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Thermomechanical characterization of a bio-composite building material: Mortar reinforced with date palm fibers mesh

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HIGHLIGHTS

- The influence of DPF mesh content on the thermomechanical proprieties of mortar based composite material is studied.
- Lightening the mortar by DPF mesh increases its thermal insulation capacity and plasticity.
- Thermomechanical diagram of mortar-DPF mesh composite material has been established.
- Mortar-DPF composite could be used advantageously as structural and insulating materials in buildings.

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ABSTRACT

This work deals with thermomechanical characterization of composite materials made from mortar and Date Palm Fibers mesh (DPF). The objective is to evaluate the thermal insulation properties as well as the mechanical performance of this material for thermal insulation of buildings. The volume percentage of date palm fibers mesh in the test samples was varied from 0% to 51%. Thermal characteristics of these samples were experimentally determined in terms of conductivity, diffusivity, capacity and effusivity. Furthermore, flexural and compressive strength of the samples were systematically evaluated. The results show that the DPF mesh has a positive effect on the thermomechanical properties of the composite material. Indeed, it significantly enhances the insulating capacity of the mortar, increases heat diffusion damping rate and makes mortar lighter. The DPF mesh also ameliorates the mortar ductility while respecting the mechanical requirements for construction materials. The mortar-DPF mesh composite could be classified among the structural and insulating materials according to the functional classification of RILEM.

1. Introduction

Due to rapid urbanization, buildings are nowadays designed without taken into account their climate environment. Construction materials are mostly based on standard mortar, which has poor thermal insulation properties. In contrast, traditional and vernacular buildings were well integrated in their environment and more sustainable as people built their houses using natural materials. This is particularly the case in the Mediterranean area and especially in Morocco. Energy consumption in the building sector accounts for approximately 25% of the annual energy use in Morocco [1]. Electricity is the predominant energy source in this sector particularly for air conditioning systems. Thermal insulation of the building envelope is one of techniques that the Moroccan public authorities has adopted to reduce energy consumed by air conditioning in building [1]. Commonly used construction materials, including synthetic insulation materials, are highly polluting, due to their CO_2 manufacturing emission and their disposal environmental issues. Therefore, in the search of sustainable building construction, attention turns to natural materials which offer several advantages, such as availability, recyclability, low cost, environmental friendly, no toxicity, no abrasion, biodegradability and good thermo-mechanical performance [2–4].

Date palm trees are abundant in pre-Saharan and Saharan areas of Morocco [5]. Indeed, Morocco ranks the 6th in terms of area of palm trees and the 11th in terms of production of dates [6]. Date

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Nomenclature

A	Area of contact (m^2)
b	Thermal effusivity ($J.m^{-2}.K^{-1}.s^{-1/2}$)
C_P	Specific heat ($J.kg^{-1}.K^{-1}$)
DPF	Date Palm Fiber
e	Thickness of sample (m)
F	Maximal load (kPa)
h	Height of the sample (m)
$h_{//}$	Width of the sample (m)
k	Thermal conductivity ($W.m^{-1}.K^{-1}$)
l	Free range of the sample (m)
m	Mass of sample (kg)
Q	Heat flux (W)
R	Electrical resistance (Ω)
Rc	Compressive strength (MPa)
Rf	Flexural strength (MPa)
RFM	Reinforced Fiber Mortar
RM	Reference Mortar (without fibers)
S	Surface of sample (m^2)
T	Temperature (°C)
t	Time (s)
U	Potential difference (V)

Greek symbols

α	Thermal diffusivity ($m^2.s^{-1}$)
β	Heat losses coefficient (W/K)
θ	Volume ratio of date palm fibers per total bulk volume of sample (%)
ρ	Density ($kg.m^{-3}$)

Subscripts

amb	Ambient
B	Box
C	Cold
c	Compacted
d	Diffusivity
f	Fiber
H	Hot
w	Water

palm trees occupy an area of around 50,000 ha, for a total of almost 5 million palm trees, representing 4.8% of the world's palm. Furthermore, Morocco expects to plant 1.7 million of palm trees by 2020 horizon [7]. A mature palm tree has approximately 30–140 leaves with spines and fibers on the petiole and renews 10–30 leaves each year [8]. The same amount of leaves dries out annually and must be removed to present important extracts. The properties of palm trees by-products depend on the variety and the region [9,10]. These by-products are commonly treated as rubbish, but recently they are used as thermal insulation materials in buildings [3,4,10–12].

Many researchers dealt with the use of palm trees by-products in construction materials due to their high thermal insulation properties. Chikhi et al. [3] studied the effect of petiole and rachis of palm trees on thermal conductivity, compressive and flexural strengths of gypsum based composite materials. The effect of the same fibers on thermal conductivity and compressive strength of mortar based composite materials has been investigated by Benmansour et al. [4]. Mechanical properties of reinforced concrete with Algerian DPF have been evaluated by Kriker et al. [13]. The effect of the addition of Algerian date palm fibers on thermal and mechanical properties of plaster concrete has been studied by Djoudi et al. [11,14].

All of these researchers have conducted experimental investigation on thermal insulation as well as on mechanical properties of composite construction materials incorporating various date palm fibers (DPF). Very interesting results were found leading to the conclusion that, adequate addition of DPF to commonly used construction materials, such as mortar, significantly enhance their thermal insulation properties while their mechanical strengths are still acceptable. However, the above-mentioned studies are limited to few thermal properties. Moreover, to the best of our knowledge, there was no scientific study of Moroccan date palm fibers mesh used as insulation add-on in mortar.

The objective of this study is to develop an energy efficient composite material that consists of a mortar reinforced with date palm fibers mesh. The bio-composite material is experimentally characterized in terms of thermal conductivity, diffusivity, thermal capacity and effusivity as well as compressive and flexural strengths.

2. Materials and experimental set up

2.1. Materials

The studied composite samples were made with cement, sand, water and date palm fibers mesh released by annual cuts of palm trees surplus (Fig. 1). The cement used is Portland CPJ 35 which is equivalent to CEM II 22.5. Its technical characteristics are in accordance with the Moroccan standard NM 10.01.004 [15]. The sand used in the study is a river one (from Nafiss river, Loudaya, Morocco) with bulk density of 1782 ± 9 kg/m^3. Its granulometry distribution, presented in Fig. 2, was performed according to the Moroccan standard NM 10-1-700 [16]. The sand was washed to remove clay particles and ensure its cleanliness. A sand equivalent test, carried out according to the EN 933-8 standard [17], showed that the mean value of the neatness of the sand was 93%. Thus, this sand was considered to be clean with very low clay content and suitable for high quality mortar. The mixing water was tap water with pH = 7.5.

Date palm fibers mesh (DPF), used as inclusions, were obtained from First Unity of Date Palm Production of Marrakesh. Prior to its use, the DPF mesh were washed with high pressure water in order to eliminate the pollutant particles. Then, these fibers were dried firstly in the sun for two days and further in an oven at 70 °C until dry state. Afterwards, the fibers with diameters less than 0.7 mm were cut with length in between 20 mm and 50 mm. In order to determine their thermo-physical properties, the DPF mesh were compacted under the maximum pressure of 9.5 kPa. Table 1 presents the thermo-physical properties of the compacted DPF mesh.

It can be seen from Table 1 that the used DPF mesh have very interesting thermal insulation properties. In particular, their thermal conductivity is significantly lower than that of Algerian DPF measured by Agoudgil et al. [9] at atmospheric pressure. Moreover, the studied DPF mesh are slightly lighter.

2.2. Composites preparation

The mortars were based on a mass ratio of 3/4 of sand and 1/4 of cement. The samples were prepared with 0.6 mass ratio of water to cement.