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Research Article

Effect of Calcination on the Thermal Properties of Bricks Done From Clay-Expanded Perlite on Insulating Walls

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Abstract: Insulation of building envelope has become a necessity in order to reduce the energy cost, that's why, we proceeded in this study to develop materials using clay and expanded perlite by doing several studies: the first concerns the variation of volume fraction on expanded perlite and the effect of the calcination on the thermal properties of the composite clay-expanded perlite. The second is the study of the distribution of temperature inside walls composed from the composite clay-expanded perlite. In order to achieve the results wanted, this study has been divided on several steps among them the determination of the kind of clay by means of X-ray diffraction. The results show that the clay sample is mainly made up of Illite/muscovite. Then the characterization of thermal properties of clay-expanded perlite before and after calcination. The third step, is the comparison of the experimental results with analytical models of equivalent thermal conductivity. The results show that the thermal conductivity decreases by adding expended perlite and calicination from 0.51(clay alone) to 0.258 (clay-100% expanded perlite) (W/m/K). Also, the calcination decreases the depth of heat flow diffusion by 5 cm and retards the diffusion of heat flow.

Keywords: Calcination, clay-expanded perlite, flash method, hot plate method, theoretical model, thermal conductivity, walls

INTRODUCTION

An improved performance material such as light weight, thermal conductivity, storage ... requires the development of new composite materials. The purpose of this study is to improve the thermal properties and the lightness of the clay by combining it with expanded perlite. That's why authors try in this study to improve the insulation of construction materials by combining clay with granular expanded perlite. Also the block clay-expanded perlite was calcinated in a tunnel stove in order to see the effect of calcination on insulating the composite material clay-expanded perlite.

A literature study on insulation building materials and expanded perlite was investigated so as to realize this study such as the work of Zukowski and Haese (2010) concerning the investigation of the effective thermal properties of a modern vertically perforated masonry unit filled with perlite insulation. Another for Gandage *et al*. (2013) determining the thermal properties of a concrete bounded with perlite. another for Abrouki (2013) concerning the characteristics of perlite in Nador city: Investigation of the basis for catalytic activity of expanded Perlite in Knoevnagel condensation. Also a lot of work have done on clay such as the work of concerning the study of the effect of cork on the thermal properties of the composite clay-cork (Mounir *et al*., 2014; Muñoz *et al*., 2013) which object is the improvement of the thermal transmittance of single-brick walls of clay bricks lightened with paper pulp. Another for Mohsen and El-Maghraby (2010) Characterizing different type of clay taken from different area in Saudia Arabia.

In the present work, we aim to improve the thermal properties of the material Illite clay by combining it with granular expanded perlite and studying the effect of calcination on the thermal properties. The thermal characterization of the materials is conducted by the use of the recent asymmetrical Hot Plate (Bouchair, 2008; Jannot *et al*., 2010; Lin *et al*., 2014; Yves, 2011) and Flash methods (Degiovanni *et al*., 1996, 1979; Parker *et al*., 1961). The effect of the variation of the volume fraction of expanded perlite and calcination on the thermal properties of the brick is also studied. A comparison of thermal properties between the blocks of clay-expanded perlite before and after calcinations was conducted to identify the best energy efficient clay/expanded perlite.

Perlite is a general term for a glassy, volcanic and rhyolitic rock which will expand when quickly heated to

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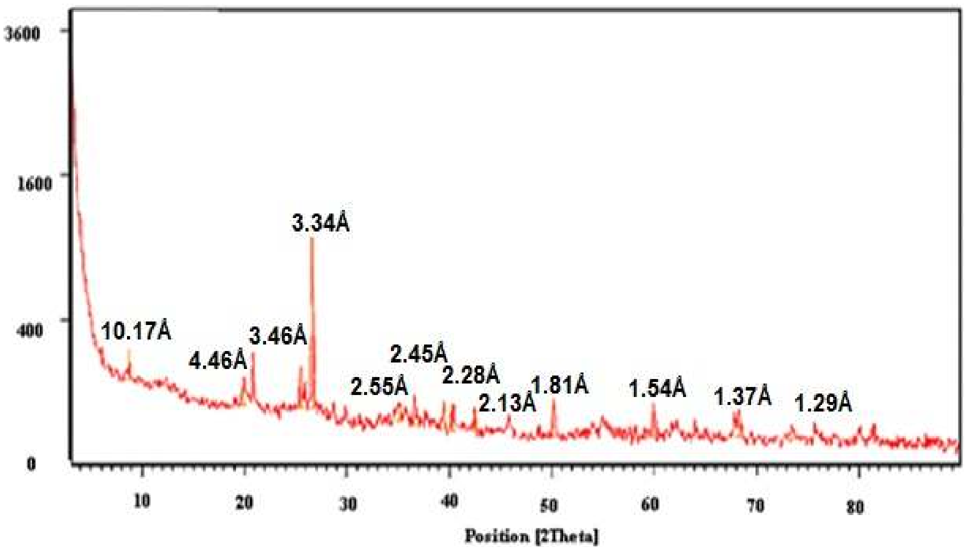

Fig. 1: X-Ray diffractometer spectrum of the clay sample extracted from Ifrane region

above 870°C. It expands up to 20 times its original volume The density of the used Moroccan expanded perlite is 80 kg/m^3; the thermal conductivity is 0.062 W/m/K (Laboratoire Public D'Eesais Et D'Etudes, 2007).

Clay is defined as a "naturally occurring inorganic material composed primarily from fine grained minerals of particle size less than 2 μm. The term clay minerals refers to a specific group of layer type aluminosilicate minerals, which contain structural hydroxyl groups and belong to the general class of phylosilicates". Clay minerals are a result of a steady chemical weathering of rocks occurring over long period of times. They are made up of two elementary blocks which are the tetrahedral sheet and the octahedral sheet. The first sheet is centered in silicon while the second is centered in aluminum.

As we will see later in this study, the clay extracted from Ben smim is mainly made up from Illite.

Illite Clay is a mineral similar to muscovite with an organization of layers (2: 1): (Te-Oc-Te); with a basal spacing of 10 Å, but is typically deficient in alkalies, with less Alumium substitution for Silicium. Thus, the general formula for the Illites is: KxAl4 (Si8-x, Alx) O20 (OH) 4, usually with $1<x<1.5$, but always with $x<2$. Thus, Illite is basically made up of one octahedral sheet and two tetrahedral sheets. Potassium bonding, that balances the charge deficiency caused by the replacement of Si4+ in the tetrahedral sheet by Al3+, makes of Illite non-swelling and non-shrinking clay. It is to be noted that this clay is frequently used in engineering applications. It can be noted that EP is natural alumino-silicate rich in SiO_2 and Al_2O_3.

Description of used materials:

Clay: The clay sample extracted from Ben Smim area close to Ifrane, was characterized through X-ray diffraction. The results are represented in the Fig. 1.

The results presented shows that the X-Ray diffraction of the powdered soil sample presents various peaks occurring at different positions. A predominance of quartz in the soil, SiO2 (d = 3.34Å) The Clayed part is composed of Muscovite/Illite (d = 10.00Å) More XRD analysis were conducted through oriented planes to study more the clay part of the sample. The results confirms the presence of the non swelling clay Illite/muscovite clay reflection d = 10.00 Å present at the angle 2θ equal 8° at the interatomic spacing. No change in the present pics was observed after ethylene glycol saturation which confirms again the absence of swelling clay in the sample.

Expanded perlite: Expanded perlite object of work was taken from Jbel Tidiennit which was already treated by Abrouki (2013).

Perlite is a glassy volcanic rock commonly light gray with a rheolitic composition and 2-5% of combined water. Commercially, the term perlite includes any volcanic glass that will expand or pop when heated quickly.

Description of experimental approach:

Samples preparation and the measurement densities: We prepared a number of four samples (clay/expanded perlite) corresponding to the four different percentage volume fraction of expanded perlite (Fig. 2). We used a normalized sieving process to take into account the effect of volume fraction of expanded perlite on the thermal properties of the medium. Our experience has been done in a mold which dimensions are 100×100×20 mm^3, in this mold we filled a volume fraction of granular expanded perlite until we get a full mold, then we considered that this volume of expanded perlite corresponds to 100% in the samples and according to this we calculated the proportion corresponding to 80%

Fig. 2: View of clay-granular expanded perlite in different volume fraction expanded perlite after calcination

as well as 60% of volume fraction granular expanded perlite in the samples. Then we added clay in order to fill in the void existing between grains of expanded perlite. We also prepared samples of clay without granular expanded perlite, having the same dimensions as the other three, in order to compare the thermal properties variation of the mixture. The fours samples were dried in a stove, to remove moisture present into the pores of each one. In order to ensure that the samples are completely dried and no moisture in left in, the dried samples were weighted several times until we observed that the mass is becoming constant. The samples were then packed in plastic bags so they can maintain uniform moisture content near zero.

For the purpose of studying the effect of calcination on thermal properties of samples, we put them in a tunnel oven of brand BERALMAR.

In order to getting a calinated samples, they must be passed on different phases in the tunnel oven. The first is that they are heated at 60-65°C, the heat of this steps is recovered from the waste of the tunnel oven using a lateral duct. The second step is the rise of the temperature to 110°C then they put them on a temperature of 780°C. Finally they are cooled by fans which gives fresh air from the exterior ambiance.

Knowing separately the densities of clay, granular expanded perlite and that of the mixture and depending on the mixture's law, we can deduce the granular expanded perlite volume fraction in each sample of the composite material according to the formula:

$$y = \frac{\rho_{c+ep} - \rho_c}{\rho_{ep} - \rho_c} \quad (1)$$

Asymmetrical hot plate methods description:

Transient hot plate method: The thermal Effusivity (E) and thermal capacity (ρc) were measured using the transient hot plate method (Jannot *et al.*, 2010). Figure 3 illustrates the experimental device of this method.

Hot Plate in steady state regime: The Hot Plate method in steady state regime (Jannot *et al.*, 2010; Yves, 2011; Yves *et al.*, n.d.) enables to characterize thermal conductivity (λ) of samples. Figure 4 illustrates the experimental device of this method, once the system reaches the steady state regime.

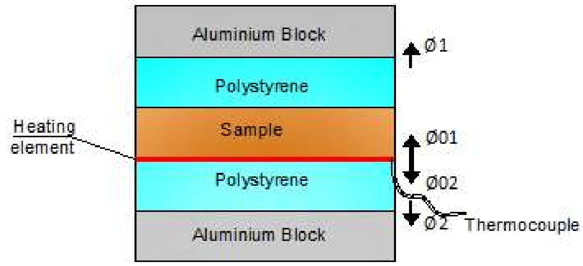

Fig. 3: View and schema of asymmetrical hot plate device in transient regime

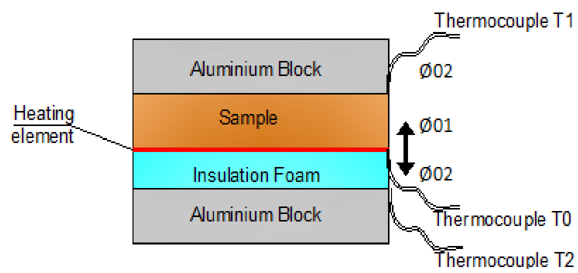

Fig. 4: View and schema of asymmetrical hot plate device in steady state regime

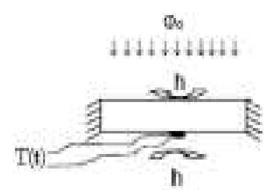

Fig. 5: Schema of flash method

Experimental approach of the flash method: This method permits to determine the diffusivity of solid (Degiovanni *et al.*, 1996, 1979; Jannot, 2011). Its principle is described in the Fig. 5. 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.

RESULTS AND DISCUSSION

Densities sample' s: The densities measurements *ρ* of the all samples were made by weighing each one and knowing their dimensions. Concerning the granular expanded perlite, it was made using the water volume variation method. The results before calcination indicate that the density is decreasing from 2029 (kg/m^3) to 1450 (kg/m^3) when the volume fraction expanded perlite is increasing. While the density after calcination decrease from 1950 to 1374 (kg/m^3) by the increasing of volume fraction of expanded perlite. We conclude the observation below:

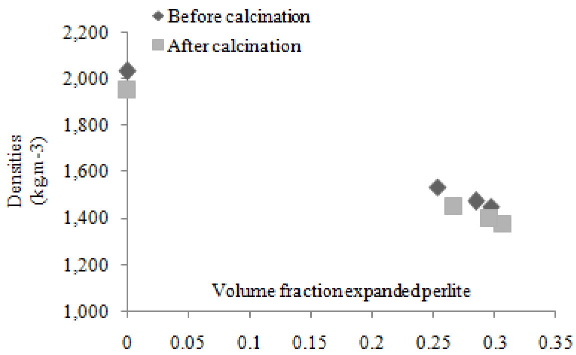

Fig. 6: View of densities according to different volume fraction expanded perlite before and after calcination

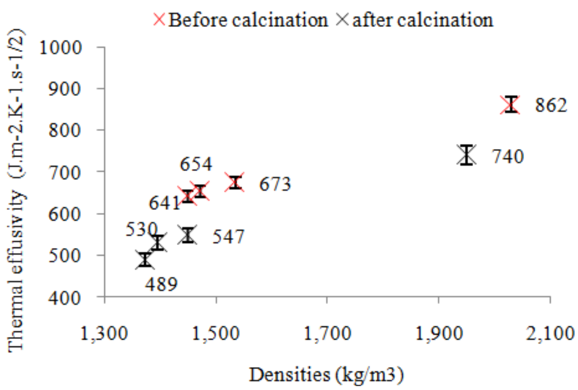

Fig. 7: View of thermal effusivity-according to densities of composite clay-expanded perlite before and after calcination

- A gain on lightness on 30%, this gain obtained is due to the creation of porosity inside the composites by adding expanded perlite
- The density of clay-expanded perlite doesn't vary a lot before and after calcination and this small variation is due to the transformation of clay into terra cotta
- Authors observe that there is a linear correlation between densities and volume fraction of materials insulting (Fig. 6).

Thermal effusivity: The results before calcination indicate that the thermal effusivity is decreasing from 862 to 641 ($J.m^{-2}.K^{-1}.s^{-1/2}$) while this property after calcination decreases from 740 to 489 ($J.m^{-2}.K^{-1}.s^{-1/2}$) when the volume fraction of expanded perlite is increasing what gives of low density. According to this, we conclude that the thermal effusivity decreases by the increase of the volume fraction of expanded perlite and this thermal property improve more by the calcination of the composite; The decrease of the thermal effusivity of our composites conduct that the material absorbs more heat flow than clay alone. Figure 7 shows thermal effusivity according to density and permit to authors to deduce a linear correlation between those parameters.

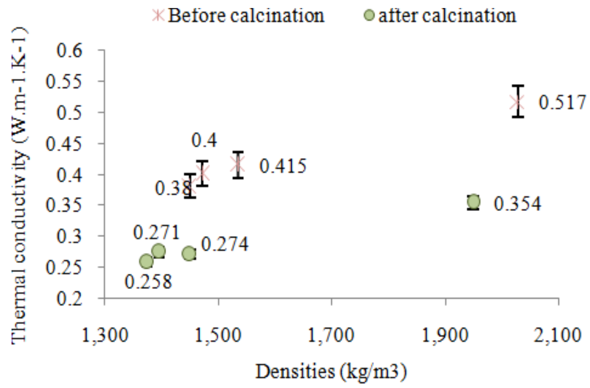

Fig. 8: View of thermal conductivity according to densities of composite clay-expanded perlite before and after calcinations

We note that the measures of error are of the order of 6% before calcination and 2% after calcinations.

Thermal conductivity: The results before calcination indicate that the conductivity is decreasing from 0.51 to 0.380 (W/m.K) while this property after calcination decreases from 0.354 to 0.258 (W/m.K) when the volume fraction of expanded perlite is increasing what gives of low density.

Figure 8 shows thermal conductivity according to density and permit to authors to deduce a linear correlation between those parameters.

The improve of thermal conductivity after calcination is due to the higher firing temperatures which produces more vitrification phases inside the matrix clay-expanded perlite.

We note that the measures of error are of the order of 1% before and after calcinations.

Thermal diffusivity: The results before calcination indicate that the diffusivity is decreasing from 5.06 to 3.71 $.10^{-7}(m^2/s)$ while this property after calcination decreases from 2.79 $.10^{-7}$ to 2.44 $.10^{-7}$ (m^2/s) when the volume fraction of expanded perlite is increasing. According to this, we conclude that the thermal effusivity decreases by the increase of the volume fraction of expanded perlite.

Adding the insulate material expanded perlite to clay reduce the thermal diffusivity so the transfer of heat flow takes more time to cross the composite clay-expanded perlite in comparison with clay alone and this thermal property improve more by the calcination of the composit.

Figure 9 shows thermal diffusivity according to density and permit to authors to deduce a linear correlation between those parameters.

We note that the measures of error are of the order of 6% before calcinations and 1% after calcinations.

Comparison between different experimental methods: The thermal conductivity can be deduced by results obtained from the transient regime and the flash

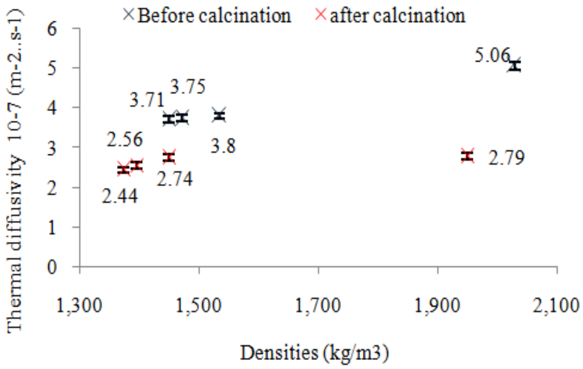

Fig. 9: View of thermal diffusivity-according to densities of composite clay-expanded perlite before and after calcinations

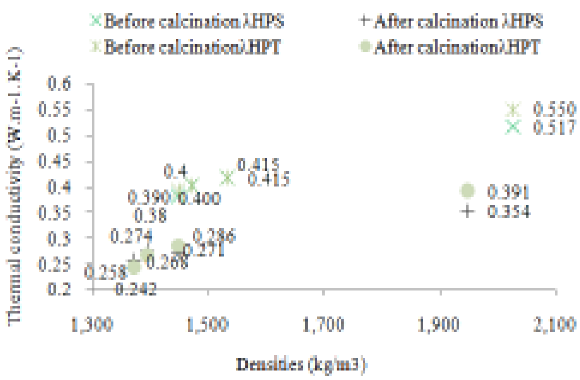

Fig. 10: Comparative figure of thermal conductivity (in transient and steady state regime) according to densities of composite clay-expanded perlite before and after calcination

method which gives thermal effusivity (E) and thermal diffusivity (a) of the samples. Also a comparison between the two methods transient and steady state regime was made to confirm the results obtained of thermal conductivity. Figure 10 shows that the curves of the two methods are similar apart the values of clay alone with a measurement error of 6% before calcinations and 10% after calcinations:

$$\boldsymbol{\lambda\_HPT} = \boldsymbol{E}\sqrt{\boldsymbol{a}} \quad (2)$$

A Comparison of the experimental results with analytical models of equivalent conductivityafter calcination: Authors compare the experimental results with theoretical models which calculate the equivalent thermal conductivity of materials of two components: A continuous phase (Clay in our case) and a dispersed phase (expanded perlite).

We use the series model (Poulaert, 1987; Wienner and Lamellare, 1912) (to calculate the lowest value) and the parallel model (Poulaert, 1987; Wienner and Lamellare, 1912) (to calculate the highest value) to determine the limits of the equivalent thermal conductivity. Moreover, the experimental results were compared to the Hamilton model (Hamilton and Crosser, 1962; Poulaert, 1987) with different value of coefficient of spherity was done to confirm the value of thermal conductivity for it we choose the values of the thermal conductivity to the steady state regime after calcinations.

Series model:

$$\lambda_{\perp\perp} = \frac{1}{\frac{1-y}{\lambda_{cont}} + \frac{y}{\lambda_{disp}}} \quad (3)$$

Parallel model:

$$\lambda_{\parallel/\!/} = (1-y).\lambda_{cont} + y.\lambda_{disp} \quad (4)$$

Hamilton model:

$$\lambda_{eq} = \lambda_{cont}\left[\frac{\lambda_{disp} + (n-1)\lambda_{cont} - (n-1)y(\lambda_{cont} - \lambda_{disp})}{(n-1)\lambda_{cont} + \lambda_{disp} + y(\lambda_{cont} - \lambda_{disp})}\right] \quad (5)$$

With:

$n = {}^{3}/_{\psi}$ cases study ψ (0.1;0.5;0.9)

Using these models in our study, we need to know the thermal conductivity of the continuous phase λ_{clay} = 0.354 (W/m.K)) and that of dispersed phase: expanded perlite λ_{ep}= 0.062 W/m.K. The authors apply these theoretical models to samples and then they represent their evolutions according to the volume of expanded perlite (Fig. 11).

According to results, we deduce that the experimental results are between the lower limit (series model) and upper limit (Parallel model. Also the experimental results of thermal conductivity of this material are represented with two models parallel and Hamilton.

We conclude that the experimental values coincide with the model Hamilton for values of ψ = 0.1 where particles take cylindrical forms on the other hand for coefficients of spherical forms of ψ = 0.9 which corresponds to spherical forms, the model becomes not representative of the experimental data.

Thickness of heat flow diffusion: An analysis was conducted to see the variation of thickness of the composite clay-expanded perlite 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:

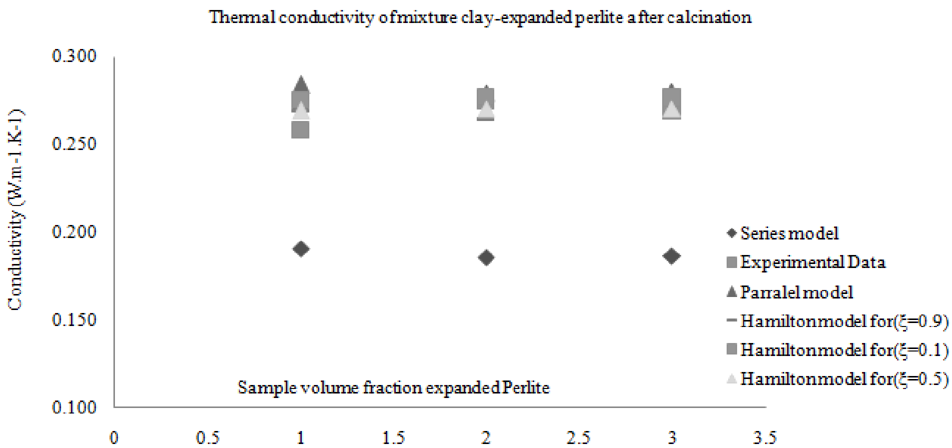

Fig. 11: Results of the experimental thermal conductivities confronted to the theoretical model for mixture of clay-expanded perlite

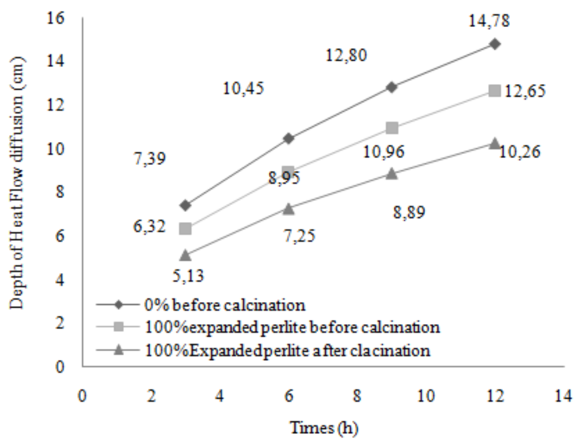

Fig. 12: Comparison of thickness diffusion between sample materials and composites according to time

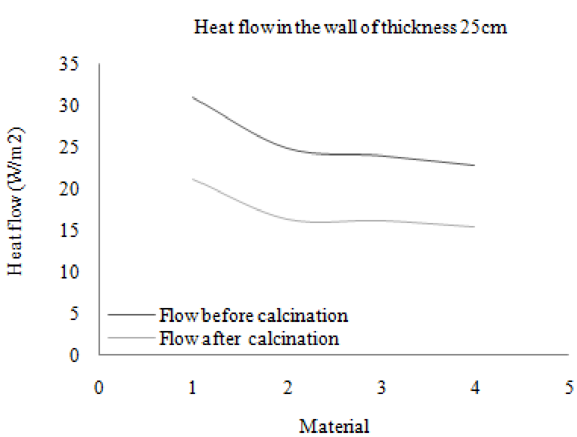

Fig. 13: Comparison of heat flux distribution before and after calcinations between materials according to time

$$t = R.Q = \left(\frac{e}{\lambda}\right) * (e.\rho c) \quad (6)$$

We conclude that:

$$t = e^2/a \quad (7)$$

According to the Fig. 12, author observe that the thickness of diffusion decreases according to time (3, 6, 9 and 12 h, respectively) by adding expanded perlite on materials from:

- (7.39, 10.45, 12.80, 14.78) (cm) Clay alone (0% expanded Perlite) to (6.32, 8.95, 10.96, 12. 65) (cm) composite clay-100% expanded Perlite before calcinations and (5.13, 7.25, 8.89, 10.26) (cm) composite clay-100% expanded Perlite after calcinations

The decrease of the depth heat flow diffusion by adding expanded perlite is due to the porosity created inside materials by expanded perlite.

According to this, author conclude that the calcination decrease more the thickness of heat flow diffusion and retards the diffusion of heat flow inside houses thing which permits a gain after calcination of 5 cm in term of depth heat flow diffusion in a period of 12 h of the composite clay-100% expanded perlite comparing to the clay alone we can use this results to control the heat flow transmitted from the exterior ambiance to the interior of houses especially for cold area where the night becomes colder and we need an important load of heating homes so by retarding heat flow until night inside walls, we can reduce the energy of heating houses.

Comparaison of heat flow diffusion for wall of thickness 25 cm before and after calcinations: In order to study the effect of calcination on the thermal behavior of walls done from clay-expanded perlite in different percentage, we compare the distribution of heat flow inside a walls of 25 cm thickness. According to Fig. 13, we conclude that:

- Varying the percentage of expanded perlite permits a reduce of penetrating heat flow of 26% before calcination instead of 50% after calcination comparing to the clay alone.

- The value of penetrating heat flow is more important after calcination attending 50% comparing to those values before calcination.

CONCLUSION

In this study a thermal characterization of clay-expanded perlite was done using the asymmetrical hot plate and Flash methods. The Illite clay with additives expanded perlite produced during this study, reduced density before calcinations (from 2029 to1450 kg/m^3), after calcinations (from1950 to 1374 (kg/m^3)).

Thermal conductivity before calcination (from 0.51 to 0.38 (W/m.K), after calcination (from 0.354 to 0.258 (W/m.K).

Thermal effusivity before calcination (from 862 to 641 J.m^{-2}.K^{-1}.s$^{-1/2}$) after calcinations (from 740 to 489 J.m^{-2}.K^{-1}.s$^{-1/2}$.).

Thermal diffusivity before calcination (from 5.06 to 3.71 .10^{-7}(m^2/s)) after calcination (from 2.79 to 2.44 .10^{-7} (m^2/s)).

Also the thermal conductivity of Characterization after calcination which was chosen because we want to produce bricks from this material was confirmed using the different experimental method studied in this research: hot plate in transient and steady state regime and method flash. Moreover this property was confronted to different theoretical model. Authors deduce according to thermal characterization that adding expanded perlite to clay makes the composites more insulating and lighter than clay alone. Also the calcination of the composite clay-expanded perlite improves its thermal properties. A comparisons of heat flow distribution and depth of heat flow were conducted concerning a wall of 25 cm thickness showing the impact of calcination on modifying the thermal properties of bricks done from clay-expanded perlite heated. A mechanical study should be conducted so as to manufacture the brick of the composite clay-expanded perlite.

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