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Granular cork size dependence of thermal properties of the composite material/granular cork bound with cement mortar.

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Abstract: This work is a contribution to understand the thermal behaviour of the ecological composite material based on granular cork embedded in cement mortar. An experimental investigation of its thermal properties was mainly performed using the recent asymmetrical transient Hot Plate method and the tiny Hot Plate method in steady state regime. This will allow compare its thermal properties with those of cement mortar without cork for motivate the proposal that this composite will be used as walls and roof insulating. A comparison of the energy performances of the composite material and cement mortar was made; it allows deducing a very interesting energy gain. The preliminary findings indicate the composite is better than cement mortar without cork in term of thermal insulation and lightness.

Keywords: ecological composite material; granular cork; mortar cement; walls and roof insulating.

1. Introduction

Cement mortar is a building material used in walls or roofs. The goal of this current work consists to improve the thermal properties and lightness of cement mortar by combining it with granular cork. Indeed, cork is natural, ecological, hydrophobic and renewable product with thermal and acoustic properties very interesting due to its microstructure and porosity. It is coming from Mediterranean area (Moroccan, Portuguese, Algerian, Tunisian…Forests). But the use of a material in building requires the comprehension of its thermal behaviour. So, authors contribute to understanding the thermal behaviour of the composite material based on granular cork embedded in cement mortar by characterizing its thermal properties using the recent asymmetrical transient Hot Plate method [1] and the tiny Hot Plate method in steady state regime [2]. The objective is to study the effect of granular cork size on the thermal properties of the middle.

Khabbazi and al. [3] made thermal properties characterization of materials based on granular cork, they study the effect of granular cork volume fraction on the thermal properties of these materials, but in this present work, the granular cork size effect on thermal properties is studied. Others previews works related to this composite material are done: Khabbazi and al. [4] conducted an experimental study of thermal and mechanical proprieties of a new insulating material based on cork and cement mortar; Silva and al. [5] presented a study about cork, its properties, capabilities and applications. These references show the practical interest of cork likely to be a material of choice for improving the energy efficiency in buildings.

2. Experimental approach and principle of the used methods

2.1. Samples preparation and their densities measurement

We prepared four samples corresponding to four different size categories of granular cork by using a normalized sieving process (d_1-D_1=2.5-5 mm, d_2-D_2=5-6.3 mm, d_3-D_3=6.3-8 mm, d_4-D_4=8-12.5 mm) for taking account the effect of granular cork size on the thermal properties of the medium. We proceeded to the preparation of samples: we filled the apparent volume of dimensions 100x100x20 mm³ by the granular cork (for each size category, granular cork occupies the apparent volume of the sample, so the volume fraction of granular cork in the four samples is constant and equal 100%), and then we add cement mortar for that it occupying the inter-granular space. Furthermore, we prepared a sample of cement mortar without granular cork, having the same dimensions as the other four, in order to compare the variation of thermal properties of the mixtures, depending on the size of granular cork, with those of the cement mortar without cork. The five samples are then drawn in a stove, to remove moisture present into the pores of each one. Next, we measure their dry masses then we pack them in plastic bags so they maintain uniform moisture content near zero. The experimental measurements will be performed on these dry samples (cf. picture Figure.1).

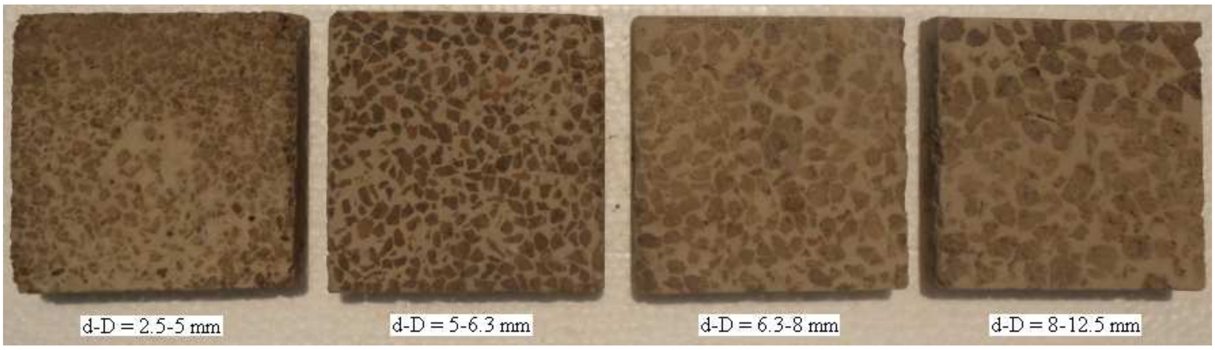

Figure 1: View of the composite material (Cement mortar + Granular cork) depending on granular cork size.

From the knowledge of the dimensions and masses of the five samples, we can easily determine the apparent density of each one. But the density of the granular cork is determined by the water volume variation method: we weigh a quantity of granular cork that we fill in a vessel containing a known water volume; the change in volume of water corresponds to the volume of impregnated cork, so we deduce the density of granular cork (The quantity of water penetrating into the granular cork is negligible considering the short duration of 5s of the experiment, due to hydrophobic character of cork).

Knowing separately the densities of cement mortar, granular cork and that of the mixture, we combine the mixture law of two components with mass conservation law to deduce the granular cork mass fraction (y) in each sample of the composite material:

$$y = \frac{(\rho_{cm+co} - \rho_{cm})}{(\rho_{co} - \rho_{cm})} \quad (1)$$

With: ρ_{co}, ρ_{cm} and ρ_{cm+co} are successively the densities of granular cork, cement mortar and that of the composite material.

2.2. Asymmetrical Hot Plate methods description

2.2.1. Transient Hot Plate method

The thermal effusivity (E) and thermal capacity (ρc) were measured using the transient hot plate method. Contrary to the classical and symmetrical Hot plate transient method [6] which required two similar samples; we used here the recent asymmetrical experimental device [1] (represented in Figure 2 (a)) that allows characterize materials by using only one sample. The system is modeled with the hypothesis that the heat transfer remains unidirectional (1D) at the center of the sample:

$$\begin{bmatrix} \theta \\ \Phi_{01} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ C_h & 1 \end{bmatrix} \begin{bmatrix} 1 & R_c \\ 0 & 1 \end{bmatrix} \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} \begin{bmatrix} 0 \\ \Phi_1 \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} 0 \\ \Phi_1 \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} \theta \\ \Phi_{02} \end{bmatrix} = \begin{bmatrix} A_i & B_i \\ C_i & D_i \end{bmatrix} \begin{bmatrix} 0 \\ \Phi_2 \end{bmatrix} \quad (3)$$

$$\Phi_0 = \frac{\phi}{p} = \Phi_{01} + \Phi_{02} \quad (4)$$

C_h the thermal capacity of the heating element per area unit: $C_h = \rho_h\ c_h\ e_h$; Rc the thermal contact resistance between the heating element and the sample. p is the Laplace parameter.

$$A = D = cosh\left(\frac{\rho c}{E} e\sqrt{p}\right);\ B = \frac{sinh\left(\frac{\rho c}{E} e\sqrt{p}\right)}{E\sqrt{p}};\ C = E\sqrt{p}\,sinh\left(\frac{\rho c}{E} e\sqrt{p}\right) \quad (5)$$

$$A_i = D_i = cosh\left(\sqrt{\frac{p}{\alpha_i}} e_i\right);\ B = \frac{sinh\left(\sqrt{\frac{p}{\alpha_i}} e_i\right)}{\lambda_i\sqrt{\frac{p}{\alpha_i}}};\ C = \lambda_i\sqrt{\frac{p}{\alpha_i}}\,sinh\left(\sqrt{\frac{p}{\alpha_i}} e_i\right) \quad (6)$$

E is the sample thermal effusivity $E = \sqrt{\lambda \rho c}$, ρc the sample thermal capacity, e the sample thickness, λ_i the Polystyrene thermal conductivity, a_i the Polystyrene thermal diffusivity, e_i the Polystyrene thickness.

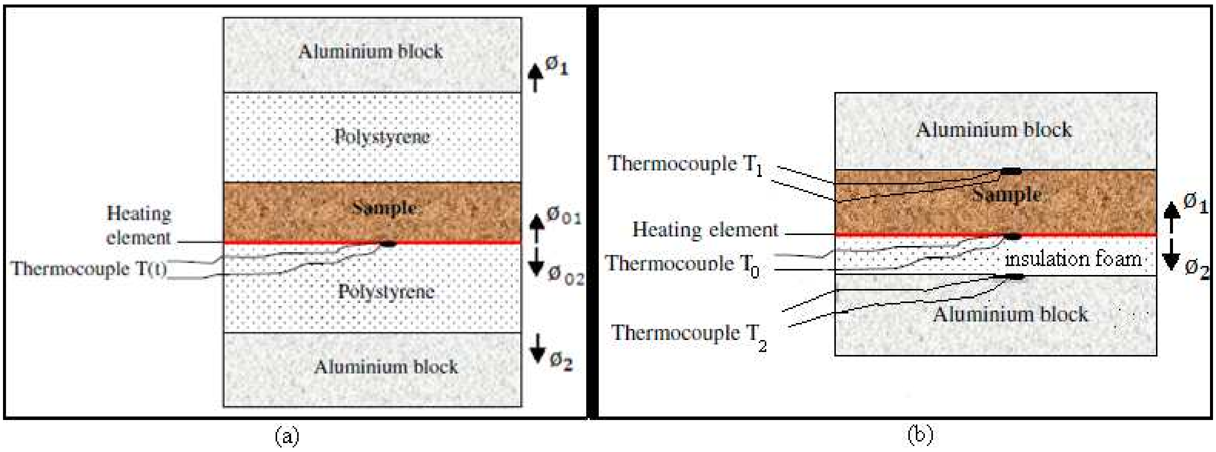

Figure 2: (a): Asymmetrical transient Hot Plate device; (b): schema of the tiny Hot Plate method in steady state regime.

Combining those five equations, the system leads to:

$$\theta(p) = \frac{\Phi_0(p)}{\frac{D_1}{B_1} + \frac{D_i}{B_i}} \quad (7)$$

The principle of the method is to estimate the value of the parameters (E), (ρc), (Rc) and (C_h) that minimize the sum of the quadratic error $\Psi = \sum_{j=0}^{N}\left[T_{exp}(t_j) - T_{mod}(t_j)\right]^2$ between the experimental curve and the theoretical curve calculated with relation (7) using the Levenberg-Maquardt algorithm [7]. The inverse Laplace transformation is realized by use of the De Hoog algorithm [8].

2.2.2. Hot Plate method in steady state regime

The tiny Hot Plate method in steady state regime [2] permits to characterize thermal conductivity (λ) of samples. Figure 2 (b) illustrate the experimental device of this method, once the system reaches the steady state regime, one can write:

$$\varnothing = \varnothing_1 + \varnothing_2; \quad \varnothing_1 = \frac{\lambda_1}{e_1}(T_0 - T_1); \quad \varnothing_2 = \frac{\lambda_2}{e_2}(T_0 - T_2) \quad (8)$$

$$\lambda_1 = \frac{e_1}{T_0 - T_1}\left[\varnothing - \frac{\lambda_2}{e_2}(T_0 - T_2)\right] \quad (9)$$

$\varnothing$ is the total flux emitted by the heating element. λ_1 the thermal conductivity of the sample as we seek to determine, e_1 the thickness of the sample; $\lambda_2 = 0.04\ W.m^{-1}K^{-1}$ and $e_2 = 10\ mm$ are successively thermal conductivity and thickness of the insulating foam.

3. Results

3.1. Density

The density measurements of the five samples were made by weighing each one and knowing their dimensions. For the granular cork, it was made using the water volume variation method. We note that the density of granular cork is constant for all size classes $\rho_{cg} = 150\ kg.m^{-3}$, so since the four size classes have the same volume fraction of cork, they will have therefore the same mass fraction of cork. The results are presented in Table 1.

Even if we have tried to elaborate samples with similar mass fraction $\left(y = \frac{\rho_{cc}}{\rho_{cm}}\right)$ of granular cork in the medium, we observe small variations (not exceeding 7%) due to the elaboration process (we can't ensure the same fraction of granular cork in the four mixtures during their elaboration). We observe a decreasing of the density of the mixture with the increasing of the granular cork size due to the increasing of mass fraction of cork in the mixtures.

Table 1: Asymmetrical transient Hot Plate method results with density and granular cork mass fraction results

Sample	E ($J.m^{-2}.K^{-1}.s^{-1/2}$)	ρc ($J.m^{-3}.K^{-1}$)	ρ (kg/m^3)	y
cm+co 2.5-5 mm	595.26	1 355 541	1 250	0.355
cm+co 5-6.3 mm	570.03	1 320 845	1 200	0.384
cm+co 6.3-8 mm	567.05	1 271 669	1 185	0.393
cm+co 8-12.5 mm	466.72	1 110 894	1 180	0.396
Cement mortar	1189.24	1 998 500	1 854	0

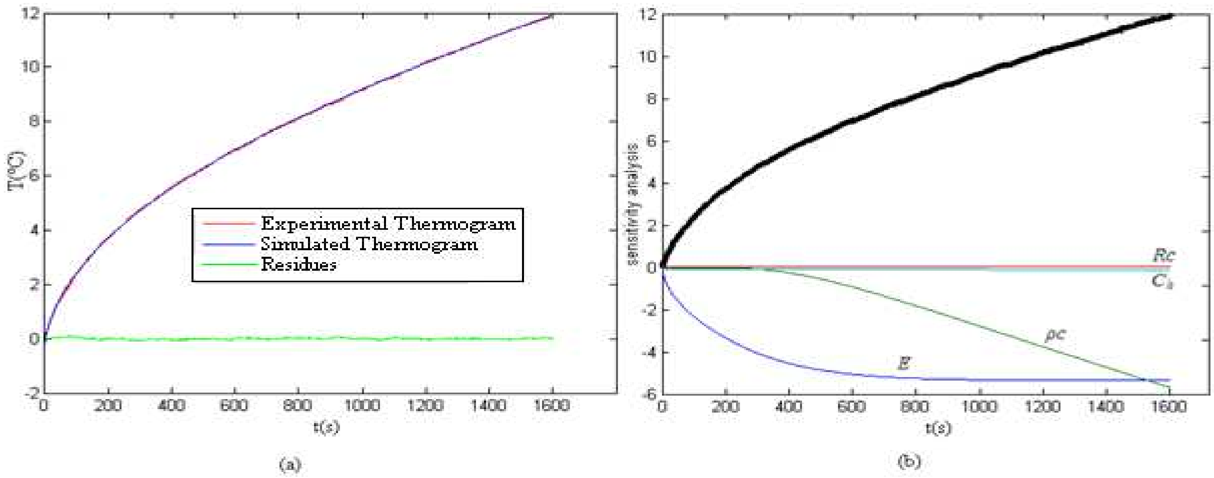

Figure 3: (a): Experimental and modeled Hot Plate temperature curves; (b): Reduced sensitivity curves of fitting parameters for the sample cm+co 5-6.3 mm.

3.2. Thermal effusivity and heat capacity by the asymmetrical transient Hot Plate method

We apply the method for each sample. Figure 3 shows the curves of the two thermograms with their residues a function of time (a), and the reduced sensitivity curves $\left(E\frac{\partial T}{\partial E};(\rho c)\frac{\partial T}{\partial(\rho c)};Rc\frac{\partial T}{\partial Rc};\ C_h\frac{\partial T}{\partial C_h}\right)$ related to the identification parameters (b). At the beginning of the experiment (short times), the thermogram is already sensitive to the parameter *E*, and then it is not at all sensitive to other parameters. From 300s, the thermogram becomes sensitive to the *ρc* parameter, its sensitivity to *E* continues to increase, for the other two parameters, the sensitivity is zero. At 1000s, the sensitivity curve of the parameter *E* reaches a saturation value and remains constant after that time; the sensitivity of the *ρc* parameter continues to increase. Around time of 1600s, sensitivity curves relating to the parameters *E* and *ρc* intersect, this means that the thermogram is enough sensitive to the calculation of these two parameters. We also note that the thermogram is not at all sensitive to parameter *Rc* and C_h, this implies that the thermal contact resistance and the heat capacity of heating element have no influence on the thermogram. Also note that the theoretical model is with a good agreement with the experimental thermogram during all time of the experiment, the residues (difference between experimental and simulated curves) are dishes along the experiment, and this shows that the 1D assumption is valid at the center of the sample during the experiment.

Table 1 shows the thermal effusivity (*E*) and thermal capacity (*ρc*) identification results. Those two thermal properties decrease with the granular cork size; this can be explained by the variation of mass fraction of cork explained in the section 3.1.

3.3. Discussions and interpretations of results

In one hand, the application of the tiny hot plate method in steady state regime [2] to the samples allowed characterizing their thermal conductivities (Table 2) that we note λ_{HPS}. In other hand, given that $E=\sqrt{\lambda\rho c}$, the experimental values of the effusivity and those of the heat capacity are used to derive the values of the thermal conductivity that we note λ_{HPT} referencing to the asymmetrical transient Hot Plate method (Table 2). We observe that the obtained values by the two Hot plate methods are exactly the same (the relative error of measurement between the two methods doesn't exceed 6% for each measurement point), which shows that the measured values of the thermal effusivity and the thermal capacity are reliable and correct.

Table 2: Results comparison between the two Hot Plate methods

Sample	λ_{HPT} $(W.m^{-1}.K^{-1})$	λ_{HPS} $(W.m^{-1}.K^{-1})$	Deviation (%)	Energy-saving (%)	Lightness Ratio
cm+co 2.5-5 mm	0.261	0.28	6.644	60	1.48
cm+co 5-6.3 mm	0.246	0.258	4.649	63	1.54
cm+co 6.3-8 mm	0.253	0.25	1.141	64	1.56
cm+co 8-12.5 mm	0.196	0.21	6.627	70	1.57
Cement mortar	0.708	0.7	1.097	-------------------	--------------

3.4. Practical interest of the composite material

This experimental thermal properties investigation of this composite material based on granular cork bound with cement mortar was made for the purpose of its use as walls and roof insulating. If we compare between two walls or roofs (one containing the composite material and the other containing cement mortar without granular cork) having the same thickness and subjected to the same temperature gradient, we can deduce the ratio of the two heat flows traversing these walls:

$$\frac{\phi_{cm+co}}{\phi_{cm}} = \frac{\lambda_{cm+co}}{\lambda_{cm}} \qquad (10)$$

This allows calculating the energy saving by using this composite material as walls or roofs insulating instead of cement mortar without cork:

$$Energie\_saving = 100x\left(1 - \frac{\phi_{cm+co}}{\phi_{cm}}\right) \qquad (11)$$

We also calculate the ratio of lightness $\left(\frac{\rho_{cm}}{\rho_{cm+co}}\right)$ compared with cement mortar according to granular cork size (Table 2). We note globally that energy saving percentage, lightness ratio increase with granular cork size; this can be explained by the mass fraction variation of cork explained in the section 3.1. So the combination of granular cork with cement mortar gives a material more insulating and lighter than cement mortar

Conclusion

This paper presents an experimental study characterizing thermal properties of a composite material based on granular cork, in order to valorize its thermal insulation and its lightness compared with those of cement mortar without cork. The preliminary findings indicates that the granular cork size have no influence on thermal properties of this composite. The comparisons allow deducing that the composite is 1.5 times lighter than cement mortar, its utilization as walls or roof insulating material should give an energy saving exceeding 50%.

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