Microstructural characterization and mechanical properties of earth stabilized mortar, determination of the Technico-Economic Optimum

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Abstract.
This study presents the experimental results of the four mineralogical and chemical analysis techniques on the earthen mortar obtained from the city of Rabat. The uni-axial compressive tests results on the cylindrical specimens for this earth, associated with various percentages of cement, make it possible to analyze the effect of the mineralogical and chemical elements on the characteristics mechanical properties. However, we determine also the interval of the technico-economic optimum. In the earthen mortar of Rabat city, the presence of calcite ($\text{CaCO}_3$), quartz $\text{SiO}_2$, kaolinite and the aluminum silicate, have amplified the improved behaviour of the material by the addition of cement. We also note that the evolution of the mechanical properties has only the importance in the [7 to 10%] interval which represents the area of effect for cement stabilization and which houses the optimum of the cement dosing.

Key words: Earth material, mortar, cement, mineralogy, mechanical tests.

Introduction
The use of earthen mortar in the construction in countries is mainly dependent on their mechanical resistance behaviors, water absorption, mineralogy and chemical. To improve the physical properties of these building materials, earth, and small amounts of cement introduced. In addition the positive impacts of these amendments on the quality of earth, a little attention has paid to their effects on the microstructure of the traditional building materials. If the chemical processes and the geotechnical properties of cement-stabilized earth has been investigated, a little study has been devoted to the assessment of the effects of cement additions on the microstructure and the physical properties of earthen mortars [1, 2, 3]. The aim of this work is to study the effects of mineralogy and cement additions of earth on the microstructure transformations and the physical properties (compressive strengths) of earthen mortars in both cases: dry and wet [4, 5, 6, 15], this earth comes from the city Rabat Morocco. We worked with the cement-stabilized earthen mortar to determine its mechanical characteristics by simple compression tests on cylindrical specimens in both cases [6, 19]. Our work has determined also the interval of the technico-economic optimum (TEO) [4, 20].

1. Material and methods
The basic raw material is from Rabat (Morocco) referenced by R. The following table summarizes the granular fraction of this earth:
Table 1. The granular fraction of the earth of Rabat (R)

<table>
<thead>
<tr>
<th>Earth</th>
<th>Granular fraction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse sands</td>
</tr>
<tr>
<td>R</td>
<td>48.46</td>
</tr>
</tbody>
</table>

The identification of the earth is completed by the analysis of clay part to define its status of consistency known as Atterberg limits: liquidity limit (WL), plasticity limit (WP) and plasticity index IP = WL - WP. These limits are given in Table 2. This table also includes the activity coefficient Ca and the specific surface area Sa.

Table 2: Limits consistency of the earth R

<table>
<thead>
<tr>
<th>Earth</th>
<th>Wp(%)</th>
<th>WL(%)</th>
<th>IP(%)</th>
<th>Ca</th>
<th>Sa (m²/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R</td>
<td>15.04</td>
<td>21.10</td>
<td>6.06</td>
<td>0.39</td>
<td>77</td>
</tr>
</tbody>
</table>

According to table 2, we conclude the earth R is inactive.

2. Results of mineralogical and chemical analyzes

The chemical and mineralogical of earthen mortar elements are analyzed to determine the proportions of the elements, by four analysis techniques, namely: X-ray diffraction, Infrared, Scanning Electron Microscope and X-ray fluorescence.

2.1. X-ray diffraction (DRX)

A global analysis of the X-ray diffraction patterns of powdered samples of earth R (Figure 1) showed the presence of calcite and quartz. The presence of calcite and the absence of portlandite show that the binders are fully carbonated. According to Mertens et al. [18] quartz is not a binder and it forms a part of the fine sand fraction of the aggregate.

![Figure 1: X-Ray Diffraction Spectrum of earth R](image-url)
2.2 Scanning Electron Microscope (SEM)

SEM is a well-established method that can offer useful information concerning the structure of the material. To better understand the evolution of the microstructure of earth samples. From the images of the earth R obtained by the SEM (Figure 2), we note that calcite is more dominance than quartz.

![SEM images](image)

Figure 2. MEB images taken on the earth R (Qz: quartz, Ca: calcite)

2.3 Analysis by fluorescence X

The fluorescence analysis makes it possible the measure the percentage of chemical elements contained in the earth sample R and the CPJ cement used in making the earthen mortars. Table 3 summarizes the rate of chemical elements:

<table>
<thead>
<tr>
<th>Composition (%)</th>
<th>Earth R</th>
<th>Cement CPJ 35</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>21.6</td>
<td>12.46</td>
</tr>
<tr>
<td>CaO</td>
<td>35.2</td>
<td>57.02</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>7.77</td>
<td>3.39</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.43</td>
<td>1.89</td>
</tr>
<tr>
<td>MgO</td>
<td>0.86</td>
<td>1.35</td>
</tr>
<tr>
<td>SO₃</td>
<td>0.204</td>
<td>1.95</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.522</td>
<td>0.62</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.354</td>
<td>0.18</td>
</tr>
<tr>
<td>MnO</td>
<td>0.104</td>
<td>0.03</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.447</td>
<td>0.11</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.574</td>
<td>-0.03</td>
</tr>
<tr>
<td>SrO</td>
<td>0.0595</td>
<td>0.015</td>
</tr>
<tr>
<td>PAF (perte au feu à 975°C)</td>
<td>28.6</td>
<td>20.90</td>
</tr>
</tbody>
</table>

There is an enrichment of CaO (35.2%) due to the presence of the matrix of carbonate and a high SiO₂ content (21.6%), due to the concentration of quartz. The losses on fire are to be linked with the presence of water.
3. Experimental results

3.1. Mechanical Results and Interpretations

The figure 3 shows the evolution of the compressive strength, modulus of elasticity and the deformation limit of the test specimens of mortar the earth R on in both cases (dry and wet).

Figure 3. The compressive strength of the dry mortar and wet as a function of the cement dosage

Figure 3 shows that the compressive strength of the earth R increases according to the cement content rate. All recent studies [9, 3, 6, 10, 11, 12, 13] have shown that the mechanical properties increase with the cement content without giving the function of this increase. Because this increase is varied according to the particle size and the mineralogical composition of the earth, which the impacts of the economic investment of cement. There is an increase of the compressive strength and the elasticity module according cement content in the dry and wet state of the earth R.

Moreover, the addition of a low content of the cement to the sandy fraction of the earth R, gives a very low variation in the compressive strength up to 7% by weight of the cement, but we obtained a very high variation of 7% to 10% in the dry state (0.175 to 0.314 MPa), in the other hand, we figure out a small variation in this interval through the wet side, in which the grains of the earth R are not completely coated by the cement, and consequently this earth needs more of the cement. This is explained by the considerable percentage (20.49%) of the clay contained in the earth, and this has been demonstrated in previous studies [17]. Indeed, it was concluded that it was difficult to stabilize an earth containing a relatively high clay content, hence the need to add more cement to make it more stable.

The mineralogical results show that the clay of the earth R and their mortar of specimens of the different cement content are formed mainly of quicklime CaO, quartz SiO$_2$, Kaolinite and the aluminum silicate which play a crucial role in the stabilization of the clay by the reaction of quicklime and water. Although the quartz is not a binder, it is constituted by a portion of the fraction of fine sand [7, 16, 17, 18]. The quartz grains of this earth are cemented by the carbonation of the lime according to the following reactions:

$$\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 \text{ (Portlandite)}$$

(2)  $$\text{Ca(OH)}_2 + \text{CO}_2 \rightarrow \text{CaCO}_3 + \text{H}_2\text{O}$$

(3)
Most researchers are mentioned in the literature [21, 22], high levels of SiO$_2$, Al$_2$O$_3$ and Fe$_2$O$_3$ in the earth are indicative for high strength and the mortar specimens are moisture resistant, more the earth R is inactive, more the clay is not sensitive to water. Bessenouci et al. [24] have concluded that the aluminum silicate has a property of being a bonding by chemical reaction with calcium hydroxide (Ca(OH)$_2$) in the presence of water at ordinary temperature. The hydrated cement matrix reacts in two ways [16]: a strong reaction with the sandy skeleton and a very weak reaction with the clay, which is already stabilized by its chemical constituents to improve the compressive strength of mortar specimens.

**Conclusion**

From this experimental study on earthen mortars prepared using in certain proportions of the cement has clearly brought that the chemical components of the clay of the Rabat (R) earth materialized by CaCO$_3$ calcite with a high SiO$_2$ (21.6%) due to the quartz concentration and the kaolinite.

The addition of the cement on the test pieces of the earthen R shows the increase in the percentage of calcite and the presence of aluminum silicate or silico-aluminous with a very small quantity. The latter is not a binder without the chemical reaction with calcium hydroxide (Ca(OH)$_2$) and water.

The compressive strength and the modulus of elasticity increase with the cement content. However, the limit deformation evolves in the opposite direction. And the calcite stabilizes other chemical constituents of the clay such as quartz and aluminum silicate. Therefore, the cement addition amplified the linkages between the sandy skeleton and the clay matrix is stabilized by these chemical constituents to make the material resistant and consequently reducing its deformability.

Concerning the capillary rise, water absorption decreases with the addition of the cement. We also note that the evolution of the mechanical characteristics does not matter that in the interval [7 at 10%] Which represents the area of effect for cement stabilization, consequently, the technico-economic optimum for stabilization will be located in this area [7%, 10%].

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