Research Journal of Applied Sciences, Engineering and Technology 12(5): 507-515, 2016
DOI:10.19026/rjaset.12.2677
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: July 13, 2015 Accepted: August 30, 2015 Published: March 05, 2016

Research Article

Thermal Inertia and Thermal Properties of the Composite Material Clay-plastic

[1]Soumia Mounir, [1]Abdelhamid Khabbazi, [1]Youssef Maaloufa, [2]Asmae Khaldoun and
[1]Yassine Hamdouni
[1]LEME, University Mohamed V-Agdal, EST Sale, 227 Avenue Prince Héritier, Sale, Maroc
[2]Al Akhawayn University, Avenue Hassan II, BP 104, 53000 Ifrane, Maroc

Abstract: Improving insulation building materials with low energy consumption becomes an obligation so as to reduce the heat energy of houses. For this purpose, a series of experimental studies were performed on composite clay-plastic. The first step in this study is the chemical characterization of clay using the fluorescence X method. The second step is thermal characterization of clay alone and the composites clay-plastic using the asymmetrical hot plate and Flash methods. The third step in the work is the verification of thermal conductivity using different theoretical models. The fourth step in this study is the study of thermal Inertia of walls done from the composite clay-plastic. Finally a study of delay of temperature, heat flow and damping factor for a wall done from those composites were conducted. The obtained results indicate that this composite presents interesting characteristics in term of insulation and thermal Inertia.

Keywords: Clay-plastic, flash method, hot plate method, material insulation, thermal conductivity, thermal inertia

INTRODUCTION

Improving insulation materials becomes among the most important scientific research worry in building in order to reduce the consumption of building envelope. However, controlling the thermal Inertia of wall has become a necessity so as to reduce the heat loss of houses and assure the best energy efficiency. For this purpose authors try in this study to improve the thermal characteristic of clay by combing it with waste of plastic as polymer insulation. The thermal characterization of this composite was done using the asymmetrical hot plate and flash methods so as to determine thermal effusively, thermal conductivity, heat capacity and thermal diffusivity. Also, thermal conductivity was confronted to different theoretical models to confirm its values. Besides, a study of thermal Inertia was done to control the heat flow penetrating inside houses by determining the depth of heat flow diffusion, the damping factor and the delay of temperature. A literature study was done on insulation building materials such as the work of Asdrubali *et al.* (2012) which treats the acoustical properties of sustainable materials both natural and from recycled materials. The work of Khabbazi *et al.* (2005) which describes the thermal and the mechanical properties of a new material based on granular cork and cement mortar by varying the percentages of cork using the box method. Also a lot of research have been done on clay bounded with additives such as the research of Mounir *et al.* (2014) which studies the thermal characterization of a mixture of clay bounded by cork and evaluates the energy saving from this composites, the work of Sutcu *et al.* (2014) in which they studied the thermal behavior of hollow clay bricks made up of paper waste and the optimization of their thermal performance where the thermal conductivity of the microporous brick materials with additives produced in this study reduced the thermal conductivity from 0.68 W/m K to 0.39 W/m K compared with that of the sample without additives. Moreover, a literature study was done concerning the thermal Inertia such as the thesis of Chahwane (2011) in which he evaluates the thermal Inertia so as to assure the best building energetic performance. According to all those studies, authors try in this study to improve the thermal properties of the material clay by combining it with the waste of plastic in order to use it in building envelope. The thermal characterization of clay- plastic was done using the recent asymmetrical Hot Plate method which permits to determine thermal effusivity and heat capacity (Bouchair, 2008; Jannot *et al.*, 2010; Lin *et al.*, 2014; Yves, 2011) and Flash method which permits to define the thermal diffusivity (Degiovanni *et al.*, 1996, 1979; Parker *et al.*, 1961). Furthermore, after determining the thermal properties of the composite clay-plastic authors studied the thermal Inertia of this composite in order to control the penetration of heat flow diffusion inside houses and by doing so can we reduce the consumption of energy in building.

Corresponding Author: Soumia Mounir, LEME, University Mohamed V-Agdal, EST Sale, 227 Avenue Prince Héritier, Sale, Maroc, Tel.: +212 6 64 85 08 29

Table 1: Chemical composition of clay

Chemical element	Percentage of chemical element (%)
SIO_2	59.600
Al_2O_3	22.400
Fe_2O_3	6.6900
Cao	0.0777
MgO	0.9700
K_2O	2.5300
TiO_2	0.8320
P_2O_5	0.4580
P.a.f	5.3400

Fig. 1: Clay-waste of plastic

Plastic waste was taken from the rejected bottle of water composed from polyethylene teraphtalate which presents a good dimensional property, a low hygroscopicity and good mechanical properties (Laetitia Vouyovitch Van Schoors, 2009).

Clay is a mineral coming from the decomposition of rock. It's a heterogeneous material on different scales. In the macroscopic scale, they are associated to another mineral (quartz, feldspath…) and in the microscopic scale they present a structure with leaves. The mineral clay is formed specially from a mixing of hydrated phyllosilicate. The majority mineral gives the names of this phyllosilicate. It is combined with a different mineral like: Carbonate; silica; oxide and hydroxide of aluminum and Ferriferous mineral (Mounir *et al*., 2014).

DESCRIPTION OF USED MATERIALS

X ray of clay: The clay sample extracted from Bensmim was characterized through fluorescence X. The chemical composition is represented in Table 1.

Chemical composition of clay: The chemical composition was done by using the fluorescence X method as presented in Table 1.

Plastic: The plastic used with clay as presented in Fig. 1 was taken from the waste of bottle done from polyethylene teraphtalate. The density of used plastic is 1380 kg/m^3; the thermal conductivity is 0.22 W/m.K. In Fig. 2 a granulometry analysis of waste plastic was done to determine the size of plastic used.

DESCRIPTION OF EXPERIMENTAL AND THEORETICAL APPROACH TO DETERMINE THE THERMAL PROPERTIES

Samples preparation and their densities measurement: Authors prepared samples as presented in Fig. 3 for clay-plastic on different percentage. The percentage of water used for this kind of Illite clay which is a non swelling clay is 0.25 (mass water per granular of clay). Moreover samples of clay-plastic were prepared with different percentage of plastic 3% and 5% using a cement mixer to achieve a good distribution. The dimensions of samples are 10×10×2 (cm) so as to specify the different percentage of additives, we fulfilled in the mold a volume of additives until we get full mold then we consider that this mass corresponds to 100% of percentage then we calculated the associated percentage After drying the samples in air ambient, we weight them and we put them in a steam room with ventilation in 60°C temperature and each 3 days, we weight them until we remark that the mass became constant in order to be sure that all the moisture existing in them are deleted. Then we proceeded to define the apparent density and according to the mixture law, we define the volume fraction of plastic in each sample according to relation (1). This relation permits to study two volume fraction of plastic: 0.418 for 3% of plastic and 0.498 for 5% plastic:

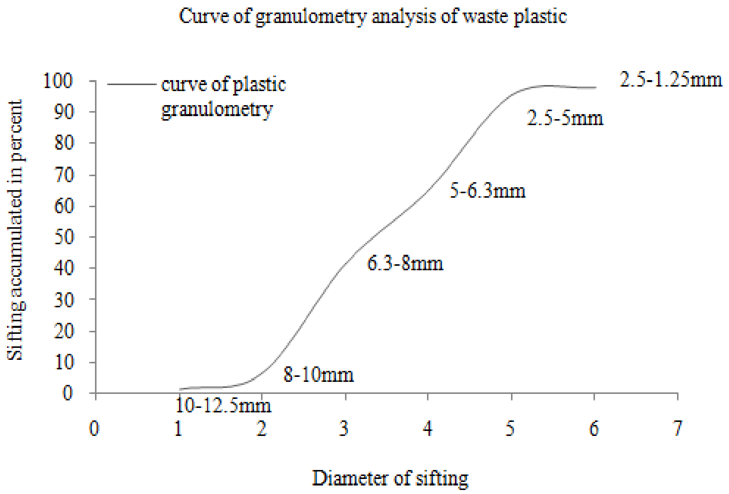

Fig. 2: Curve of granulometry analysis of waste plastic

Fig. 3: View of the composite clay-plastic on different percentage of plastic

$$y = \frac{\rho_{c+ad} - \rho_c}{\rho_{ad} - \rho_c} \tag{1}$$

With: $\rho_{ad,}$ ρ_c and ρ_{c+ad} are successively the densities of additives, clay and that of the composites.

Asymmetrical hot plate methods description:

Transient hot plate method: The hot plate method in transient regime permits to define the thermal effusivity and heat capacity, contrarian to the traditional method, this one permit the thermal characterization using only one sample (Jannot *et al*., 2010; Mounir *et al*., 2014; Yves, 2011). The system modeled using the hypothesis of 1D heat transfer, using the minimization of sum quadratic error:

$$\Psi = \sum_{j=0}^{N} \left[T_{exp(t_j)} - T_{mod}(t_j)\right]^2 \tag{2}$$

Between the theoretical and experimental curves calculated using the algorithm Levenberg-Maquardt (Marquardt, 1963).

Combining those equations, the system leads to:

$$\theta(p) = \frac{\Phi_0\,(p)}{\frac{D_1}{B_1} + \frac{D_i}{B_i}} \tag{3}$$

Hot Plate method in steady state regime: The Hot Plate method in steady state regime (Jannot *et al*., 2010; Yves, 2011; Yves *et al*., n.d.) permits to characterize thermal conductivity (λ) of samples. Figure 2b illustrates the experimental device of this method, once the system reaches the steady state regime, we can write:

$$ø = ø_1 + ø_2;\ \ ø_1 = \frac{\lambda_1}{e_1}(T_0 - T_1);$$
$$ø_2 = \frac{\lambda_2}{e_2}(T_0 - T_2) \tag{4}$$

$$\lambda_1 = \frac{e_1}{T_0 - T_1}\left[ø - \frac{\lambda_2}{e_2}(T_0 - T_2)\right] \tag{5}$$

ø is the total flow emitted by the heating element. λ_1 The thermal conductivity of the sample that we look for, e_1 the thickness of the sample; $\lambda_2 = 0.04$ W/m.K and $e_2 = 10$ mm: are successively thermal conductivity and thickness of the insulating foam.

Flash method:

Experimental approach of the flash method: This method permits to determine the diffusivity of solid (Degiovanni *et al*., 1996, 1979) its principle is described in the Fig. 4. We send a strong luminary flow on the sample's parallel faces in a short period. A thermocouple in touch with the bottom face permits to register the rise of temperature in the moment when the face receives the flash. A modeling of heat transfer in the sample has been done to estimate the thermal diffusivity with the experimental thermogram.

According to Laplace: The method of quadruples permits to write:

$$\begin{pmatrix} \theta_1\,(p) \\ \Phi_1\,(p) \end{pmatrix} = \begin{bmatrix} cosh(qe) & \frac{1}{\lambda qS} sinh(qe) \\ \frac{1}{\lambda qS} sinh(qe) & cosh(qe) \end{bmatrix}$$
$$\begin{pmatrix} \theta_2(p) \\ \Phi_2(p) \end{pmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{pmatrix} \theta_2(p) \\ \Phi_2(p) \end{pmatrix} \tag{6}$$

According to the Laplace transformation:

$$\Phi_1(p) = L(\varphi_0\,(t) - h.\theta_1\,(p)) \tag{7}$$

We combine this relation we have:

$$\theta_2(p) = \frac{\varphi_0}{p}\frac{1 - e^{(-pt_0)}}{C + 2Ah + Bh^2} \tag{8}$$

Theoretical model to check the value of thermal conductivity: Authors compare the experimental results with theoretical models which calculate the equivalent thermal conductivity of materials of two components: a continuous phase (Clay) and a dispersed phase (plastic or plastic). Different theoretical model were used to confirm the thermal conductivity for instance: Series model (Wienner *et al*., 1912; Poulaert, 1987), parallel model (Wienner *et al*., 1912; Poulaert, 1987), model (Maxwell, 1954; Poulaert, 1987;

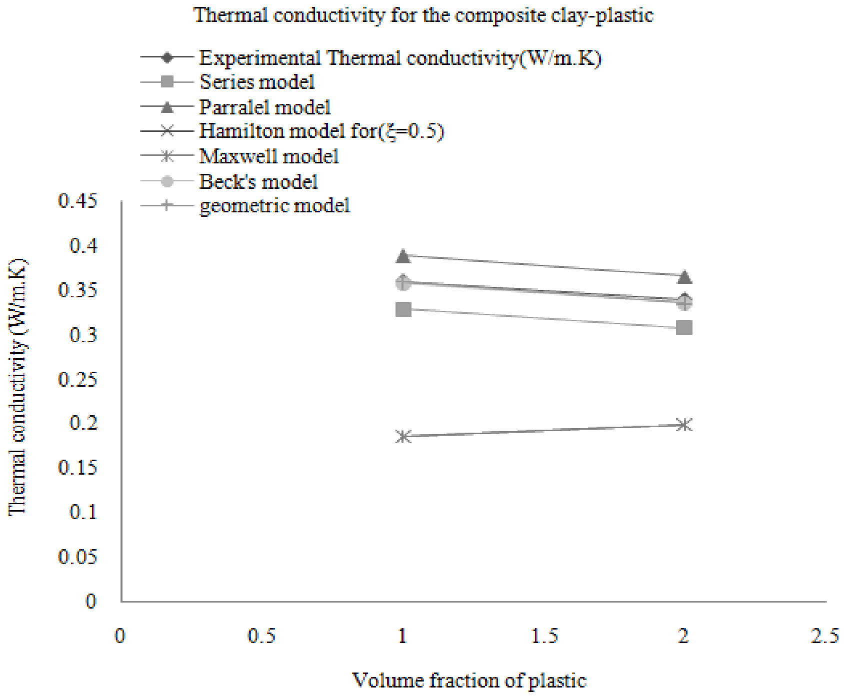

Fig. 4: Thermal conductivity of the composite clay-plastic

Hamilton and Crosser, 1969; Poulaert, 1987; Woodside and Messmer, 1961) and beck's model.
Series model:

$$\lambda_{\perp\perp} = \frac{1}{\frac{1-y}{\lambda_{cont}}+\frac{y}{\lambda_{disp}}} \qquad (9)$$

Parallel model:

$$\lambda_{\parallel /\!/} = (1-y).\lambda_{cont} + y.\lambda_{disp}$$

(10)

Maxwell model:

$$\lambda_{eq} = \lambda_{cont}\left[\frac{2\left(\frac{\lambda_{disp}}{\lambda_{cont}}\right)^2(1-y)+(1+2y)\frac{\lambda_{disp}}{\lambda_{cont}}}{(2+y)\frac{\lambda_{disp}}{\lambda_{cont}}+1-y}\right] \qquad (11)$$

Hamilton model:

$$\lambda_{eq} = \lambda_{cont} \left[\frac{\lambda_{disp}+(n-1)\lambda_{cont}-(n-1)y(\lambda_{cont}-\lambda_{disp})}{(n-1)\lambda_{cont}+\lambda_{disp}+y(\lambda_{cont}-\lambda_{disp})}\right] \qquad (12)$$

With (n=3/ξ) ((for ξ = 1, we return the Maxwell model).
Woodside and Mesmer's model:

$$\lambda_{eq} = {\lambda_{disp}}^{y} * {\lambda_{cont}}^{(1-y)} \qquad (13)$$

Beck's model:

$$\lambda_{eq} = \sqrt{\lambda_{\parallel /\!/} * \lambda_{\perp\perp}} \qquad (14)$$

DESCRIPTION OF THEORETICAL APPROACH TO MEASURE THE THERMAL INERTIA

According to the thesis of Chahwane (2011) and the ISO 13786 an analysis was conducted to see the variation of thickness of binders according to time of diffusion of heat flow using the relation (3). The relation between the thickness and the time of diffusion of the heat flow inside a homogenous component inside building is defined as the product of heat capacity and thermal resistance of the same component.
Dept of heat flow diffusion:

$$\delta = \sqrt{(\lambda * T\ / \Pi * \rho c)} \qquad (15)$$

$$\xi = d\ /\ \delta \qquad (16)$$

Matrix transfer of homogenous layer:

$$Z = [Z11\ Z12\ Z21\ Z22]$$

where,

$$Z11 = Z22 = \cosh(\xi) * \cos(\xi) + j\sinh(\xi) * \sin(\xi) \qquad (17)$$

$$Z12 = \xi/2\lambda * \{\sinh(\xi) * \cos(\xi) + \cosh(\xi) * \sin(\xi) + j\,[\cosh(\xi) * \sin(\xi) - \sinh(\xi) * \cos(\xi)]\} \qquad (18)$$

$$Z21 = \lambda/\xi * \{sinh(\xi) * cos(\xi) - cosh(\xi) * sin(\xi) + j[sinh(\xi) * cos(\xi) + cosh(\xi) * sin(\xi)]\} \quad (19)$$

Matrix transfer of a building component: We have:

$$Z_{\mathrm{ee}} = Z\_s2 * Z * Z\_s1 \quad (20)$$

$$Z_s = \begin{matrix} 1 & \text{-Rs} \\ 0 & 1 \end{matrix} \quad (21)$$

Thermal conductance:

$$L11 = A * Y1 = (A * Z11 - 1)/Z12$$
$$L22 = A * Y2 = (A * Z22 - 1)/Z12 \quad (22)$$

Thermal admittance Y_{mn} advance:

$$\Delta t_Y = (T / 2\Pi) * arg [\![(Y]\!]_{mn}) \quad (23)$$

Damping factor: The thermal transmittance U is calculated according to the ISO 6946.

$$f = 1 / (U * |Z12|) \quad (24)$$

Delay of damping factor:

$$\Delta t_f = (T / 2\Pi) * arg [\![(Z]\!]_{12}) \quad (25)$$

RESULTS

Density: The identification of the apparent density was measured by knowing the mass and the dimensions of samples and the results were presented on Table 2. The results of apparent density obtained from the composite clay-plastic permits a gain of 13% for 3% plastic, 16% for 5% plastic because adding plastic on clay creates porosity inside material thing which makes it lighter. The composite clay-plastic permits a gain on lightness of 13% for 3% plastic and 16% for 5%.

Thermal effusively by the asymmetrical transient hot plate method: The analysis of thermal effusivity as presented in Table 3 for the composite clay-plastic permits a gain in term of thermal effusivity of 5% for the percentage 5% plastic and 3% for the percentage 3% plastic. So we deduce that the composite clay-plastic doesn't present a significant reduce of thermal effusivity so the local built by this composites will exchange energy quickly with its surroundings instead of clay-plastic which presents an important reduce of thermal effusivity for the percentage 5%.

Thermal conductivity and heat capacity by the method hot plate in steady state regime: The analysis of thermal conductivity as presented in Table 4 for the composite clay-plastic permits a decrease of thermal conductivity of 34% for the percentage 5% plastic and 29% for the percentage 3% plastic. so we deduce that the composite clay-plastic present a significant reduce of thermal conductivity so the local built by this composite will be more insulating.

Theoretical model of thermal conductivity: Thermal conductivity of the composite clay-plastic as presented in Fig. 4 was analysed showing that the value of thermal conductivity is between the lower limit series model and the upper model parallel model. The Maxwell model is clearly far to represent our middle

Table 2: Density of different composites

Samples Series	$\rho_{\mathrm{composite}}$ (kg/m^3)	y_{additif}	Gain on lightness (%)
Clay+plastic 3% (w/g = 0.25)	1757.5	0.418	13
Clay+plastic 5% (w/g = 0.25)	1706.0	0.498	16
Clay (w/g = 0.25)	2029.0	-	-

Measurement error = 100* (ρ $_{\text{sample}}$-ρ $_{\text{mean value}}$)/ρ $_{\text{mean value}}$ Gain = $100 * (\frac{\rho_{clay}-\rho_{composite}}{\rho_{clay}})$

Table 3: Results of thermal effusively samples

Samples series		Ec_{omposite} ($J.m^{-2}.K^{-1}.s^{-1/2}$)	Measurement error (%)	Gain (%)
Clay+plastic 3% (w/g = 0.25)	1	851.5	1.5	3
	2	840.0	0.1	
	3	825.0	1.6	
	Mean value	838.8	-	
Clay+plastic 5% (w/g = 0.25)	1	820.2	0.1	5
	2	823.0	0.4	
	3	816.0	0.5	
	Mean value	819.7	-	
Clay (w/g = 0.25)	1	864.0		-
	2	861.0		
	3	862.0		
	Mean value	862.3	-	

Measurement error =100* (E $_{\text{sample}}$- E $_{\text{mean value}}$)/E $_{\text{mean value}}$ Gain = $100 * \left(\frac{E_{clay}-E_{composite}}{E_{clay}}\right)$

Table 4: Results of thermal conductivity and heat capacity

Samples series		$\lambda_{composite}$ (w/m.k)	Measurement error (%)	Gain on thermal conductivity (%)	ρc (J/m^3.k)
clay+plastic 3%	1	0.37	2.8	29	1 085 044
(Wc/g = 0.25)	2	0.35	2.8		1 014 493
	3	0.36	0.0		1 071 429
	Mean value	0.36	-		1 056 988
clay+plastic 5%	1	0.35	4.0	34	1 067 073
(Wc/g = 0.25)	2	0.34	1.0		1 030 303
	3	0.32	5.0		984 615
	Mean value	0.34	-		1 027 331
clay (Wc/g = 0.25)	1	0.51	0.6	-	1 005 917
	2	0.5	2.6		980 392
	3	0.53	3.2		1 053 678
	Mean value	0.51	-		1 013 329

Measurement error =100* (λ_{sample}- $\lambda_{mean\ value}$)/ $\lambda_{mean\ value}$ Gain= $100 * (\frac{\lambda_{clay}-\lambda_{composite}}{\lambda_{clay}})$

Table 5: Results of thermal diffusivity

Samples Series		$a_{composite}$ 10^{-7} ($m^2.s^{-1}$)	Measurement error (%)	Gain (%)
Clay+plastic 3% (w/g = 0.25)	1	3.41	0.1	33
	2	3.45	1.3	
	3	3.36	1.4	
	Mean value	3.41	-	
Clay+plastic 5% (w/g = 0.25)	1	3.28	0.1	35
	2	3.30	0.7	
	3	3.25	0.8	
	Mean value	3.28	-	
Clay (w/g = 0.25)	1	5.07	0.1	0
	2	5.10	0.7	
	3	5.03	0.7	
	Mean value	5.07	-	

Measurement error = 100* (a_{sample}- $a_{mean\ value}$)/$a_{mean\ value}$ Gain = $100 * (\frac{a_{clay}-a_{composite}}{a_{clay}})$

because the granular plastic doesn't resemble to spheres. Concerning the Hamilton model, the low values of sphericity parameter, ($\xi \in]0,1]$) represent those of equivalent thermal conductivity near to those of parallel model. But for its maximum value $\xi = 1$, the equivalent conductivity of Hamilton return to the Maxwell model. The model the most representative is the geometric and the beck's model which they consider that the granular of plastic are well distributed in the matrix clay.

Thermal diffusivity by the flash method: The analysis of thermal diffusivity as presented in Table 5 for the composite clay-plastic permits a decrease of thermal diffusivity of 41% for the percentage 5 and 17% for the percentage 3% plastic. Concerning the composite clay-plastic it presents a gain of 35% for the percentage of 5% plastic and 33% for the percentage 3% plastic. so we deduce that the composite clay-plastic present a significant reduce of thermal diffusivity so the local built by this composite will be retards the transfer of heat flow more than a local built by clay-plastic.

Depth of heat flow diffusion: Figure 5 presents the depth of heat flow diffusion on 24 h. We remark that this depth decreases when the volume fraction of plastic increases, so the waste plastic play the role of retarding the exterior heat flow to penetrate inside houses, because it creates porosity inside material and this is proved by the measure of density of the composites. This result can be used in order to decrease the heat loss of homes by controlling the penetration of exterior heat flow until night when the exterior ambiance become more colder.

Maximum Delay between the exterior and the interior temperature: Figure 6 presents the maximum delay between the exterior and interior temperature according to different wall's thickness (20, 25 and 30 cm), we observe that the composite clay-5% plastic presents the maximum delay of temperatures, so when we increase the volume fraction of waste plastic; we create an important delay between the exterior and the interior temperature. Also, we deduce that this characteristic of delaying temperature is a very important result for cold area such as Atlas of Morocco which presents a very high peak of temperature in the midday and very cold one at night. So an important delay of temperature permits to store temperature at day and injected it at night in houses.

Figure 7 presents the maximum delay of exterior and interior heat flow density according to different wall's thickness 20, 25 and 30 cm), we observe that for the thickness 20 and 25 cm the composite clay-5% plastic which presents the maximum delay of heat flow density. According to this, we conclude that the increase of volume fraction of plastic retards the penetration of the exterior heat flow inside the interior ambiance.

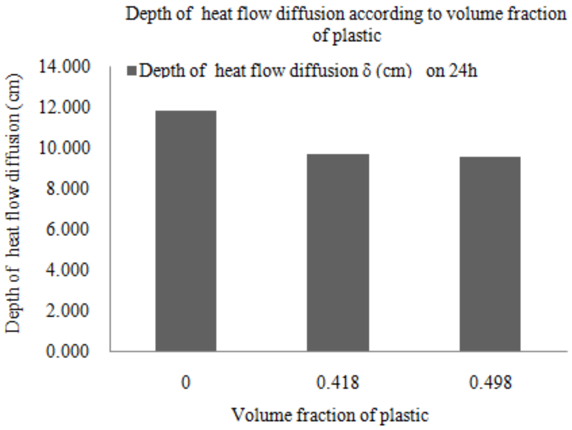

Fig. 5: Depth of heat flow diffusion according to time

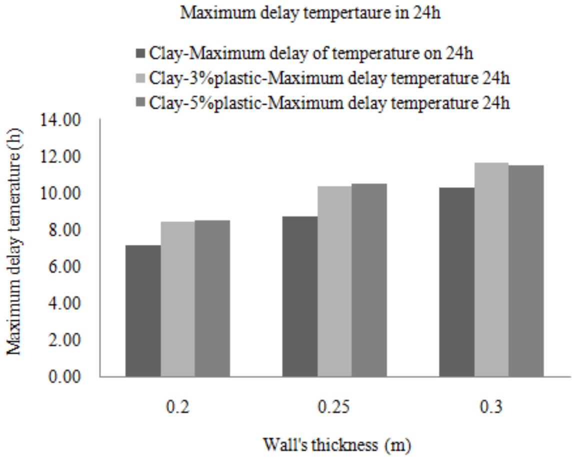

Fig. 6: Maximum delay of temperature

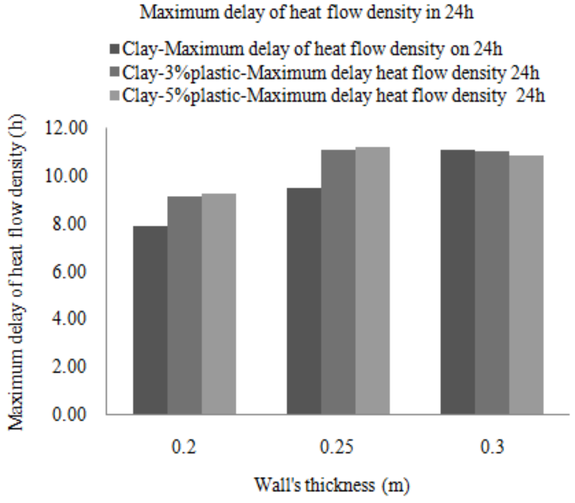

Fig. 7: Maximum delay of heat flow density

Thermal transmittance of the materials clay, clay-3% plastic and clay-5% plastic: Figure 8 presents the thermal transmittance of the 3 materials according to different wall thickness and it indicates that the

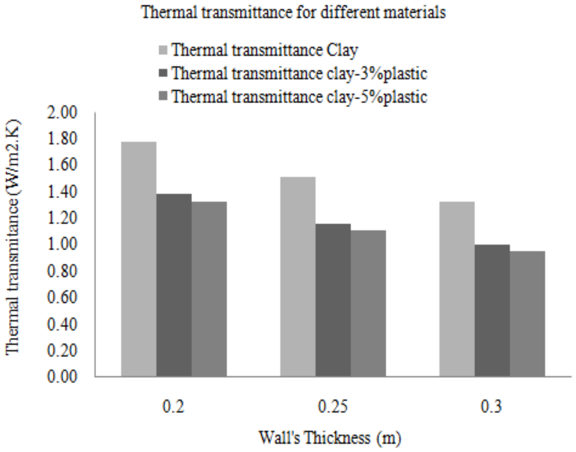

Fig. 8: Thermal transmittance of the different materials studied

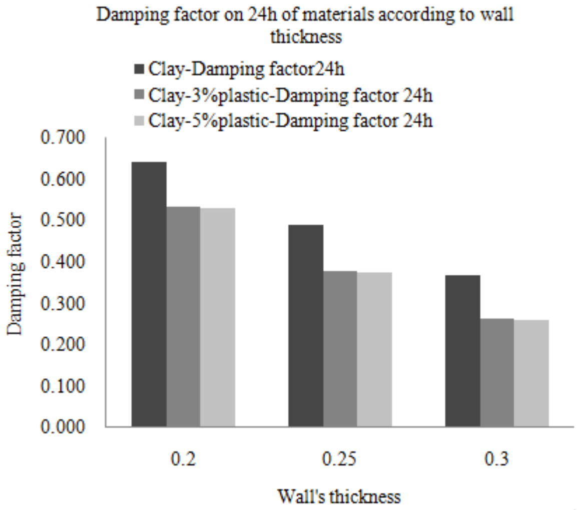

Fig. 9: Damping factor on 24h according to different wall's thickness

composite clay-5% plastic has the lowest thermal transmittance because this composite had the lowest value of thermal conductivity, so adding waste plastic on clay decreases the value of wall heat loss and by doing so it decreases the building energy consumption. The thermal transmittance is calculated according to ISO 6946.

Damping factor of the materials clay,clay-3% plastic and clay-5% plastic: Figure 9 presents the damping factor of heat flow according to different wall's thickness 20, 25 and 30cm), we observe that the composite clay-5% plastic presents the best characteristics in term of retarding the penetration of heat flow inside houses comparing with clay alone. The composite clay-5% plastic presents a damping factor of 0.26 for the 30 cm wall's thickness, so this result is very interesting for insulation walls of cold area because just 26% of exterior heat flow penetrates inside houses. We conclude that the additive waste plastic acts as a barrier of exterior heat flow.

ACKNOWLEDGMENT

LEME EST Sale presents special thanks for the team's research of LEMTA INPL Nancy, INSA Lyon and Akhawayn University for their Help so as to realize this study.

CONCLUSION

In this study a comparison of thermal properties was done for unfired blocks: clay, clay-3% plastic and clay-5% plastic using the asymmetrical hot plate and flash methods. The results obtained confirm that the composite clay-5% plastic presents the best thermal characteristics in term of thermal conductivity by a gain of 34%, thermal effusivity by a gain of 5% and thermal diffusivity by a gain of 35%. Also, an analysis of thermal transmittance was conducted to demonstrate that the composite clay-5% plastic had presents a gain of 28% for 30cm wall's thickness comparing with clay alone. Moreover, a study of thermal Inertia were conducted by determining the depth of heat flow diffusion, delay of maximum temperature, heat flow density and damping factor, the results proves that when the volume fraction of plastic increases the depth of heat flow diffusion decreases from (11.77 to 9.54 cm), the delay of the maximum temperature and heat flow density increases. Furthermore, analyses of damping factor were conducted proving that when the volume fraction of plastic increases, the exterior heat flow will be more damped. The use of the unfired blocks clay-plastic permits the best control of the exterior heat flow without expanding the energy of calcinations and by doing so, can we assure the best energy efficiency of dry climate area such as Bensmim region.

REFERENCES

Asdrubali, F., S. Schiavoni and K. Horoshenkov, 2012. A review of sustainable materials for acoustic applications. Build. Acoust., 19: 283-312, Doi: 10.1260/1351-010X.19.4.283.

Bouchair, A., 2008. Steady state theoretical model of fired clay hollow bricks for enhanced external wall thermal insulation. Build. Environ., 43: 1603-1618, Doi: 10.1016/j.buildenv.2007.10.005.

Chahwane, L., 2011. Valorisation de l'inertie thermique pour la performance énergetique des bâtiments. Ph.D. Thesis, Université de Grenoble, French.

Degiovanni, A., J.C. Batsale and D. Maillet, 1996. Mesure de la diffusivité longitudinale de matériaux anisotropes. Rev. Gén. Therm., 35: 141-147, Doi: 10.1016/S0035-3159(96)80010-9.

Degiovanni, A., M. Laurent and R. Prost, 1979. Mesure automatique de la diffusivité thermique. Rev. Phys. Appl., 14: 927-932, Doi: 10.1051/rphysap: 019790014011092700.

Hamilton, R.L. and O.K. Crosser, 1969. Thermal conductivity of heterogeneous systems. Ind. Eng. Chem., 1(3): 187-191.

Jannot, Y., V. Felix and A. Degiovanni, 2010. A centered hot plate method for measurement of thermal properties of thin insulating materials. Meas. Sci. Technol., 21: 035106, Doi: 10.1088/0957-0233/21/3/035106.

Khabbazi, A., M. Garoum and O. Terahmina, 2005. Experimental study of thermal and mechanical properties of a new insulating material based on cork and cement mortar. AMSE J. Adv. Model. Simul., 74(7): 73.

Laetitia Vouyovitch Van Schoors, 2009. Vieillissement hydrolytique des geotextiles polyester (polyethylene terephtalate): Etat de l'art. Bulletin des Laboratoires des Ponts et Chauss´ees, pp: 133-154. Retrieved from: https://hal.archives-ouvertes.fr/hal-0035048 7/document.

Lin, W., P.M. Fulton, R.N. Harris, O. Tadai, O. Matsubayashi *et al*., 2014. Thermal conductivities, thermal diffusivities and volumetric heat capacities of core samples obtained from the Japan Trench Fast Drilling Project (JFAST). Earth Planets Space, 66: 48, Doi: 10.1186/1880-5981-66-48.

Marquardt, D.W., 1963. An algorithm for least-squares estimation of nonlinear parameters. J. Soc. Ind. Appl. Math., 11: 431-441, Doi: 10.1137/0111030.

Maxwell, J.C., 1954. A Treatise on Electricity and Magnetism. 3rd Edn., Dover Publications, New York.

Mounir, S., Y. Maaloufa, A.B. Cherki and A. Khabbazi, 2014. Thermal properties of the composite material clay/granular cork. Constr. Build. Mater., 70: 183-190, Doi: 10.1016/j.conbuildmat.2014.07.108.

Parker, W.J., R.J. Jenkins, C.P. Butler and G.L. Abbott, 1961. Flash method of determining thermal diffusivity, heat capacity and thermal conductivity. J. Appl. Phys., 32: 1679-1684, Doi: 10.1063/1.1728417.

Poulaert, B., 1987. Le matériau polymere: de l'isolant au conducteur thermique. Thesis, Université catholique de Louvain-Faculté des sciences appliquées laboratoire physico-chimique et de physique des matériaux-Laboratoire des hauts polymères.

Sutcu, M., J.J. del Coz Díaz, F.P. Álvarez Rabanal, O. Gencel and S. Akkurt, 2014. Thermal performance optimization of hollow clay bricks made up of paper waste. Energ. Buildings, 75: 96-108, Doi: 10.1016/j.enbuild.2014.02.006.

Wienner, O., D. Lamellare and O. Wienner, 1912. Lamellare Doppelbrechung. Phys. Z., 5: 332-338.

Woodside, W. and J.H. Messmer, 1961. Thermal conductivity of porous media. II. Consolidated rocks. J. Appl. Phys., 32(9): 1699-1706.

Yves, J., 2011. Théorie et pratique de la Métrologie thermique. Laboratoire d'Energétique et de Mécanique Théorique et Appliquée (LEMTA).

Yves, J., R. Benjamin, D. Alain, n.d. Measurement of thermal conductivity and thermal resistance with a tiny hot plate. LEMTA, Nancy-Université, CNRS, 2, avenue de la Forêt de Haye, BP 160 - 54504 Vandoeuvre Cedex France, pp: 11-31.