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### RESEARCH ARTICLE

## STUDY OF THE INFLUENCE OF ADDING CRUSHED TYPHA FIBER ON THE THERMAL PROPERTIES OF SEBIKOTANE CLAY: APPLICATION OF THE COMPOSITE FOR BUILDING ENERGY EFFICIENCY

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#### Abstract

Typha australis is a low-carbon, invasive plant in the Senegal River valley, making access difficult for fishermen. Due to its widespread availability in the country, this article explores its potential by combining it with clay to study its influence on the thermal properties of the clay material. Thermal characterisations using hot plate and asymmetric hot wire methods in transient conditions were carried out to evaluate the contribution of typha fiber to the clay material. The characterisation results show a decrease in conductivity from  $0.77 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$  to  $0.20 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$  and in thermal effusivity from  $1579 \text{ W} \cdot \text{s}^{1/2} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$  to  $568 \text{ W} \cdot \text{s}^{1/2} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$  when the percentage of typha fiber incorporated into the material increases from 0 to 8%. Based on the results obtained, the clay-typha composite could contribute to the energy efficiency of the building.

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#### Introduction:-

In recent years, the issue of climate control and energy efficiency in buildings has been raised. Building on this momentum, the Paris Agreement was adopted at COP21 in December 2015 and entered into force on 4 November 2016. The agreement's objective is based on three main areas, namely mitigating global temperature rise to "well below"  $2^\circ\text{C}$  by 2100 compared to pre-industrial levels and continuing efforts to limit the increase to  $1.5^\circ\text{C}$  [1]. Added to this is RE2020, which is part of the same vision, namely to reduce energy consumption in housing, develop low-carbon buildings, and ensure comfortable living conditions [2]. To meet these requirements, there is an urgent need to promote geo- and bio-based materials. These highly accessible materials offer a range of advantages that deserve to be highlighted in the construction industry. Among their many advantages are good thermal inertia, carbon storage capacity, and availability at very affordable prices.

Several studies have been conducted, including one on the influence of adding natural fiber on the thermal properties of earth-based materials. Gratién KIKI et al. [3] worked on improving the thermal comfort of buildings by using the thermal inertia of clay-couch grass composite materials. The modelling and measurement of the thermal properties of a porous wet medium, laterite brick with millet husks, was carried out by Bal et al. [4]. The work of

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Mounir et al.[5] focuses on the thermal inertia and thermal properties of clay-wool composite material. A study of the energy efficiency and thermal properties of clay-straw composite material was conducted by El Azhery et al.[6]. Mouhamed Lamrani et al.[7], focused their research on the thermal characterisation of a new, efficient building material made from clay and olive tree waste. This article aims to carry out the thermal characterisation of a pure clay material and clay-typha composites to assess the contribution of typha to the thermal properties of raw clay.

### Materials and Methods:-

#### Preparation, composition, and manufacture of samples:

The clay used in this manuscript comes from the town of Sebikotane, located 24 km from Thiès. Once in the laboratory, it was first dried at 105 degrees Celsius for 24 hours, then crushed with a hammer and sieved through a 1 mm mesh sieve. Figure 1 below shows the different stages of clay material processing. The Typha australis used in this report was obtained in the town of Richard Toll in the Saint-Louis region. It was dried for two weeks, then cut with a machete and crushed by a machine. An 8 mm mesh sieve was used to recover the passers. Figure 2 shows the crushed Typha.



**Figure 1: Preparation of clay**



**Figure 2: Crushed Typha**

The samples are made from a mixture of one kilogram (1 kg) of raw materials (clay + crushed typha fiber) to which water is added for mixing. The percentage of crushed typha incorporated varies from 0 to 8% in 2% increments. The raw materials are dry mixed to obtain a homogeneous mixture. The amount of water added for mixing was determined using the general formula:  $E = 0.25 A + 0.27 B$ , where A and B are the respective mass percentages of clay and typha fiber[8].

Test specimens measuring  $10 \times 10 \times 3 \text{ cm}^3$  were then made and dried in the open air, away from direct sunlight, until their mass had completely stabilised. Figure 3 shows the different test specimens obtained.



**Figure 3: View of the clay-typha composite with different percentages of typha**

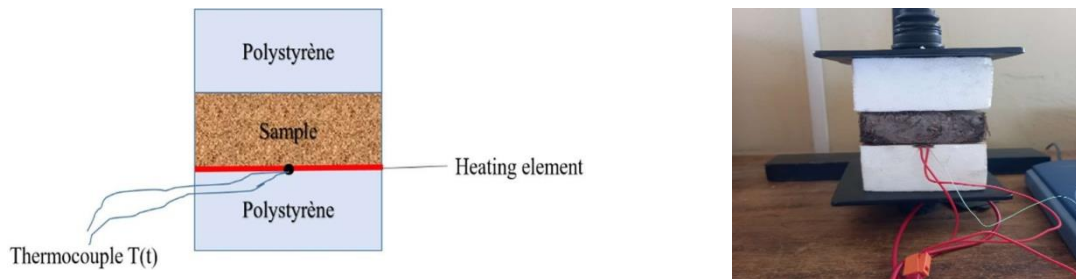
#### **Method for thermal characterisation of samples:-**

##### **Asymmetric hot plate method in transient conditions:-**

As it can be difficult in some cases to obtain two samples with identical composition and water content, asymmetric setups with a single sample were preferred for characterising the materials. Two techniques were used: the hot plate method, designed to estimate the thermal effusivity of the sample, and the hot wire method, used to evaluate its thermal conductivity.

The hot plate method involves using a flat probe, with dimensions equivalent to those of the sample, placed on a deformable insulator (polystyrene). A thermocouple, consisting of two thin wires, is attached to the centre of the probe, on the side in contact with the insulator. The sample to be characterised is then placed above the probe, and the assembly is completed with a second polystyrene block positioned above the sample [9].

**The schematic diagram of the hot plate method is shown in Figure 4:**



**Figure 4:** Schematic diagram of the asymmetric hot plate method with a semi-infinite sample. A constant current is passed through the heating element, and the temperature change is recorded at 0.1s intervals. The thermal effusivity of the sample is estimated using the complete method.

#### **Complete method:**

##### **The following assumptions are made:**

- ❖ transfer is 1D at the centre of the device,
- ❖ the heating element is at a uniform temperature (thin body),
- ❖ contact resistance is negligible on the insulating side,

**The temperature is uniform and constant throughout the system at the initial moment. The temperature at the centre of the probe is expressed as:**

$$T(t) = \frac{R_{el}}{S} I^2 \mathcal{L}^{-1} \left\{ \frac{1}{p \frac{mc}{S} p + \left[ 1 + R_c \frac{mc}{S} p \right] E \sqrt{p}} + E_i \sqrt{p} \right\}$$

**Where:**

- $T$  Temperature rise of the probe  
 $R_c$  Contact resistance at the interface between the heating element and the material to be characterised  
 $m$  Mass of thermocouple + heating element  
 $c$  Heat capacity of the thermocouple + heating element  
 $E_i$  Thermal effusivity of the material to be characterised  
 $E$  Thermal effusivity of the known insulating material  
 $p$  Laplace variable  
 $S$  Surface area of the heating element  
 $\phi_0$  Heat flux density dissipated in the heating element

**With:**

$$\phi_0 = \frac{R_{el}}{S} I^2$$

The inverse Laplace transform is performed using the Matlab programme "invlap" based on De Hoog's algorithm. The Matlab programme "leasqr" based on the Levenberg-Marquart algorithm is used to estimate the values of the parameters  $E$ , and  $\frac{mc}{S}$  and  $R_c$  that minimise the sum:

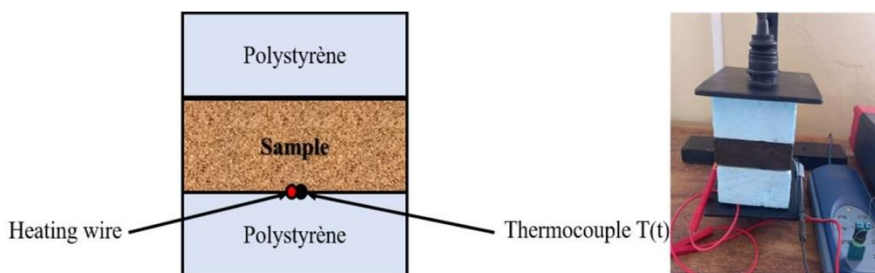
$$S = \sum_{i=1}^N [T_{exp}(t_i) - T_{mod}(t_i)]^2 \quad [10]$$

Where  $N$  is the number of measurement points

#### Asymmetric hot-wire method in transient conditions:

The hot wire setup consists of creating a groove in the polystyrene block in order to insert a resistive wire, to which a thermocouple is glued in the centre. The sample to be characterised is placed above the resistive wire, and the assembly is completed by a second polystyrene block positioned above the sample [11].

The schematic diagram is shown in Figure 5.



**Figure 5:** Schematic diagram of the asymmetric hot wire method with a semi-infinite sample. A constant current  $I$  is passed through the heating element, and the temperature change is recorded at 0.1s intervals.

The inverse Laplace transform is performed using the Matlab program "invlap" based on De Hoog's algorithm. The Matlab program "leasqr", based on the Levenberg-Marquardt algorithm is used to estimate the conductivity value [10].

#### Characterisation results and discussions

As stated above, the hot wire and asymmetric hot plate methods were used to determine the thermal properties of our different materials.

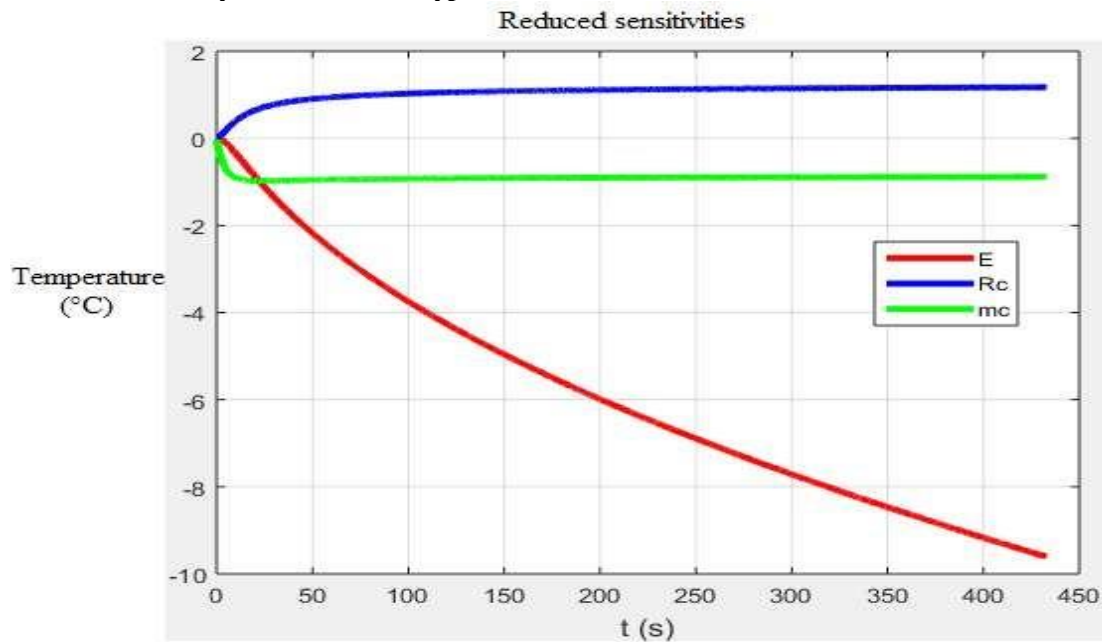
### Measurement of thermal effusivity

The results of the thermal effusivity measurements for the typha clay composites are shown in Table 1.

**Table 1: Thermal effusivity of the samples studied**

Constituent Sample	Crushed typha fiber in % by mass	Sebikotane clay in % by mass	Thermal effusivity ( $W \cdot s^{1/2} \cdot m^{-2} \cdot K^{-1}$ )
EO	0	100	1579
E1	2	98	1213
E2	4	96	1079
E3	6	94	954
E4	8	92	568

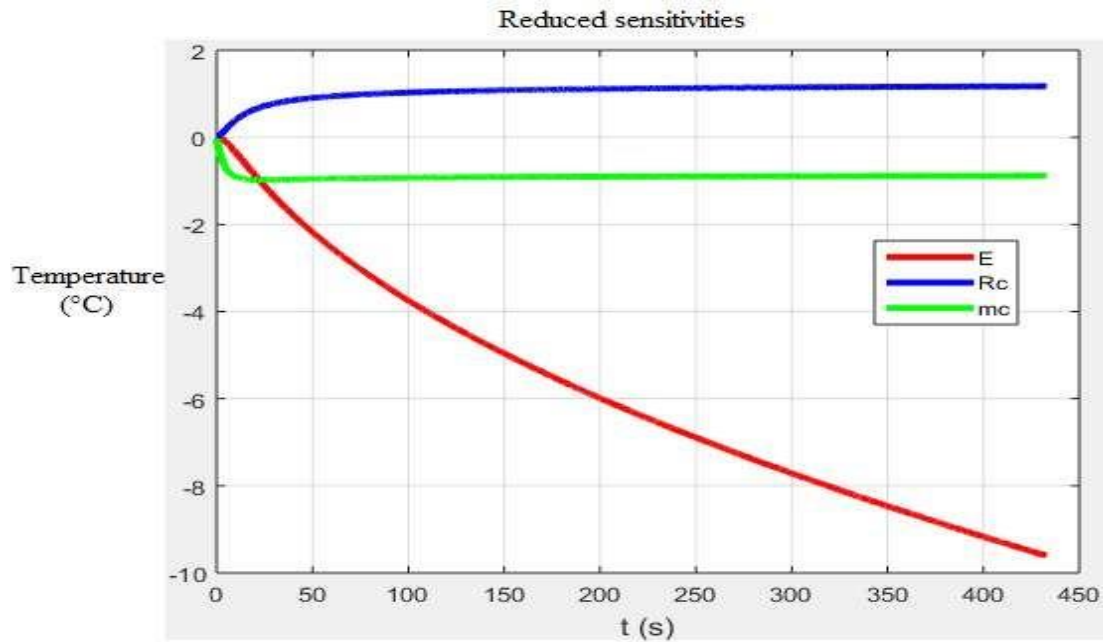
Figure 6 shows the reduced sensitivity curve obtained when estimating the thermal effusivity of the clay mixture with 8% by mass of crushed typha.



**Figure 6: The reduced sensitivity curve obtained after estimating the parameters of the clay- ground typha fiber composite with 8% typha content.**

The results show that only the thermal effusivity (red curve) of the material is sensitive to temperature during the experiment. This indicates that the measurement intensity is sufficient for the properties of the materials to be sensitive to temperature alone.

The model, experimental, and residual curves obtained by estimating the properties of the materials using an asymmetric hot plate model from the Matlab programme are shown in Figure 7.



**Figure 7: Model, experimental, and residual curves obtained during an asymmetric hot plate experiment with typha clay composite with 8% typha content.**

We note that the model and experimental curves are in very good agreement up to 350s. These show the validity of the 1D model at the centre of the sample. This finding is validated by the observation that the residuals remain flat for 350s. The thermal effusivity value is therefore well estimated with the complete model between 1 and 350s.

**Measurement of the thermal conductivity of materials:**

The results of measuring the thermal conductivity of our materials using the asymmetric hot wire method in transient conditions are summarised in Table 2.

**Table 2: Thermal conductivity of the samples studied**

Constituent Sample	Crushed typha fiber in % by mass	Sebikotane clay in % by mass	Thermal conductivity (W. m <sup>-1</sup> . K <sup>-1</sup> )
EO	0	100	0.77
E1	2	98	0.45
E2	4	96	0.31
E3	6	94	0.26
E4	8	92	0.20

Figure 8 shows the estimated thermal conductivity of the clay mixture with 8% typha.

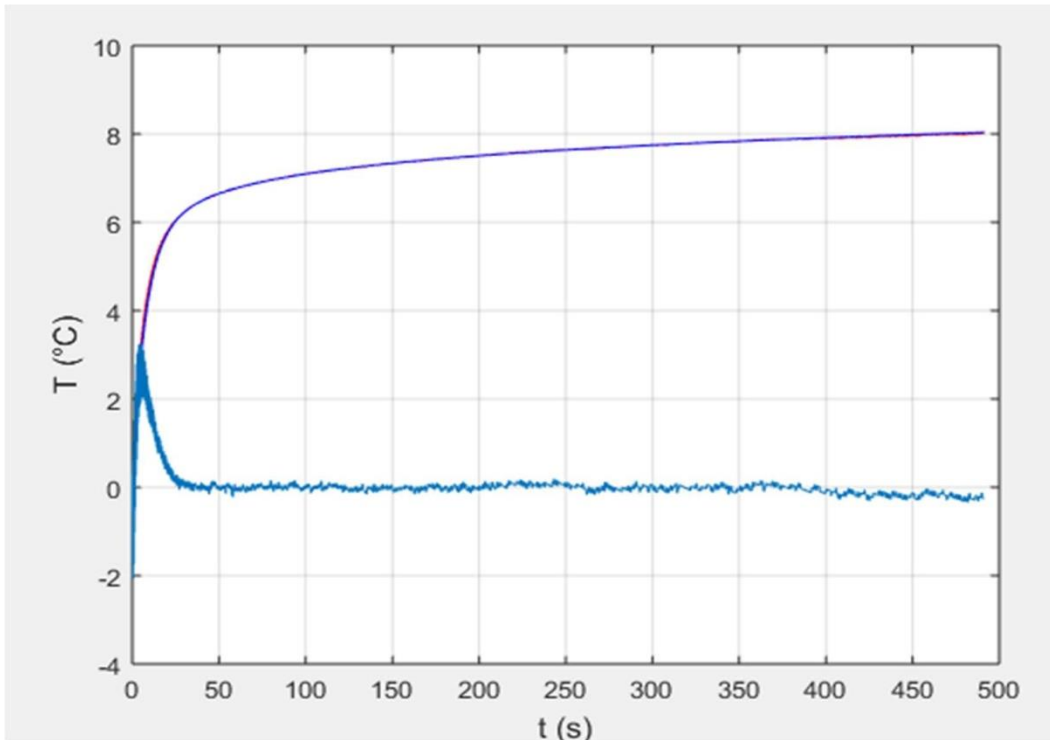
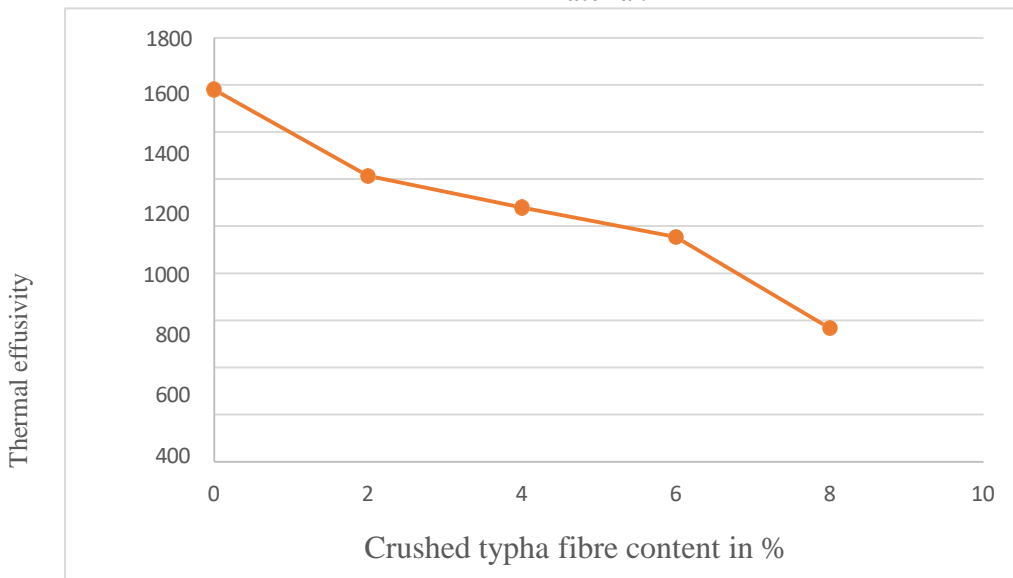


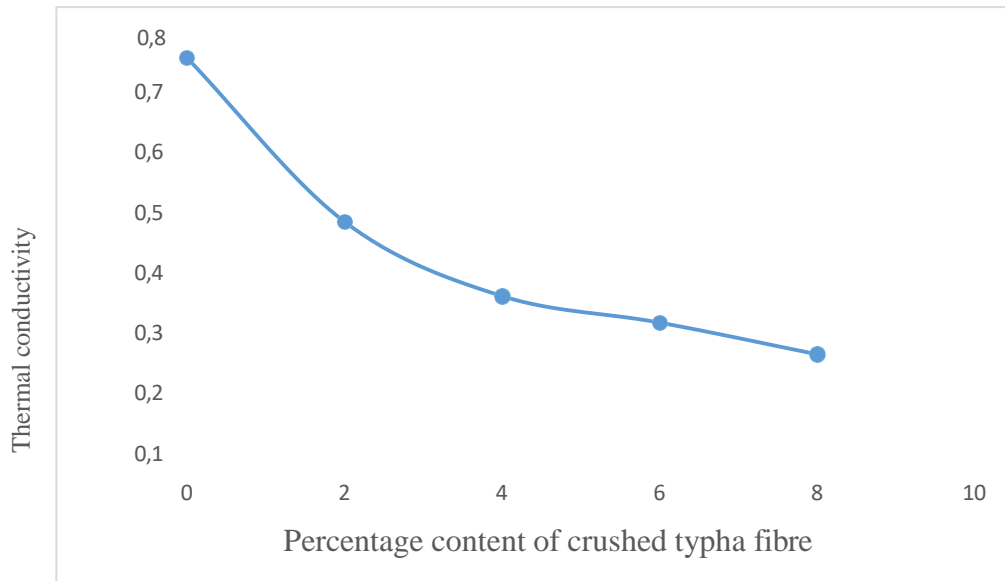
Figure 8: Model curve, experimental curve, and residual curve obtained during an asymmetric hot wire experiment with the clay-typha composite with 8% typha content.

In this figure, the residuals remained low and flat between 25 and 400s. The criterion of minimising the quadratic deviations between the model curves and the experimental points is therefore validated. The conductivity estimates for our materials using the complete model are therefore valid.

Figures 9 and 10 illustrate the influence of adding typha fiber on the thermal properties of pure clay material.



**Figure 9:** Evolution of the thermal effusivity of clay composites with crushed Typha fibers



**Figure 10: Thermal conductivities of clay composites with crushed typha fibers**

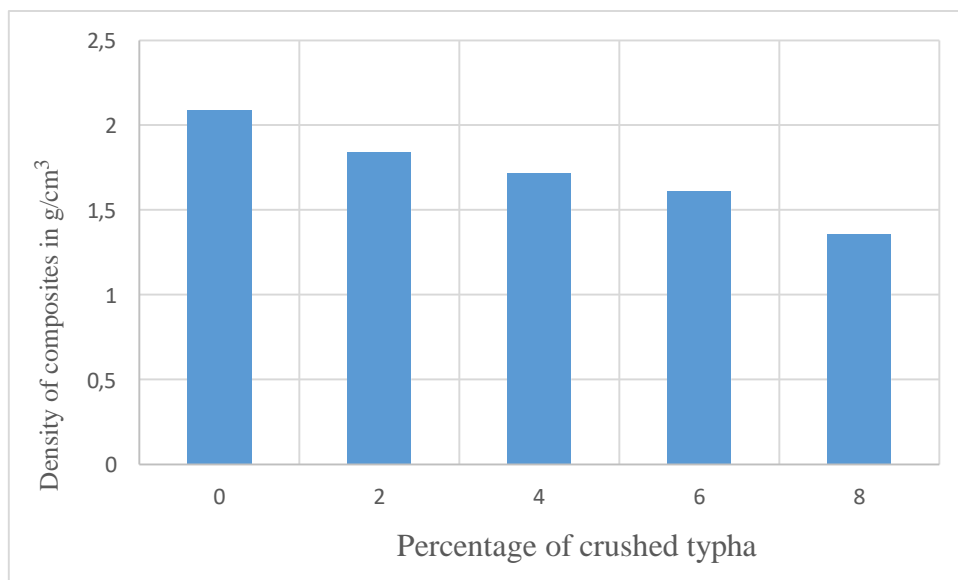
Curves 9 and 10 show a decrease in the conductivity and effusivity of the typha clay composites as the percentage of typha incorporated increases. The thermal effusivity values vary from  $1579 \text{ W} \cdot \text{s}^{1/2} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$  to  $568 \text{ W} \cdot \text{s}^{1/2} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$  when the addition of typha to the pure clay material increases from 0% to 8%.

Thermal conductivities vary from  $0.77 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$  to  $0.20 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$  when the typha content in the clay material increases from 0 to 8% of the total mass of the mixture. Typha is a porous material. Adding it to the clay material increases the porosity of the composites. As air is a good insulator, its presence improves the thermal properties of typha fiber clay composites. Our results are in the same range as those obtained in the study of clay and olive tree waste, which are  $0.65$  to  $0.29 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$  in terms of thermal conductivity. Thermal effusivity varies from  $1001$  to  $595 \text{ W} \cdot \text{s}^{1/2} \cdot \text{m}^{-2} \cdot \text{K}^{-1}$  [7].

The results of the study of the thermal conductivities of straw-clay composites for building envelope insulation, which range from  $0.75 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$  to  $0.29 \text{ W} \cdot \text{m}^{-1} \cdot \text{K}^{-1}$  [12], are also comparable to the thermal conductivity results of our materials.

**Density of composites:-**

The density of the composites was determined by the mass-to-volume ratio of the composites. Figure 11 below shows the influence of adding typha fiber on the density of pure clay.



**Figure 11: The influence of adding typha fiber on the density of pure clay.**

The results show that the density of the composites decreases almost linearly with the increase in typha fibers in the pure clay material. It goes from 2.09 g/cm<sup>3</sup> for the pure clay material to 1.36 g/cm<sup>3</sup> for the clay-typha composite with a typha content of 8% of the total mass of the mixture. These results are consistent with the results of the study on the influence of adding olive pomace on the density of pure clay [7] and those carried out on palm wood-based eco-composites [13]. This reduction is mainly due to the lightness of the incorporated fibers and their porous structure [14].

**Practical interest of the composite studied:-**

The influence of adding typha fiber on the thermal properties of pure clay was assessed using the formula  $\text{Gain} =$

$$\frac{\lambda_{\text{Argile}} - \lambda_{\text{composite}}}{\lambda_{\text{Argile}}} \times 100 \text{ [5].}$$

Reductions of 74% and 64% were observed in thermal conductivity and thermal effusivity, respectively, when the percentage of typha fiber incorporated increased from 0 to 8%. The energy gain between the pure clay material and the crushed Typha fiber clay composite is therefore 74%. In terms of the lightness of the composites, at 8% typha, it is 35%. The use of this composite in construction will improve indoor comfort, reduce air conditioning energy bills, and therefore contribute to improving energy efficiency.

**Conclusion:-**

The incorporation of Typha australis fiber into the clay material improved its thermal properties and made it more energy efficient. The composite can therefore be an interesting alternative to cement-based materials for ensuring the energy efficiency of buildings. Considering our results from the physical and mechanical characterisation of the clay-typha composites. The addition of 8% typha to can be used as infill for walls. Stabilisation of the composite could be considered to improve its physical and mechanical performance.

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