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Experimental thermal properties characterization of insulating cork–gypsum composite

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HIGHLIGHTS

- The asymmetrical Hot Plate method was mainly used to characterize cork–gypsum composite.
- A comparative study based on other experiments is performed.
- Thermal conductivity results were confronted to different theoretical models.
- The composite is three times more insulating and two times lighter than gypsum.
- Weighted geometric mean equation is found to agree well with the measured thermal conductivity.

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ABSTRACT

Gypsum plaster is a building material used in walls or false ceilings. The aim of this paper consists on the improvement of thermal properties and lightness of gypsum plaster by combining it with granular cork collected from Moroccan Maamora's forest. This composite material is intended to be used in false ceiling such as cork–gypsum board instead of plasterboard; its use will be a contribution to improve energy efficiency in buildings. By varying the granular cork size, an experimental investigation of thermal properties of gypsum based composite material with embedded granular cork was mainly performed using the asymmetrical transient Hot Plate method. A comparative study based on other experiments (Differential Scanning Calorimeter and Steady state Hot Plate) was realized and the thermal conductivity results were confronted to different theoretical models of equivalent thermal conductivity determination. The experimental results exhibit a good agreement with the weighted geometric mean equation.

1. Introduction

Energy consumption in building continues to increase, the improvement of energy efficiency is necessary to reduce this consumption. Thermal properties enhancement of building materials is one of the tracks that aim to contribute to the improvement of energy efficiency in buildings. Gypsum plaster is a building material usually used as false ceiling. The present work consists to enhance thermal properties of gypsum plaster by combining it with cork. Indeed, cork is natural, hydrophobic and renewable product with thermal and acoustic properties very interesting due to its microstructure and porosity. It is coming from Mediterranean area (Moroccan, Portuguese, Algerian, Tunisian…Forests). The main objective of this work is to study how the embedded cork modifies thermal properties of gypsum plaster; this study will be a contribution to the understanding of the thermal behavior of this composite for motivate the proposal that it will be used in false ceiling as cork–gypsum board.

Some studies have already been established and published about composite materials containing gypsum plaster: Toppi and Mazzarella [1] realized experimental correlations for thermal properties estimation of gypsum based composite materials with micro-encapsulated Phase Change Material; Hui et al. [2] prepared and characterized the n-nonadecane/cement composites as thermal energy storage materials in buildings. Alicia Oliver [3] realized thermal characterization of gypsum boards with PCM included. Li et al. [4] prepared and characterized properties of gypsum-based heat storage and preservation material.

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Nomenclature

c	specific heat (J kg^{-1} K^{-1})
C_h	thermal capacity of the heating element per area unit (J m^{-2} K^{-1})
d	small diameter (mm)
D	large diameter (mm)
e	thickness (m)
E	thermal effusivity (J m^{-2} K^{-1} $s^{-1/2}$)
h	convective heat transfer coefficient (W m^{-2} K^{-1})
I	current (A)
p	Laplace parameter
R	electrical resistance of the heating element
Rc	thermal contact resistance between the heating element and the sample
S	heat exchange surface between the heating element and the sample
t	time (s)
T	temperature (°C)
Ψ	quadratic error between experimental and theoretical curves
U	voltage (V)
y	granular cork mass fraction in the mixture
w/g	water–gypsum ratio
η	parallel model fraction
λ	thermal conductivity (W m^{-1} K^{-1})
ρ	density (kg m^{-3})
ρc	thermal capacity (J m^{-3} K^{-1})
$\o$	heat flux density (W m^{-2})
Φ	Laplace transform of the heat flux density
θ	Laplace transform of the temperature
ξ	sphericity parameter

Subscripts

co	granular cork
co–gy	cork–gypsum composite material
cont	continuous phase
disp	dispersed phase
exp	experimental
gy	gypsum
h	heating element
HPS	Hot Plate method in steady state regime
HPT	asymmetrical transient Hot Plate method
i	polystyrene insulating blocks
j	index points of the thermogram
mod	model
N	number of points of the thermogram

Few studies about composite materials are based on granular cork: Khabbazi et al. [5] conducted an experimental study of thermal and mechanical proprieties of a new insulating material based on cork and cement mortar; Silva [6] presented a study about cork, its properties, capabilities and applications. Pereira [7] wrote a book about biology production and uses of cork. These last three references show the usefulness of cork likely to be a material of choice in thermal insulation applications. Hernández–Olivares et al. [8] developed cork–gypsum composites for building applications; they present mechanical properties, microstructure, acoustic properties and only thermal conductivity of cork–gypsum composite, they did not present all its thermal properties. They found thermal conductivity corresponding to high density of composites: 0.1255 (W m^{-1} K^{-1}) for 578 (kg m^{-3}), 0.1869 (W m^{-1} K^{-1}) for 600 (kg m^{-3}) and 0.1995 (W m^{-1} K^{-1}) for 864 (kg m^{-3}).

The objective of this paper is to characterize all thermal properties of cork–gypsum board composite (cf. picture Fig. 1) having a lower density and being more insulating.

Several characterization studies of porous materials have been completed and published using the Hot Plate transient method and other methods. Jannot et al. [9] used the symmetrical device of Hot Plate method to characterize the thin insulating materials. Bal et al. [10] adopted the recent asymmetrical device to characterize the laterite based bricks with millet waste additive material. Coquard et al. [11–13] conducted an experimental and theoretical study of the hot-ring method, the Hot-Disk method and the hot-wire method applied to low-density thermal insulators. Cherki et al. [14] studied the granular cork content dependence of thermal diffusivity, thermal conductivity and heat capacity of cork–gypsum composite using mainly the Flash method and Hot Plate method in steady state regime. Laaroussi et al. [15] characterized thermal properties of a sample prepared using mixture of clay bricks by the asymmetrical transient Hot Plate method. All this motivated authors to adopt the recent asymmetrical transient Hot Plate method [10] and extend its application in the case of porous lightweight composite materials.

As the studied composite is a complex medium containing a double porosity (porosity of cork and that of gypsum plaster), authors gave a special attention to the aspect of thermal properties characterization for come out with reliable results. To this end, authors have pushed this experimental study by using several characterization methods (Differential Scanning Calorimeter and Steady state Hot Plate) and have conducted a comparative study of the results obtained with these methods. Finally, the validity of certain equations for the thermal conductivity of two-omponent systems is examined.

2. Description of used materials

2.1. Gypsum

Plaster is a building material used for coating walls and ceilings. Plaster starts as a dry powder similar to mortar or cement and like those materials it is mixed with water to form a paste which liberates heat and then hardens. Unlike mortar and cement, plaster remains quite soft after setting, and can be easily manipulated with metal tools or even sandpaper. These characteristics make plaster suitable for a finishing, rather than a load-bearing material. The term plaster refers to gypsum plaster or hemihydrated gypsum. Gypsum plaster is produced by heating gypsum to about 150 °C:

$$2CaSO_24 \cdot H_2O + \text{Heat} \rightarrow 2CaSO_4 \cdot H_2O + 3H_2O \text{ (released as steam)}.$$

Hemihydrated gypsum is presented in two different phases, the α-hemihydrates or autoclaved plaster, and the β-hemihydrates or stucco plaster. Commercial plaster for building applications is mainly composed of α-hemihydrates and β-hemihydrates. The water–gypsum ratio (w/g) in the mixing process can vary for 0.6–0.8 or higher. When the dry plaster powder is mixed with water, it re-forms into gypsum. The setting of unmodified plaster starts about 10 min after mixing and is complete in about 45 min; but not fully set for 72 h. The gypsum used in this work has been obtained by mixing hemihydrated gypsum (extracted from gypsum deposit located in the vicinity of Safi city, Morocco) with water, using a water–gypsum plaster of 0.7 by mass. This gypsum has a density of 800 (kg m^{-3}) corresponding to thermal conductivity of 0.3 (W m^{-1} K^{-1}), as can be experimentally assessed by testing of samples 100 × 100 × 20 mm^3 in three measurement points.

2.2. Cork

Cork is an impermeable, buoyant material, a prime-subset of bark tissue that is harvested for commercial use primarily from Quercus suber (the Cork Oak), which is endemic to southwest Europe and northwest Africa. Cork is composed of suberin,