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# Unique method for complete thermal characterization of thick materials Civil Engineering

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**Abstract**

This document proposes a method sufficient alone to estimate all the thermo-physical properties of a heavy construction material. The method is applied to the characterization of new building materials (lightweight concrete), made from ronier fibers or rice husk with the cement matrix as supporting fibers.

***Keywords:*** Mixing cement fiber Palmyra, rice husk cement mixture, lightweight concrete, diffusivity, heat capacity, conductivity, effusivity.

## Introduction

The thermophysical characterization of building materials is a relatively new concern. Formerly, there was only interested in the strength of the frames for securing investments or to fight against insecurity. But the need for comfort and growing demand for more energy (Rajat, 2012) and the resulting corollaries of soaring prices and environmental pollution (Citherlet, 2007), make it necessary to reconsider the quality of building materials. Thus, new designs direct research towards the introduction of phase change materials. delete. Other areas of research are organized around relief the physical mass of concrete and therefore the cost of achieving it (Merzoud, 2008) (Fertikh, 2011) but at the same time improving its thermal efficiency by incorporating it plant biomass. In doing so, many industrial and domestic solid waste is recycled (Levacher, 2010), which participates in the partial resolution of environmental problems, and reinforces the concept of green building advocated by the government. The success of all these investigations depends to a large part of the improvement of methods of characterization of these latest updates, exclusive composite materials. The thermo-physical properties estimation methods previously known here have been previously developed to characterize thin materials, homogeneous and good conductors in general. But with the need become essential to characterize heterogeneous thick materials and new composite materials that are involved increasingly in civil engineering, they have been adapted to meet this new demand. However, none of these methods is in itself sufficient to provide all the thermophysical parameters (conductivity, heat capacity and diffusivity effusive) of a material. One has indeed often use different methods to estimate these parameters. Under these conditions, the results obtained are highly impaired by cross details of these methods. The methods of measuring steady require a long time (about an hour) handling, and the change in humidity over time, then leads to results affected by errors. However, some methods yield quite satisfactory

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results. The method of guarded hot plate (Vivancos delete. et al, 2009) and boxes method, developed by the Laboratory of Solar Thermal Studies and the University Claude Bernard Lyon, leading to the estimation of the thermal conductivity only.

As for the methods under varying conditions, they are often used for heterogeneous biological materials to high humidity. These methods also called transients are implemented on the basis of the full differential equation of heat flow as determined by Carslaw and Jagger (1959). The method of hot wire leads to a good estimate of the conductivity of a material provided to minimize the difference between a theoretical curve and an experimental curve. Technical single rod for its part was the subject of numerous publications including those of (Perrin, 1987) and (Laurent, 1989 and 1991). Its principle is based on the measurement of the elevation of the temperature of a cylindrical metal rod of known resistance introduced in the materials studied. The technique allows, for the implementation of the linear regression, to estimate the thermal conductivity of granular material, sufficiently pasty materials and even of consolidated materials. Regarding the Warm Ribbon method, it allows estimating the conductivity and effusivity. It goes through the operation to short times of a hot plane type of behavior in the center of the probe, linked to a heat flow perpendicular to the tape. But also the long-time operation of a hot wire type of behavior when the flow becomes comparable to a radial flow. Measurement accuracy depends on the estimated time that assumes different specific behaviors of the flow of the stream. The method also induces a contact resistance which influences the correct estimation of the various phases of the flow of heat. TPS technology (Transient Plane Source) developed by (Gustafsson, 1991) meanwhile, allows simultaneous measurement of volumetric specific heat and thermal diffusivity, in the dry state and when saturated.

We propose in this work a method that eliminates the difficulties associated with the introduction of foreign bodies in materials characterization and present the advantage of providing all the thermo-physical properties of the element studied. We applied to the characterization of composite materials Fibre-Cement Rônier and Rice Cement Balls.

## Materials and Methods

It is composed of: a transmitter that sends a calibrated flow on the sample to be characterized, of an insulator (polystyrene) in which is embedded the sample to minimize the edge effects in the process heat diffusion in the material, but also to maintain its second face isolated, of two thermocouples attached to each side using a thermal paste to monitor the temperature on both sides, of a flow meter associated with thermocouple disposed the front panel to monitor the flow during the sample excitation time and a data acquisition system for real-time recording of temperature and flow. Two samples are examined in this work. They are made from cement that is the matrix supporting the palmyra fiber for the first and rice hulls for the second. The palmyra fibers (see photograph in figure 2) may come from the release of machining palmyra wood (*Gbaguidi et al, 2010*) or the direct conversion of the stem (trunk palmyra) fiber. The palmyra whose scientific name is borassus aethiopum mart is a woody plant "monocotyledon" plant classified as a priority by FAO experts (FAO, 2004). It is a renewable resource that produces wood rot and termite resistant Service with a low rate of water absorption of the fibers. According to an experimental study of mechanical performance achieved in the context of use as reinforcement in concrete plant, the borassus aethiopum mart has a tensile strength and a high modulus of elasticity similar to those of steel with a withdrawal rate no longitudinal (Gbaguidi *et al* 2010). It is a very abundant plant with innumerable qualities that justify the interest focused on the study of the thermal properties of composites based on its fibers. As for rice, whose scientific name is *Oryza sativa*, it is a culture massively produced, known throughout the world. After treatment, rice generates significant amounts of waste (rice balls: see photograph (Figure-3) that contribute to the enhancement of environmental pollution. However, rice hulls, due to their chemical composition are made of cellulose, ash and especially of silica ($SiO_2$ content estimated at 20%) that make them attractive for research points.

**Figure 1 Schematic of the measuring device**

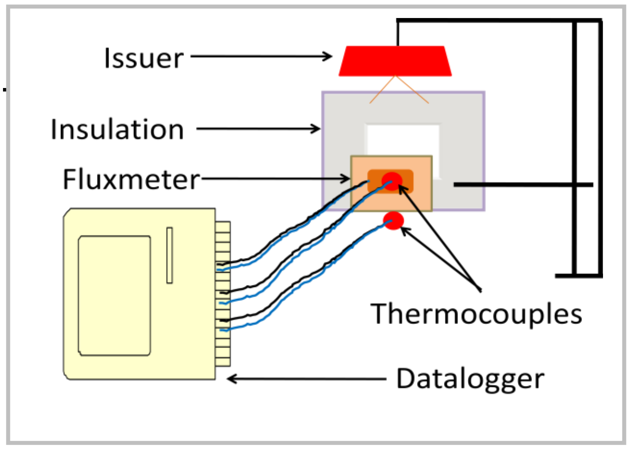


**Figure 2 Appearance of palmyra fiber**

These fibers have been embedded in a cementitious matrix according to a suitable dosage in water. At the end of these operations a lightweight concrete composition is obtained whose samples are shown in figures 4 and 5 which follow.

**Figure 3 Appearance of rice husks**

**Figure 4 Appearance of composite fiber cement palmyra (rônier)**

**Figure 5 Appearance composite rice cement armor according the water dosage**

## Method

The different methods of properties thermophyques measures outlined above, only provide conductivity and for the effective diffusivity and the effusivity. When you need to know all the thermal characteristics of a material are often used in different processes or methods Each one influences the final result by the errors inherent in their implementation. The method we present in this work has the significant advantage, to provide all the thermophysical parameters of the studied element: conductivity, diffusivity, specific heat and capacié effusivity.

### Principle of the method

Thick blade $L$ is subjected to a constant stream $q_0$ from a time $t = 0$, on the face $x = L$, while its other face $x = 0$ is perfectly thermally insulated (see figure 1). The thermocouples arranged on each side keep track of changing temperatures on these faces. The flowmeter allows to monitor the flow in the material to locate later, the time interval during which it remains constant. The data logger allows real-time recording of the entire measurement process. After a sufficiently long time (about six minutes), changing temperatures on both sides due to a combination of three distinct phenomena. First, there is the initial temperature of the material before the start of the experiment that we call $T_0$.

Then, when subjected to the stream, it first heats its surface and by conduction heart warms. The surface does not reach a limit temperature, since the heat flow imposed remains constant. This temperature difference should be compared to the overall elevation of the material temperature. Temperature inhomogeneities can be measured by comparing the heat flow imposed $q_0$ and the flux transferred by conduction within the material, $q_{con} \propto k\Delta T\, S/L$ where $S$ is the characteristic surface of the material exchange herethe characteristic surface of the material exchange here is in our experience reduced single and $L$ its thickness characteristic. $V \cong S \times L$ is the volume of the material, it follows that

$$\Delta T_{inhomogne} = \frac{q_o L^2}{kV}$$

Taking into account a unit surface and a convection inherent to experimental conditions (the radiative source at about 70 cm from the surface of the material and the measuring device in a large room), we are led to reassess the temperature in homogeneities:

$$\Delta T_{inhomogne} \approx \frac{q_o L}{3k}$$

Finally, the environmental temperature is a global evolution over time, and is worth

$$\Delta T_{el.globale} = \frac{q_o t}{\rho C_p L}$$

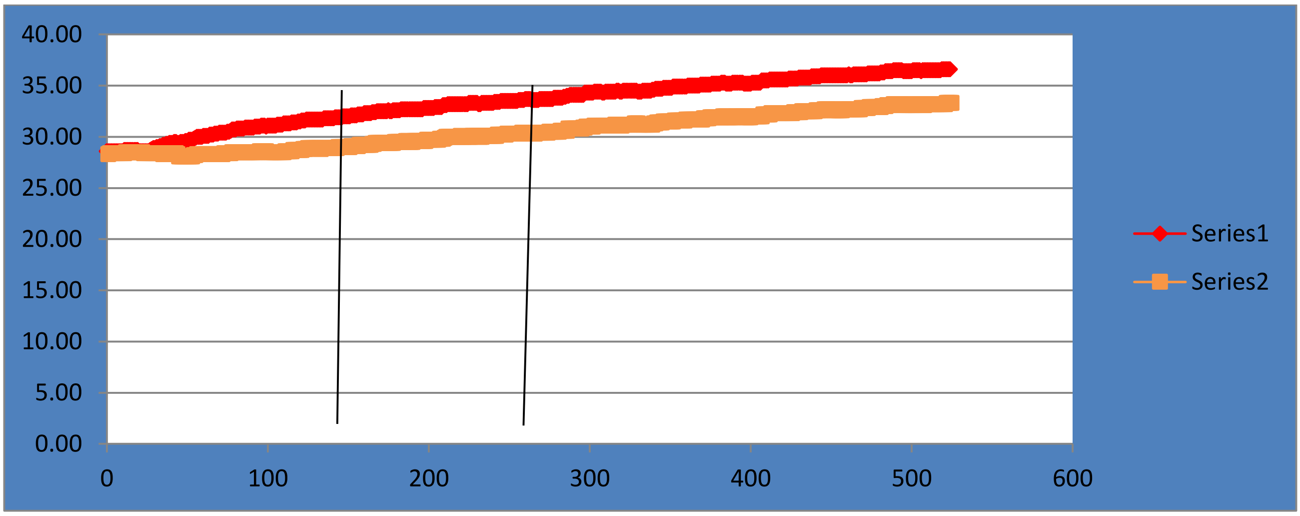
It comes as changing temperatures on both sides of the material is given by:

$$T(0,t) \approx T_0 + \frac{q_0 t}{\rho C_p L} - \frac{q_0 L}{6k}$$

$$T(L,t) \approx T_0 + \frac{q_0 t}{\rho C_p L} + \frac{q_0 L}{3k}$$

Furthermore, the thermograms faces on the recorder are as shown in figure 6

**Figure 6 The thermograms of the faces, upper (red), bottom (orange) of a blade**




These samples, whose mechanical and physical properties are fairly well known (delete DOKO et al, 2013), are the subject of this method thermophysical characterization.

**Figure 7: Determination of the useful field and estimate the slope p Fibre 1**

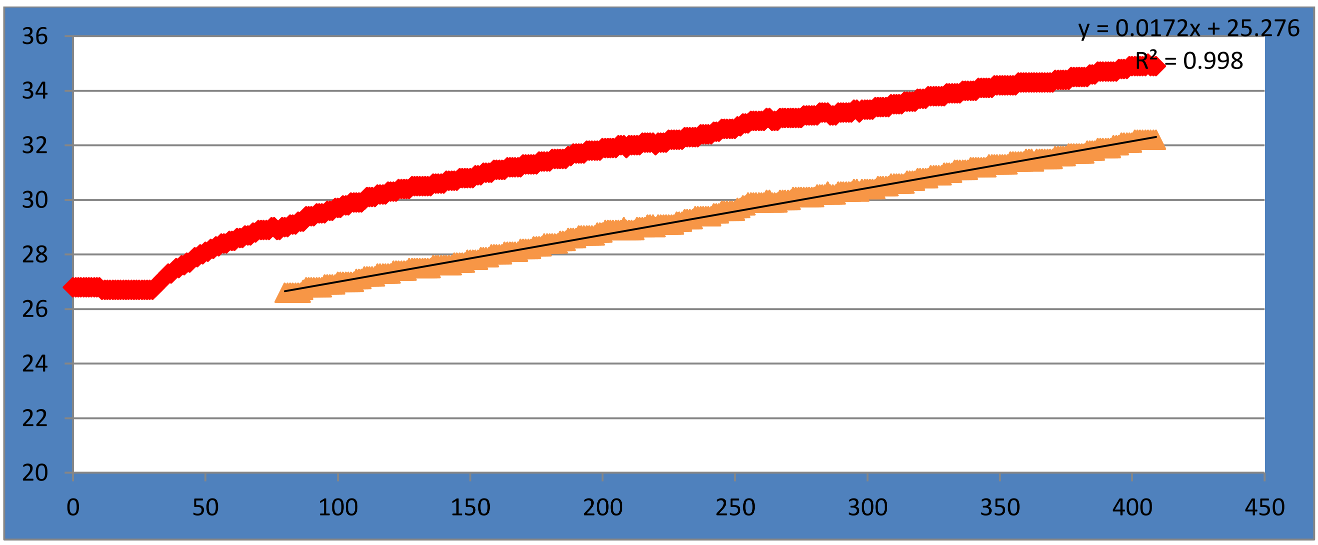


**Figure 8: Determination of the useful field and estimation of slope p Rice1**

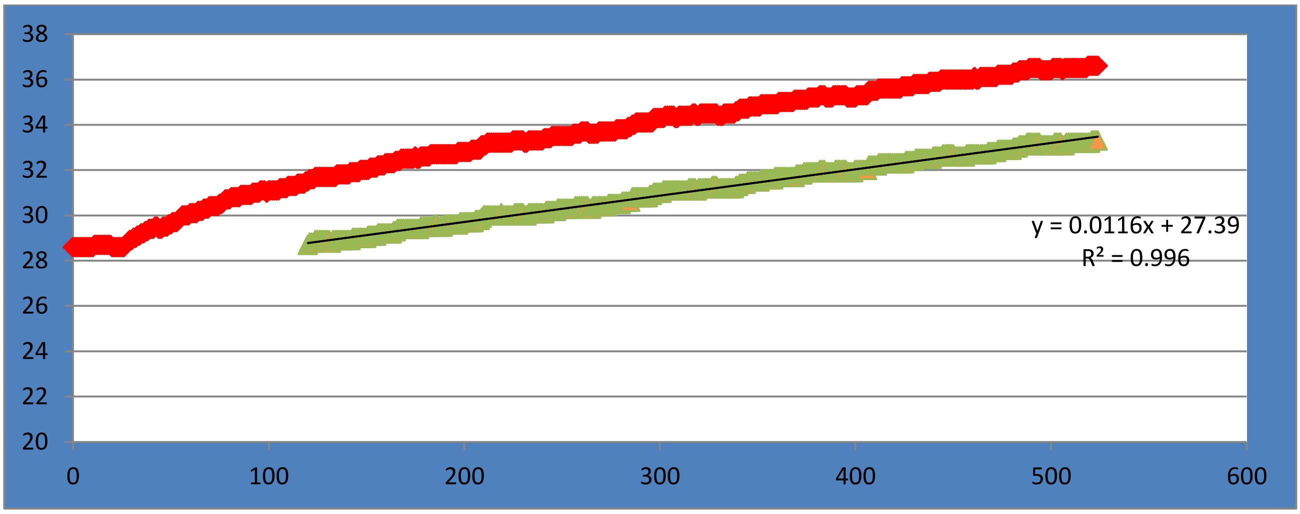



**Figure 9: Evolution of the flux density on the front face of Fibre1**

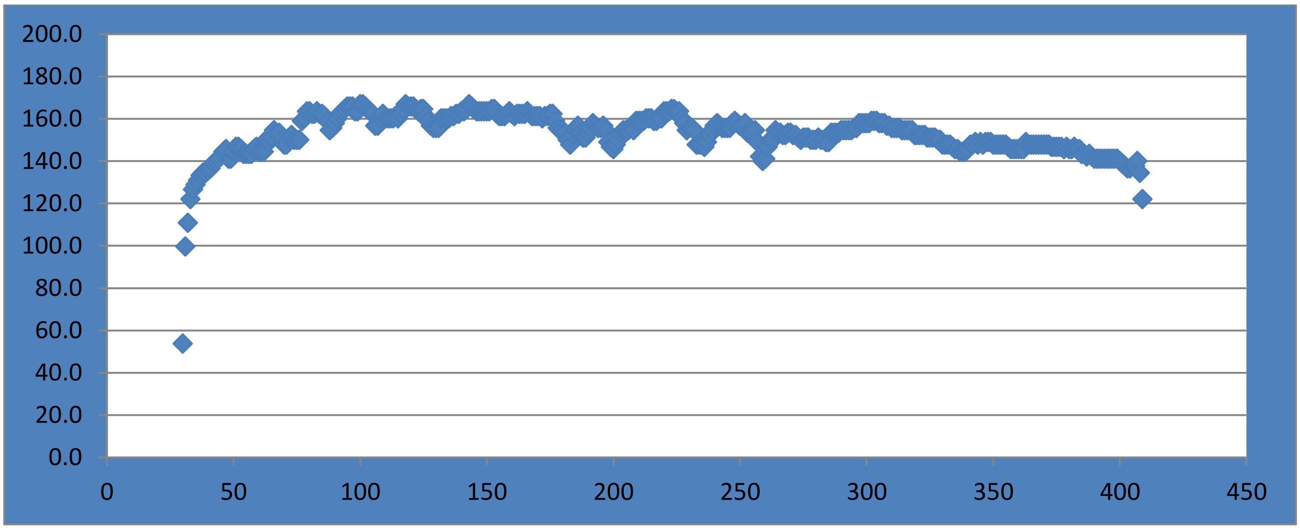



**Figure 10 Evolution of the flux density on the front Rice1**

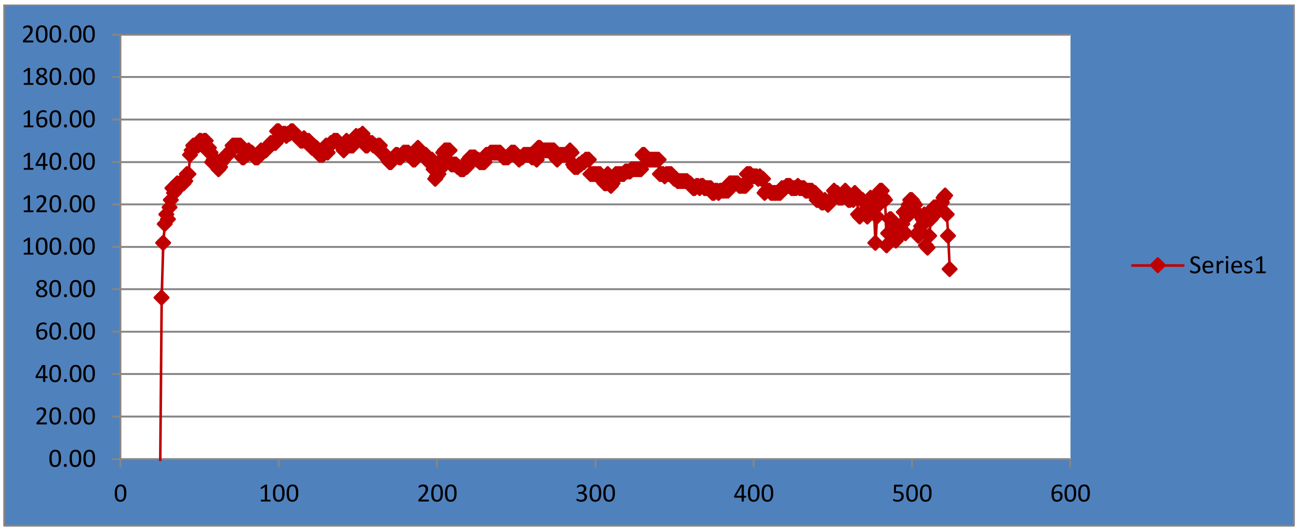


**Figure 11: Variation of the temperature difference Fibre1**

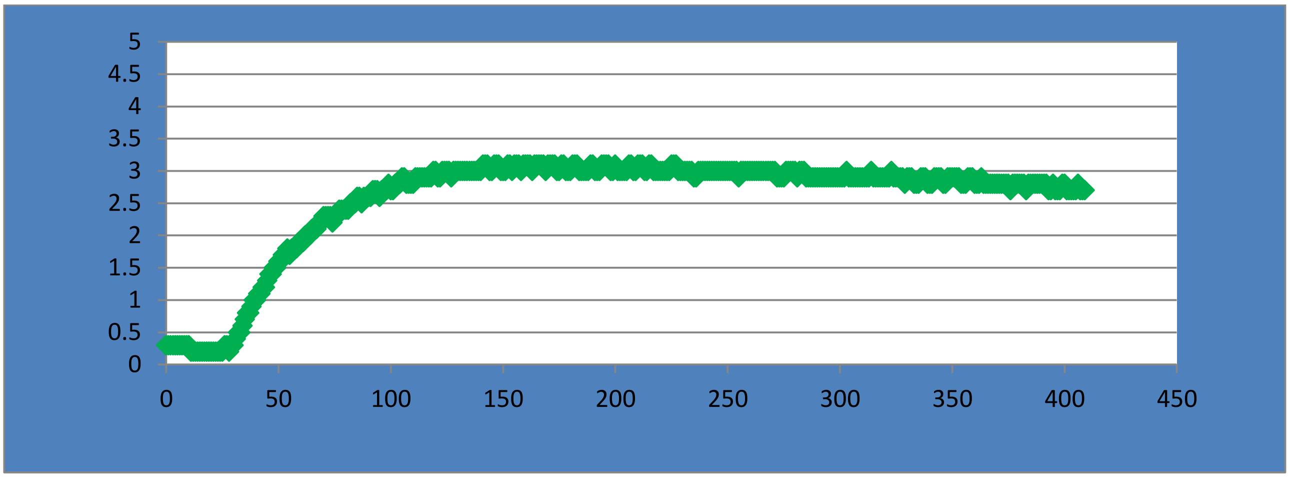



**Figure 12 Change in Rice1Temperature difference**

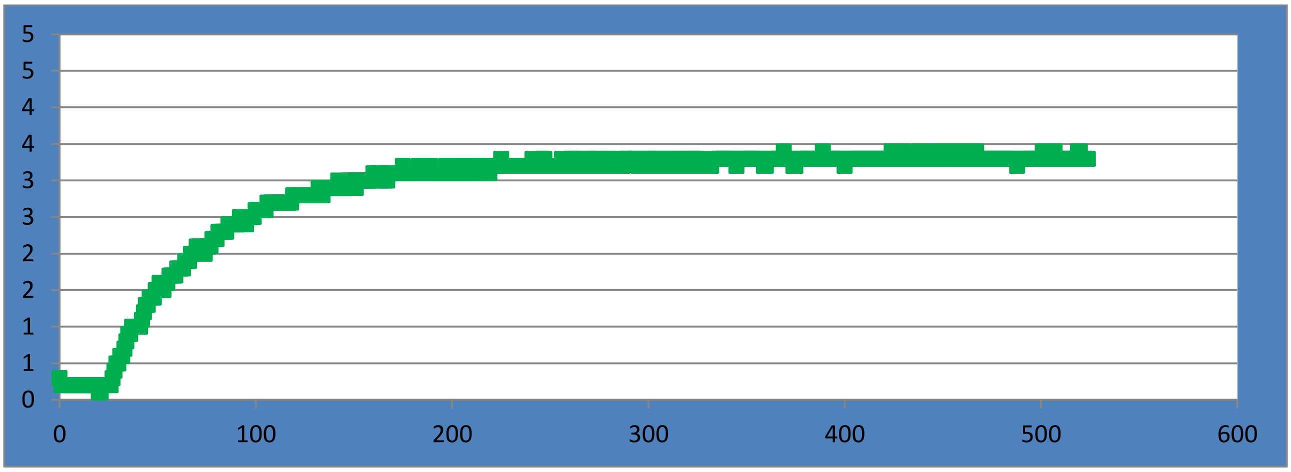



**Table 1 Proportions used for the composition of mixtures**

| Aggregates | Rice husks | | Palmyra fiber | |
|---|---|---|---|---|
| Diameters particles / fibers | Mixture sieved (MF) | Mixture coarse | Mixture sieved (MF) | Mixture coarse |
| [2.5; 5[ | 16,67% | 40% | 16,67% | 40% |
| [1.25; 2.5[ | 16,67% | 30% | 16,67% | 30% |
| [0.63; 1.25[ | 33.33% | 20% | 33.33% | 20% |
| [0.315; 0.63[ | 33.33% | 10% | 33.33% | 10% |

In the following, the experimental results regarding Fibre1: MF = 400; E / C = 0.6; e = 1cm and Rice1: MG = 500; E / C = 0.25; e = 1 cm are then presented, a table of the results of measurements on all samples is exposed to the end.

$t_1$ $t_0$ $t_2$

It is remarkable that the expressions (4) and (5) are approximations of the same slope of curve equations

$$p = \frac{q_0}{\rho C_p L}$$

The observation is confirmed on the thermograms of figure 6, showing that for certain values of time, $t \in [t_1, t_2]$, curves were behaviors parallel lines. The useful range of parameter estimation is precisely the place where this curve behavior is observed.

Since the slope p is determined, it is possible to deduce the thermal capacity by:

$$\rho C_p = \frac{q_0}{pL}$$

On the other hand, at an arbitrary time $t_0$ the difference between both thermograms is given by the relation:

$$\delta T = T(L, t_0) - T(0, t_0) = \frac{q_0 L}{3\,k} + \frac{q_0 L}{6\,k} = \frac{q_0 L}{2\,k}$$

From the expression (8), it can be possible to deduce the conductivity k by the equation:

$$k = \frac{q_0 L}{2\,\delta T}$$

Thermal effusivity can be calculated easily by the formula:

$$e = \sqrt{k \rho C_p} = \frac{q_0}{\sqrt{2 p \delta T}}$$

$\delta T$

Finally, the diffusivity can be estimated even in the event of infringement of the flow level $q_0$ by the formula:

$$a = \frac{k}{\rho C_p} = \frac{q_0 L}{2\,\delta T} . \frac{pL}{q_0} = \frac{pL^2}{2\,\delta T}$$

## Data Processing

The previously described method was applied to the estimation of thermophysical properties of two species of samples one based fiber palmyra and the other with rice balls. The various samples subjected to the experiment are coded as indicated below:

- Fibre means: Mixture fiber cement palmyra,
- Rice means: Mixture of rice husk cement,
- MFX / E / C means : MF sifted mixture. X indicates the density of the mixture. E / C indicates the water-cement ratio,
- MGX / E / C means: MG coarse blend. X indicates the density of the mixture. E/ C indicates the water-cement ratio,
- e represents the thickness in centimeters of the experimental sample.

Samples are indeed facts Blend Coarse (MG) or sieved mixture (MF). For particle diameters of fibers between a given interval, the (MF) differs from (MG) by its percentage in the composition. (See the table below for details). Figures (7) and (8) show the following experimental determination of the useful area and the estimation of the slope p for both samples. Thus, the slope obtained for the fiber palmyra is $p_f = 0.017$ and that obtained for rice is$p_r = 0.011$. Similarly, the $q_0$ flux density is determined graphically from the curve of evolution of the flow on the front face of the sample. For this it is necessary to identify an area in which the flow remains constant or varies very little. It appears in Figure (9), that $q_0$ varies very little within the range of 140 to 160 and this, over a relatively wide time of 150 to 350 seconds. Similarly, it can be seen in Figure (10), that $q_0$ fluctuates very little in the range of 125 to 148 of a time range of 150 to 350 seconds. The desired thermo-physical properties will be estimated in the following, to $q_0$ values thus identified. The last value coming into consideration in the method is the gap between the two thermograms $t_0$ a value of time.

As in previous cases, a graphical representation of this function away, can read and retain value as the one for which this function remains constant over a long period of time. Figures (11) and (12) describe the graphical representations of the differences between the temperatures on the front panel and the rear panel. It is noteworthy in (figure 10), the gap remains constant at three (3) over a time interval ranging from 100 to 350 seconds around. It is therefore relevant to take as a deviation $\delta T = 3$ for this sample there. Regarding the (figure 11) the gap remains constant at 3.2 over a time range 230-450 seconds around. In this case $\delta T = 3.2$ is the chosen standard. It is important to note that the fact that the principle of the method is based on a parallel evolution of thermal images at one time, it is necessary to look for the manifestation of this phenomenon in the density curves flow and temperature difference, to make estimates at these locations.

## Results and Discussion

Overall, the materials examined are less dense than the mortar, so less able to store energy as mortar. But also less conductive heat which is confirmed by their low conductivity relative to the latter. On the other hand, they facilitate less heat exchange with the environment as mortar, evidenced by their low effusivity compared to that of the mortar. In this same logic, they are less diffusive. Given all the above, it would be more favorable if the concerns of a building to be made are to have less heavy (therefore less expensive) and relatively well insulated, to choose one of those materials that the mortar. By cons if the concern is to store energy in the walls of the building to its future use, mortar is better. There a significant absorption capacity of thermal energy, but also ease the returned to the environment. The composition of the mixtures giving the different samples, has a remarkable influence on the results. Indeed, the thermal characteristics of Riz2 are all greater than those corresponding Riz3. The blends are screened and Coarse respectively, densities are identical to (400) but the water-cement ratios are different, respectively (0.3) and (0.4). The same is done with Fibre1 and Fibre2, except that for this case, the sifted mixture in the report that the highest water-Cement (0.6) against (0.4). However, the thermal characteristics of Fibre 2 are greater than those homologues Fibre1. So it can be concluded that the differences observed in the samples of the same species (Rice-Rice) and (Fibre-Fibre) are not due to the nature of the blend (Coarse-sieved) but rather to the water-cement ratio that they contain. Excess water seems eroded the thermo-physical properties of the samples. A direct consequence is that by varying this factor, it is possible to obtain a specific material for a specific use.But when the materials are different (and Rice1 Fibre3) for example, the previous observation is no longer verified. Although the water-cement ratio is higher at Fibre3 (0.4) against (0.25) for Rice1 all Fibre 3 thermophysical characteristics are higher than those of Rice1 with the exception of the heat capacity, which is 833 334 for Fibre3 against 1,240,910 for Rice1. Regarding Riz3 and Fibre2, they are identical in all respects due to their composition. The highest thermal characteristics are noted at Fibre2. So at equal composition, an appropriate choice can be worn on a particular material for a predictable result. The estimation results of thermophysical parameters of the tested samples are shown in Table 2

**Table 2 Summary of outcome measures**

| Specification | RoCp ($J.m^{-3}.K^{-1}$) | Conductivity k(W/m.K) | Effusivity ef($J.K^{-1}.m^{-2}.s^{-1/2}$) | Diffusivity a($m^2.s^{-1}$ ) |
|---|---|---|---|---|
| Riz1=MG500/E/C=0.25/e=1 | [1136364; 1345455] | [0.20; 0.23] | [471; 558] | 1.72.1O$^{-7}$ |
| Riz2=MF400/E/C=0.3/e=1.1 | [909091; 1060606] | 0.260 | [490; 5.22] | 2.66.10$^{-7}$ |
| Riz3=MG400/E/C=0.4/e=1.14 | [674764; 809717] | [0.16; 0.17] | [331; 372] | 2.26 |
| Fibre1=MF400/E/C=0.6/e=1 | [823529; 941176] | [0.23; 0.27] | [438; 501] | 2.83.10$^{-7}$ |
| Fibre2=MG400/E/C=0.4/e=1.35 | [864198; 987645] | [0.32; 0.33] | [522; 569] | 3.48.10$^{-7}$ |
| Fibre3=MF500/3/C=0.4/e=1.14 | [777778; 888889] | [0.31; 0.36] | [492; 562] | 4.10$^{-7}$ |

**Table 3 Average values of measurement results**

| Spécification | RoCp (J.m$^{-3}$.K$^{-1}$) | Conductivité k(W/m.K) | Effusivité e(J.K$^{-1}$.m$^{-2}$.s$^{-1/2}$) | Diffusivité a(m$^{2}$.s$^{-1}$ ) |
|---|---|---|---|---|
| Riz1=MG500/E/C=0.25/e=1 | 1240910 | 0.22 | 515 | 1.72.1O$^{-7}$ |
| Riz2=MF400/E/C=0.3/e=1.1 | 984849 | 0.260 | 506 | 2.66.10$^{-7}$ |
| Riz3=MG400/E/C=0.4/e=1.14 | 742241 | 0.17 | 352 | 2.26.10$^{-7}$ |
| Fibre1=MF400/E/C=0.6/e=1 | 882353 | 0.25 | 470 | 2.83.10$^{-7}$ |
| Fibre2=MG400/E/C=0.4/e=1.35 | 925922 | 0.33 | 546 | 3.48.10$^{-7}$ |
| Fibre3=MF500/3/C=0.4/e=1.14 | 833334 | 0.34 | 527 | 4.10$^{-7}$ |
| Mortier | 1952586 | [1; 100] | [1400; 140028] | 5.1.10$^{-7}$ |

## Conclusion and outlook

The method presented in this work offers the advantage of allowing the estimation of all the thermo-physical properties of a material. The difficulties caused by cross clarification due to the combination of several methods to estimate the thermophysical properties of a material are eliminated. It is applied to the characterization of new materials developed from releases from rice husking and the palmyra fibers. It has provided a better understanding of these materials by giving the opportunity to make a wise choice in a given use. It revealed that the composition of mixtures used in the preparation of a particular material, the E/C ratio, seriously influences the characteristics coefficients of it. With the results now available, it can be considered a simulation followed by a validation to confirm the analyzes made on these materials. The research will be continued in this direction in the future.

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