Construction and Building Materials 148 (2017) 811–823

Contents lists available at ScienceDirect

Construction and Building Materials

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

Moisture content influence on the thermal conductivity of insulating building materials made from date palm fibers mesh

Lahcen Boukhattem [b,c,*], Mustapha Boumhaout [a,b], Hassan Hamdi [a,b], Brahim Benhamou [a,b], Fatima Ait Nouh [b]

[a] Energy Process Research Group, LMFE, CNRST Associated Research Unit (URAC 27), Faculty of Science Semlalia, Cadi Ayyad University, Marrakesh, Morocco
[b] EnR2E, National Center of Studies and Research on Water and Energy, CNEREE, Cadi Ayyad University, Marrakesh, Morocco
[c] LMPEQ, National School of Applied Sciences, Safi, Cady Ayyad University, Marrakesh, Morocco

HIGHLIGHTS

- Thermal conductivity and density of DPF-B and composite increase with water content.
- Lightening the mortar by DPF mesh increases its thermal insulation capacity.
- DPF-B and composite MDPF51% could be used as insulating materials in buildings.
- Measured DPF-B and composite thermal conductivities are best predicted by two models.

ARTICLE INFO

Article history:
Received 4 March 2017
Received in revised form 29 April 2017
Accepted 5 May 2017
Available online 18 May 2017

Keywords:
Date palm fibers mesh
Mortar
Water content
Thermal conductivity
Theoretical models

ABSTRACT

Vegetal fibers used alone or as additive in composite construction materials bear a growing interest owing to their several advantages such as their lightening and insulation effects. However, they are very hydrophilic. An experimental study was carried out on the water absorption and effect of humidity on thermal conductivity and density of binderless board of date palm fibers (DPF) mesh and a composite based on mortar reinforced with different percentage of DPF mesh varying from 0% to 51%. The obtained results show that the thermal conductivity and density of binderless board and composite increase significantly with volumetric water content. The incorporation of DPF mesh in the mortar has a positive effect, regardless of the water content of the composite, as it lowers its density (lightening effect) and decreases its thermal conductivity (insulation effect) owing to the increase of its total porosity. The addition of DPF to mortar lowers its water retention capacity related to the open porosity which is a positive effect when considering that trapped water increases the thermal conductivity of the insulating materials. The experimental findings on the evolution of thermal conductivity with water content of DPF mesh boards and MDPF composites were fitted to the theoretical models available in the literature. The best fitting models were used to identify the values of the intrinsic thermal conductivities of DPF and mortar.

1. Introduction

Buildings are worldly recognized as important energy consumption sector needing suitable policies to commit to green growth concerns. The Moroccan government launched a thermal regulation for the building envelope in November 2014 in order to enhance sustainability on energetic consumption and population's life quality [1]. The thermal regulation for buildings in Morocco (RTCM) uses either performance or prescriptive approaches based on setting limit values of the walls heat transmission coefficient U and glazing rate for 6 identified climatic zones. The main insulation materials existing in the Moroccan market are: cork, rock wool, glass wool, polyurethane, expanded polystyrene, extruded polystyrene and perlite [2]. These materials are expensive as most of them have to be imported. On the other hand, these materials are often noxious and have a negative impact on human health as well as on the environment [3]. Vegetal fibers used alone or as additive in composite construction materials bears a growing interest owing to their several advantages such as availability, low cost, biodegradability, renewability, abundance, absence of toxicity and polluting effects. In addition, these vegetal fibers ensure a good

* Corresponding author at: EnR2E, National Center of Studies and Research on Water and Energy, CNEREE, Cadi Ayyad University, Marrakesh, Morocco.
E-mail address: l.boukhattem@uca.ma (L. Boukhattem).

http://dx.doi.org/10.1016/j.conbuildmat.2017.05.020
0950-0618/

Nomenclature

Ab	absorption (%)
B	board
DPF	date palm fibers
k	thermal conductivity ($W.m^{-1}.K^{-1}$)
m	mass (kg)
P	porosity (%)
Rs	residual saturation (%)
MDPF	mortar-DPF composite
RM	reference mortar (without fibers)
t	time (min)
U	heat transmission coefficient ($W.m^{-2}.K^{-1}$)
V	volume (m^3)
W	water content (%)

Greek symbols

ε	volume fraction of the layers oriented perpendicular to the heat flux direction
ε'	volume ratio of (air + water) phase
δ	volume ratio of water phase
θ	volume ratio of date palm fibers per total bulk volume of sample (%)
ρ	density ($kg.m^{-3}$)

Subscripts

abs	absolute
air	air
b	bulk
c	closed
dry	dry state
e	effective
f	fiber
hyd	hydrostatic
m	mass
mo	mortar
o	open
r	real
s	solid matrix
sat	saturation state
t	total
v	volumetric
w	water
wet	wet
$\perp$	series
//	parallel

adhesion between fibers and solid matrix while providing good thermal performance for the composite [4–6].

The vegetal materials used alone or as additive have drawn attention of many researchers in last decades. Ngohe-Ekam et al. [7] have carried out an experimental study on the influence of density on the thermophysical properties of tropical woods. Agoudjil et al. [8] have investigated the thermophysical, the chemical and the dielectric properties of three varieties of date palm wood. They noticed that date palm wood could be a good candidate for the development of efficient and safe insulating materials when compared to other natural materials. Xu et al. [9], Zhou et al. [10,11] and Panyakaew et al. [12] have studied the thermal conductivity and bulk density of natural insulation boards made from kenaf, straw, cotton stalk, bagasse and coconut husk. They reported that the thermal conductivity of the studied materials increases with their bulk density.

Khedari et al. [13] have investigated the thermal conductivity of a material composed of cement, sand and fibers of coconut and durian waste. Their experimental investigation revealed that the addition of these fibers reduces the thermal conductivity of the composite samples and yields a lightweight material. The effect of barley straws addition on the thermophysical properties of sand concrete has been carried out by B. Belhadj et al. [4]. They found that the barley straws additive improves the thermal conductivity, specific heat and density of composite. Bederina et al. [14] found that addition of wood shavings to sand concrete reduces the density and thermal conductivity of the composite. Djoudi et al. [15] and Braiek et al. [17] carried out experimental studies and modeling of the effect of date palm fibers addition on thermo-mechanical properties of plaster concrete. They noticed that the thermal conductivity and density of the composite decreases as the fraction of fibers increases. Porosity, Young's modulus thermal resistance and time lag of gypsum based composites reinforced with DPF were studied by Chikhi [16]. The results showed that the addition of DPF on gypsum induces an increase of porosity, time lag and thermal resistance of composites.

On the other hand, vegetable fibers are known to be very hydrophilic [5] and this may impact negatively their insulating capacity. Therefore, a deeper investigation on thermal conductivity of fibers and their composite materials as function of moisture content is required. Korjenic et al. [18] carried out investigation on impact of moisture on thermal conductivity of boards made from natural fibers (jute, flax and hemp) and concluded that moisture has higher influence on boards made from higher hydrophilic fibers.

Water absorption, thermal conductivity and compressive strength of mortar reinforced with date palm fibers were experimentally investigated by Benmansour et al. [19]. They noticed that addition of DPF allows lightening of mortar and permits increasing its insulating capacity, whereas the water absorption leads to an increase of its thermal conductivity. The concerned date palm fibers are rachis and petiole type, while the study of the influence of moisture on thermal conductivity was limited to a composite containing 10% of DPF.

The influence of moisture content on the thermal conductivity and thermal diffusivity of wood–concrete composite has been studied by Taoukil et al. [20]. Their experimental results revealed that the thermal conductivity of composite decreases as wood shavings content is increased and increases rapidly with water content. They then fitted their experimental findings by Krischer–Kroll and Chaudhary–Bhandari models. Rahim et al. [21] have investigated the thermal properties of three bio-based materials (hemp concrete, flax concrete and rape straw concrete) as function of water content and temperature. They noticed that the thermal conductivity of these materials provides a good thermal insulating capacity. They have also used the self-consistent scheme (SCS) model to calculate the thermal conductivity of the studied materials and obtained results in accordance with measurements.

DPF mesh may be used advantageously in form of insulating binderless boards (DPF-B) or as reinforcement to mortar (MDPF composite) to reduce its thermal conductivity. In a previous study, Boumhaout et al. [6], which dealt with thermomechanical characterization of mortar reinforced with DPF mesh, the authors concluded on the positive effects (lightening and enhancing insulation capacity) of addition of DPF mesh to mortar. They also showed, through the thermomechanical diagram of the MDPF