

DETERMINATION OF THERMAL AND PHYSICAL PROPERTIES OF PALMYRA WOOD (BORASSUS AETHIOPUM MART.) FROM MALFANA IN CHAD

**NGARGUEUEDJIM KIMTANGAR Ernest, DOROKO Haman, BASSA
BRUNO**

LERTI: Laboratoire d'Etude et de Recherche en Techniques Industrielles (LERTI),
Faculté des Sciences Exactes et Appliquées, Université de N'Djamena, B.P. 1027,
N'Djaména, Tchad

DOROKO Haman, G.E. NTAMACK

GMMA: Groupe de Mécanique - Matériaux - Acoustique, GMMA, Département de
Physique, Faculté des Sciences, Université de Ngaoundéré B.P. 454, Ngaoundéré,
Cameroun

S. CHARIF D'OUAZZANE

LMTM: Laboratoire de Mécanique, Thermique et Matériaux, Ecole Nationale de
l'Industrie Minérale, ENIM, B.P. 753 Rabat, Maroc

ABSTRACT

Palmyra or Borassus aethiopum Mart is a timber that is used in the traditional construction of housing and semi-modern yet its thermal characteristics are very little known. The aim of this work is to determine experimentally thermo physical characteristics of palmyra wood of Chad. In this contribution, we will determine the moisture content and density of the wood palmyra and we use the method of guarded hot plate to estimate the thermal conductivity in different parts of the specimen namely the Heart, and the sapwood duramen after reaching steady state. Given the results, we note that the thermal conductivity of palmyra wood depends on its anatomical structure and humidity. The lighter parts are more insulating and remain always with high humidity. Note also that the heat spreads more in the direction parallel to the fibers than perpendicular to the fibers.

Key words: Rôniers, Palmyra, Heart, Sapwood, Duramen, Thermal Conductivity, Thermal Resistance, Density, Humidity.

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1. INTRODUCTION

Building materials are often chosen for their thermo physical properties. In addition, most of the thermo physical properties of conventional building materials such as concrete, concrete block, earth amongst others are known [1, 2, 3, 4 and 5]. The *Borassus aethiopicum* Mart [6] is a widely used wood as a local building material in several buildings in Chad. Unfortunately in the literature, few data are available to justify its use as a construction material [7]. The work presented in this article is intended to identify and develop the thermo physical characteristics of palmyra wood of Chad to justify and promote its use in buildings. The Palmyra is a composite material; in this paper we have essentially determined the characteristics of each of its individual components.

2. MATERIALS AND METHODS

We aim to determine as thermal properties, thermal conductivity and strength palmyra items. And as physical properties, we will determine the density and humidity of the elements of this material. These characteristics are critical in assessing the quality of a material with respect to the mechanical comfort, heat and mass. But before describing the experiences that allow us to determine these properties, we will first present the morphology of palmyra wood.

2.1. Structure of palmyra wood

A cross section of a palmyra trunk shows that it is made from the center to the periphery of three) parts: the heart, the sapwood and duramen as shown in Figure 1 (a). Its morphology is contrary to the other woods as seen in figure 1 (b).

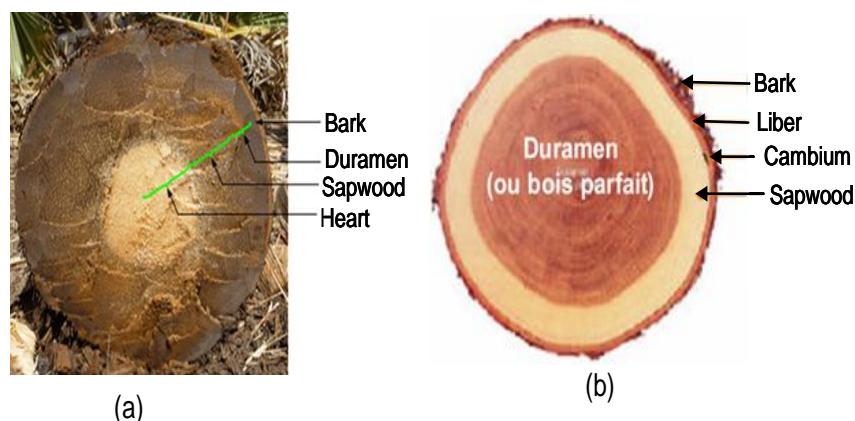


Figure 1 Different parts of two kind of wood: (a): parts of palmyra wood [8], (b): parts of other woods [9]

Longitudinally, the palmyra presents heterogeneities, because it is composed of various forms of different elements and characteristics according to the directions as shown in Figure 2.

The tangential direction corresponds to the annual growth rings and radial direction is that of wood rays, perpendicular to dark circles.

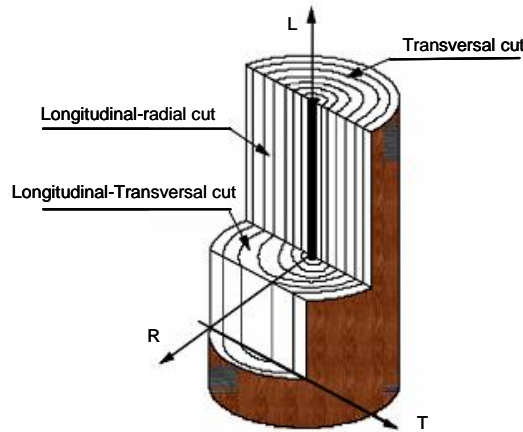


Figure 2 Normal and tangential palmyra wood structures [9].

2.2. Experimental determination of thermo physical properties of palmyra wood

2.2.1. Mode of manufacture of test specimens

To perform the experiments, we must first make the test specimens. The cuboid specimens were taken from the palmyra male, aged about 30 years and measuring 20 m high with an average diameter of 56 cm. The palmyra wood was cut in a village located 18 Km west of the city Mandélie (Department of Chari) in Chad, with the agreement of the competent authorities. We made pieces made entirely of duramen, sapwood and heart by making longitudinal sections (Figure 1 and Photo 1 and 2).



Photo 1: Sample Technique

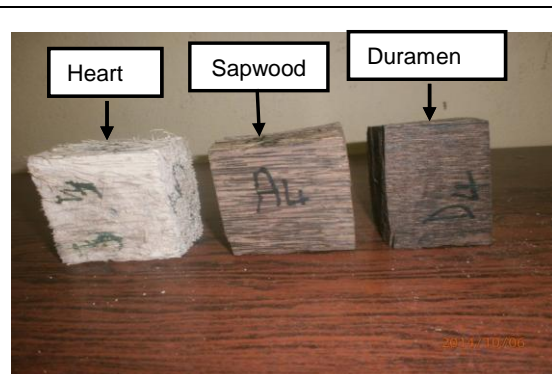


Photo 2: Specimens of the three parts of the palmyra wood

2.2.2. Techniques of estimation of thermo physical sizes

2.2.2.1. Basic Theories

Several methods are used to measure the thermo physical characteristics of wood: We have the principle of the method of the heating plate [10, 11], the flash method [12]

and the hot wire method [12]. Among these methods, we used the method of guarded hot plate to equipment availability at the Laboratory for the Study and Research in Industrial Techniques (LERTI) of the Faculty of Exact and Applied Sciences (FSEA) / University of N'Djamena.

The means of guarded hot plate is to maintain a temperature difference between two plates A and B, flat, parallel and brought respectively to constant temperatures T_A and T_B (Figure 3). A sample of the material to be studied, weakly conductive solid is placed between the plates [10, 11 and 13].

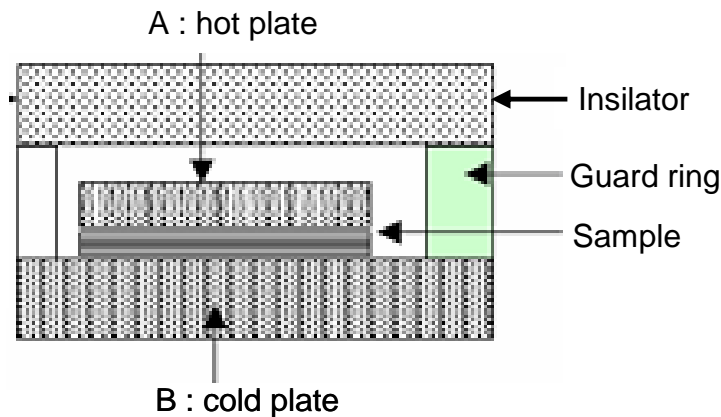


Figure 3 Principle of measurement of thermal conductivity by means of guarded hot plate [10, 14].

A. Evaluation of thermal conductivity

The thermal conductivity λ ($\text{Wm}^{-1}\text{K}^{-1}$) is determined by the relationship:

$$\lambda = \frac{\varphi e}{S\Delta T} \quad (1)$$

Where φ is the flux crossing the surface of the sample (in W), e is the sample thickness (in m), S is the surface of the sample (in m^2) and $\Delta T = T_A - T_B$ (K) is the temperature difference between both surfaces of the sample.

B. Determination of thermal resistance

The thermal resistance R_{th} (Km^2W^{-1}) is calculated by the equation:

$$R_{th} = \frac{e}{\lambda} \quad (2)$$

C. Sample humidity

The method to accurately determine the moisture content is the method by dehydration. Humidity H (%) is given by the following expression:

$$H(\%) = \frac{m_1 - m_2}{m_2} \times 100 \quad (3)$$

Where m_1 is the mass (kg) of the sample in the wet state, m_2 is the mass (kg) of the sample after drying.

D. Density

The density ρ (kg / m³) is given by: $\rho = \frac{M}{V}$ (4)

Where M is the mass (kg), $V = L \times l \times e$ the volume (m³), L, W and e respectively denote the length, the width and the thickness of sample.

2.2.2.2. Materials and conducting trials

The materials below have helped us in identifying thermal characteristics:

- 1 electronic stopwatch,
- 1 plywood as insulation.
- 1 calibrated digital thermometer to 200 ° C with an accuracy of 0.1 ° C in place of the thermocouple,
- 1 Electrical balance precision calibrated 0.1g,
- 1 hotplate which maximal power is 630W at a maximum temperature of 370 ° C,
- Clay to isolate the edges of the sample and ensure the assumption of unidirectional propagation of heat.

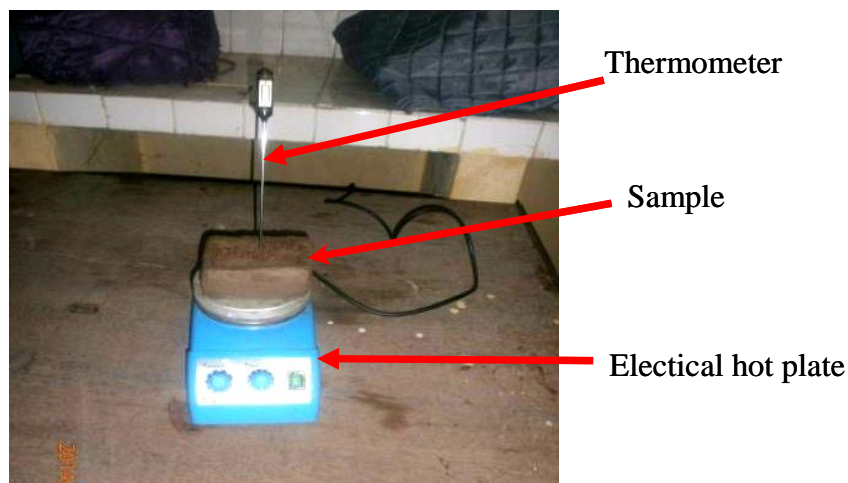
Samples are cut and planed in rectangular form of about 5cm thick. Two configurations were studied:

- First configuration: the flow direction is parallel with the axis of the sample faces of the fibers (direction parallel to the fibers).
- Second configuration: the flow direction is perpendicular to the fiber axis.

The experimental procedure consists in imposing on one face a constant temperature. The sample is placed by its uninsulated S_1 on the front plate (figure 4). We imposed on this side S_1 a temperature $T_1 = 150$ ° C constant, corresponding to a thermal power of 255W. It falls every 10 minutes, the temperature T_2 on the face S_2 opposite to the face S_1 using a digital thermometer until stabilization of the temperature T_2 .

The temperature difference between the temperatures T_1 and T_2 is used to draw the curves of evolution of the temperatures in the sample and calculating the thermal conductivity and thermal resistance due to the formulas (1) and (3), respectively.

Photo 4: Experimental method guarded hot plate in LERTI.



For the determination of the physical characteristics (humidity and density), we used:

- 1 Electrical balance precision calibrated 0.1g,
- An oven set to a temperature of 103 ° C (± 2 °C), type Mettler PM4600 Delta Range brand
- 1 desiccator for cooling after drying,
- Blue balls (meaning absence of moisture in the medium),
- 1 heat-resistant glove
- 1 wooden clamp.

The procedure for determining the moisture content is as follows:

- Number the samples,
- Weigh the wet samples (mass m_1)
- Insert the sample into the oven,
- Wait for the temperature rise to 103 ° C and hold for 3 hours time,
- Remove the samples from the oven and put them in the dryer,
- Add to the samples in the desiccator beads heated blue for cooling,
- Wait 20 to 25 minutes,
- Remove samples for a second weighing to know the mass (m_2) after drying.

3. RESULTS AND DISCUSSION

3.1. Humidity rate

The results of experiments to determine the moisture content of the duramen, sapwood and heart of palmyra wood are summarized in Table 1.

Table 1 Values of the moisture content of sapwood, duramen and heart.

Palmyra Part	N° specimens	m_1 (g)	m_2 (g)	H (%)	Average of H (%)	Standard deviation
Duramen	1	162,30	145,6	11,46	12.41	1,3505
	2	163,26	144	13.37		
Sapwood	1	79,2	66,24	19,5	19,35	0,2121
	2	81,05	68	19,20		
Heart	1	54.30	44.77	21.28	21.65	0.3750
	2	49.9	40.89	22.03		

Considering the results in Table 1, we see that the humidity in the heart is the highest (21.65%), followed by the humidity in the sapwood (19.35%) and it is the duramen which has the lowest rate (12.41%) near the reference humidity (12%) according to the French standard (NF B51-002). It shows that from the heart of Palmyra to the periphery, the humidity decreases. This is justified by the fact that it is through the heart as the transport of nutrients and water takes place in the palmyra according to its anatomy.

3.2. From the density

Table 2 shows the density of specimens of sapwood and duramen taken from the same part of the log of the palmyra, and the density of heart of the bulge of this wood.

Table 2 Density of different parts of palmyra.

No specimens	L(m)	l(m)	e (m)	m (Kg)	V (m ³)	ρ (Kg /m ³)	ρ_{moy} (Kg /m ³)	Standard deviation
Duramen								
1	6.10^{-2}	$5,4.10^{-2}$	5.10^{-2}	$145,6 .10^{-3}$	$1,62.10^{-4}$	898,7654	902	
2	6.10^{-2}	$5,3.10^{-2}$	5.10^{-2}	144.10^{-3}	$1,59.10^{-4}$	905,6603		
Sapwood								
1	$6,2.10^{-2}$	$5,3.10^{-2}$	5.10^{-2}	$66,24.10^{-3}$	$1,643.10^{-4}$	403,1649	391	
2	$6,3.10^{-2}$	$5,7.10^{-2}$	5.10^{-2}	68.10^{-3}	$1,7955.10^{-4}$	378,7245		
Heart								
1	$6,2.10^{-2}$	$5,6.10^{-2}$	5.10^{-2}	$44,77.10^{-3}$	$2,442.10^{-4}$	183.3333	179	
2	$6,1.10^{-2}$	$5,3.10^{-2}$	5.10^{-2}	$40,89.10^{-3}$	$2,345.10^{-4}$	174.3710		

The results in Table 2 show that the density of the duramen is the highest average. This is justified by the fact that during the growth of Palmyra, its structure is denser towards the periphery giving greater weight to the duramen. Furthermore, we find that the density increases radially, that is to say, it is low in the heart and great in the outskirts of the wood. Table 3 gives the values of the densities at 12% humidity (French standard NF B51-002).

Table 3 densities of the moisture content of 12%

Part of the wood	Density (Kg / m ³)	Moisture content (%)
Sapwood	242,77	12
Duramen	872,402	
Heart	99.22	

Figures 4 and 5 show the evolution of the temperature T_2 in the studied samples

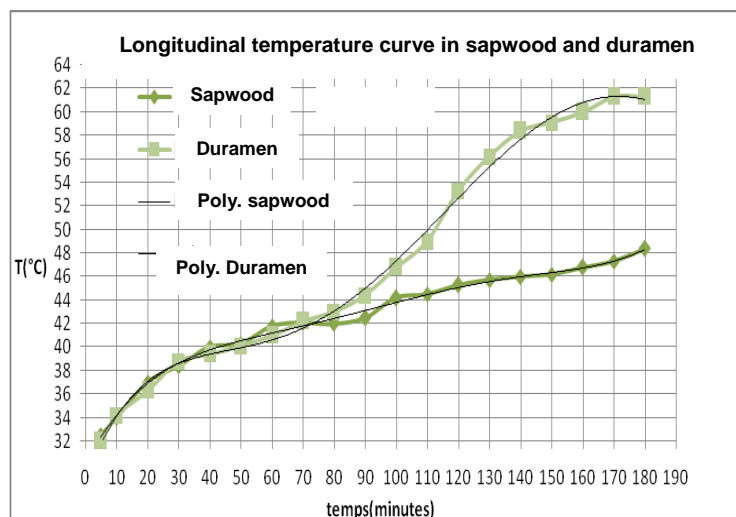


Figure 4 Evolution of T_2 Curves in the sapwood and duramen parallel direction.

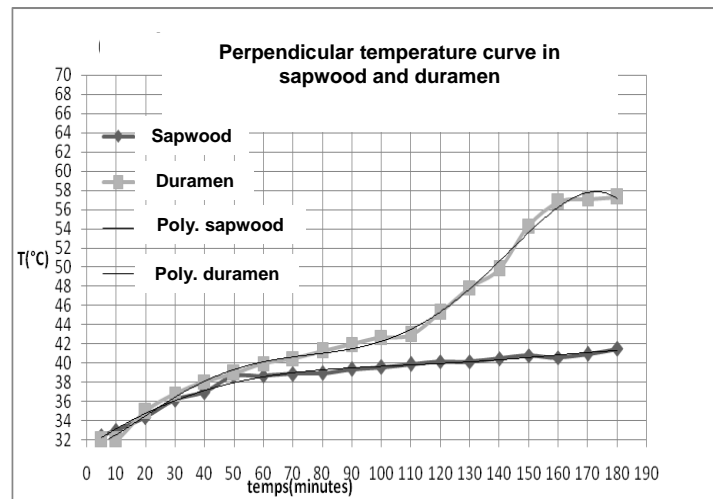


Figure 5 T_2 evolution curves in the sapwood and duramen in the perpendicular direction

Figure 4 shows that for a flow direction parallel to the fiber direction, the variations of temperature in the sapwood and duramen grows in the similar in duration from 5 to 70 minutes at the same temperature range of 32 to 42.2 °C. For 70 to 180 minutes time interval corresponding to the temperature ranges of 42.2 to 61.3 °C, the sapwood conducts less heat than the duramen.

In Figure 5, the curves of the temperatures in the sapwood and the duramen grow similarly between the times ranging from 5 to 50 minutes corresponding to the axis of temperature ranging from 32 to 39 °C. Between the time interval from 50 to 180 minutes corresponding to the temperatures of 39 and 57.3 °C respectively. The duramen conducts heat better than the sapwood and tends towards its stabilization temperature is about 57.3 °C. We can say that the sapwood better slows the speed of the flow of heat than the heartwood.

The values of the thermal conductivities are influenced not only by the density of the samples, but also by the moisture content and the fiber direction. It appears, according to Table 4, the thermal conductivity of the sapwood remains below that duramen whatever the direction of flow with respect to that of the fibers; it proves that the duramen is more conductive heat than the sapwood.

Table 4 Test results on heart of wood, sapwood and Duramen of palmyra

Wood part	Heart		sapwood		Duramen	
	perpendicular	paralle	perpendicular	paralle	perpendicular	paralle
Fiber direction	perpendicular	paralle	perpendicular	paralle	perpendicular	paralle
Moisture content (%)	21,02 ± 0,375		19,35 ± 0,2121		12,41 ± 1,3505	
Density (Kg/m ³)	179 ± 6,3373		391 ± 17,3029		902 ± 4,8792	
ΔT (°K)	110,1	108,9	108,5	101,6	92,7	88,7
thermal Conductivity (W/m K)	0,1159	0,1172	0,1176	0,1256	0,1377	0,1437
Thermal résistance (m ² °K/W)	0,4314	0,4266	0,4251	0,3980	0,3631	0,3479

From Table 4 we can say that more a material is insulating high will be it thermal resistance, i.e. its ability to oppose the heat exchange is greater.

Shown in Tables 5 the Heart of palmyra (central part of snoring) has great insulating than the sapwood and duramen.

Table 5 presents some values of thermo physical properties of palmyra wood and some other building materials.

The thermal conductivity of building materials is the most characteristic needed for a comfortable accommodation in the habitat. From Table 5 we can say that the palmyra wood, compared with other building materials, is scientifically best ranked in the field of thermal comfort than concrete and bricks stabilized and unstabilized. However, it has a low insulating power than the cork and bamboo date palm Ftimi.

Table 5 Comparison of results with other Habitat building materials [10, 13 and 14].

Material	Density of the material (Kg/m ³)	thermal Conductivity (Wm ⁻¹ K ⁻¹)
Normal Concrete	2400	1,83
Clay brick	4133,33	0,586
Clay brick stabilized at 12% of cement	4133,33	0,719
Limestone	2350	2,0
bamboo Cork	150-250	0,048
Palmer date (Ftimi)	355	0,103
Heart of palmyra wood	179	0,116
Sapwood of palmyra	391	0,121
Duramen of palmyra	902	0,141

4. CONCLUSION

This work aimed to determine thermo physical characteristics of palmyra wood of Chad for thermal comfort in the home. Several methods for estimating these variables have been considered with their respective advantages and disadvantages. We used the means of guarded hot plate.

The propagation of heat was unidirectional, for that several techniques have been used to have rectangular pieces, for each part of the timber namely the heart, the sapwood and duramen.

The moisture content and density are determined for all test specimens.

Given the results, we note that the thermal conductivity of palmyra wood depends on its anatomical structure. The lighter parts are insulating. Thus, the heat spreads more quickly in the duramen than in the other parts of the timber.

The direction parallel to the fibers provides a greater ability to spread the heat than the perpendicular direction.

Comparing the results obtained with other building construction materials the palmyra should be classified among the best materials for thermal comfort in low embodied energy habitat.

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