JP Journal of Heat and Mass Transfer
© 2024 Pushpa Publishing House, Prayagraj, India
https://www.pphmjopenaccess.com
http://dx.doi.org/10.17654/0973576324004
Volume 37, Number 1, 2024, Pages 55-66 **P-ISSN: 0973-5763**

STUDY OF THE THERMO-PHYSICAL PROPERTIES OF WOOD FROM THE FORESTS OF THE COMOROS ISLANDS: CASE OF EUCALYPTUS ROBUSTA

Abdallah Charkaoui[1,*], Abdelkrim Moufakkir[1], Sara Belarouf[3], Nora Bouhaddour[1], Fatima Kanibou[1], Chaimae Boussaq[1], Salah El Alami[2], Asmae Arbaoui[1] and Abderrahim Samaouali[1]

[1]Team Thermodynamic-Energy
Energy Center
Department of Physics
Faculty of Sciences
Mohammed V University
B.P. 1014 in Rabat 10090, Morocco

[2]Laboratory of Condensed Matter and Interdisciplinary Sciences
Faculty of Sciences
Mohammed V University in Rabat
4 Avenue Ibn Battouta, B.P. 1014, Morocco

Received: October 9, 2023; Accepted: December 8, 2023

Keywords and phrases: wood, eucalyptus Robusta, water content, thermal conductivity, volumetric heat capacity, thermal effusivity, thermal diffusivity.

*Corresponding author

How to cite this article: Abdallah Charkaoui, Abdelkrim Moufakkir, Sara Belarouf, Nora Bouhaddour, Fatima Kanibou, Chaimae Boussaq, Salah El Alami, Asmae Arbaoui and Abderrahim Samaouali, Study of the thermo-physical properties of wood from the forests of the Comoros Islands: case of Eucalyptus Robusta, JP Journal of Heat and Mass Transfer 37(1) (2024), 55-66. http://dx.doi.org/10.17654/0973576324004

This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Published Online: January 29, 2024

[3]Department of Fundamental and Applied Sciences (DSFA)
Agronomic and Veterinary Institute of Hassan II
Rabat, Morocco

Abstract

The main objective of this work is to study the influence of water content on the thermo-physical properties of a sample of solid Eucalyptus Robusta wood from the Comoros Islands, with dimensions $(75.60\,\text{mm} * 75.71\,\text{mm} * 75.56\,\text{mm})$ and density $\rho = 793.7\,\text{Kg/m}^3$ in the direction perpendicular to the growth fibers (longitudinal direction). The robust CT-meter is used to determine thermal conductivity and volumetric heat capacity, while the other properties are calculated. The results obtained show that thermal conductivity, volumetric heat capacity and thermal effusivity all increase sharply with water content, while thermal diffusivity, which should normally decrease, but increases. This may be explained by the fact that the sample has not been in water for too long. Finally, thermo-physical properties depend on the external environment, in particular, water content.

Nomenclature

λ : thermal conductivity (W/m.K)

D : thermal diffusivity (m^2/s)

E : thermal effusivity ($J/K.m^2.S^{0.5}$)

ρC : volumetric heat capacity ($kJ/m^3.K$)

m_h : wet mass of sample (Kg)

m_s : anhydrous mass (once placed in the study at 60° for 24h) (Kg)

ρ : sample density (Kg/m^3)

v : sample volume (m^3)

m : sample mass (Kg)

w : mass water content (%)

1. Introduction

Today, energy consumption is one of the world's major concerns, with the building sector consuming over 40% of the total energy produced worldwide and emitting over 30% of CO_2 emissions. Building materials are often more expensive and far from the majority of the population, so the use of locally available materials is affordable despite their limited durability [1, 2].

Wood is a building material that is renewable and more widespread in nature. However, its use in building envelopes is limited by constraints linked to its heterogeneous, hygroscopic and anisotropic characteristics, which influence its thermo-physical and mechanical properties.

All building materials are characterized by thermo-physical properties (thermal conductivity, thermal diffusivity, thermal effusivity, specific heat, coefficient of thermal expansion, density, specific gravity, etc.) and mechanical properties (Young's modulus, resistance to rupture, shear modulus, hardness, Poisson's ratio, etc.). Wood is a good moisture regulator in buildings. Its thermal properties such as thermal conductivity, diffusivity and heat capacity are influenced by the nature of the wood species, density, anatomical direction, water content, temperature, mechanical load, etc. [2].

Originating in Australia, eucalyptus wood benefits from minimal scientific research to the detriment of other types of wood species such as poplar, mahogany, beech, oak, etc. The Union of the Comoros is a country of volcanic origin located at the northern entrance to the Mozambique Channel between Madagascar and the east coast of Africa. Eucalyptus Robusta was the most planted species, covering an area of 200ha with a yield of 350m^3/ha. The industrial valorization of Eucalyptus Robusta would be an asset for the country's economic development and a major scientific breakthrough [9].

The main objective of this article is to highlight the influence of water content on the thermo-physical properties of Eucalyptus Robusta wood from the Comoros Islands, in order to gain a better understanding of this material and its implication in the building sector in the Comoros archipelago, and to contribute to its scientific valorization on an international scale.

2. Material and Experimental Methods

2.1. Material studied

The sample we studied is a cubic-shaped Eucalyptus Robusta wood from the Comoros Islands, with dimensions $(75.60mm * 75.71mm * 75.56mm)$ and a density of $793.7Kg/m^3$.

2.2. Physical characteristics of the material

Table 1. Physical characteristics of sample

Mass m (g)	Volume (mm^3)	Density (Kg/m^3)
348.28	432480	793.7



Figure 1. Eucalyptus Robusta wood sample.

2.3. Experimental methods

2.3.1. Techniques for obtaining water content

To obtain the water content of the sample studied, we proceeded experimentally as follows: the sample was oven-dried at a temperature of 60°C for 24h, and its dry mass was measured using a Brehm model BP2000 balance with an accuracy of 0.01g. We then sprayed water on our sample in all three directions, so that we could measure the wet mass while varying the percentage of water content. Knowing the dry mass m_s and the wet mass m_h, the mass water content is calculated by:

$$w = \frac{m_h - m_s}{m_s}. \quad (1)$$

2.3.2. CT-meter principle

The conductivity meter used for experimental measurement of thermo-physical properties is the CT-meter belonging to the Thermodynamics-Energetics Laboratory of the Rabat Faculty of Science. It consists of a computer that displays the data and a probe inserted between two samples under consideration. With this device, we can obtain the thermo-physical properties of solid materials (aerated concrete, bricks, powdered substances, earth, bitumen, etc.) as well as liquid materials using a wire probe [3].

We measured the thermo-physical properties: thermal conductivity and volumetric heat capacity, of our sample along the three orthotropic directions, namely longitudinal (L), radial (R) and tangential (T), at an ambient temperature of 25°C using the CT-meter described above on one hand, and on the other hand, the other thermo-physical properties: thermal diffusivity and thermal effusivity are calculated as a function of two others (thermal conductivity and volumetric heat capacity).

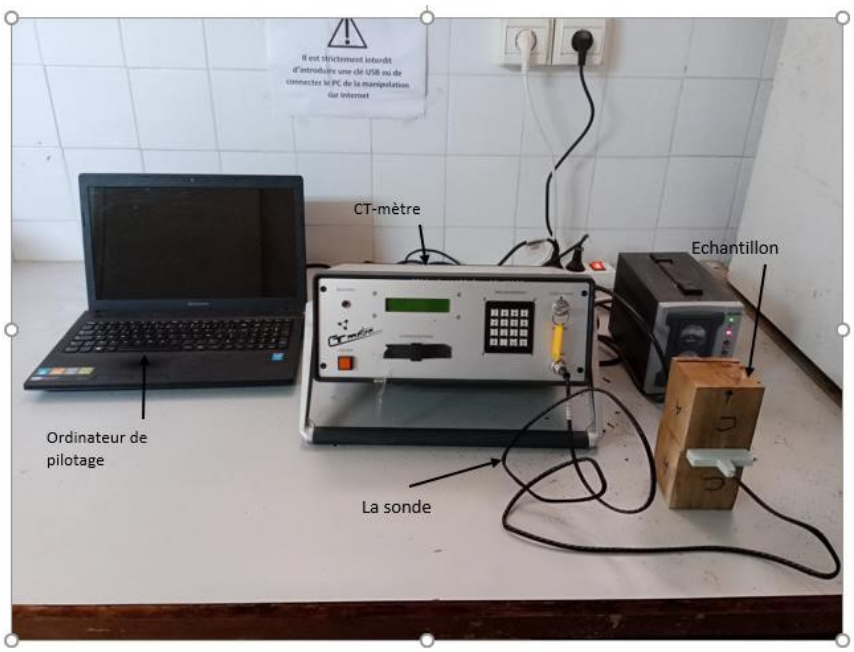


Figure 2. Thermophysical properties measurement device (CT-meter).

3. Results and Discussions

The tables below (Table 2) show the values for thermal conductivity, volumetric specific heat capacity, thermal diffusivity and thermal effusivity obtained during the experiment.

Table 2. Results of thermal physical properties

Water content w (%)	Thermal conductivity λ (W/m.K)		
	Longitudinal direction	Radial direction	Tangential direction
0.0369	0.373	0.308	0.298
0.0459	0.386	0.313	0.308
0.0577	0.402	0.31	0.32
0.0738	0.412	0.335	0.302
0.0810	0.440	0.305	0.31

Water content w (%)	Volumetric heat capacity (kJ/m^3.K)		
	Longitudinal direction	Radial direction	Tangential direction
0.0459	2408	1371	1327
0.0513	2479	1451	785
0.0577	2507	1494	1324
0.0690	2573	1369	1363
0.0738	2596	1478	1356

Water content w (%)	Thermal effusivity (J/K.m^2.S$^{0.5}$)		
	Longitudinal direction	Radial direction	Tangential direction
0.0513	945	665	537
0.0577	982	681	651
0.0659	989	665	642
0.0738	998	671	648

Water content w (%)	Thermal diffusivity (*10^{-4}(m^2/s))		
	Longitudinal direction	Radial direction	Tangential direction
0.0369	1.42	2.29	2.28
0.0459	1.60	2.28	2.29
0.0577	1.68	2.07	2.42
0.0690	1.72	2.36	2.22

Since wood is a heterogeneous, anisotropic and hygroscopic material, we have only considered results obtained in the direction perpendicular to the wood fibers (longitudinal direction).

The analysis of the various thermo-physical property values (thermal conductivity, volumetric heat capacity, thermal effusivity and thermal diffusivity) is set out in the following.

3.1. Thermal conductivity

The evolution of thermal conductivity as a function of water content is

shown in Figure 3. An analysis of this curve reveals that water content has a strong influence on thermal conductivity. The latter increases significantly as water content rises. This property is enhanced by the fact that, in the dry state and in the absence of interstitial water, heat transfer is essentially carried out by the fiber, while when water content increases, heat transfer is mainly conveyed by the interstitial water in the material. Some studies have considered the dependence between thermal conductivity and water content to be quasi-linear [4].

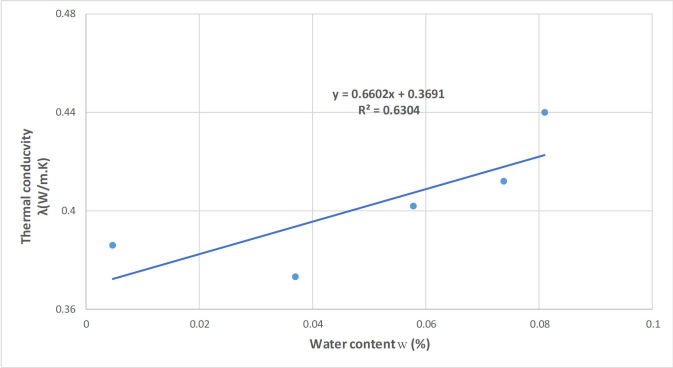


Figure 3. Variation in thermal conductivity as a function of water content.

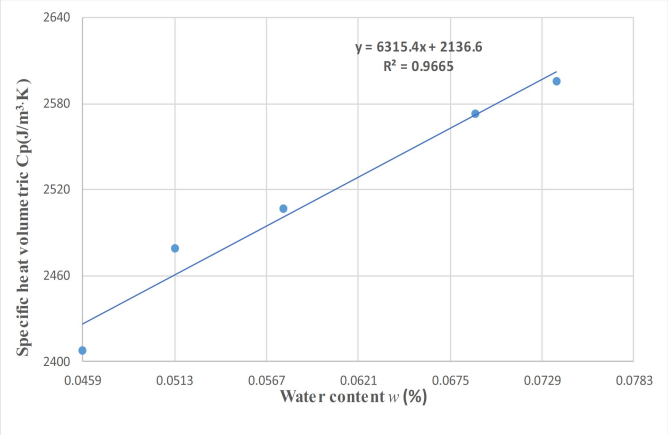


Figure 4. Variation in volumetric heat capacity as a function of water content.

3.2. Volumetric heat capacity

The variation in volumetric heat capacity as a function of water content is shown in Figure 4. We found that specific heat capacity increases linearly with water content. The growth of this property as a function of water content is explained by the difference in the heat capacities of wood particles and water. Indeed, we know that the heat capacity of water is significantly higher than that of wood. Consequently, the amount of water trapped in the wood structure increases the heat capacity of the wood.

These results are in agreement with those found in the literatures by several authors. These include [5, 6].

3.3. Thermal effusivity

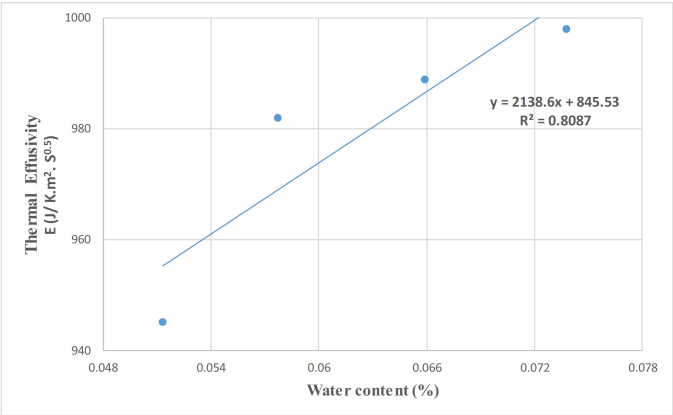


Figure 5. Thermal effusivity as a function of water content.

Figure 5 shows thermal effusivity as a function of water content. It can be seen that thermal effusivity increases with water content, as do thermal conductivity and specific heat capacity. Thermal effusivity is a function of conductivity and volumetric heat capacity, as can be seen from formula

$$E = \sqrt{\rho C \lambda}. \tag{2}$$

The rapid variation of these two properties with water content explains the result obtained. Indeed, a number of studies based on the influence of this

property with water content have been conducted, in particular, those [5, 7] have led to similar results.

3.4. Thermal diffusivity

Thermal diffusivity is one of the most widely studied thermo-physical properties in the literature.

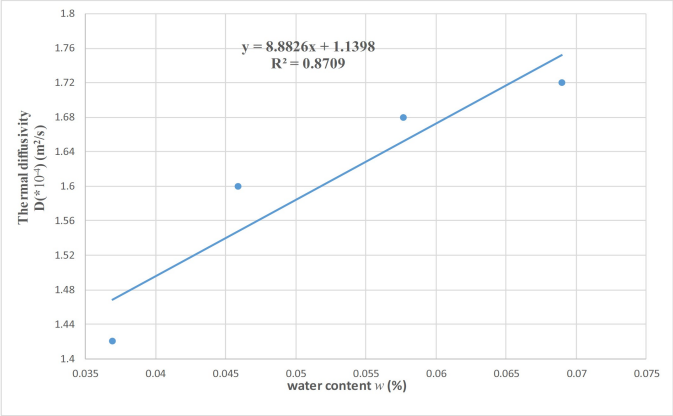


Figure 6. Thermal diffusivity as a function of water content.

Much of this research is devoted to highlighting the influence of water content on this property. Figure 6 shows the evolution of thermal diffusivity as a function of water content for our wood sample. We noticed that thermal diffusivity increased with water content. This result can be explained by the variation in volumetric heat capacity (ρC) and thermal conductivity (λ) as a function of water content, which is linked by the equation

$$D = \frac{\lambda}{\rho C}. \tag{3}$$

The same phenomenon was observed in other materials such as concrete/ wood composite [4] and lateritic soil-based material (Meukam et al. [10]).

However, thermal diffusivity is expected to decrease with increasing water content, because during wood humidification, liquid water with low diffusivity $(1.44 * 10^{-7} \mathrm{m}^2/\mathrm{s})$ replaces dry air, whose thermal diffusivity $(\text{approximately } 2.10^{-5} \mathrm{m}^2/\mathrm{s})$ is much higher than its own.

4. Conclusion

Based on the results obtained, we can emphasize that wood is a hygroscopic, heterogeneous and anisotropic material. We note that thermo-physical properties such as thermal conductivity, volumetric heat capacity, thermal effusivity and thermal diffusivity are influenced by water content. We also found that these properties vary rapidly in the longitudinal direction.

The linear regression coefficients R^2 obtained for all the different curve plots are 0.870, 0.767, 0.952 and 0.935, respectively, for thermal diffusivity, thermal effusivity, volumetric heat capacity and thermal conductivity. This shows the strong correlation between these two data taken in pairs. This result is confirmed by [8].

We have found numerous studies in the literature dealing with the effect of water content on thermo-physical properties.

In the future, we will be investigating the influence of temperature, density and moisture content on thermo-physical properties, as well as mechanical properties.

Acknowledgment

Thanks to the team of Thermodynamic-Energy, Energy Center, Department of Physics, Faculty of Sciences, Mohammed V University, Morocco.

References

[1] Isabelle Bohnke, Étude expérimentale et théorique des traitements thermiques du bois. Caractérisation physico-mécanique des bois traités. Génie des procédés, Ecole Nationale Supérieure des Mines de Saint-Etienne, 1993.

[2] C. Houngbeme, A. Djossou, C. A. Houngan et al., Influence de la teneur en eau sur les propriétés thermo physiques des bois Pterocarpus et d'Afzelia, SFT2020-164, 2020.

[3] A. Moufakkir, Centre de Recherche: Centre de Recherche en Énergie Structure de Recherche: Équipe de Thermodynamique et Énergétique Discipline: Physique Spécialité: Mécanique et Énergétique, 2021.

[4] D. Taoukil, A. El Bouardi and T. Ajzoul, Effect of the incorporation of wood wool on thermo physical proprieties of sand mortars, KSCE J. Civ. Eng. 16 (2012), 1003-1010.

[5] R. R. N. Mvondo, J. C. Damfeu and P. Meukam, Influence of moisture content on the thermophysical properties of tropical wood species, Heat Mass Transfer 56 (2020), 1365-1378.

[6] D. Taoukil, A. El Bouardi, F. Sick et al., Moisture content influence on the thermal conductivity and diffusivity of wood-concrete composite, Construction and Building Materials 48 (2013), 104-115.

[7] H. C. Aristide, A. Christophe, D. A. Armand et al., Measurement of thermal effusivity and thermal conductivity at various water content for two tropical wood species, Procedia Engineering 127 (2015), 48-55.

[8] F. Bobda, J. Claude Damfeu, R. R. Ngono Mvondo et al., Thermal properties measurement of two tropical wood species as a function of their water content using the parallel hot wire method, Construction and Building Materials 320 (2022), 125974. doi:10.1016/j.conbuildmat.2021.125974.

[9] Mette Løyche Wilkie, Évaluation des Ressources Forestières Mondiales, FAO, Comores, 2010.

[10] P. Meukam, Y. Jannot, A. Noumowe and T. C. Kofane, Thermo physical characteristics of economical building materials, Construction and Building Materials 18 (2004), 437-443. doi:10.1016/j.conbuildmat.2004.03.010.