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Hygric properties and thermal conductivity of a new insulation material for building based on date palm concrete

Bourhaneddine Haba [a], Boudjemaa Agoudjil [a,*], Abderrahim Boudenne [b,*], Karim Benzarti [c]

[a] Batna 1 University, LPEA Laboratory, 05000 Batna, Algeria
[b] Université Paris Est Creteil (UPEC)/CERTES, 61 Av. du General de Gaulle, 94010 Créteil cedex, France
[c] Université Paris-Est, Laboratoire Navier, UMR 8205, IFSTTAR, F-77447 Marne-la-Vallée cedex, France

HIGHLIGHTS

- Porosity, water uptake and drying kinetics were investigated for date palm concrete.
- Dry cup method for the measurement of water vapor permeability.
- Sorption isotherm was determined for a wide range of relative humidity, and afterward moisture diffusivity evolution was obtained.
- Thermal conductivity measurements for both dry and moist state at various levels of temperature were measured.

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ABSTRACT

Experimental investigations of hygric and thermal conductivity properties of a new biocomposite material dedicated for construction which contains cement, sand and water and reinforced with 15 wt% of date palm fibers were carried out. The investigations were based on the measurement of water vapor permeability, of sorption isotherm, of moisture diffusivity and thermal conductivity. The results reveal that the presence of date palm fibers improves the performance and the efficiency of the composite material: lowering of water vapor diffusion resistance, enhancement of moisture transfer. The results were compared to other kind of biocomposite materials used for construction. Finally, we have shown the effect of temperature on thermal conductivity for both moist and dry states.

1. Introduction

Sustainable development is one of the main scientific, economic and social challenges of the building efficiency, which requires both limiting environmental impacts and ensuring certain economic and social criteria.

Natural building is a way to achieve more sustainable construction. It promotes alternative materials, technologies and methods of construction that can reduce significantly resource and energy consumption, and provide better energy efficiency without causing pollution and damaging health and eco-systems [1]. On the other hand, the increased environmental awareness encourages to use "green" and "high thermal performance" building materials in order to reduce energy and raw materials consumption [2], and contributes effectively to progress towards the sustainable development.

Among bicomposite materials, mineral binders reinforced with vegetal fibers (most often vegetal wastes) are a promising orientation with regard to sustainable development. The main goal is to take advantage from the physical properties of the vegetal fibers and the mechanical properties of the mineral binder. The use of natural fibers has many advantages such as: being derived from a renewable resource, require a low energy inputs in their manufacture [3], they can be easily disposed of at the end of their life cycle by composting or by recovery of their calorific value in a furnace [4,5]. Furthermore, they could be used as a possible input to lighten concrete mixtures [6]. In this context, several natural materials are being used since the dawn of times, like hemp shiv, flax shiv and straw bales.

Date palm wood is another important renewable material to reduce building heat loss. Agoudjil et al. [7] investigated the thermophysical, chemical and dielectric properties of the date

* Corresponding authors.
E-mail addresses: b.agoudjil@yahoo.fr (B. Agoudjil), boudenne@u-pec.fr (A. Boudenne).

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palm wood. The experiments were performed on samples cut out from the petiole in a square plate shape. The authors underlined that the date palm wood is a good candidate for the development of efficient and safe insulating materials, as they show a thermal conductivity of 0.083 $W.m^{-1} K^{-1}$. This previous paper includes also all the information regarding the date palm; original, availability, main division parts, amount of the recovered material, etc.

Lime and gypsum are widely used binders for making composite materials, while conventional ordinary Portland cement (OPC) is the most common binder generally used to design low cost lightweight insulation materials in the area of building and construction [8–11]. Furthermore, cement has a beneficial impact on the mechanical properties of the material [12].

In the literature, several studies have investigated the thermophysical and mechanical characteristics of composite materials reinforced with date palm fibers which were obtained by grinding the date palm wood (petiole and rachis of Algerian date palm trees) into a crusher. Benmansour et al. [13] investigated the use of a new material, composed of natural cement, sand, water and date palm fibers. The results showed that the incorporation of the date palm fibers reduces the thermal conductivity, the density and the compressive strength of the composite, while it increases the water absorption capacity. The authors underlined that according to the fibers size and concentration, the composites can satisfy the structural and/or insulating requirements for lightweight concrete. In the same way, Chikhi et al. [3] developed a new biocomposite material containing date palm fibers and gypsum. The results revealed that the thermal conductivity, the water absorption and the mechanical strength are all strongly influenced by the content of date palm fibers. Furthermore, Chikhi et al. [14] highlighted that the loading of date palm fibers increases the air entrainment and porosity level of gypsum materials. Finally, these authors indicated that this new kind of composites exhibits good thermal and mechanical performances, which makes it suitable for thermal insulation applications. Other kind of date palm fibers were used for composite materials. Boumhaout et al. [15] investigated the thermomechanical characterization of composite materials made with cement, sand, water and date palm fibers mesh.

The investigation of the thermophysical and mechanical behaviors of building materials are not sufficient, since the hygric properties can strongly influence the hygrothermal behavior of the building envelop, and consequently the energy efficiency of buildings [16]. Among these properties, water vapor sorption and water vapor permeability have been widely investigated in many works [2,17–19]. Collet et al. [18] investigated the effect of the composition and manufacturing of hemp concretes on their hygric properties. These authors focused on three kinds of hemp concrete: precast compacted hemp concrete, sprayed hemp concrete and molded hemp concrete. The results revealed that these materials are highly porous, with open and interconnected porosity. Besides, they are classified as excellent (or nearly excellent) hygric regulators according to their high moisture transfer and storage capacities. The authors assumed that the composition and the manufacturing method have a low but non negligible impact on hygric properties of hemp concretes. Rahim et al. [2,19] compared the hygric properties of flax lime concrete and rape straw concrete with hemp concrete. The results showed that these materials have very interesting hygric properties and exhibit an excellent moisture buffer capacity.

In the present paper, we focused on the study of hygrothermal properties of date palm concrete for a single formulation including cement-based binder reinforced with 15 wt% of date palm fibers (DPF). This formulation have shown interesting results of thermophysical properties for the requirements of insulating lightweight concrete in buildings [12].

2. Material

Date palm concrete (DPC) is a biocomposite material consisting of cement-based binder reinforced with short date palm fibers. This biocomposite was prepared in the laboratory, according to the procedure detailed by Benmansour et al. [13]; nevertheless, the formulation and the manufacturing method may have an impact on the hygric properties such as for hemp concrete [18]. The solid constituents are Portland cement, sand and date palm fibers, with weight contents of 62%, 23% and 15% respectively. These constituents were chosen because of many reasons: (i) Portland cement can produce materials with high mechanical performance; (ii) sand is basically used as filler with cement and leads to the production of economic pastes; (iii) vegetal fibers (in particular date palm fibers) are used generally as reinforcement in order to enhance the physical properties of the matrix. Furthermore, with these weight contents mentioned above, mechanical strength and thermal conductivity of the bio-composite are consistent with the use in the field of thermal insulation of buildings [13], with respect to RILEM classification [20].

The water-cement ratio was used as w/c = 0.68. This ratio is obtained experimentally and depends on the used constituents as well as the presence of fibers. This value leads to the production of homogeneous pastes easy to work with it and can easily be molded. The date palm fibers used in this study are characterized by a fine size distribution, with lengths of 3 mm in average.

Fig. 1A shows a typical DPC sample (of dimension 15 cm × 15 cm × 15 cm). Fig. 1B shows the optical microscope view of DPC surface and Fig. 1C represents SEM view of date palm fiber which shows multi-cellular fibers with a cylindrical shape.

3. Methods

3.1. Porosity

Porosity is a very important physical parameter which may affect both hygric and thermal properties of building materials. The total porosity and apparent open porosity are widely used to investigate the void content of the building materials.

3.1.1. Total porosity

The total porosity can be determined using the apparent density and the solid density, as given in Eq. (1) [21]. These densities indicate respectively the mass of a unit volume of a material in its natural state (*i.e.,* with pores and voids) and in its true state (*i.e.*, without including pores and voids).

$$\varnothing = (\rho_m - \rho)/\rho_m \quad (1)$$

where $\varnothing$: total porosity in vol%, ρ_m: solid density in $kg.m^{-3}$, ρ: apparent density in $kg.m^{-3}$.

The pycnometer method is effective for determining the solid density of a material; it involves filling air spaces in material (a few grams of DPC) with acetone.

The material is considered homogeneous since it contains short fibers of length 3 mm and the size of the biocomposite sample is more than 10 times higher than the size of the fibers. Thus, the size of used composite samples can be considered as homogeneous and representative of our material. Different mass measurements were collected using this method, with an accuracy of 0.001 g.

3.1.2. Apparent open porosity

The apparent open porosity measurement was performed using the vacuum saturation method. A dry sample (10 cm × 9 cm × 3 cm of dimension) was placed in a desiccator and air was evacuated during several hours using a vacuum pump, then the water was injected until total immersion of the sample. After 24 h as a saturation time, the open porosity can be deduced from three mass measurements (with an accuracy of 0.01 g): dry mass, saturated mass obtained by weighing in air and saturated mass obtained by hydrostatic weighing.

3.2. Water uptake

The water uptake behavior was investigated to simulate the effect of the rainwater. Two experiments were used to investigate the water absorption behavior until saturation of the material.