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Young's modulus and thermophysical performances of bio-sourced materials based on date palm fibers

Mourad Chikhi*

Unité de Développement des Equipements Solaires, UDES/Centre de Développement des Energies Renouvelables, CDER, Bou Ismail, 42415, W. Tipaza, Algeria

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ABSTRACT

The present work is a part of a large project aimed at design and development of new composite materials containing date palm fibers (DPF) primarily suitable for thermal insulation in various sectors, especially in the building sector. On one hand, porosity (P) and Young's modulus (E) of gypsum based composites reinforced with DPF were investigated. On other hand, thermal resistance and time lag of composites were also studied. The results showed that E of DPF reinforced gypsum materials is mainly affected by the interfacial adhesion between matrix and DPF. The effect of DPF sizes and loadings is highly significant on the stiffness of gypsum. It's noted that the adding of DPF on gypsum induces an increase of both time lag and thermal resistance of composites. This new biocomposite can be used as a raw material for reinforcement gypsum materials in order to produce a friendly biocomposite materials to use for thermal insulation in buildings.

1. Introduction

Gypsum plaster is one of the earliest building materials. The gypsum plaster boards are used extensively for interior walls or ceilings because of their simple manufacturing features, environmental friendliness, aesthetics, low price and their excellent fire resistance properties [1,2]. Several works [3,4] demonstrated that a high porosity is strongly related to a low density and to poor mechanical properties such as low strength, and to good thermal insulating properties such as low thermal conductivity. It's noted that a low strength causes a limitation of the application of gypsum boards [1]. To address this weakness, many fibers are extensively applied to reinforce the gypsum materials such as glass fiber [1], mineral additive [5], polymer fibers [1,2,5] and PCM materials [6]. These inclusions contribute somewhat to the improvement of the gypsum plasterboards in terms of mechanical or thermal properties, but they have also some drawbacks [7]. In 2009, Wu [8] developed an environmental friendliness composite material consisting of gypsum plaster and glass fibers (GFRG) intended to be used in residential, commercial and industrial buildings. However, the results of the in-plane flexural strength of GFRG walls shows a difficult, if not an impossible application due to the relative slips between the infill concrete cores and the GFRG panel. Sing and Garg [9] reported that glass fibers could not contribute to the strength improvement if their length is shorter than 12 mm. However, for gypsum plasterboards, the normal thickness is about 12 mm, which indicates that applying longer fibers will cause mixing problems. Recently, several authors [1,5] mentioned that the incorporation of a high amount of polymer fillers on gypsum induced a considerable increase of the cost and problems relating to the mixing process. Besides, the elasticity modulus of the composite whether smaller than the gypsum without polymers additives. The cost and performances problems induced on using synthtique reinforcements in gypsum promote the use of natural fibers.

Natural fibers have recently become attractive for researchers, engineers and scientists as an alternative component for composite materials. Due to their low cost, fairly good mechanical properties, high specific strength, non-abrasive, eco-friendly and bio-degradability characteristics, they are exploited as alternative for the conventional fiber, such as glass, aramid and carbon [10,11]. Natural fibers, have been used by several authors in order to improve thermal insulating, mechanical and physical properties of composite materials [12,13]. The use of natural fibers as a reinforcement in composites generates a lot of parameters which can modify the intrinsic properties (thermophysical, mechanical and microstructural) of the matrix, such as, fibers content, porosity, moisture and water absorption [3,13,14]. The addition of natural fibers in gypsum materials, leads to produce new natural composites with good physical properties for use in the building sector [3,12,15]. In previous work [3], a new biocomposites based on

* Corresponding author.
E-mail address: chikhimourad06@yahoo.fr

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Nomenclature

R_{th}	Thermal resistance ($W^{-1}\,m^2\,K$)
t	Thickness of the material (m)
k	Thermal conductivity ($W\,m^{-1}\,K^{-1}$)
T	Periodic cycle of temperature variation (h)
cp	Specific heat ($Wh\,kg^{-1}\,K^{-1}$)
ρ	Density ($kg\,m^{-3}$)
Φ	Time lag (h)
F	Applied force (N)
L	Support span (m)
l	Width of sample (m)
d	sample deflection under F (m)
E	Young's modulus (Mpa)
φf	Masse weight fraction of fibers (wt.%)
a	Diffusivity ($m^2\,s^{-1}$)
m	Weight (Kg)
Qf	Weight fraction of fibers (%)
P	Porosity (%)
Subscript	
m	matrix
f	fiber
r	real density
b	bulk density

gypsum materials reinforced by date palm fibers (DPF) have been developed; where the experimental results show that the loading of DPF in the gypsum decreased the thermal and mechanical properties of gypsum. This new biocomposite exhibited a good thermal insulating performance which leads to replace the gypsum panels.

The thermophysical characteristics of building materials are an important factor controlling heat transfer, thermal comfort and energy saving in the building envelope [14,16]. According to Aste et al. [17], buildings must be designed to possess a great thermal inertia in order to achieve comfortable ambient temperature. Thermal inertia depends on two parameters namely time lag and decrement factor which depend on thermophysical properties of materials [18]. In our previous study [3], it has been proven that using 5% of DPF in gypsum matrix allows obtaining a composite with good thermal and mechanical properties. The thermal conductivity alone does not accurately reflect the thermal performance or represent a reliable energy conservation indicator for walls [19]. Kontoleon et al. [18] have studied the influence of concrete density and concrete thermal conductivity of various wall assemblies on the dynamic thermal characteristics, such as the decrement factor and time lag. The results indicate that the increase of the thermal conductivity of the concrete helps to reduce the time lag. Maalouf *et al.* [20] investigated the transient hygrothermal behavior of a hemp concrete envelope under summer conditions in France. The authors have shown that the hemp concrete induces low thermal effusivity which means that it can store less energy and thus superheating problems in summer can occur.

Another important property of natural fiber-based composite materials is the Young's modulus. It presents a variety of results, this is a consequence of the fact that the properties of natural materials are strongly influenced by the type of fiber, the nature of the matrix and filler, the compatibility between them, materials processing technology and conditions, the dispersion or distribution of the filler in the matrix, as well as the interfacial structure and Morphology [14,10].

The present work is a part of an overall research project which tends to develop a new biocomposite materials intended for buildings. This study aims, on one side investigate experimentally the effect of DPF loading and porosity content on the Young's modulus of gypsum. On the other side, the study of the effect of thermal resistance of the composites on their time lags is performed.

Table 1
Chemical composition of gypsum.

Elements	*wt. %*
O	48.86
Mg	0.87
Al	0.80
Si	1.32
S	21.46
Ca	26.68
Total	100

2. Materials and experimental

2.1. Materials

2.1.1. Date palm fibers (DPF)

The natural fibers used in this study as reinforcement is the date palm fibers (DPF) collected from the oasis of Laghrous (Biskra, Algeria). The parts of date palm wood used are the petiole, bunches and rachis. Two different DPF sizes were used (3 and 6 mm).

The details of the drying, cutting and grinding process are presented in a previous work [3].

2.1.2. Gypsum

The matrix used is the gypsum provided by Knauf Algeria®, where the chemical composition is shown in Table 1. The chemical composition were investigated using X-Ray Diffraction. From this table it's cleary that on one hand, the gypsum is mainly consisted of $CaSO_4{}_{-}0.5H_2O$. On the other hand, the amount of Ca and S are higher than the Si and Mg ones.

2.2. Samples preparation

The samples were prepared with seven different weight fractions (0, 1.2, 3, 5, 7, 8 and 10%) of DPF, and tested for the mechanical and thermal properties after fourteen and twenty-eight days. The details of the samples preparation are already presented in our previous work [3].

Two different series of composite samples were manufactured, HG/DPF_3 and HG/DPF_6 using 3 and 6 mm of DPF size respectively. HG indicates the hemihydrate gypsum.

From the mixture law Eq. (1), the weights of fibers and matrix corresponding to the DPF weight fractions are calculated from Eq. (2).

$$m_c = m_f + m_m \tag{1}$$

$$m_f = m_m\left[\phi_f/\left(1-\phi_f\right)\right] \tag{2}$$

With: m_c, m_f and m_m are respectively the weight of the composite, fibers and the matrix (gypsum + water); ϕ_f is the weight fraction of fibers used for the manufacturing of the composites.

For a water/gypsum ratio (w/g) of 0.6, the calculated weights of fibers are shown in Table 2.

Fig. 1 shows a picture of composite sample based on gypsum materials reinforced with date palm fibers.

2.3. Characterization

2.3.1. Thermophysical properties measurements

The thermal conductivity of the composites was measured using the CT-meter device [3]. The measurement technique is based on the hot wire method and allows the estimation of the thermal