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Development and thermal characterization of an innovative gypsum-based composite incorporating phase change material as building energy storage system

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ABSTRACT

This study aims at developing a new integrated component in a passive solar wall to achieve high thermal energy storage potential in building materials. This component was manufactured by conditioning the paraffin inside 24 copper tubes, which were regularly inserted and aligned in a gypsum matrix.

Firstly, an investigation by means of a differential scanning calorimeter (DSC) was carried out to obtain the latent heat and the transition temperature of the selected phase change material (paraffin). Secondly, an additional study was conducted to gauge the improvement of energy storage performance in classical construction material (gypsum) when incorporating paraffin by the method of transient guarded hot plates.

The results of this experiment revealed a clear improvement in different thermal properties when integrating paraffin in the composite. Besides, the results showed that the composite-PCM prevents the leakage of the molten paraffin during phase transition and proved a good thermal stability.

1. Introduction

Because of the increasing demand on thermal comfort in buildings, energy consumption has gone up dramatically in the last 20 years. Studies showed that a major part of energy is lost in controlling indoor climate. To cut down this huge consumption of energy new technologies in building construction and services are required. In this context, thermal energy storage is considered as one of the most advanced methods to be applied in building structure to improve the energy efficiency [1]. Among the different methods of thermal energy storage, the latent energy storage method which involves using phase change material was an attractive technique in view of the fact that it provides a high energy storage density and it is also capable of storing heat at a constant temperature level, which corresponds to the phase transition temperature of the phase change material [2–5].

A large number of phase change materials (organic, inorganic, and eutectic) have been widely used by researchers in thermal comfort enhancement because of their advantages of storing and releasing large amounts of energy during phase change process [6]. To mention, paraffin as one of the investigated PCMs has been considered as the most promising thanks to its high heat storage capacity, good thermal and chemical stability, little super-cooling, and low cost [7–10]. However, the leakage and the low thermal conductivity problems of paraffin limit its application in some fields; this means that paraffin is not convenient to use directly as phase change materials. It needs to be conditioned in order to prevent, for instance, leakage of molten paraffin [11,12].

In this pretext, the technology of micro-encapsulation of paraffin has recently been developed as an effective means to expand the application of PCMs, which allow solving the leakage problem of the molting paraffin during phase transitions and allows PCMs to be incorporated simply into construction materials [13–15]. A variety of investigations about the incorporation of the encapsulated paraffin in building materials showed limited success, due to the problem of the low thermal conductivity of the paraffin, which can reduce the rate of storing and releasing energy of paraffin during the melting and solidification process respectively [16].

The objective of this research work is therefore to fabricate a new building material that could provide passive regulation of indoor temperature by artificially augmenting the heat capacity of classical construction materials; this can be done by incorporating paraffin inside classical construction material. The elaborated material exhibits features of high energy storage density, a high

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Nomenclature

Latin letters

t	time, (s)
L	Latent heat, (kJ/kg)
C	specific heat capacity, (J kg^{-1} K^{-1})
T	Temperature, (K)
Q	energy per mass stored (kJ/kg)
e	Thickness (m)

Greek symbols

φ	Heat flux density (W/m^2)
λ	thermal conductivity, (W m^{-1} K^{-1})
ρ	density, (kg m^{-3})

Subscripts

eff	effective
exch	exchanger
init	initial
s	solid
l	liquid
sens	sensible
m	melting

thermal conductivity of heat exchange, and an absence of molten paraffin leakage.

More to the point, in the current work, a new composite-PCM is manufactured by conditioning the paraffin inside metallic tubes regularly spaced and aligned in a gypsum matrix. The result is an excellent thermal energy storage material characterized by high thermal conductivity of the copper tubes and a high latent heat of the paraffin. The latent heat and the temperature transition of the paraffin included in the composite-PCM were both measured by using a Differential Scanning Calorimeter. On the other hand, the examination of the effect of the incorporation of the paraffin on the thermo-physical properties of a construction material was carried out by using the guarded hot plates method.

2. Material and experimental

2.1. Materials

(a) The phase change material, which is an alkane commonly used for thermal energy storage in building applications [17] is a commercial Paraffin wax (Fig. 1), purchased from the Sasol Wax Company and used in this study.

Table 1
Thermo-physical properties of paraffin wax.

Thermo-physical property	Value (unit)
Density	900 (kg/m^3)
Thermal conductivity	0.233 (W m^{-1} K^{-1})
Thermal diffusivity	1.309.10^{-7} (m^2 s^{-1})
Specific heat capacity	1978 (J kg^{-1} K^{-1})

Paraffin wax has many advantages such as high thermal energy storage capacity, compatibility with container material, phase change temperature fitted to application, and a low cost. Thermo-physical properties of paraffin wax are listed in Table 1 [17].

(b) The construction material used to study the effect of PCM addition on the heat storage capacity was Tunisian gypsum. The reasons behind the selection of this material in this work are its affordability and its good thermal and acoustic resistance. Gypsum is usually found in partition walls and located in the interior side of wall as a cladding element [18].

2.2. Elaboration of gypsum-based composites incorporating paraffin

This section describes the preparation protocol of the novel composite PCM that combine the high thermal energy storage of the paraffin and the large thermal conductivity of the cooper.

The elaboration of the PCM composite goes through several steps:

In the first step, copper tubes supplied by Goodfellow are placed and aligned in a rectangular aluminum mold of internal dimension (200 × 200 × e mm^3) and with an equidistant distribution of 1 mm between the tubes (Fig. 2). Each tube has an internal diameter of 3.2 mm, the external diameter is of 4 mm with a length of 200 mm.

In the second step, a certain amount of gypsum powder was mixed together with some milliliters of water, then it was stirred continuously at high speed until a pasty mixture was obtained (Fig. 3). The gained mixture was poured into the mold, slightly compressed and eventually allowed to stand at an ambient temperature for 48 h.

Finally, paraffin was melted at a temperature above the melting temperature. After that, all copper tubes were filled with the molten paraffin wax very rapidly by using a hermetic syringe.

In the above preparation method, a form stable PCM composite plate of dimension 200 × 200 × 10.83 mm^3 and mass 637.6 g was prepared (Fig. 4). The chosen form of the sample enables its

Fig. 1. Paraffin wax.