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The Directional Thermal Diffusivity of Rattans of Benin, Ghana and Nigeria by The Regular Regime Method

Sinmenou Dagbégnon[1] · Awanto Christophe[1] · Vodounnou Edmond Claude[1] · Sinmenou Agnankpe M.G.Josias[2] · Vianou Antoine[1] · Foudjet Amos[3]

[1]Ecole Polytechnique d'ABOMEY-CALAVI de l'Université d'ABOMEY-CALAVI (BENIN).
[2]Université de Sciences et Technologies de Beijing (R.P. CHINE).
[3]Université de DSCHAMP (CAMEROUN).

ABSTRACT
The use of wood products as furniture for the manufacture becomes more and more important over the years. At the same time, the vegetation cover of the sub region is undergoing a severe degradation which seriously compromises the environment. The use of non-timber forest products such as bamboo and rattan in furnishings and even reinforcement in civil engineering of the physical characterization of rattans from Ghana, Nigeria imported to Benin and Benin, we have emphasized the directional thermal diffusivity of rattans in Benin, Ghana and Nigeria by the regular regime method. We've obtained respective for axial and radial diffusivity the following results in case of: Benin rattan: 0.033192 and 0.653326 $m^2s^{-1}10^{-6}$; Nigerian rattan: 0.032164 and 0.641273 $m^2s^{-1}10^{-6}$; Ghana rattan: 0.316815 and 0.616851 $m^2s^{-1}10^{-6}$. Those results obtained were compared with those already existing for some woody species. They confirmed not only the validity of our experimental system but also the relevance of the regular regime for the measurement of diffusivity. So, the rattan has a lower radial and respective axial diffusivity than teak (0.242 and 0.143) $m^2s^{-1}10^{-6}$, ebony (0.228 and 0.176) $m^2s^{-1}10^{-6}$, and the copolymer (0.354 and 0.133) $m^2s^{-1}10^{-6}$ Rattan has a lower radial and respective axial diffusivity than teak (0.242 and 0.143) $m^2s^{-1}10^{-6}$, ebony (0.228 and 0.176) $m^2s^{-1}10^{-6}$, and the copolymer (0.354 and 0.133) $m^2s^{-1}10^{-6}$.

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Introduction

According to the demographics and living standards increase in the sub region in general and in Benin in particular, [1] furniture needs coupled with the export of wood have increased sharply.

As a result, the use of forest products in the manufacture for furniture has become more and more important over the years. Consequently, there is a strong pressure on the environment with the vegetation cover of the territories of the sub region in continuous degradation. Particularly in Benin, the pressure on wood resources is actually so strong that the development of the production of these products (rattans and bamboos) must be seriously considered not only from the point of view of protecting the environment but also of the economic and social well-being of the rural population. [2-3]. To do this, it is important to follow some research on this speculation. On the understanding that Beninese artisans use much more rattans from Nigeria and Ghana, and then rattans are part of the Benin flora [4-10], we undertook to carry out investigations with a view to a better knowledge of their mechanical and physical characteristics, in particular thermo-physics.

Thus, we determined the directional coefficients of these rattans by measuring their thermal diffusivity by the regular regime method [11].

The Rattan

Rattan is from the palm family (palmae), it is a no-wood forest product (NWFP) such as bamboo [13-15]. It is very abundant in tropical and subtropical areas of Asia, notably in India, Pakistan, Malaysia and Cambodia. They grow relatively faster than most forest species known hitherto, whether imported or local. They both serve in multiple uses: building houses, making furniture, weaving, crafts and food [16-17]. They are important sources of foreign exchange and employment for these Asian countries and some in Latin America and Africa, which use them in various ways [15-19]. The socio-economic importance of rattan in the intertropical world justifies the importance of research in its field [3, 20-22]. This economic importance has aroused the enthusiasm for a large number of research projects focusing mainly on economics, trade, ecology, taxonomy and culture [6, 14, 16, 23-25]. Similarly, several studies have been devoted to the anatomy on which the physico-thermal and mechanical properties of rattans depend [26-31].

In West and Central Africa, there are 4 kinds genus of rattan, representing 16 species [6, 32]. African rattans are an integral part of the livelihood strategies of a large part of the rural population and provide the basis for a thriving construction industry. While most rattan species are used locally in a multipurpose manner, there are two more common and more common species, Laccosperma secundiflorum (formerly known as Ancistrophyllum) and Eremospatha macrocarpa, which are used regionally and are used at both as a means of subsistence or for commercial purposes [16-18].

From Fig. 1, at the top, the first picture is a rattan plant, the second one shows a crop of rattan canes, and the third is rattan nuggets. Below, a swinging rattan armchair and a rattan lamp.

Corresponding Author: Dagbegnon Sinmenou, Tel: 00229 96314321
Email: sinmjos1@yahoo.fr

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Figure 1: Plant of rattan and objects made in Rattan

Experimental

Most methods of measuring thermal diffusivity are based on chronological thermograms from which we go back to diffusivity using the exact analytical solutions obtained in theory. According to Vianou A. in [33], we distinguish several methods including:

- The hot wire method;
- The flash method;
- The periodic plan method and.
- The box method.

All these methods use either:

- the identification of the singular points on the thermogram, which sometimes gives errors of appreciation;
- the use of abacus, which is tedious;
- the hypothesis of unidirectional propagation of heat; Which imposes severe experimental constraints;
- a good recognition of the position of the probe ; resulting in uncertainties [34-35].

We opted for the so-called regular plan method. Indeed, in the case of anisotropic materials such as wood, this method seems to be the most appropriate, since it has the advantage of making it possible to simultaneously measure the diffusivities in the two main directions of conduction of the wood [36-37].

If CARSLAW (HS) and JEAGER (JC) deserve to have implicitly alluded to this method in their works [38] in 1946 and [39] in 1959, it is to LEONTIEV and KOJINOV [40] To which it has come back to show in their manual "Theory of exchanges of heat and mass" that starting from the regular regime of thermal evolution of a solid, it is possible in certain conditions to determine the thermal diffusivity of Materials using experimental chronological thermograms.

VIANOU Antoine [11] with GIRARDAY (A) [36], GIRARDAY (A) and POLONIEKI (G.) [41] proposed the regular regime method for measuring the diffusivity of materials [42], [43].

The experimental device

The experimental device is composed of: a thermostatic water bath maintained at a constant temperature of 40° C in which the test specimens are immersed and a computer connected to a digital temperature meter with 12 channels as shown in Fig. 2.

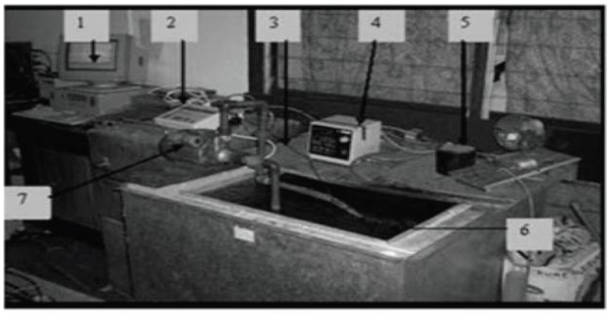

Figure 2: Experimental device to determine thermal diffusivity by regular regime method; 1 - Computer control , 2 - Data acquisition system, 3 - J type thermocouple, 4 – Thermocryostat, 5 – Agitator, 6 - Thermostatic bath, 7 - Water pump

The specimens

Specimens were taken from cane samples from Benin, Nigeria and Ghana:

- Benin in the Djèrègbé village in the commune of Sèmè-Kpodji, 5 km from Porto-Novo, the capital of Benin;
- Nigeria in the swampy area of Badagry;
- Ghana in the Koumassi region.

Geometry of the test pieces

For each test, two test pieces were made of:

- radius R1 and R2;
- half-height: H1 and H2 with H1 = 1.5 H2.

The test with two test pieces makes it possible to obtain a system of two equations with two unknowns. This makes it possible to determine the diffusivity values along the axial and radial directions.

Installation of thermocouples on test specimens

In order to obtain reliable signals, the thermocouple is positioned as close as possible to the center of the specimen and so that the water cannot enter the specimen. To satisfy this requirement, the orifice was made with a drill of one (1) mm diameter on the one hand and was closed on the other hand with a waterproof adhesive.

Waterproofing of test specimens

Since rattan, like wood in general, being a porous material, a prolonged stay in the water would make it take water, or possibly saturate it. Such a phenomenon can substantially modify the thermophysical properties of the material. To circumvent it, a little bit, we varnished the bases two bases of the test pieces. Their lateral faces absorbing very little water (less than 5% of their weight) during the four hundred seconds that the experiment lasts allow them to undergo varnishing.

Assumptions and equations

For the implementation of the regular regime method, simple geometry specimens are generally used. In our experiments we used test tubes in short form.

First, let us formulate the following assumptions:

- the transfers are three-dimensional with symmetry: an axial diffusion and a radial diffusion with T = T (x, r, t) ;
- the medium is assumed to be homogeneous, which implies that a true relation in a "representative element of volume, EVR" can be extended to the whole volume of the sample;
- the thermo-physical properties are independent of temperature;

- the heat exchanges between the fluid and the test piece satisfy the Fourier mixed conditions ;
- The axes of anisotropy are the same with the coordinate axes ; At time t_0, the temperature T_0 of the test piece is uniform.

By noting that the thermal field in a straight and short cylinder is a combination of the thermal field in an infinite cylinder and the thermal field of an infinite plate (see Fig. 3) [36]; Heat transfers are governed by the following system of equations:

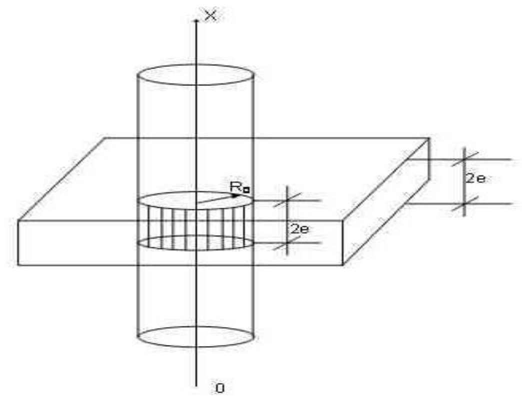

Figure 3: Intersections of an infinite cylinder and an infinite plate

In Ox direction :

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{a}\frac{\partial T}{\partial t} \qquad (1)$$

With the initial conditions:

$$T(x, t) = T_0 \text{ à } t = 0 \text{ for the } -e \leq x \leq +e \qquad (2)$$

And the conditions at the limits

$$\frac{\partial T}{\partial x} + \frac{h_x}{\lambda_x}(T - T_f) = 0 \text{ at } x = \pm e \qquad (3)$$

In the OR direction:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} = \frac{1}{a}\frac{\partial T}{\partial t} \qquad (4)$$

With the initial conditions:

$$T = T(r, t) \text{ et } T(r,0) = T_0 \qquad (5)$$

And the conditions at the limits

$$\frac{\partial T}{\partial r} + \frac{h_r}{\lambda_r}(T - T_f) = 0, \text{ en } r = R_0 \qquad (6)$$

As symmetrical consequence, it has:

$$\frac{\partial T}{\partial r} = 0 \text{ at } r = 0, \text{ and } \frac{\partial T}{\partial x} = 0 \text{ at } x = 0 \qquad (7)$$

For $t \to \infty$ $T(x, r, t) = T_f$

In these relationships: e = half-height of the cylindrical specimen [m], R_0=radius [m], T_f=set T=T (x, r, t)=variable temperature [K], point temperature of the thermostat bath [K], λ_x =Conductivity of the material in the direction Ox [W/m.K], λ_r =Conductivity of the material in the radial direction [W/m.K], h_r=coefficient of thermo convective exchanges relative to the lateral surface [W/m².K], h_x= thermo convective exchange coefficient relative to base surfaces [W/m².K].

The solutions of equations (1) to (6) are:

For axial transfer

$$\theta_x = \frac{T(x,t) - T_f}{T_c - T_f} \qquad (8)$$

For radial transfer

$$\theta_r = \frac{T(r,t) - T_f}{T_0 - T_f} \qquad (9)$$

As a reduced solution, the general solution is on the form [43]

$$\theta = \theta_x \times \theta_r \qquad (10)$$

This can be written in the form:

$$\theta = \sum_{i=1}^{\infty}\sum_{j=1}^{\infty} A_{ij} F_{ij} \exp[-(n_{ix}2\frac{a_{ix}t}{e^2} + n_{jr}2\frac{a_{jr}t}{R_0^2})] \qquad (11)$$

with:

$a_{ix} = \frac{\lambda_{ix}}{\rho c}$; diffusivity corresponding to the axial direction

$a_{jr} = \frac{\lambda_{jr}}{\rho c}$; diffusivity corresponding to the radial direction;

λ_{ix} and λ_{jr} are respectively the conductivities along the axis Ox and according to the radius R;

A_{ij}; F_{ij}; n_{ix}; n_{jr} are constants.

It demonstrates with Vianou in [11] that they depend on the Biot number ($Bi = h_{moy} R_0 / \lambda$), sequence numbers i and j and the coordinates (x, r) the registration point of the thermogram. From a certain value of time giving high numbers Fourier $F_0 \geq 0{,}23$ ($F_0 = at/e^2$, the series (7) is well described by the first term to better than 1% of the reduced temperature Is well given by the relation [33]:

$$\theta = A_{11}F_{11}\exp\left[-(n_{1x}^2\frac{a_{1x}t}{e^2} + n_{1r}^2\frac{a_{1r}t}{R_0^2})\right] \qquad (12)$$

Which expresses that the reduced temperature evolves exponentially: it is this form of variation which is called *Regular Regime*.

$$\text{Writing } m = n_{1x}^2\frac{a_{1x}}{e^2} + n_{1r}^2\frac{a_{1r}}{R_0^2} \qquad (13)$$

Then $\theta = A_{11}F_{11}\exp[-mp] = A\exp(-mt)$ from which:

$$\ln\theta = \ln\frac{\Delta T}{\Delta T_0} = -mt + Cte$$

$$\text{or } \ln\Delta T = -mt + Cte \qquad (14)$$

$\tau = 1/m$is also called the fundamental time constant, [s]

If the regime is regular with F0 ≥0.23, it is possible to obtain m graphically from the timing diagram. Ln (ΔT) with ΔT = T (x, r, t) $-T_f$ or go up to m by a linear regression carried out directly on the points obtained experimentally. The work of Vianou in 1994 [33] have shown that when the Biot number is high, for example greater than or equal to 100, the coefficients n_{1x} and n_{1r} are constant and equal to: n_{1x} = 1.57 and n_{1r} = 2.40. Under these conditions m can be written: [33]

$$m = \frac{(1{,}57)^2}{e^2} a_{1x} + \frac{(2{,}40)^2}{R_0^2} a_{1r} \qquad (15)$$

The number Bi ≥100 reflects the fact that the film resistance (at the surface) is negligible compared to the internal resistance in the process of propagation of heat in the material. In this case, it is no longer necessary to know the exact values of the thermo-convective exchange coefficients. The determination of the directional thermal diffusivities of an anisotropic material such as wood by the regular regime method requires two distinct measurements on two samples of different characteristic

dimensions (e_1, R_1) and (e_2, R_2).
In the case of cylindrical specimens, the radial transfer represents for the wood the transverse transfer (perpendicular to the direction of the fibers); whereas the axial transfer represents for the wood the longitudinal transfer (according to the direction of the fibers). By using two specimens of respective heights and radii (e_1, R_1) and (e_2, R_2), we find a system of two equations with two unknowns.
Referring to formula (15), the system is written [33]:

$$\begin{cases} m_1 = \frac{(1,57)^2}{e_1^2} a_{1x} + \frac{(2,40)^2}{R_1^2} a_{1r} \\ m_2 = \frac{(1,57)^2}{e_2^2} a_{1x} + \frac{(2,40)^2}{R_2^2} a_{1r} \end{cases} \quad (16)$$

The solving of this equations system gives the diffusivity values a_{1x} and a_{1r} and the relative uncertainties.

$$\frac{\Delta a_{1r}}{a_{1r}} = \frac{\Delta m_1}{m_1} + \frac{\Delta m_2}{m_2} + 2(\frac{\Delta e_1}{e_1} + \frac{\Delta e_2}{e_2}) + 2(\frac{\Delta R_1}{R_1} + \frac{\Delta R_2}{R_2})$$

The absolute uncertainties calculation take in account the uncertainty of measurement and the uncertainty associated with the material. They are put down for Plexiglas and Table 2.

Results and Discussion

Validity study of the experimental dispositive device

To validate the experimental dispositive device, we carried out some tests including the determination of the diffusivity of Plexiglas by the regular regime. Two test pieces with the following dimensions were used: Test tube1- Diameter: $\varphi_1 = 2R_1 = 28$mm and Height: $H_1=2e_1=24$ mm; and Test tube2-Diameter: $\varphi_2 = 2R_2=28$mm and Height: $H_2=2e_2=22$ mm. With formula 16 we calculated the axial as well as radial diffusivity of the Plexiglas obtained the following results:

$a_{1x} = 0.1060 \times 10^{-6}\ m^2s^{-1} \pm 0.0097\ 10^{-6}\ m^2s^{-1}$;
$a_{1r} = 0.1020 \times 10^{-6}\ m^2s^{-1} \pm 0.00939\ 10^{-6}\ m^2s^{-1}$.

It's noticed for the Plexiglas $a_{1r}=a_{1x}=a$. This equality proves that it is an isotropic material on the one hand and that on the other hand the regular regime method is good for the determination of the directional transfer coefficients of the heat in a material.

Diffusivity calculation of the threes rattans

The specimens made from these samples have the dimensions mentioned in the Table 1 below.

Table 1: Specimens dimensions

	DIMENSION OF THE SPECIMENS FOR AXIAL DIFFUSIVITY				DIMENSION OF THE SPECIMENS FOR RADIAL DIFFUSIVITY			
	Specimens 1 Diameter (φ) and Height (H=2e) [mm]		Specimens 2 Diameter (φ) and Height (H=2e) [mm]		Specimens 1 Diameter (φ) and Height (H=2e) [mm]		Specimens 2 Diameter (φ) and Height (H=2e) [mm]	
	φ	H	φ	H	φ	H	Φ	H
BN	18.89	66	19.02	44	19.11	66	19.24	44
NG	34.63	66	34.61	44	28.40	66	28.42	44
GH	38.99	66	39.34	44	39.55	66	40.02	44

BN: Rattan from Benin; NG: rattan from Nigeria; GH: Rattan from Ghana.

With the formula 16 we've calculated the axial and radial diffusivity of these materials.

Table 2: Axial and radial diffusivity of the rattan of Benin, Ghana and Nigeria

BN		NG		GH	
a_{1x} [$m^2s^{-1}10^{-6}$]	a_{1r} [$m^2s^{-1}10^{-6}$]	a_{1x} [$m^2s^{-1}10^{-6}$]	a_{1r} [$m^2s^{-1}10^{-6}$]	a_{1x} [$m^2s^{-1}10^{-6}$]	a_{1r} [$m^2s^{-1}10^{-6}$]
0.033192± 0.006567	0.653326± 0.012903	0.032164± 0.005671	0.641273± 0.115844	0.316815± 0.05007	0.616851± 0.0980663

With those results, it noticed that:
The rattan has a lower radial and respective axial diffusivity than teak (0.242 and 0.143) $m^2s^{-1}10^{-6}$, ebony (0.228 and 0.176) $m^2s^{-1}10^{-6}$, and the copolymer (0.354 and 0.133) $m^2s^{-1}10^{-6}$ previously determined by VIANOU Antoine [11], ,COULIBALY A. [44], GBOHAYIDA Sylvain [45], ALLOGNON HOUESSOU Elisabeth Akoivi [46] and VODOUNOU Edmond [47], Houngan Aristide and Al [48].
Driving less heat than conventional materials, because of its anatomical structure with enough voids [49], [50], rattan is now discovered as an ideal material with regard to fire resistance.
The use of rattan for reinforcement in concrete (research in progress at the laboratory of analysis of the Ecole Polytechnique of Yaoundé in Cameroon) [51] is thus justified in the same way with respect to the transmission of heat. This has so a notable influence on the thermal comfort in the building.

Conclusions

The rationalization of the use of rattan in crafts and construction requires the study of its thermal, physical and mechanical properties. In this framework, we presented the results of our research work on thermophysical studies, in particular the determination of directional parameters of heat diffusion through rattan canes from Benin, Nigeria and Ghana by the regular regime method.
This is how we have recorded results that show that:
- Both for axial and radial diffusivity, the rattan of Benin has higher values than those of the rattan of Nigeria, which are also higher than those of the rattan of Ghana. These results may also be explained by the density of each of these materials.
- The radial diffusivity of the rattan is much greater than that of the axial, as opposed to the results obtained with the same experimental device for conventional woody materials. This result is justified by its anatomical structure which presents axially many voids and radially a very compact and hard crown.
With the results obtained can allow a more using of rattans in the ways of the valuation of local materials and in the same time for the environment preservation.

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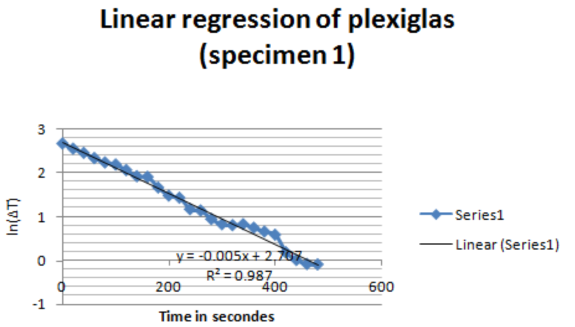
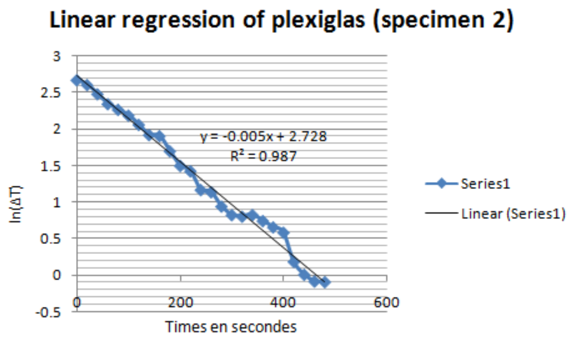
Annexes

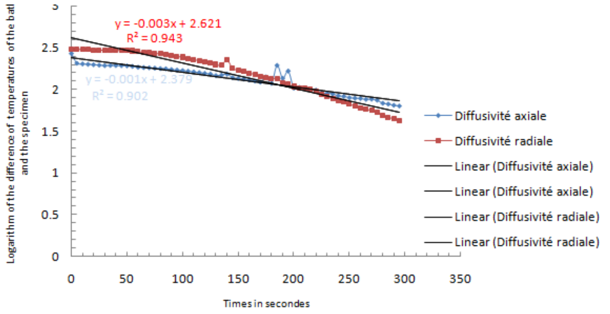


(a)

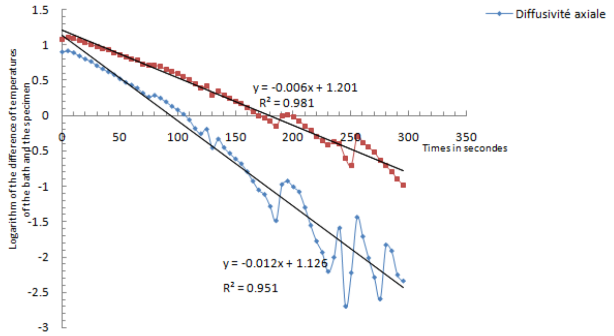


(b)

Figure 1: Linear regression of Plexiglas (a) specimen 1, (b) specimen 2



(a)



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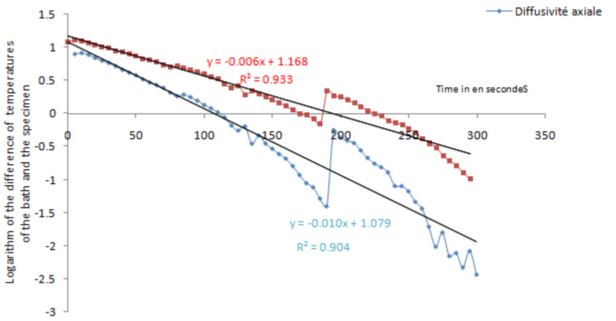
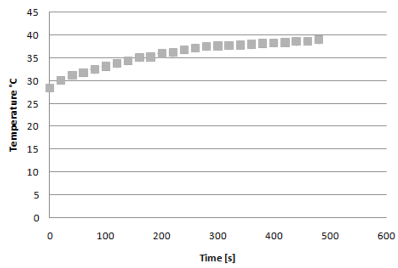
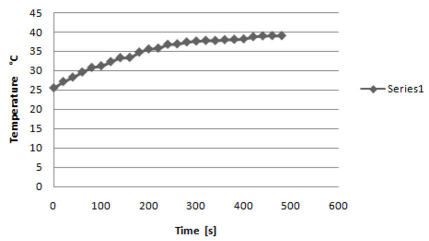


(c)

Figure 2: Thermal diffusivity of the (a) Nigerian Rattan, (b) Benin Rattan, (c) Ghanan Rattan



(a)



(b)

Figure 3: Thermogram of Plexiglas (a) specimen 1, (b) specimen 2