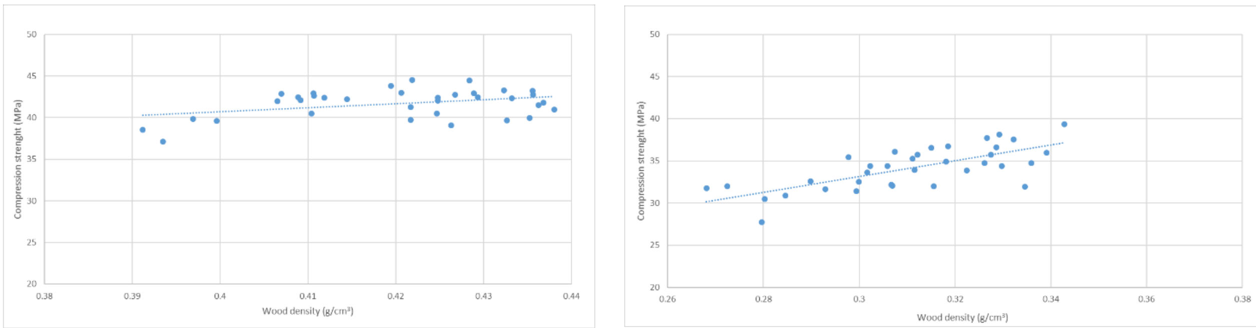
Physical properties	Sample n.	Mean	Standard dev.
Wood density (g/cm^3) (MC 4%)	30	0.32	0.02
Basic density (g/cm^3)	30	0.30	0.02
Radial shrinkage (%)	30	1.27	0.26
Tangential shrinkage (%)	30	1.92	0.25
Volumetric shrinkage (%)	30	3.32	0.45

The mechanical properties of thermally treated samples are reported in table 4. Likewise the physical features, a general reduction of studied mechanical properties was observed in heat-treated wood, as widely reported in other wood species [9, 25, 26]. These values are overestimated as they were indicated at the equilibrium moisture content of the laboratory conditions.
Axial compression strength was reduced from 36,6 of untreated wood to 34,2 MPa; of heat-treated wood static bending strength from 61,1 to 37,6 MPa; Brinell hardness from 12,21 N/mm^2 to 8,30 N/mm^2. The reduction, compared to untreated wood at 10% EMC, was respectively 18,1, 41,4 and 32%. However, the data presented at the same laboratory conditions indicated the differences in the behavior of both untreated and thermally treated wood that must be considered different even if they come from the same species. Akundele et al. [27] observed a stability improvement in heat treated ayous at 160 and 200°C.

Table 4. Mechanical properties of heat-treated wood (MC= moisture content).

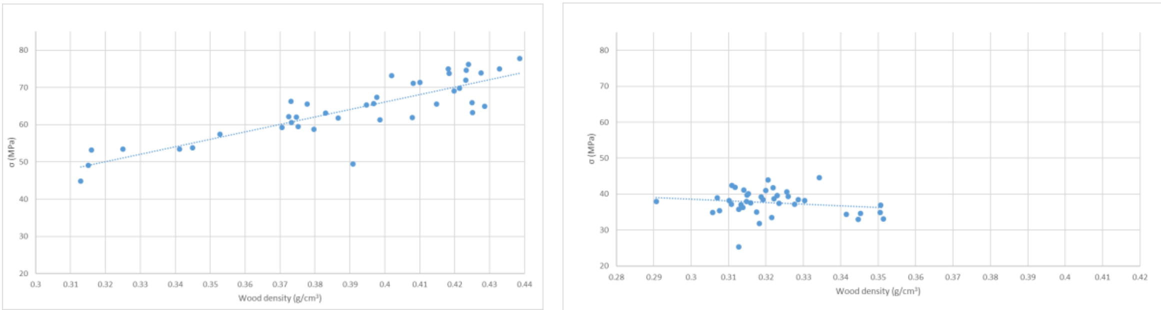
Mechanical properties	MC (%)	Sample n.	Mean	Standard dev.
Compression strength (MPa)	4	35	34.14	2.52
Static bending strength (MPa)	4	40	37.59	3.58
Brinell hardness HB (N/mm^2)	4	68	8.30	1.05

The axial compression (Figure 1) shows increasing trend in function of wood density both in untreated and heath-treated wood. Whereas, the increasing trend of the static bending strength in function of wood density was only shown in untreated wood (Figure 2).



(**a**) (**b**)

Figure 1. Compressive strength as a function of density in Ayous (**a**) Untreated wood; (**b**) thermally treated wood. (**a**): y = 47.91x + 21.58; R^2 = 0.1392. (**b**): y = 93.07x + 5.2294; R^2 = 0.5165.



(**a**) (**b**)

Figure 2. Bending strength as a function of density in ayous (**a**) Untreated wood; (**b**) thermally treated wood. (**a**) y = 200.38x - 14.065; R^2 = 0.7273. (**b**) y = -44.492x + 51.896; R^2 = 0.0279.

It was observed that equilibrium moisture content of untreated wood was 10%, whereas heat-treated wood reached 4% of moisture content, exposed to the same laboratory environmental condition. This evidence was due the chemical modification that make the treated wood less hygroscopic [9, 28, 29]. Fabiyi et al. [30] found in ayous treated at moderate high temperatures the decrease of water absorption due to the reduction in the number of hydroxyl groups. Thermal modification improves the durability of wood exposed to degradation agents [12,31].

3. Conclusion

The modification of mechanical and physical properties was related to alteration induced by the industrial thermal treatment at 215 °C. The physical characteristics benefit from the heat treatment above all for the reduction of shrinkage and for the greater stability to thermo-hygrometric variations. These effects are due to deterioration of chemical structure and cell wall compounds induced by the high temperature. Confirm of this hypothesis comes from the reduction of the equilibrium moisture content of the material. Further studies about this issue can contribute to determine the influence of the specific thermal cycle on the physical and mechanical properties of ayous.

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