IOP Conf. Series: Materials Science and Engineering 446 (2018) 012002 doi:10.1088/1757-899X/446/1/012002

The influence of the expanded clay granules ratio on the thermal conductivity and thermal diffusivity of gypsum plaster-based composites's.

Khaoula Amarray[b], Mohammed Garoum[a*], Saad Raefat, Najma Laaroussi and Aziz Ettahir.

Materials, Energy And Acoustics Team (MEAT), Mohammed V University in Rabat - EST Salé, 11060, 227 Avenue Prince Héritier, Morocco.
[a]garoum1@yahoo.fr, bkhaoulaamarray@research.emi.ac.ma

Abstract. Thermophysical properties of building materials such as thermal conductivity and thermal diffusivity are mandatory in any study of thermal performance of buildings. In this work, measurements of these two thermophysical properties were performed on four circular samples prepared by mixing gypsum plaster with different mass proportions of expanded clay granules. The water ratio was kept constant in all mixtures. Then the thermal diffusivity and thermal conductivity were determined using the flash method and the hot plate respectively. Results show that the addition of the expanded clay granules to the gypsum plaster has a negative impact on the thermal properties. This was due to absorption of the mix water and plaster by the clay granulates at the earlier operation of samples preparation.

1. Introduction

Understanding the thermophysical properties of building materials is nowadays considered a necessity in the building sector in order to wisely choose the most technically and economically efficient building. In order to achieve the desired objectives regarding the thermal insulation of buildings, it is advantageous to minimize the cost of construction and decrease its energy bill. The principle of insulation has always been based on the juxtaposition of several insulating materials, which is expensive, occupies a significant volume and enables limited energy efficiency. The use of lightweight aggregates can overcome this problem, due to their favourable thermal characteristics, their porous structure and their mechanic resistance.

Researches related to the improvement of thermophysical characteristics of composite materials based on cement, clay and plaster are unlimited. DAVRAZ et al. [1] studied the effects of unit weight, porosity and grain size on the thermal conductivity of various light aggregates. As for MAALOUFA et al. [2] tempted to improve the thermal properties of clay by adding cork or aggregates of pearlite and make a comparison between the two mixtures. The purpose of BUMANIS et al. [3] study is to identify a relationship between the mechanical and thermal properties of cement mixed with expanded glass aggregates. A thermomechanical study of lightened concrete with cork and olive pomace was made by EL BAKKOURI et al. [4]. A comparison made by CHERKI et al. [5] between the thermal properties of a composite material based on cork and plaster with those of plaster is conducted in order to motivate the use of this mix material as false ceiling. Lamrani et al. [6] investigated the experimental study of thermal properties of a new ecological building material based on peanut shells and plaster. Raefat et al. [7] discussed the influence of adding expanded granular perlite to gypsum plaster thermal diffusivity using a numerical estimation based on the global minimization procedure. In this study, we study the effect of expanded clay granules on the thermophysical characteristics of plaster-based materials.

2. Experience program

2.1. Materials and mixture proportions

This study was conducted to characterize the influence of the incorporation of expanded clay beads Figure 1 on the thermophysical properties of plaster. Before determining the sample formulations we measured the physical properties of the aggregates. These characteristics concern the particle size distribution, the bulk densities as well as the water absorption of aggregates. Each value selected for these different characteristics is derived from an average calculated on three measurement results in order to ensure good and representative results. After classifying the different particle sizes of the expanded clay beads, we obtained three classes (8-10mm), (10-12.5mm), (12.5-16mm). The aggregates of the class (12.5-16mm) are subsequently dried in an oven at 70 ℃ before making samples for a period of 10 days until the mass becomes constant (the state of constant mass is assumed when the mass does not vary by more than 0.1% after 1 hour of drying). Four cylindrical samples of $100 \times 100 \times 20\, mm^3$, presented in Figure 2, were prepared consisting of gypsum plaster and expanded clay granules. The mixing rate remained the same for all mixtures (0.625), the only variable is the granule's mass fraction, which is 2%, 6% and 10% compared to pure plaster sample of 0%, and these proportions are picked in order to evaluate the influence of expanded clay beads on the thermal properties of plaster. To minimize the moisture content in the pores, the four samples were dried in the oven at 65 °C for one week after 24 hours of air drying.

Figure 1. View of the class (12.5-16mm) of expanded clay granules

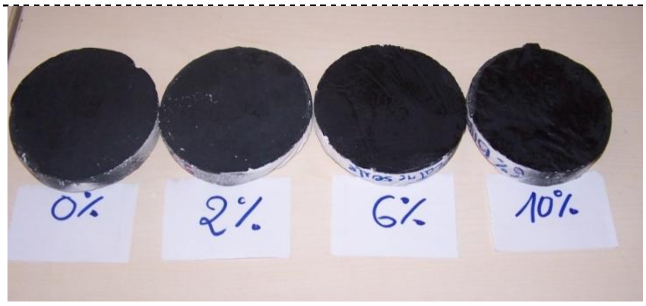

Figure 2. The four samples studied

2.2. Experimental method

2.2.1 Transient Hot plate method

It is the most straightforward method dedicated to thermal conductivity measurement. The method is based on the measurement of the temperature at the centre of a circular heating element of $(100 \times 100 \times 0.1mm^3)$ inserted between two samples [8]. Its electric resistance is $R = 101.51\,\boldsymbol{\Omega}$**.** The principle of the method is to apply a voltage U = 12.08V through the heating element interposed between the sample and the polyethylene foam. A thermocouple is glued to the inner face of the heating element. The sample, heating element and insulating foam are placed between two aluminium blocks whose thermal conductivity is too high to bring the system to steady state as quickly as possible [9]. Its schematic is illustrated in Figure 3.

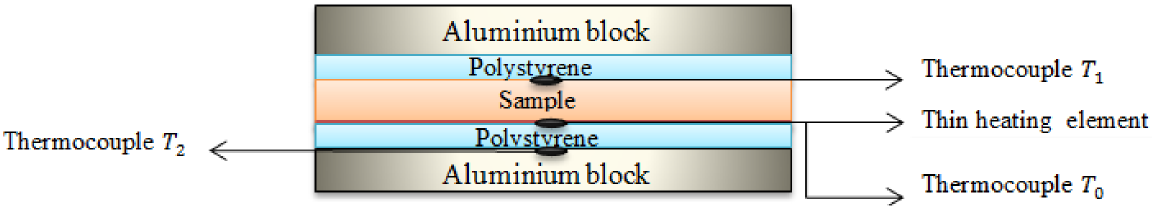

Figure 3.Schema of experimental device

The thermal conductivity of the sample is calculated using the following equation:

$$\lambda = \frac{e_1}{T_0 - T_1}\left[\frac{U^2}{R.S} - \frac{\lambda_2}{e_2}(T_0 - T_2)\right] \quad (1)$$

With e_1 is the sample's thickness, $e_2 = 10\,mm$ is the heating element thickness, $\lambda_2 = 0.047\,W.m^{-1}.K^{-1}$ *is* the thermal conductivity of the heating element *and* S corresponds to its section.

2.3. Flash method

The concept of the method is very basic. As indicated in figure 5 the front face of a sample of ($100 \times 100 \times 20\,mm^3$) receives a uniform pulse of radiant energy $\Phi_0(W.m^{-2})$ of a short duration τ coming from flash lamp. A thermocouple in contact with the rear face of the sample makes it possible to record the rise in temperature at the moment when the front face receives the pulse. The thermal effusivity value is calculated from the temperature response on the opposite side of the sample. Thermal diffusivity is estimated either by the parker method [10] or by the Degiovanni method [11]. The increase of the temperature difference (T (t) - T (0)) is defined via its Laplace transform indicated by:

$$\theta(p) = \frac{\frac{q}{p}(1 - e^{-\tau p})}{h^2\frac{sonh(ke)}{\lambda k} + 2hcosh(ke) + \lambda k.sinh(ke)} \quad (2)$$

τ is the elapsed time from the flash pulse heating and p stands for the Laplace parameter and $k = \sqrt{\frac{p}{a}}$, a, λ and e are respectively, the thermal diffusivity, the thermal conductivity and thickness of the sample.

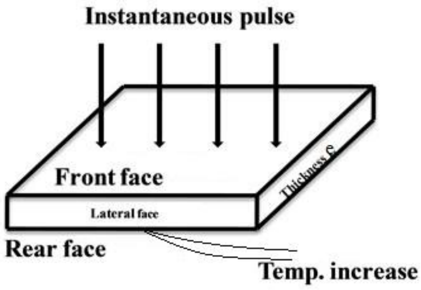

Figure 4.Schematic of the Flash method

3. Results and discussion

3.1. Density

Table 1 groups the results of measurement of the bulk density of the 4 samples according to their volumes and their masses after drying.

Table 1. Samples dimensions and density.

Samples	Thickness (m)	Diameter (m)	Mass (kg)	Density $\rho(kg.m^{-3})$
PA10	2.205	10.37	168.17	928
PA6	2.145	10.05	163.21	933
PA2	1.998	10.10	152.9	955
PA0	1.855	10.05	141.33	965

PA10, PA6 and PA2 represent the plaster samples mixed with different mass fractions of expanded clay granules of 10%, 6% and 2% respectively. While PA0 represents the pure plaster sample used as the reference. From Fig 5, which represents the density as a function of the mass fraction in the four mixtures, we noticed that when the mass fraction of expanded clay granules increases, the bulk density of the sample decreases. The composite's density decreased from $965\ (kg/m^3)$ of PA0 to 928 $(\mathrm{kg/m^3})$ for PA10. In fact following the increase in the fraction of expanded clay granules, the porosity of the plaster increases, this explains the decrease in the density.

3.2. *Thermal conductivity*

The thermal conductivity of gypsum plaster embedded with expanded clay granules was obtained by the hot plane method in stationary regime. The average values and the measurement deviation were presented on table 2.

According to table 2, we notice a significant increase in thermal conductivity up to 41% from 0.1847 W/m.k for PA0 to 0,315 W/m.k for PA10. This increase could be related to the first quantity of water and plaster absorbed by aggregates during the samples preparation; indeed. The departure of a certain proportion of water and plaster inside the aggregates after being dried leads to the increase of the apparent thermal conductivity of the composite samples with their clay granules mass proportion.

Table 2. Thermal conductivity values of mixtures.

Mixture	Test	The thermal conductivity λ(W/m/K)	Measurement deviation (%)
PA0	1	0.1872	1.34
	2	0.1835	0.67
	3	0.1835	0.67
	Mean value	**0.1847**	
PA2	1	0.2283	4.33
	2	0.2412	1.08
	3	0.2464	3.25
	Mean value	**0.2386**	
PA6	1	0.2857	0.26
	2	0.2863	0.05
	3	0.2873	0.30
	Mean value	**0.286**	
PA10	1	0.320	1.55
	2	0.314	0.44
	3	0.312	1.11
	Mean value	**0.315**	

3.3. Thermal diffusivity

Table 3. Thermal diffusivity values of mixtures.

Mixture	Test	$a \times 10^{-7} (m^2/s)$ Parker	Measurement deviation (%)	$a \times 10^{-7} (m^2/s)$ Degiovanni	Measurement deviation (%)
PA0	1	1.797	3.086	1.722	6.217
	2	1.722	1.216	1.617	0.259
	3	1.777	1.938	1.550	4.391
	4	1.754	0.619	1.542	4.885
	Mean value	**1.7432**		**1.621**	
PA2	1	1.809	2.964	1.827	0.385
	2	1.854	0.550	1.793	1.484
	3	1.894	1.596	1.797	1.264
	4	1.9	1.918	1.863	2.363
	Mean value	**1.864**		**1.82**	
PA6	1	2.25	4.022	2.276	7.498
	2	2.13	1.525	2.091	1.240
	3	2.135	1.294	2.066	2.421
	4	2.137	1.202	2.036	3.838
	Mean value	**2.163**		**2.117**	
PA10	1	2.628	1.399	2.551	0.552
	2	2.529	2.421	2.544	0.276
	3	2.605	0.511	2.455	3.232
	4	2.605	0.511	2.598	2.404
	Mean value	**2.592**		**2.537**	

Results presented in table 3 show that the thermal diffusivity obtained using the flash method of the foor samples studied. We find that for the same class of granules, the thermal diffusivity increased from $1.7432 \times 10^{-7} (m^2/s)$ for PA0 (pure gypsum plaster) to $2.592 \times 10^{-7} (m^2/s)$ with the increase of the proportion of the expanded clay granules in the mixtures. The evolution of the thermal diffusivity as a function of the mass fraction of the expanded clay balls is at the same order of magnitude as the thermal conductivity with an increase of 32%.

4. Conclusion

The present work treated an experimental study on the thermal behaviour of plaster composite materials and expanded clay granules when they are both mixed. Conductivity and thermal diffusivity were measured using the hot plate and flash methods respectively. Knowing the dimensions and the mass of the mixtures, the density was deduced easily. The influence of the incorporation of expanded clay granules on thermophysical properties on a composite material based on plaster was examined. The analysis of the experimental results leads to the conclusion that the diffusivity and the thermal conductivity of the composite material increased, contrary to the decreasing of the density. The increase on the conductivity and the thermal diffusivity is mainly due to the amount of water absorbed by the expanded clay granules. As perspective, in further studies the insulation of clay granules should be treated carefully in order to prevent the clay aggregates absorption.

References

[1] A. E. A. Mertin Davraz, Murat Koru, "The effect of physical properties on thermalconductivity oflightweight aggregate," vol. 15, pp. 85–92, 2015.
[2] Y. Maaloufa, S. Mounir, A. Khabbazi, J. Kettar, and A. Khaldoun, "Thermal Characterization of Materials based on Clay and Granular: Cork or Expanded Perlite," *Energy Procedia*, vol. 74, pp. 1150–1161, 2015.
[3] D. Architektūra, I. R. Statyba, G. Bumanis, D. Bajare, and A. Korjakins, "Mechanical and Thermal Properties of Lightweight Concrete Made from Expanded Glass," vol. 2, no. 2, 2013.
[4] A. El Bakkouri, H. Ezbakhe, T. Ajzoul, and A. EL Bouardi, "ETUDE THERMOMECANIQUE DU BETON ALLEGE AVEC DU LIEGE ET DU BETON ALLEGE AVEC DES GRIGNONS D'OLIVE," no. May, 2016.
[5] D. B. A.Cherki, A.Khabbazi, B.Remy, "Granular cork content dependence of thermal diffusiv thermal conductivity and heat capacity of the compos site material / Gran nular cork bound with plaster .," vol. 42, pp. 83–92, 2013.
[6] M.Lamrani, N.Laaroussi, A.Khabbazi, M.Khalfaoui, M. Garoum and A. Feiz, "Experimental study of thermal properties of a new ecological building material based on peanut shells and plaster," *Case Stud. Constr. Mater.*, 2017.
[7] RAEFAT, Saad, GAROUM, Mohammed, LAAROUSSI, Najma, et al. Thermal diffusivity and adiabatic limit temperature characterization of consolidate granular expanded perlite using the flash method. In : *IOP Conference Series: Materials Science and Engineering.* IOP Publishing, 2017. p. 012004.
[8] Y. Jannot, V. Felix, and a Degiovanni, "A centered hot plate method for measurement of thermal properties of thin insulating materials," *Meas. Sci. Technol.*, vol. 21, no. 3, p. 35106, 2010.
[9] Y. Jannot and B. Remy, "Measurement of thermal conductivity and thermal resistance with a tiny hot plate," no. August 2015, 2010.
[10] W. J. Parker, R. J. Jenkins, C. P. Butler, and G. L. Abbott, "Flash Method of Determining Thermal Diffusivity, Heat Capacity, and Thermal Conductivity," vol. 1679, 1961.
[11] A. Degiovanni, M. Laurent, R. Prost, A. Degiovanni, M. Laurent, and R. P. Mesure, "Mesure automatique de la diffusivité thermique," 1979.