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Elaboration and properties of a composite bio-based PCM for an application in building envelopes

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HIGHLIGHTS

- An eco-friendly material was prepared to enhance the heat capacity of buildings.
- Coconut fat was found as a suitable bio-based PCM for TES in building envelopes.
- Recycled cardboards and natural clay powder were used to prepare the PCM's matrix.
- The prepared material shows the potential for enhancing thermal inertia of building envelopes.

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ABSTRACT

This study aims to develop a novel composite Phase Change Material (PCM) using eco-friendly and low-cost components for an application of improving thermal inertia of building envelopes. The Coconut fat recovered from underused feedstocks was selected as a bio-based PCM for its good Thermal Energy Storage (TES) characteristics. This bio-based PCM was incorporated in a composite matrix prepared in the laboratory from natural clay and cellulose fibers. The direct immersion method with no vacuum treatment was followed as a simple incorporation process of the bio-based PCM into its matrix. The results of thermal and physicochemical characterizations show that the prepared composite-PCM has the potential to be used for passive TES in building envelopes in order to enhance their thermal inertia.

1. Introduction

Nowadays, the building sector becomes one of the most significant energy-consuming sectors in the world because of the excessive use of heat and air conditioning systems. Thermal Energy Storage (TES) in building envelopes is an effective mean for a solution to this problem.

The methods which can be used to enhance the thermal performance of building envelopes with the TES techniques can be categorized into two: the sensible heat storage and the latent heat storage [1]. The ratio between the building envelopes' size, volume, materials used and their thermal mass represent the most significant factors that influence its thermal response [2,3]. Therefore, the traditional constructions which included heavy envelopes presented good thermal comfort conditions thanks to the thickness of their stone and earthen walls. Since these ones prevented deviations between comfort conditions and indoor temperatures. In that case, the thermal energy was stored inside the building skins as sensible heat energy due to their large heat capacitance.

Today, the need for high-rise constructions leads to design lightweight envelopes. Consequently, the thermal comfort in buildings cannot be obtained following the sensible heat storage process, and the excessive inside heat sources may not be smoothed by the building structure. In this case, Phase Change Materials (PCMs) may be used to ensure the thermal comfort in the indoor environments thanks to the Latent Heat Thermal Energy Storage (LHTES) applications [7,8].

Unlike sensible heat storage, LHTES provides higher energy storage capacity in a reduced temperature variation from storage

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to retrieval [4]. Thus, in the last four decades, the use of PCMs became a topic with a lot of interest among architects and engineers [5,40].

Despite the particular interest given to The PCMs, their practical applications in the building envelopes remain hindered. The causes are the high-cost of the commercialized PCMs and the complexity of the incorporation processes of the microencapsulated PCMs into building materials. This makes the PCMs applications more expensive. It should be noted the cost of non-encapsulated PCMs is about 7 times lower than that of the microencapsulated PCMs [20].

Researchers have reported that among the three techniques of incorporating PCMs into building materials which are: the immersion, the impregnation and the direct mixing of encapsulated PCMs [8]; the first and the second techniques represent the simplest ones [13].

This research work deals with the preparation of a composite-PCM using low-cost and eco-friendly components and following a straightforward process of incorporating the PCM into its matrix. Accordingly, coconut fat was recovered from underused feedstocks at low-cost. It was selected as a bio-based PCM for its desirable TES properties in building applications. Since this PCM melts and freezes at temperatures close to those of the human body comfort and it has a suitable latent heat capacity.

Cellulose fibers prepared from recycled cardboards were partially used in the preparation of the bio-based PCM's supporting material. It is essential to note that recycled cardboards were already used in the building industry. The purpose was to prepare panels for building elements (roofs, walls, and floors) [6,9]. This presented promising performances in terms of thermal insulation [10].

Natural clay was added to the cellulose fibers as a binder. Graphite was used with different weight fractions to improve the thermal conductivity of the composite-PCM by accelerating its phase change processes [11,12]. The bio-based PCM selected in this study was incorporated in its matrix following the direct immersion; as this is a straightforward incorporation method of the PCM in its supporting material [14,15]. Preliminary tests were carried out in the laboratory to overcome the drawbacks of the immersion method which have already been reported in the literature as: the leakage of the PCM from its supporting material in the melted state and the risk of chemical interaction between the bio-based PCM and its matrix [21].

The properties of the prepared composite-PCM were characterized by means of thermal and physicochemical characterizations. The objective is to determine its effectiveness as a construction material for a possible application in building envelopes. The first envisaged application is to fill the cavities between two external panels of building skins or to enhance the internal faces of the outer walls.

Thus, a thermal treatment of the prepared composite-PCM samples was done on filter paper at 50 °C for 90 min in an oven. This test aimed to identify their performance to retain the bio-based PCM in the melted state without leakages. Fourier Transformed Infrared Spectroscopy (FT-IR) was chosen for the chemical characterization. Differential Scanning Calorimetry (DSC) was performed to identify the thermal properties of the bio-based PCM and the composite-PCM. Scanning Electron Microscopy (SEM) was carried out to observe the microstructure of the prepared matrix and that of the composite-PCM. The Hot-Disk apparatus was used to measure the thermal conductivity of the diverse composite-PCM samples and that of the bio-based PCM. Thermo Gravimetric Analysis (TGA) verified the thermal stability of the composite-PCM in its working temperature range.

The motivation behind this research paper is to identify the properties of the novel composite bio-based PCM prepared from eco-friendly and low-cost components. In addition, the aim is to prove the effectiveness of a straightforward manufacturing process in the elaboration of a novel composite-PCM. The ultimate objective is then to enhance the thermal inertia of building envelopes and to reduce the energy consumption.

2. Materials and methods

2.1. Materials

In this experiment, the coconut fat was selected as a bio-based PCM (Fig. 1a). This PCM is a vegetable fat purchased at low-cost from SLAMA FRERE Group of refining and packaging of vegetable fats and oils, Tunis (Tunisia). This vegetable fat is composed of fatty acids. Its latent heat capacities of melting and freezing were determined experimentally as 106.17 J/g and 107.34 J/g respectively. Its respective melting and freezing temperatures were found at 22.63 °C and 17.44 °C.

The bio-based PCM's supporting material was prepared in the laboratory from: cellulose fibers (Fig. 1c), natural clay powder (Fig. 1b) and graphite (Fig. 1d). Cellulose fibers were prepared in the laboratory by recycling cardboards whereas the natural clay powder was purchased from S N A I C (**S**ociété **A**lgérienne **I**ndustrielle & **C**ommerciale), Algiers, (Algeria). Figs. 2 and 3 show the particle size distribution curves of the natural clay powder and the graphite used in the experiment respectively, Table 1 lists their particle size parameters.

The X-Ray Diffraction pattern (XRD) (Fig. 4) performed with D2-PHASER BRUKER X-Ray Diffractometer of the natural clay powder used in this experiment shows the presence of Kaolinite, Quartz, Hematit, Illite and Tridymite.

2.2. Preparation of the cellulose fibers

All kinds of cardboards which had completed their function and thrown away were recovered to be used in the preparation of the composite-PCM for an application of improving thermal inertia of external walls of building envelopes. First, a dough was prepared from the recovered cardboards by keeping them in water for two days. The goal of this operation was to separate each woven fiber from another. Subsequently, the resulting dough was dried in an oven for 24 h at 105 °C before being ground using an electric grinder.

2.3. Preparation of the composite-PCM

The bio-based PCM's supporting material was prepared at first. So, the cellulose fibers, the natural clay powder and graphite were mixed together in order to coat the cellulose fibers with a thin layer of the natural clay powder and to have a regular distribution of the particles of graphite in the prepared material. Table 2 lists the appropriate mixing ratios of cellulose fibers, natural clay and graphite used in the preparation of the different samples of the matrix. Distilled water was added to each mixture with a weight fraction of 1: 1. At the end of this step, a homogeneous paste was obtained, and then it was poured into a heavy steel mold on which a slight uni-axial force of 2 KN/m2 was exerted using a hydraulic press. Small cuboid samples of (40 mm × 40 mm × 10 mm) dimensions were obtained. These

Fig. 1. Images of the different composite-PCM's components: a) Bio-based PCM, b) Natural clay, c) Cellulose fibers, d) Graphite.