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Review

# Measurement of thermal properties of brick materials based on clay mixtures

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## HIGHLIGHTS

- Transient, steady state hot-plate and flash methods used for clay thermal properties.
- A comparative study based on the different experimental results is performed.
- The specific heat, thermal conductivity and diffusivity measurements are discussed.
- Numerical simulations of 3D-transient heat conduction conducted for validations.

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## ABSTRACT

Thermal properties of building materials such as clay used in construction are measured using transient and steady state hot-plate and flash methods. The experimental methods are applied to measure the thermal properties of clay samples. The estimation of these thermal characteristics is based on a one dimensional model. A tridimensional model of the heat transfer in the system is considered to determine the validity conditions of the one dimensional model used to represent the center temperature. The use of a brick as a thermal insulating material requires prior knowledge of all its thermal properties. For that purpose, we have conducted an experimental study in order to characterize the thermal properties of brick samples, coming from the Moroccan Slaoui's factory. The thermal diffusivity "$a$", specific heat "$c$" and thermal conductivity "$\lambda$" of this clay are experimentally obtained and their values are reported for design purposes. Finally, a comparative study based on different experimental methods is performed and the measurements are compared. The error estimations are found less than 3%.



**Contents**



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**Nomenclature**

| | |
|---|---|
| $a$ | thermal diffusivity ($m^2\ s^{-1}$) |
| $c$ | specific heat ($J\ kg^{-1}\ K^{-1}$) |
| $C_h$ | thermal capacity of the heating element per area unit ($J\ m^{-2}\ K^{-1}$) |
| $e$ | thickness (mm) |
| $e_h$ | thickness of heating element (mm) |
| $E$ | thermal effusivity ($Wm^{-2}\ K^{-1}\ s^{1/2}$) |
| $h_c$ | convective heat transfer coefficient ($Wm^{-2}\ K^{-1}$) |
| $I$ | current intensity (A) |
| $L$ | sample and heating element length and width (m) |
| $p$ | laplace parameter |
| $R_e$ | electrical resistance of the heating element ($\Omega$) |
| $Rc$ | thermal contact resistance between the heating element and the sample ($K\ m^2\ W^{-1}$) |
| $S$ | heat exchange surface between the heating element and the sample ($m^2$) |
| $t$ | time (s) |
| $T$ | temperature (°C) |
| $T_0$ | initial temperature of the system (°C) |
| $U$ | voltage |

*Greek symbols*

| | |
|---|---|
| $\Psi$ | quadratic error between experimental and theoretical curves |
| $\lambda$ | thermal conductivity ($Wm^{-1}\ K^{-1}$) |
| $\rho$ | density ($kg\ m^{-3}$) |
| $\rho c$ | volumetric thermal capacity ($J\ m^{-3}\ K^{-1}$) |
| $\phi_0$ | heat flux density ($Wm^{-2}$) |
| $\phi$ | laplace transform of the heat flux density |
| $\theta$ | laplace transform of the temperature |

*Subscripts*

| | |
|---|---|
| M | mean value |
| *al* | aluminum |
| exp | experimental |
| mod | model |
| *h* | heating element |
| *p* | polystyrene |
| *s* | sample |
| *HPS* Hot | plate method in steady state regime |
| HPT | asymmetrical transient Hot Plate method |
| DSC | differential scanning calorimeter |

## 1. Introduction

Clay is commonly defined as an earthy material that is plastic at certain water contents and hardens when heated. Most products obtained from clay have been investigated for building applications. It is widely used in making bricks which are made out of clay-bearing subsoil. Hollow bricks of several widths are used in single and double walls construction. Hollow bricks are lighter and easier to handle, and have different thermal properties according to the shape and to the number of holes. Some brick designs have very high thermal insulation properties, making them suitable for zero-energy building.

Several methods for measuring the thermal properties of various solid materials are well known. Many studies have been published concerning the characterization of thermal properties of materials. Toppi and Mazzarella [1] have carried out experimental correlations for thermal properties estimation of composite materials. Khabbazi et al. [2] conducted an experimental study of thermal and mechanical properties of new insulating material based on granular cork embedded in cement mortar. Jannot et al. [3] used the symmetrical transient hot plate method which requires two similar samples to characterize thin insulating materials. Recently, Bal et al. [4] adopted the asymmetrical device to characterize the laterite based bricks with milled waste additive materials by using only one sample. André et al. [5] presented an experimental set-up based on the hot wire method for the thermal characterization of materials. Coquard et al. [6,7] investigated an experimental and theoretical study of the hot-ring method applied to low density thermal insulators. An application to the thermal resistance and thermal conductivity measurement of a heterogeneous material is presented by Jannot et al. [8], who used a tiny hot plate. The consequences in terms of thermal conductivity and specific heat have been studied in [9], using the laser flash technique. Hernández-Olivares et al. [10] suggested the use of cork-gypsum composites for building applications. They reported the mechanical properties, microstructure, acoustic properties, but only the thermal conductivity of cork-gypsum composite.

Many experimental methods for thermal materials properties characterization have been performed from research efforts all over the world. The aim of this paper is for investigating experimental methods for estimating the thermal properties of clay samples (coming from the Moroccan Slaoui's factory). The thermal properties of clay samples are reported, in order to provide industrial designers with values based on high levels of confidence.

## 2. Chemical analysis of clay sample

The hollow Slaoui's bricks, made of clay mixed with 22% water are hardened by drying for three hours at 110 °C before being fired. The bricks are burnt at a temperature of 780 °C for 24 h. The thermal properties of clay bricks are influenced by the chemical and mineral content of the raw materials, the firing temperature, and the atmosphere in the kiln. A rational analysis is necessary to determine the relative proportions of substances which may be present in the clay bricks. For the determination of substance compositions, a complete chemical analysis is necessary [11].

The brick produced is a complicated mixture and it is necessary to study its chemical and physical properties. The physical properties are affected by the chemical composition of the clay and the impurities present in pure clay. The Slaoui bricks are made from several types of clay. Typical compositions of the two main clays used are reported in Tables 1 and 2.