**Improvement of insulation thermal qualities of two kinds of clays by combining them with granular cork**

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**Abstract**

This work has been done to improve thermal insulation qualities of two kinds of clay by combining them with granular cork. The clays compared, were taken from two regions in Morocco near Rabat and Ifrane. The thermal properties of the two composites were measured using the asymmetrical hot plate method in steady state and flash method. A comparison of energy gain has been done between the clays to confirm the behavior of cork in the clay matrix.

**Keywords:** Rabat clay, Ifrane clay, Asymmetrical Hot plate method, Flash method, Thermal insulation, Energy gain.

**1. Introduction**

Insulation is the most effective way of improving a home's energy efficiency and can make your home more comfortable as it acts as a barrier to heat flow - reducing the amount of warmth escaping in winter and reducing the amount of heat entering in summer. In fact, by correctly installing insulation in ceilings, in walls, and under floors, you can effectively reduce heating costs by up to 50%\(^{[1]}\) and help to reduce greenhouse gas emissions. Unfired clay blocks proved to be less costly and more energy efficient. On the one hand, since clay will be extracted from the region itself and will be sun baked, unfired clay blocks will not require firing and transportation costs that usually largely affect the price of the brick. The aim of this current work consists of improving and comparing the thermal properties and lightness of clay by combining it with the granular cork in two regions from Morocco: Rabat and Ifrane region. Indeed,
cork [2] is a 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). The thermal properties of the two composites studied were characterized using the hot plate method in steady-state regime[3–5] and flash method[6][7].

2. Experimental

2.1. Chemical composition of clays

The chemical composition of Ifrane’s clay was determined using the fluorescence X[8].

Table 1. Chemical composition of Clay

<table>
<thead>
<tr>
<th>Chemical Element</th>
<th>Percentage of chemical element (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>59.6</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>22.4</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>6.69</td>
</tr>
<tr>
<td>CaO</td>
<td>0.0777</td>
</tr>
<tr>
<td>MgO</td>
<td>0.97</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.53</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.832</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.458</td>
</tr>
<tr>
<td>P.a.f</td>
<td>5.34</td>
</tr>
</tbody>
</table>

The chemical composition of Rabat’s clay was determined using the fluorescence X[9].

The Rabat’s clay was taken from a company which combine the red, the grey and the yellow ans cellars clays taken from two regions called Romani and khemisset near Rabat.

Table 2. Chemical composition of Rabat’s clay

<table>
<thead>
<tr>
<th>Composition mass (%)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Red clay from Romani</td>
</tr>
<tr>
<td>SiO₂</td>
<td>49.45</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>14.24</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>5.03</td>
</tr>
<tr>
<td>CaO</td>
<td>3.76</td>
</tr>
<tr>
<td>MgO</td>
<td>12.97</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.77</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.78</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.1</td>
</tr>
<tr>
<td>Carbonates</td>
<td>5.1</td>
</tr>
</tbody>
</table>

Table 3. Percentage composition of Rabat’s clay

<table>
<thead>
<tr>
<th>Type of Clay</th>
<th>Red Clay (Romani)</th>
<th>Grey Clay (Romani)</th>
<th>Yellow Clay (Romani)</th>
<th>Clay Cellars (Romani)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition of clays</td>
<td>57.14%</td>
<td>14.28%</td>
<td>14.28%</td>
<td>14.28%</td>
</tr>
</tbody>
</table>
2.2. Samples preparation and their densities measurement

Authors prepared a series of four samples corresponding to four different percentage volume fractions of granular cork which size is (d-D= 6.3-8mm) by using a normalized sieving process to take into account the effect of volume fraction of granular cork on the thermal properties of the medium. We proceeded with the preparation of many samples. Our experiments have been performed in a mold with dimensions are 100x100x20mm³. In this mold, we filled a volume fraction of granular cork until we get a full mold, then we considered that this volume of cork corresponds to 100% in the samples and according to this; we calculated the proportion corresponding to 80% as well as 60% of volume fraction granular cork. Then we added the clay in order to fill in the void existing between grains of cork. Furthermore, samples were prepared of clay only in order to compare the thermal properties’ variation of the mixture. The samples were put in a stove, to remove the remaining moisture existing into the pores of each one. Next, dry masses are measured and packed in plastic bags, so they can maintain uniform moisture content near zero. The experimental measurements were performed on these dry samples material.

![Figure 1](image1.png)

**Figure 1:** View of the composite Ifrane clay-cork with different percentage of cork.

![Figure 2](image2.png)

**Figure 2:** View of the composite Rabat clay-cork.

From the knowledge of the dimensions and masses of the fours samples, the apparent density can be easily determined. But, the density of the granular cork was determined by the water volume variation method: weighing a quantity of granular cork that filled 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 experiment’s duration which’s 5s, due to hydrophobic character of cork).

Knowing separately the densities of clay, granular cork and using the mixture’s law, one can deduce the granular cork volume fraction in each sample of the composite material according to the formula shown below:

\[
y = \frac{(\rho_{cm} \times \omega_{cml})}{(\rho_{cml} - \rho_{cm})}
\]  (1)
2.3. Method used: flash and hot plate in steady state regime

2.3.1. Flash Method: Experimental approach of the flash method

![Figure 3: Scheme of flash method.](image)

This method permits to determine the thermal diffusivity of a solid. Its principle is described in figure 3 and in the following sentences describes this method roughly. We send a strong luminary flow on the parallel faces of the sample 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 according to the experimental thermogram. Using Laplace transform

\[
\theta_1(p) = L[T_1(t) - Ta], \theta_2(p) = L[T_2(t) - Ta], \theta_1(p) = L[f_1(t)], F_2(p) = L[f_2(t)]
\]  

(2)

The method of quadruples permits to write:

\[
\begin{bmatrix}
\phi_1(s) \\
\phi_2(s)
\end{bmatrix} = \begin{bmatrix}
\cosh q s & 1 \\
\sinh q s & 0
\end{bmatrix}
\begin{bmatrix}
\theta_1(s) \\
\theta_2(s)
\end{bmatrix} = \left[\begin{bmatrix}
A & B \\
C & D
\end{bmatrix}\right] \begin{bmatrix}
\phi_1(s) \\
\phi_2(s)
\end{bmatrix}
\]  

(3)

\[
\phi_0(t) = \phi_1(t) + h[T_1(t) - Ta],
\]

(4)

In the behind face \( \phi_2(t) - h[T_2(t) - Ta] \)

(5)

So in the space of Laplace:

\[
\phi_1(t) = L[\phi_0(t)] - h \theta_1(p), \phi(t) = \phi_0 \text{ if } t < t_0, \phi(t) = 0 \text{ if } t > t_0
\]  

(6)

According to the Laplace transformation:

\[
\phi_0(p) = L[\phi_0(p)] = \frac{\phi_0}{p[1 - \exp(-pt_0)]}
\]  

(7)

We combine this relation we have

\[
\theta_2(p) = \frac{\phi_0}{p} \cdot \frac{1-\exp(-pt_0)}{C+2Ah+Bh_2}
\]  

(8)
2.3.2. Hot Plate method in steady state regime

The Hot Plate method in steady-state regime [2] permits characterizing thermal conductivity (λ) of samples. Figure 2 (b) illustrates the experimental device of this method. Once the system reaches the steady-state regime, one can write:

\[ \varphi = \varphi_1 + \varphi_2; \quad \varphi_1 = \frac{\lambda_1}{e_1} (T_0 - T_1); \quad \varphi_2 = \frac{\lambda_2}{e_2} (T_0 - T_2) \]  \tag{9}

\[ \lambda_1 = \frac{e_1}{T_0 - T_1} \left[ \varphi - \frac{\lambda_2}{e_2} (T_0 - T_2) \right] \]  \tag{10}

![Figure 4: Scheme of the Hot Plate method in steady state regime.](image)

\( \varphi \) is the total heat flux emitted by the heating element. \( \lambda_1 \) the thermal conductivity of the sample as we seek to determine, \( e_1 \) the thickness of the sample; \( \lambda_2 = 0.04 \text{ W.m}^{-1}.\text{K}^{-1} \) and \( e_2 = 10\text{mm} \) are successively thermal conductivity and thickness of the insulating foam.

3. Results and discussion

3.1. Density

The density measurements of all samples were made by weighing each one and knowing their dimensions. Concerning the granular cork, it was made using the water volume variation method. Different samples were prepared and investigated with the variation of the volume fraction percentage of granular cork in the medium. The results are presented in figure 5.

The results of Bensmim clay characterization indicate that the density is decreasing from 2029 (kg.m\(^{-3}\)) (clay alone) to 1109 (kg.m\(^{-3}\)) (composite100%-cork). But for Rabat’s clay the density is decreasing from 1790 (kg.m\(^{-3}\)) (clay alone) to 1045 (kg.m\(^{-3}\)) (composite100% cork). According to this results and the figure 5, authors deduce that cork has an important role to improve lightness of both Bensmim and Rabat clay. The volume fraction of the materials studied was calculated and presented in table 3.
Table 3. Volume fraction of cork in the materials studied.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Bensmim volume fraction of Clay</th>
<th>Rabat volume fraction of Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>c+co 6.3-8 mm (100%) (W/g=0.25)</td>
<td>0.491</td>
<td>0.456</td>
</tr>
<tr>
<td>c+co 6.3-8 mm (80%) (W/g=0.25)</td>
<td>0.474</td>
<td>0.422</td>
</tr>
<tr>
<td>c+co 6.3-8 mm (60%) (W/g=0.25)</td>
<td>0.337</td>
<td>0.322</td>
</tr>
<tr>
<td>Clay</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 5: Curve of density according to the variation of fraction volume of cork

\[
\rho_{ben} \text{ is the apparent density of Bensmim's clay}
\]
\[
y_{ben} \text{ is the volume fraction of Bensmim's clay}
\]
\[
\rho_{rbt} \text{ is the apparent density of Rabat's clay}
\]
\[
y_{rbt} \text{ is the volume fraction of Rabat's clay}
\]

3.2 Thermal conductivity by the hot plate method in steady state regime

The hot plate method was used in the steady-state regime to characterize the thermal conductivity. According to figure 6, results show that thermal conductivity of Bensmim clay decreases from 0.51 (Clay alone) to 0.246 (W.m\(^{-1}\).K\(^{-1}\)) (for composite clay-100% cork). But for the Rabat clay, it decreases from 0.406 (Clay alone) to 0.23 (W.m\(^{-1}\).K\(^{-1}\)) (for composite clay-100% cork). According to the figure 6, we deduce that cork has an important role to improve the insulation of both clay: Bensmim and Rabat.
3.3. Thermal diffusivity by the Flash method

To characterize the thermal diffusivity, the flash method was used. According to figure 7 results, indicate that the thermal diffusivity of Bensmim’s clay decreases from $5.07 \times 10^{-7}$ (clay alone) to $3.09 \times 10^{-7} (m^2.s^{-1})$ (clay-100% cork) by the increase of volume fraction cork from 0 to 0.489. Also, for Rabat’s clay, the thermal diffusivity decreases from $2.76 \times 10^{-7}$ (clay alone) to $2.15 \times 10^{-7} (m^2.s^{-1})$ by the increase of volume fraction cork from 0 to 0.458. According to this, we deduce that cork has an important role on reducing thermal diffusivity of the clay.

3.4. Comparison of the gain between the composites materials

Analyses of gain in term of thermal conductivity, thermal diffusivity and lightness were done and results are shown below:


\[
\text{gain}_{\text{density}}(\text{Bensmim}) = 1 - \frac{\rho_{\text{clay}}}{\rho_{\text{compo}}} = 45%
\]

\[
\text{gain}_{\text{density}}(\text{Rabat}) = 1 - \frac{\rho_{\text{clay}}}{\rho_{\text{compo}}} = 42%
\]

\[
\text{gain}_{\text{thermal conductivity}}(\text{Bensmim}) = 1 - \frac{\lambda_{\text{compo}}}{\lambda_{\text{clay}}} = 51%
\]

\[
\text{gain}_{\text{thermal conductivity}}(\text{Rabat}) = 1 - \frac{\lambda_{\text{compo}}}{\lambda_{\text{clay}}} = 43%
\]

\[
\text{gain}_{\text{thermal diffusivity}}(\text{Bensmim}) = 1 - \frac{a_{\text{compo}}}{a_{\text{clay}}} = 39%
\]

\[
\text{gain}_{\text{thermal diffusivity}}(\text{Rabat}) = 1 - \frac{a_{\text{compo}}}{a_{\text{clay}}} = 22%
\]

The expected improvements in densities, thermal conductivity and thermal diffusivity of the materials compared to pure clays can be determined. For the apparent density, the lie is between 42-45%. For the thermal conductivity, the lie is between 43 and 51%. However, for the thermal diffusivity, the lie is between 22 and 39%.

### 3.3. Discussions and interpretations of results

Thermal characterizations of Bensmim and Rabat clays were done using the asymmetrical hot plate method in steady-state regime and flash method so as to determine thermal conductivity and thermal diffusivity. Also, apparent densities were determined in order to compare the impact of adding cork on the lightness of the composite clay-cork wherever the kind of clay used, the analyses of results indicate that the cork permits gain on the lightness of above 40%. Both type of clay dry and coastal region show reduction density above 40%. Moreover, the analyses of thermal conductivity confirm the advantage of cork which permits gain of more than 40%. Absolute figures now for thermal diffusivity to differences (17).

It was to be expected that the cork according to its microstructure, porosity and the hydrophobic characteristic improve the parameters density and thermal characteristics of the composite materials compared to pure clay. The gain obtained differs not from different clay as far as the composite density and thermal conductivity are concerned. A greater difference was determined for the gain in thermal diffusivity.

### 4. Conclusion

In this research project, different composite materials of different clay (Bensmim and Rabat) with different percentages of cork granulate in it were investigated with respect to their density, thermal conductivity, and thermal diffusivity. Considerable improvements in density reduction, thermal conductivity and thermal diffusivity were obtained.

Materials composites investigated have led in general to roughly a reduction of 50% for density and thermal conductivity, a bit less for thermal diffusivity. The origin of the clay was of lower relevance.
Results encourage performing dynamic simulations of example buildings using composite materials with different contents of cork.

The simulations should be coupled with economic simulations in order to draw the best possible conclusions of applying such materials in adequate building constructions.

Acknowledgements

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References


5. A. Bakr Cherki, Mesure des propriétés thermophysiques d’un matériau composite isolant à base de granulats de liège et de plâtre, Mohammed V Agdal, 2014.


