Energy and Buildings 140 (2017) 268–279

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Estimation of the thermophysical properties of date palm fibers/gypsum composite for use as insulating materials in building

Aymen Braiek[a,*], Mustapha Karkri[b], Ali Adili[c], Laurent Ibos[b], Sassi Ben Nasrallah[a]

[a] Ecole Nationale d'Ingénieurs de Monastir, Laboratoire d'Etudes des Systèmes Thermiques et Energétiques (LESTE), Avenue Ibn Eljazzar, 5019 Monastir, Tunisia
[b] Université Paris-Est, Centre d'Etude et de Recherche en Thermique, Environnement et Systèmes (CERTES), 61 av. Général de Gaulle, 94010 Créteil, France
[c] Centre de Recherches et des Technologies de l'Energie, Laboratoire des Procédés Thermiques, Route touristique de Soliman, B.P. 95, Hammam-Lif 2050, Tunisia

ARTICLE INFO

Article history:
Received 11 May 2016
Received in revised form 8 December 2016
Accepted 1 February 2017
Available online 3 February 2017

Keywords:
DPF/gypsum composite
Thermophysical properties
Periodical method
Flash method
Thermal insulation
Energy saving

ABSTRACT

This work aims to develop a new composite material to improve the thermophysical properties and the lightness of gypsum plaster made with date palm fibers for the purpose of reducing the building energy consumption. This composite material is intended to be used in walls or false ceilings. Date palm fibers-gypsum boards could be used instead of plaster boards as thermal insulators in buildings. By varying the mass fraction of date palm fibers (from 0 to 20%), an experimental investigation of the thermo physical proprieties of gypsum reinforced with date palm fibers was mainly performed using the periodical and flash methods which were coupled to an inverse technique. The experimental results of thermal conductivity showed a good agreement with the theoretical model developed by Woodside and Mesmer for the determination of equivalent thermal conductivity.

1. Introduction

The building sector has a big share of the world's total energy consumption due to the increasing demand for buildings. Several attempts have been made to improve energy efficiency in the building sector. In this respect, the enhancement of building materials' thermal properties is of great importance. In fact, the gypsum plaster is used for construction, especially in walls or false ceilings. It is sensitive and adapts, with difficulty, to hot or cold climatic conditions. In order to lower energy consumption, the present paper aims to enhance the thermophysical properties of gypsum plaster by mixing it with date palm fibers. Indeed, the date palm fibers are a natural and renewable product with very interesting thermophysical and acoustic properties for the development of efficient insulating materials. They come from Mediterranean area (Tunisia, Algeria, Morocco,. . .etc.). Some works have already reported on composite materials containing gypsum plaster. Cherki et al. [1] studied the thermal properties of a gypsum-based composite material with embedded granular cork using the asymmetrical transient hot plate method. Toppi and Mozzarella [2] carried out an experimental study on the thermal properties of gypsum-based composite materials with microencapsulated Phase Change Material. Oliver [3] studied the thermal characteristics of gypsum boards with PCM included. Moreover, a few works dealt with composite materials which are based on date palm fibers such as the studies of Benmansour et al. [4] who conducted an experimental study of the thermal and mechanical properties of a new insulating material based on natural mortar reinforced with date palm fibers. Kriker et al. [5] studied the mechanical properties of date palm fibers and concrete reinforced with date palm fibers in hot-dry climate. Tlijani et al. [6] used the periodical method coupled with Levenberg-Marquardt method to determine the thermal properties of date palm wood. Agoudjil et al. [7] conducted an experimental study of the thermo physical, chemical and dielectric properties of three varieties of date palm wood.

Several researchers are mainly concerned with the characterization of porous materials using the periodical method, the hot plate method and other methods. Mounir et al. [8] studied all the thermal properties of granular cork-clay composite using the flash method and the hot plate method. Another work of Mounir et al. [9] handled the thermal characterization of a clay-wool composite using the same methods. Coquard et al. [10–12] used the hot-disk method, the hot-wire method and the hot-ring method to characterize the thermal insulators. Jannot et al. [13] used the symmetrical

* Corresponding author.
E-mail address: braiekaymen772@yahoo.fr (A. Braiek).

http://dx.doi.org/10.1016/j.enbuild.2017.02.001
0378-7788/© 2017 Published by Elsevier B.V.

Nomenclature

a	Thermal diffusivity ($m^2 s^{-1}$)
b	Thermal effusivity ($J m^{-2} K^{-1} s^{-1/2}$)
c_p	Heat capacity ($J kg^{-1} K^{-1}$)
E_s	Energy saving
e	Thickness (m)
f	Frequency (Hz)
$\tilde{H}$	Experimental heat transfer function
H	Theoretical heat transfer function
h	Heat transfer coefficient ($W m^{-2} K^{-1}$)
Q	Thermal quadrupole
p	Laplace parameter
T_c	Calculated temperature (K)
T_m	Measured temperature (K)
$\tilde{T}$	Fourier transform of the temperature (K)
$\tilde{T}_0$	Ambient temperature (K)
t	Time (s)
t_c	Heating time (s)
V_i	Gaver–Stehfest's coefficients function

Greek symbols

β	Vector of estimated parameters
λ	Thermal conductivity ($W m^{-1} K^{-1}$)
θ_f	Laplace temperature on the front face of the sample ($K s^{-1}$)
θ_r	Laplace temperature on the rear face of the sample ($K s^{-1}$)
ϕ	Heat flux, filler fraction
ψ	Heat flux density ($W m^{-2}$)
ρ	Density ($kg m^{-3}$)
ω	Pulsation

Subscripts

m	Measured, mass fraction
c	Calculated, composite
g	Gypsum
dpf	Date palm fibers
v	Volume fraction
exp	Experimental
th	Theoretical
cont	Continuous phase
disp	Dispersed phase
real	Real part of complex
imag	Imaginary part of complex

device of the hot plate method to characterize thin insulation. Laaroussi et al. [14,15] used the asymmetrical transient hot plate method to characterize the thermal properties of a sample prepared using mixtures of clay bricks. Lachheb et al. [16,17] determined the thermal properties of phase change composite materials using the periodical method.

This work is dedicated to improving the experimental set-up and the estimation procedure for a better identification of the thermo physical properties of gypsum plaster reinforced with date palm fibers (DPF). Parameter identification is performed by the minimization of errors between the theoretical and the experimental results. To this end, we have conducted this experimental study using two characterization methods (periodical and flash methods). Besides, we have carried out a comparative study of the results obtained with these methods. Finally, the validity of the experimental thermal conductivity of the two-component system (DPF and gypsum) was examined.

2. Experimental investigation

In this section, gypsum samples with date palm fibers were prepared to obtain an insulating building material. The morphologies of DPF and DPF based gypsum composite were carried out using a scanning electron microscopy (SEM). The effect of DPF addition in the ratio of 5%, 10%, 15% and 20% by weight on thermal conductivity, diffusivity, effusivity and capacity was investigated. The thermophysical properties were identified using the periodical and flash methods associated to an inverse technique.

2.1. Materials and sample preparation

The used composite materials were made from gypsum and date palm fibers (DPF). The gypsum used is natural gypsum in powder form. It is produced from natural rocks in a mine near the city of Zaghouan in Tunisia. From the chemical point of view, the gypsum is calcium sulfate dihydrate, obtained by mixing a certain amount of water with calcium sulfate dihydrate powder and the chemical reaction which takes place is:

$$CaSO_4 \cdot (1/2)H_2O + (3/2)H_2O \rightarrow CaSO_4 \cdot 2H_2O + \text{heat} \quad (1)$$

The gypsum used in this work was obtained by mixing hemihydrated gypsum with water, using a water–gypsum ratio (w/g) of 0.6 in the mixing process. The gypsum, which we have obtained, has a density of 1322 (Kgm^{-3}) corresponding to a thermal conductivity of 0.45($Wm^{-1} K^{-1}$).

The use of DPF as fillers in gypsum seems to be a very promising option. It is a natural and renewable product with good thermal and acoustic properties. This allows using it as a thermal insulator for construction in a lot of cities in Tunisia. The various thermophysical and dielectric properties, the chemical composition and the morphology of the DPF used in this study are already summarized in [7]. Thermal conductivity of DPF is low which improve the thermal characteristics of gypsum and consequently increases its thermal insulation capacity. The date palm fibers have a thermal conductivity of 0.083 $Wm^{-1} K^{-1}$ which is lower to or close than the thermal conductivity of several natural insulating materials like: banana ($\lambda = 0.117\ Wm^{-1} K^{-1}$ [18]), hemp ($\lambda = 0.115\ Wm^{-1} K^{-1}$ [19]) and Sisal ($\lambda = 0.07\ Wm^{-1} K^{-1}$ [20]). The density value of DPF in this work was 276kg m^{-3} which is also lower than the density value of banana, sisal and is slightly higher than the hemp. We think that the use DPF as fillers in construction materials will be a good candidate for the development of efficient insulating materials.

The composite samples were obtained by mixing gypsum and water with different mass fractions of DPF (0, 5, 10, 15 and 20%) with a mean diameter of 2 mm (Fig. 1). The DPF and gypsum powder were mixed together with water at a water–gypsum ratio by mass of (w/g = 0.6). Then, we stirred continuously at a high speed for 10 min until a pasty mixture was obtained. After that, the prepared mixture was versed into cubic molds (45 × 45 × 8 mm). The samples were dried at ambient temperature for 48 h in the molds and 28 days after demoulding.

2.2. SEM investigations

A Hitachi S 800 scanning electron microscope (SEM) was used to study the morphology of (DPF) and DPF/gypsum composite and examine the extent of homogeneity of the DPF in gypsum matrix. The DPF and the DPF/gypsum samples were attached to conducting silver plates were, then, coated with a layer of gold in a vacuum chamber. The SEM images were performed by the secondary electron imaging method, with a tension of acceleration of the beam of 15 kV.