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## Article

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## Thermal study of clay bricks reinforced by sisal-fibers used in construction in south of Morocco

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### Abstract

Clay is a local construction material used in a traditional building, it has many environmental, social and cultural benefits. The present research study focuses on improving the thermophysical properties of clay extracted from Erfoud city in the south-east of Morocco by incorporating natural additives such as sisal fibers. Several samples were prepared and their thermophysical properties were characterized experimentally using the steady state hot plate and the flash methods to estimate the thermal conductivity and the thermal diffusivity, respectively. The results showed a significant interest in the future use of this composite material in the construction buildings in order to ensure thermal comfort and reduce greenhouse gas emissions (CO<sub>2</sub>). The dynamic thermal simulation was performed of the traditional building Ksar Lamaadid in Erfoud city in order to get energy savings without affecting indoor comfort levels according to outside temperatures.

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**Keywords:** Ecological composite materials; Thermophysical properties; Clay-sisal fibers; Thermal comfort; Greenhouse gas emissions

### 1. Introduction

The clay material is considered as a sustainable, ecological and highly thermally inert material and is widely used for the construction of traditional buildings. This is indeed the case in southern Morocco where the climate is dry and cold in winter and hot in summer. The thermal performances of clay material can be improved by incorporating natural additives to obtain a higher insulating composite material.

The literature reveals several studies that have been conducted on improving thermal comfort in traditional construction based on raw clay. Aboubou et al. [1] studied the thermal properties of a soil-based composite taken from the Bamako region with different percentages by weight of rice husks and found that the addition of this additive reduced the thermal conductivity. Lamrani et al. [2] reinforced the clay matrix with three types of ecological

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additives (date palm fibers, straw fibers, and olive grain waste). The results show a reduction in density, conductivity and thermal diffusivity. The effect of the incorporation of plant fibers on the density and thermal conductivity of clay mixtures was investigated by Liuzzi et al. [3]. Similarly, Calatan et al. [4] reported that the use of hemp fibers has a positive impact on mechanical strength and thermal conductivity. Experimental characterization of the thermal properties of brick materials based on fired clay was carried out by Laaroussi et al. [5,6]. El Azhary et al. [7] characterized the thermal properties of three types of unfired clay collected from three different regions in Morocco. The same authors improved the thermophysical properties of the unfired clay extracted from the Ouarzazate city by adding a straw [8]. Mahamat et al. [9] noted that the thermal conductivity and diffusivity of the soil from N'Djamena in Chad increase with water content.

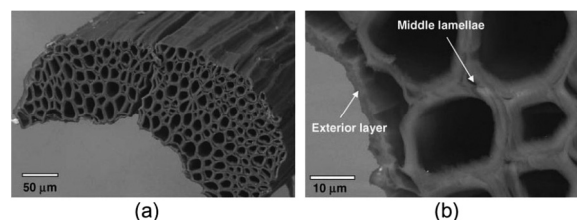
The present research consists of studying the incorporation effect of sisal fibers on the thermophysical properties of unfired clay collected from the Erfoud city. Experimental characterization of the thermophysical properties of this composite was conducted using the steady state hot plate and the flash method to measure thermal conductivity and thermal diffusivity, respectively. The apparent density and specific heat were deduced. Thereafter, the dynamic thermal simulation was carried out on “Ksar Lamaadid” in the Erfoud city to assess its thermal comfort and its environmental benefits to use the proposed material in a residential building located in south of Morocco.

## 2. Materials and experimental methods

### 2.1. Used materials

**Clay:** The used unfired clay material is extracted from Erfoud earth city, in south-eastern Morocco. This region is characterized by a dry climate, cold in winter and warm in summer.

**Sisal:** Sisal is a natural plant of the “agavaceae” family as reported by Mishra et al. [10]. It generally grows in the arid climate with a very short renewal time. Sisal fibers are extracted from this plant using several techniques. The morphology of sisal fiber is described in Fig. 1, it consists of many individual fibrous cells with a diameter of about 6 – 30  $\mu\text{m}$  (Fig. 1a). These cells are connected to each other by the central lamellae (Fig. 1b). De Andrade Silva et al. [11] have indicated that the sisal fibers are composed of 54%–66% cellulose, 12%–17% hemicellulose, 7%–14% lignin, 1% pectin and 1%–7% ash. It has several advantages, namely its low density, availability, low cost, high rigidity and high durability, which justifies its use in the building sector as a reinforcement for floors and plasterboard as detailed by Achour [12].



**Fig. 1.** Sisal fibers morphology: (a) individual fibrous cells; (b) detail of middle lamellae [11].

### 2.2. Sample preparation

The composite material under study is composed of Erfoud clay material, water, and sisal fibers. The raw material was crushed into small particles (Fig. 2a). The sisal fibers (Fig. 2b) were washed with water to remove impurities, then dried and cut into 2 cm pieces. The prepared samples of clay by considering two mass fraction of sisal fiber (2% and 4%) were made in cylindrical steel molds with a diameter of  $d = 100$  mm and a thickness of  $e = 20$  mm. For comparison purposes, a sample without fiber called a “Pure clay” was prepared. The water was gradually added to the mixture with a mixing rate of  $\text{water/clay} = 0,2$ . Manual stirring is necessary to ensure a good homogenization of the dough. The samples were dried in the open air for 2 days, then in the oven at  $60$  °C for 3 days during which the mass of the samples was weighed until the total removal of moisture. Finally, the samples were packed in plastic bags to ensure their dry condition. Fig. 2c shows the characterized samples.



Fig. 2. (a) The raw clay material; (b) The sisal fibers; (c) the characterized samples.

### 2.3. Experimental methods

#### Hot plate method in a steady state regime

The steady-state hot plate method aims to determine the thermal conductivity  $\lambda$  (W/m K) of the materials as in the work of Jannot et al. [13], it consists in transmitting a uniform heat flux through the front surfaces of the sample and the insulating foam and recording the temperature evolution of the rear surfaces. The heating element is a circular electrical resistance ( $R_e = 100 \Omega$ ) with diameter  $D = 100$  mm and thickness  $e = 0,2$  mm.

The experiment device design is composed of two aluminum blocks to ensure a constant temperature on the unheated sides. Three type K thermocouples are placed in the center of the faces. Where  $T_0$  represents the temperature measured at the lower face center of the heating element,  $T_1$  is measured on the unheated face of the sample, and  $T_2$  is measured on the unheated face of the polyethylene, as shown in Fig. 3. The heat flows through the sample  $\phi_s$  and the polyethylene  $\phi_p$  are assumed to be unidirectional. Once the steady state regime is established, the thermal conductivity of the characterized sample is calculated using Eq. (2).

$$\phi_T = \frac{U^2}{R_e S} = \phi_S + \phi_P \quad (1)$$

$$\phi_S = \frac{e_s}{T_0 - T_1} \times \left[ \frac{U^2}{R_e S} - \frac{\phi_P}{e_p} - (T_0 - T_2) \right] \quad (2)$$

where  $\lambda_s$  and  $e_s$  denote the thermal conductivity and the thickness of the characterized sample, respectively.  $\lambda_p$  and  $e_p$  represent the thermal conductivity and the thickness of the polyethylene, respectively.

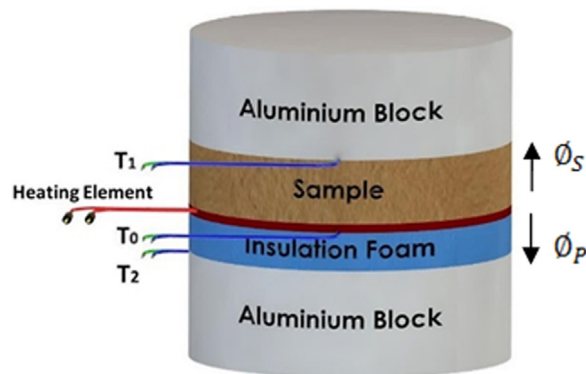


Fig. 3. Schema of hot plate method in a steady-state regime.

#### Flash method

The thermal diffusivity estimation of materials a ( $m^2/s$ ) is based on the use of the flash method. The flash method principle scheme is described in Fig. 4 that consists by sending on the studied sample front side, a luminous flux of  $\phi'_0 = 1000$  W for a short time ( $\tau = 8$  s). The temperature on the back side of sample is measured and stored  $T(e,t)$ .

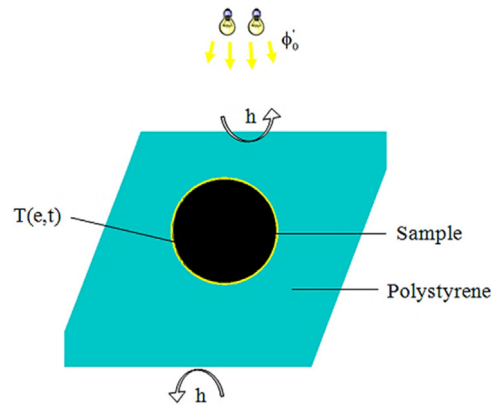


Fig. 4. Schema of flash method.

The sample is tinted in black in order to absorb all the flux generated and is surrounded by a polystyrene to minimize the thermal losses on the sides. The heat transfer equation is solved in Laplace space to obtain Eq. (3).

$$\theta(e, p) = \frac{j \cdot T_{\max} \cdot F(p)}{\left[ \text{Cosh}(\sqrt{j}p) (b_{i1} + b_{i2}) + \text{Sinh}(\sqrt{j}p) \left[ \frac{jp + (b_{i1} \cdot b_{i2})}{\sqrt{j}p} \right] \right]}; j = \frac{e^2}{a} \quad (3)$$

where  $a$  and  $e$  are the thermal diffusivity and the thickness of the sample, respectively,  $F(p)$  represents the heat generation time dependence function  $f(t)$  in the Laplace domain,  $b_{i1}$  and  $b_{i2}$  are the Biot numbers,  $T_{\max}$  is the adiabatic limit temperature. Numerical inversion of Eq. (3) makes it possible to obtain the expression of the theoretical temperature  $T_{th}$  of the rear face of the sample as a function of the parameters  $e$ ,  $T_{\max}$ ,  $a$ ,  $b_{i1}$ ,  $b_{i2}$ , and  $t$ . Those parameters will be estimated from the experimental data and their optimal values can be obtained by minimizing the squared distance between the inverse theoretical model and the experimental thermogram according to Marquardt [14].

$$M(e, T_{\max}, b_{i1}, b_{i2}) = \sum_{i=1}^N [T_{\text{exp}}(t_i) - T_{th}(e, T_{\max}, a, b_{i1}, b_{i2}, t_i)]^2 \quad (4)$$

### 3. Results and discussion

#### 3.1. Experimental results

The thermophysical properties of the studied samples were measured using experimental methods. Three tests were conducted for each sample and a mean value was calculated and presented in Table 1. The apparent density of the composite material based on clay and sisal fiber has been determined by knowing its dry mass and measured volume. It is clearly remarked that the apparent density has been reduced as the sisal fiber content increases. The gain in lightness was 12.3%. This lightening is mainly due to the porosity created in the material by the addition of sisal fibers. The thermal conductivity is one of the most important thermal properties indicating the power of a material to conduct the thermal heat. The results show that the incorporation of sisal fibers has a considerable effect on the reduction of thermal conductivity, with a rate of 11.2% for the composite material (clay + 4% of

**Table 1.** The variation of thermal properties according to mass fraction of additive material.

Proprieties	$\rho$ (kg/m <sup>3</sup> )	$\lambda$ (W/m K)	$a$ (m <sup>2</sup> /s)	$c_p$ (J/kg K)
Pure clay	1725.2	0.649	3.368	1116.95
2%	1602.7	0.590	3.197	1151.48
4%	1574.9	0.576	3.116	1173.74

sisal fiber). This decrease is mainly due to the creation of air-filled pores in the composite and the sisal fibers low thermal conductivity.

According to the experimental results, we found that the incorporation of sisal fibers reduced the thermal diffusivity by 8%. This result shows the ability of the composite material to delay the heat transfer within the building. The specific heat  $c_p$  (J/kg K) can be calculated by combining the apparent density, thermal conductivity and thermal diffusivity  $c_p = \lambda/(\rho \times a)$ . The calculation results showed that the incorporation of 4% sisal fibers in the clay allows increasing its thermal insulation capacity by 5%.

Based on those results, it can be concluded that sisal fibers can improve the thermophysical properties of raw clay. The characterized composite material can contribute to thermal comfort in traditional buildings in southern Morocco. Moreover, sisal fiber is recognized for its mechanical performance as indicated by Belaadi et al. [15]. Also, it is used to strengthen soils by Hejazi et al. [16] and to improve the mechanical properties of building materials by Mattone [17].

### 3.2. Thermal dynamic simulation: case study

Erfoud is a town in southern Morocco, in the Tafilalet-region. While many Ksars have existed for centuries, Erfoud was built new by the French around 1920's. Ksar Maadid is an ancient Ksar, build of soil in the 14th century (Figs. 5, 6).



Fig. 5. Ksar Maadid in Arfoud city.

The Ksar Maadid (Fig. 7) is simulated using Design builder software (Design Builder 5) [18] based on energy-plus calculation to improve the energy efficiency of the used material. The ventilation rate including infiltration is about 36 m<sup>3</sup>/h/pers with density occupancy of 0.20 pers/m<sup>3</sup>. The thermal simulation of Ksar Maadid is performed for a hot climate of Erfoud where the maximum of outdoor temperature exceeds 43 °C.

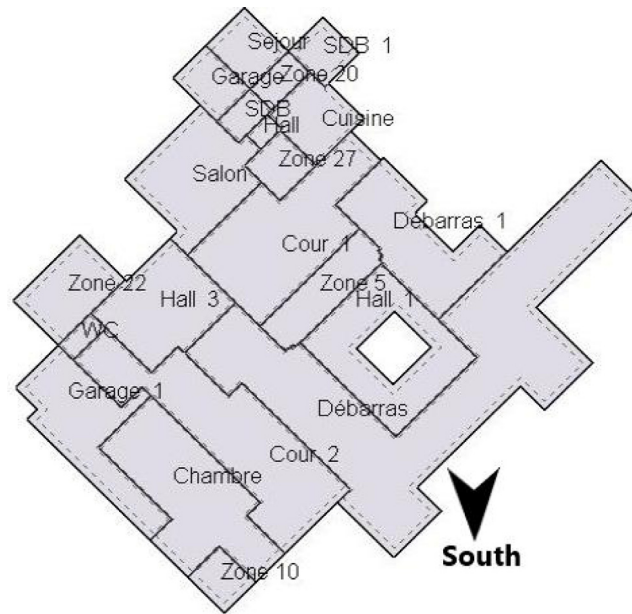
The Fig. 8 presents the hourly temperature variation of inside the building according to exterior environment during the year. By comparing the two types of the studied building envelopes with the R-values varied from  $R_{\text{clay}} = 0.77 \text{ m}^2 \text{ K/W}$ , to  $R_{4\%} = 0.86 \text{ m}^2 \text{ K/W}$ , for the same wall thickness ( $e = 50 \text{ cm}$ ), we can deduce that the addition of 4% percent of sisal induces the decreasing of the thermal losses through building walls and the diminishing of the indoor temperature fluctuations. The analysis of temperature profiles upgrades the thermal energy performance and comfort conditions to raise the internal temperature of the building to the temperature of 15 °C, even though the minimum outdoor temperatures reached  $-4 \text{ °C}$  in the coldest period. The used material walls can better ensure a satisfactory comfort during winter without using heating system, compared to the standard construction.

During the hottest period, the maximum of external temperature exceeds 43 °C, though the maximum internal temperatures reached 35 °C for the wall envelope and the annual mean temperature is reduced to 26 °C.

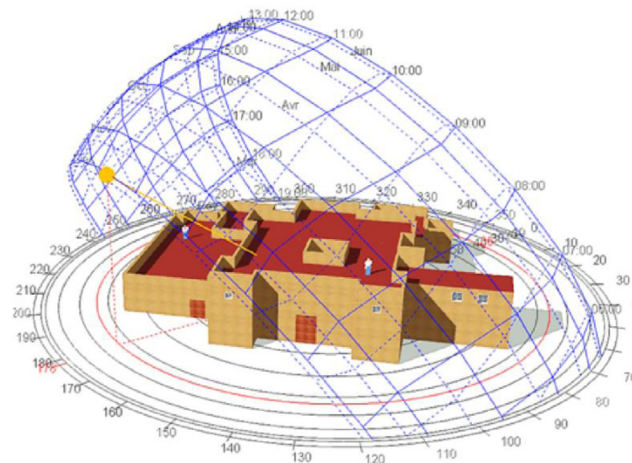
## 4. Conclusion

The application of new composite building material based on natural fibers offers several environmental and socio-economic benefits. The present study focused on the experimental characterization of thermophysical





**Fig. 6.** Spatial distribution of building (975 m<sup>2</sup>).



**Fig. 7.** The simulated building model.

properties of new composite building material based on raw clay and sisal fibers, and on the dynamic thermal simulation of Ksar Lamaadid located in Erfoud city in the south of Morocco.

The addition of sisal fibers (4%) can reduce the thermal conductivity of the composite material with about 11.2%. Similarly, the thermal diffusivity has been reduced by about 8%. While the thermal capacity has been increased with a rate of 5%. In addition, sisal fibers lighten the building material, as its density has been reduced to 12.3%.

The use of new composite material in construction of Ksar Lamaadid can ensure the thermal comfort without heating or cooling systems and can reduce the greenhouse gas emissions of about 62 442 kg of CO<sub>2</sub>/year because the reduce energy consumption have a big impact on CO<sub>2</sub> emissions.

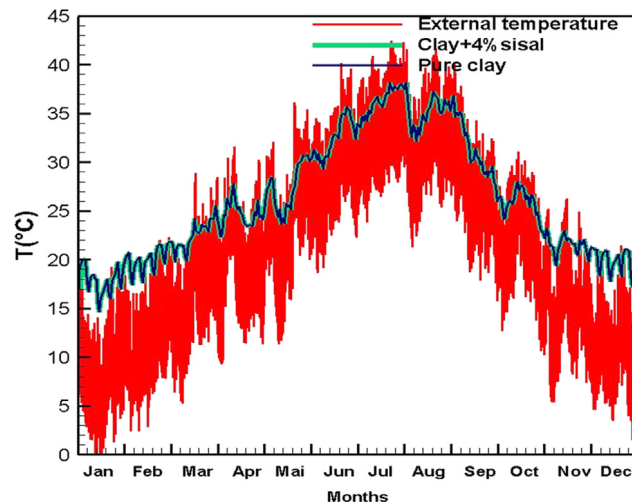


Fig. 8. The hourly temperature variation inside and outside the building during the year according to used material.

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## References

- [1] Aboubou I, Diabaté Lamissa, Mengy Gilbert. Détermination de la conductivité thermique de matériaux de construction à bamako (balle de riz). *J Sci Ing* 2004;4:1–6.
- [2] Lamrani Mohammed, Mansour Majid, Laaroussi Najma, Khalfaoui Mohammed. Thermal study of clay bricks reinforced by three ecological materials in south of morocco. *Energy Procedia* 2019;156:273–7.
- [3] Liuzzi Stefania, Chiara Rubino, Pietro Stefanizzi. Use of clay and olive pruning waste for building materials with high hygrothermal performances. *Energy Procedia* 2017;126(2017):234–41.
- [4] Calatan Gabriela, Hegyi Andreea, Dico Carmen, Mircea C. Determining the optimum addition of vegetable materials in adobe bricks. *Proc Technol* 2016;22:259–65.
- [5] Laaroussi Najma, Cherki Abou Bakr, Garoum Mohammed, Khabbazi Abdelhamid, Feiz Amir-ali. Thermal properties of a sample prepared using mixtures of clay bricks. *Energy Procedia* 2013;42:337–46.
- [6] Laaroussi Najma, Lauriat Guy, Garoum Mohammed, Cherki Abou Bakr, Jannot Yves. Measurement of thermal properties of brick materials based on clay mixtures. *Constr Build Mater* 2014;70:351–61.
- [7] El Azhary Karima, Raefat Saad, Laaroussi Najma, Garoum Mohammed. Energy performance and thermal proprieties of three types of unfired clay bricks. *Energy Procedia* 2018;147:495–502.
- [8] El Azhary Karima, Chihab Yassine, Mansour Majid, Laaroussi Najma, Garoum Mohammed. Energy efficiency and thermal properties of the composite material clay-straw. *Energy Procedia* 2017;141:160–4.
- [9] Mahamat Ahmat-Charfadine, Barka Mahamat, Tahir Abakar Mahamat, Soultan M, Gaye Salif, Beye AC. Thermo-physical properties of local materials used in the construction of chad. *Am J Civ Eng* 2015;3(5):140–9.
- [10] Mishra Supriya, Mohanty Amar K, Drzal Lawrence T, Hinrichsen MG. A review on pineapple leaf fibers, sisal fibers and their biocomposites. *Macromol Mater Eng* 2004;289(11):955–74.
- [11] De Andrade Silva Flavio, Toledo Filho Romildo Dias, De Almeida Melo Filho, Joao, Fairbairn Rego EDM. Physical and mechanical properties of durable sisal fiber–cement composites. *Constr Build Mater* 2010;24(5):777–85.
- [12] Achour Abderraouf. Etude des Performances des Mortiers Renforcés de Fibres Naturelles: Valorisation des Plantes Locales (Thèse de doctorat), 2017.
- [13] Jannot Yves, Felix Vincent, Degiovanni Alain. A centered hot plate method for measurement of thermal properties of thin insulating materials. *Meas Sci Technol* 2010;21. 035106.
- [14] Marquardt Donald W. An algorithm for least-squares estimation of nonlinear parameters. *J Soc Ind Appl Math* 1963;11(2):431–41.
- [15] Belaadi Ahmed, Bezazi Aberrezak, Bourchak Mostefa, Scarpa F. Tensile static and fatigue behaviour of sisal fibres. *Mater Des* 2013;46:76–83.
- [16] Hejazi Sayyed Mahdi, Sheikhzadeh Mohammad, Abtahi Sayyed Mahdi, Zadhoush A. A simple review of soil reinforcement by using natural and synthetic fibers. *Constr Build Mater* 2012;30:100–16.



- [17] [Mattone Roberto](#). Sisal fibre reinforced soil with cement or cactus pulp in bahareque technique. *Cem Concr Compos* 2005;27(5):611–6.
- [18] Desing Builder software, version 5.