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Experimental study of the thermal conductivity of the plaster reinforced palm-trees-fibers

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Abstract: Gypsum plaster is a building material used in walls or false ceilings. This work studies the thermal properties of a new construction material made with plaster and palm-trees-fibers. In this paper, thermal conductivity of this sample was determined by the "DICO" method. Four insulating materials containing different percentages of palm tree fibers were prepared and examined. Furthermore, the interface of palm-trees-fibers was observed by Scanning Electron Microscopy (SEM). Results show that the reinforcement of plaster by palm tree fibers decreases the thermal conductivity. In addition, the experimental results of thermal conductivity at different mass ratio were compared with the theoretical model (series model, parallel model and Krischer model).

Keywords: palm, fibers, plaster, thermal conductivity, insulating materials.

1. Introduction

Materials based on natural fibers from renewable raw material resources are now becoming increasingly popular. Due to its low mass density and cell structure, they show very good and thermal insulation properties, of the better and more advantageous than synthetic fibers. In this context, the aim of this work is to build a new sample of insulating materials based on palm-trees-fibers. The objective of this work is to study how the embedded palm-trees-fibers modifies thermal properties of plaster, this study will be a contribution to the understanding of the thermal properties of this composite for motivate the proposal that it will be use in false ceiling as palm-trees-fibers-plaster board. The objective of this work is to build a new sample of insulating materials based on palm-trees-fibers and plaster at different percentages of palm-trees-fibers (2%, 5%, 8% and 10%) and to determine an effective thermal conductivity a composite. To this end, we compare the experimental results and the theoretical models (serial, parallel and Krischer models) which calculate the effective thermal conductivity of composite.

2. Experimental

2.1. Materials

Plaster is a building material used for coating walls and ceilings. Plaster is a hydraulic binder, made from a white rock that is gypsum. Whose gypsum is a calcium sulphate hydrate ($CaSO_4.2H_2O$). The natural fibers used in this work are the date palm collected by the oases of the Tunisian South. Palm tree fibers are natural and renewable with very interesting thermal properties thanks of their porosity. The part used in this work is the trunk, presented in figure 1. The fibers obtained have a diameter between 0.7-1.1mm.

Figure 1: The fibers after pulling out from trunk of date palm

2.2. Composites preparation

The objective of this work is to determine an effective thermal conductivity of the sample realized that can be used for the insulation of the walls. Five samples were prepared at different mass ratio (0%, 2%, 5%, 8% and 10%) (see an example in figure 2).

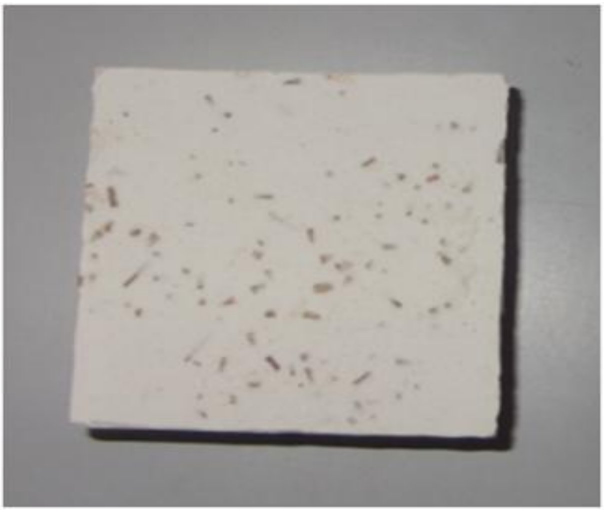

Figure 2: Examples of the composite samples

Furthermore, each sample was prepared, with a dimension 44*44*12 mm^3, in order to compare the variation of thermal conductivity of palm-trees-fibers-gypsum with those of gypsum without palm tree fibers. For all the samples, the percentages for water used in the plaster is (W/g = 0.8).

2.3. Thermal conductivity measurement

Thermal conductivity measurement was obtained using a periodic method “DICO”, detailed in the literature [1]. The general principle of the experimental set-up is shown in figure 3.

The method is based on the use of a low temperature modulation in a parallelepiped-shaped sample (44 mm*44 mm*12 mm^3) and allows obtaining all of these thermo physical parameters in only one measurement with their corresponding statistical confidence bounds [2]. The composite sample is fixed between two metallic plates (brass to the lower plate and copper to the top plate). A good thermal exchange and contact between the different elements and the sample is ensured by using conducting grease. The front side of the first metallic plate is heated periodically using a sum of five sinusoidal signals. The temperature is measured using thermocouples placed inside both two metallic plates [3]. The thermo physical parameters of the composite are identified by comparison between the experimental and theoretical heat transfer functions [4]. The system under consideration is modeled by one dimensional quadruple theory [5]. The experimental heat transfer function is calculated at each excitation frequency as the ratio between the Fourier transform temperatures of the front and rear plates.

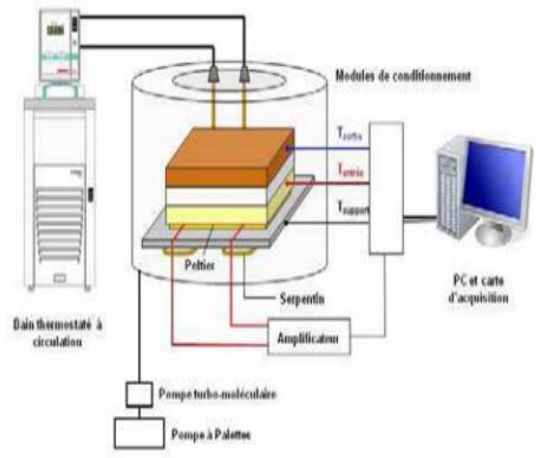

Figure 3: Experimental set-up of periodic method: DICO

3. Modeling of effective thermal conductivity

Each sample is a porous medium formed by a solid phase, a liquid phase and a gaseous phase. To model the expression of the effective thermal conductivity of each sample, we take the following hypotheses of simplification:

- Convection is negligible inside the pores.
- Temperature is low.
- The material is opaque.
- The physical characteristics are constant.
- The mass diffusion is absent.
- The term source is absent.

3.1. Serial model

In this approach, we consider that composite material of a solid phase (plaster + palm-trees-fibers) and a two phases; the gaseous phase (air) and liquid phase water. So we introduce the concept of the thermal conductivity of a solid1 (plaster) λ_{s1}, a solid2 (palm-trees-fibers) λ_{s2} and that of a fluid phase λ_f and a liquid phase λ_l.

A serial model defines the minimum theoretical limits of thermal conductivity limits of thermal conductivity for a three-phase system. In the series model, the components are conceptually aligned perpendicularly to the heat flow [6, 7].

The effective thermal conductivity of the sample showing the series arrangement is given by:

$$\lambda_{effs} = \frac{1}{\frac{\varepsilon_{s1}}{\lambda_{s1}} + \frac{\varepsilon_{s2}}{\lambda_{s2}} + \frac{\theta}{\lambda_l} + \frac{(\varepsilon - \theta)}{\lambda_g}} \qquad (1)$$

Where

ε_{s1} is the volume fraction of the solid1 phase

ε_{s2} is the volume fraction of the solid2 phase

θ is the moisture content

ε is the total porosity

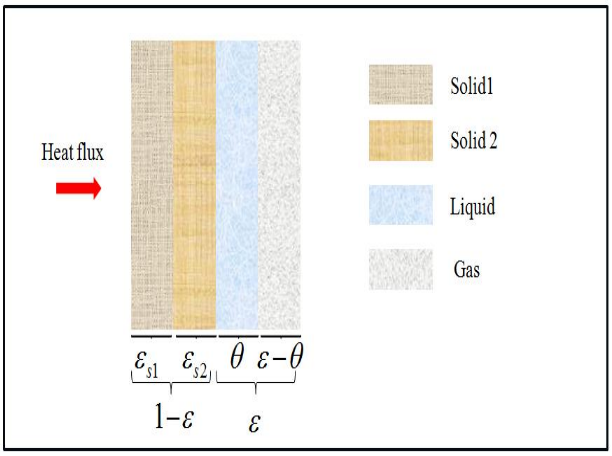

Figure 4: Serial model

3.2. Parallel model

A parallel model defines the maximum theoretical limits of thermal conductivity for a three-phase system. In the parallel model, the three phases are aligned along the same direction of the heat flow [6, 7].
The effective thermal conductivity in this case can be given by the following expression:

$$\lambda_{effp} = \varepsilon_{s1}\lambda_{s1} + \varepsilon_{s2}\lambda_{s2} + \theta\lambda_{l} + (\varepsilon - \theta)\lambda_{g} \tag{2}$$

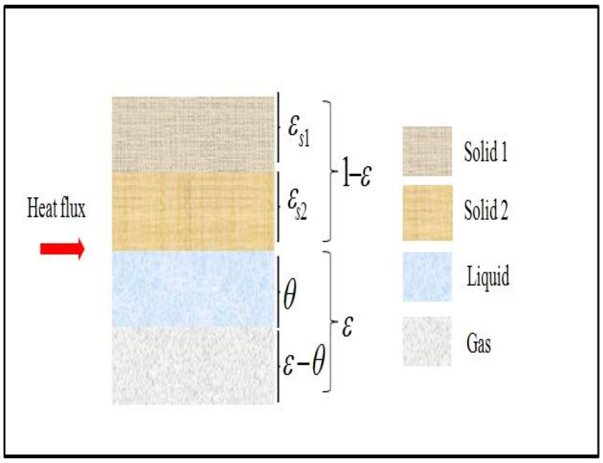

Figure 5: Parallel model

3.3. Krischer model

Krischer (1963) proposed another model by combining parallel and series models and using the distribution factor u . The following equation describes the Krischer model defined by the following expression:

$$\lambda_{effk} = \frac{1}{\dfrac{u}{\lambda_{effp}} + \dfrac{(1-u)}{\lambda_{effs}}} \tag{3}$$

Where λ_{effp} and λ_{effs} are the effective conductivities by the parallel and the series model, respectively, while u is the volume fraction of layers oriented perpendicularly to the direction of the heat flow is arranged in series with the complementary fraction ($1-u$) of layers oriented parallel to the direction of heat flow.

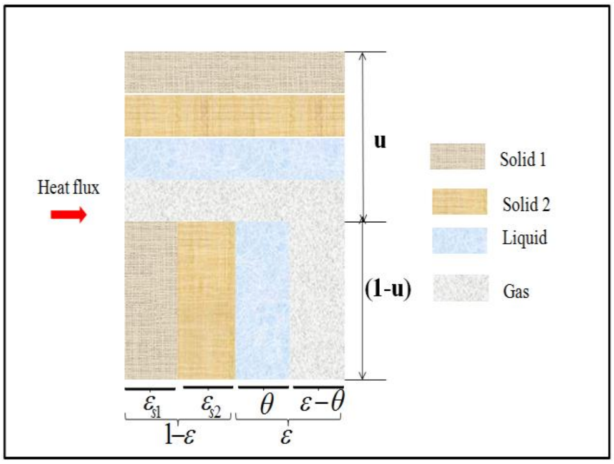

Figure 6: Krischer model

4. Results and discussion

4.1. Surface modification of palm-trees- fibers

The morphology and the surface of the fibers were observed by scanning electron microscope (SEM) of the vegetable fibers. The device used for observing the microstructure is a scanning electron microscope JEOL 6301F.

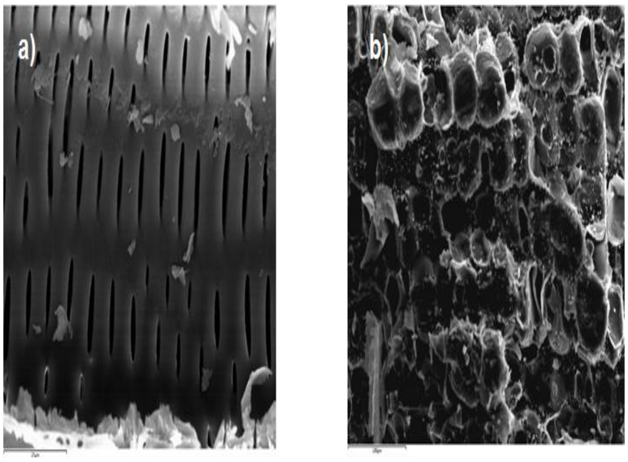

Figure 5: Scanning Electron Microscope (SEM) view of a trunk fiber. Scale bar equal to: (a) 25 μm, (b) 100 μm

SEM images of trunk fibers are shown in the figure 5. The surface of the fibers is cylindrical; it is irregular with many impurities, cells and pores which allow it good adhesion to other material. It is a typical surface of a natural fiber [8].

4.2. Dry density of the composite

The palm-trees-fibers are lighter than plaster (figure 6). This lightness is essentially due to the porous structure of palm-trees-fibers. The addition of fibers increases the porosity of our composite and therefore makes it lighter. For a mass percentage of fibers from 0 to 10%, the reduction in the density is about 16.5%. Thus, the first advantage of the use of palm-trees-fibers is the lightening of the composite.

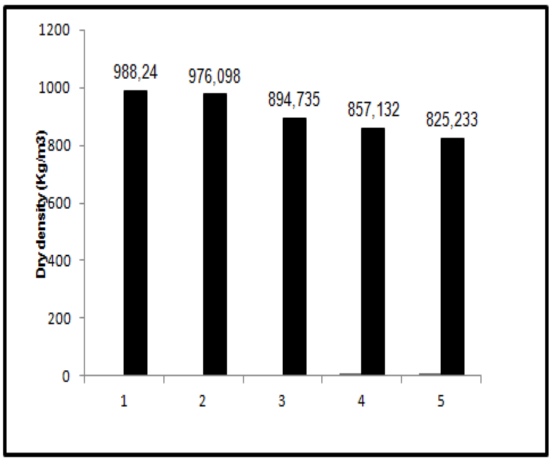

Figure 6: Dry density of all samples

4.3. Comparison of the experimental results with analytical models of effective thermal conductivity

Table 1 summarizes the variation of thermal conductivity according to the percentages of fibers. It is clear that the thermal conductivity of plaster matrix reinforced with palm-trees-fibers decreases with increasing fiber content. This result is related to the insulating properties of palm-trees-fibers, which have a low thermal conductivity and their ability to block heat flux. Furthermore, the increase in porosity decreases the density of the insulating materials and consequently its thermal conductivity. This result is reported in the literature, when increasing vegetable fiber content, there is a progressive decrease in thermal conductivity [9, 10].

Table 1: Measured values of the thermal conductivity of the palm tree based materials for different fiber contents

Palm fiber mass ratio *(%)*	Density *(Kg/m^3)*	Thermal conductivity λ*(W/mK)*
2	976.098	0.304
5	894.735	0.252
8	857.132	0.237
10	825.233	0.232

The most insulating material is observed with 10% by mass of date palm fibers. The thermal conductivity of composites decreases from 0.431 W/m.K for the sample without fibers to 0.232 W/m.K for the most insulating material. Moreover, it has the advantage of being a natural, harmless and less-expensive product.
Figure 7 presents the comparison between the experimental evolution of the thermal conductivity as function of the fibers mass ratio and the simulated by theoretical models (Parallel model, serial model and Krischer model). As can be seen, the Krischer model approaches better measurement results. The krischer model considered both layers in parallel and serial layers, which seems more logical. This confirms the concordance between the theoretical and experimental values. We can conclude that the values calculated by Krischer model are relatively comparable to the experimental values.

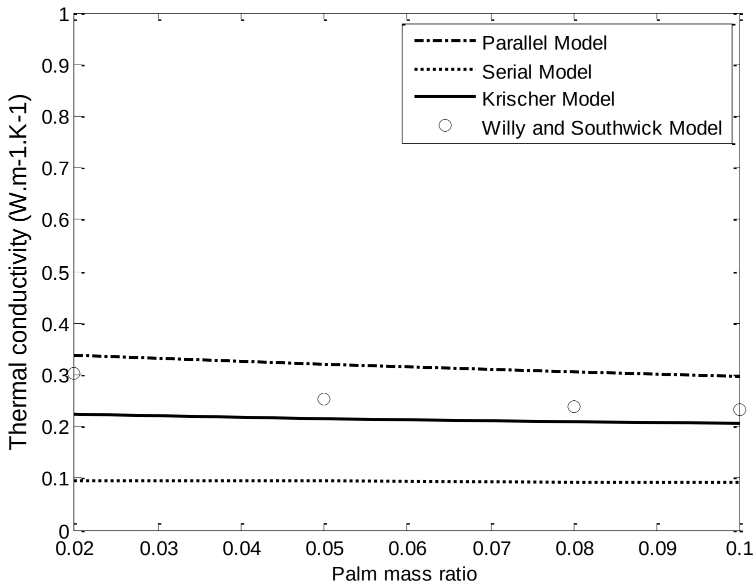

Figure 7: Comparison between the experimental evolution of the thermal conductivity as function of the fiber mass ratio and the simulated by theoretical models (serial model, parallel model and Krischer model)

5. Conclusion

In this paper, we have modeled the effective thermal conductivity of insulating materials. In this work, we have studied the effect of the fiber mass ratio on the effective thermal conductivity of the insulating plate realized in our laboratory. Therefore, the measured thermal conductivity was compared with the different analytical models (serial, parallel and Krischer models).

It has been found that the thermal conductivity of composites made of palm-trees-fibers is increased with increase of fiber content and the krischer model is able to correlate the heat transfer in porous materials.

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