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A monographic Study of the Military Forts
Of the city of Bejaia and an analysis of their building systems

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Abstract
Béjaïa City had known during the different dynasties, many forts that had lasted up to the French colonization an oven up to nowadays. Most of these forts are from Spanish building and had sometimes been restricted, this, according to some building of medieval and ancient time.

During the Spanish conquest in 1509 under Pierre De Navarre, three great edifices were built. A fortress was built in “the Star Castel”, (a castle from medieval period), which was called “the Imperial fort”, nowadays called “Moussa Fort”. Secondly, he restricted “the Abdel-Kader fort”, an ancient, fort. He also fortified the ancient citadel, neigh boring the sea, near the naval dockyard, On the Roman port seat.

These military forts are quite different in their architectural typology, but present a lot of similitude in their building systems, thus, we can notice, the use of bricks, dried stones and mortar lime.

Each material of construction has specific physical, chemical and mechanical characteristics. This specificity is the result of the nature of geological resources and their modes of manufacture.

The objectives of this study are the identification and inventory of various construction systems and the characterization of their materials of construction. Through this study, we determined the physical, chemical and mechanical characteristics and the mineral composition of clay bricks, jointing mortars and coating mortars (plaster).

Keywords: Bejaia city, Spanish fortifications, building systems, Characterization of materials, mineralogical composition, bricks, mortars.

1. Introduction

Knowledge of historical buildings must be based in knowledge of their materials and constructive systems. Knowing the characteristics of materials, is an important source of information for understanding the historical and archaeological evolution of mortars, and towards finding a mortar with the characteristics similar to old mortar, which can then be used in the restoration of historical monuments.

In the case of Algeria, studies relating to materials and constructive systems are recent and cover only a portion of its historical and archaeological heritage. The forts of Spanish period were the subject of very few studies, particularly as regards their building materials.

In recent decades, research on masonry binders has essentially focused on the characterization of the materials used in historic buildings (Palazzo-Bertholon 1998 Coutlas, 2003). This new line of research opened a sphere towards new knowledge and perception of materials, through a scientific and analytical approach.

The mortar could be used for several purposes, such as, filling, grouting or coating. Whatever its use, the base components are the same: These mortars consist of sand and lime, to which have
been added other components, such as the broken tiles or crushed bricks and in some cases, broken stone

The first aim of this study is to identify the different materials used in the Spanish forts of Bejaia, as well as the construction techniques and their implementation, which reveals to us all of the local knowledge and mastery of the builders of that time. The second aim is to characterise of ancient lime based mortars, used in the forts and to identify their chemical and mineralogical composition, as well as its production techniques.

The buildings selected as part of this study are:

1.1. The qasabah (Old Citadel)

Built at a cove’s end, on the foundations of the old Roman port, the Qasabah is located southwest of the city, overlooking the entire bay. Its origin is however unclear: for some historians (De Beylié, 1909), the place was built by the Spaniards, whereas Brunschwing thinks, it is likely Almohades who built the Qasabah.

A report about Bejaia in 1833 (Lemercier, 1833), made by the military engineering, confirms that the lower part of the Qasabah dates back to different Islamic eras, whereas the upper part was built by the Spaniards. Its shape and design date back to the sixteenth century.

The Qasabah was described (Feraud, 1869) as a rectangle which one side is adjacent to the city. It is flanked by strongholds or bastions and by three very high and very massive towers, with murder holes.

It has experienced several transformations; the oldest part is the left part and is located southwest of the wall; it is characterized by its heterogeneity. The part facing the sea, in the south, has undergone many repair operations with recyclable materials at different periods, following the destructions caused by cannonballs (Fig1).

![Fig. 1- qasabah (Naima Mahindad, 2012)](image)

1.2. The imperial castel (Bordj Moussa)

This fort, also known as “The Imperial Castle” during the Spanish period (Epalza, 1988), and called “Fort Moussa” by the locals and “Fort Barrral” by the French (Feraud, 1869), is located on a high mound in the middle of the upper part of the city.

This location has attracted all the dynasties that succeeded one another on this land, from Romans to French, which enabled it to always play a prominent role in the city. Later, under the Spanish presence, in 1548, Charles V ordered that a fortress, called Fort imperial, be built on the location of Ancient palace hammadite (Castel of Star). Upon the arrival of the Ottomans, the imperial fort, instead of being abandoned by the Spaniards, was the scene of a fierce struggle.

Just before the French conquest, this fort, was in poor condition (Feraud, 1869). It had, according to the metaphor used by engineering officers (Vivien, 1834), the shape of a “priest cap” of 160 meters long. It was composed of a ground floor, a platform and a jumper.

However, the French carried out some works to consolidate, repair and “restructure” the fort from the inside. The repair dealt with the gateway, the southern part of the frontage and some openings. The consolidation rather dealt with the inner part of the fort, while the redevelopment was achieved by dividing the height of the arches in half to create, in the ground floor, a liquids store and, in the first floor, a flour store, connected by a lift.
Currently, this addition has been removed and all that space is used as a museum (Fig. 2).

Fig. 2- The imperial Castel (Naima Mahindad, 2014)

2. The construction system

The analysis of the evolution of constructive processes of the forts of the city of Bejaia, allowed us the identification of constructive techniques and building materials used in the medieval period and especially Spanish in these buildings.

There are several varieties of walls according to their appliances and their thicknesses. There are walls which alternate at regular intervals rows of bricks and rubble and other walls with an irregular composition, mostly of bricks or rubble.

2.1. Regular Homogeneous walls with a single bed of bricks.

These walls are made exclusively with a single material which is brick, also called "opus testaceum", they are arranged over the entire width of the wall.

The thickness of this type of walls varied between 10 cm when the bricks are stretcher bond, to 25 -30 cm when they are header bond

**a- Regular homogeneous walls with several brick beds**

This type of masonry elements constitutes the load-bearing walls of the forts. These walls are composed with a double to triple or quadruple rows of bricks.

The thickness of these walls varies from 40 to 60 cm and can reach in the case of external walls, 1m to 1m20 wide.

**b- Regular and irregular mixed walls**

This type of wall is known by the "Opus Mixtum" appellation.

There are several varieties of this type of walls according to disposition of the materials and their thicknesses. There are walls which alternate at regular intervals the rows of bricks and rubble and other walls with irregular apparatus, mostly bricks or rubble (Fig.3)

Fig. 3- Regular mixed wall (Naima Mahindad, 2016)
2.2. Walls in earthen rammed

a. Walls in earthen rammed with brick facings.

The facing is made up of several brick beds both in the inner facing and in the outer facing.

The mixture which constitutes the blockage between the two facings is consists of a mixture of tuff, bricks and crushed stone.

These walls reach for the Citadel of Bejaia 4.40m and 2m 80 for Bordj Moussa (Fig.4).

b. Walls in earthen rammed with irregular mixed walls.

They consist of a facing that alternates cut stone beds, rubble and bricks in disparate ways. The solid bricks are laid flat. This construction system is called (opus mixtum).

Between the two facings, there is a blockage consisting of crushed stone, gravel, tuff and lime. All the masonry is laid with lime mortar.

c. Walls in earthen rammed with different facings in a homogeneous regular structure

The interior and exterior facings are different: The interior cladding is made of brick, the bricks are placed alternately, one rowed in header and another in stretcher while the other cladding is realized with stones on All its thickness. The squared stones are of small dimensions and mortar with lime based mortar. A mixture of tuff, lime, stones and also vegetable additions occupies the space between the two facings. This mixture is poured per part and compacted as and when (Fig.5).

3. Characterization of mortars

In this study, we chose six (04) samples of grouting and coating, found at the Qasbah and at the imperial castle (Bordj Moussa). These mortars show the visual changes as regards their colours and textures.

In the Qasbah of Bejaia, the samples are coded MJQ for jointing mortars and MFQ for coating mortars:

- MJQ: Its color is varied between the orange and yellow. It also contains grains of lime and significant red and brown particles. It is highly compact in apparence and not brittle to the touch.

- MFQ: Its color is whitish. It also contains grains of lime and shows the presence of black-brown particles of various sizes and brick fragments. It is highly compact in appearance and not brittle to the touch.

In the Imperial Castel (Bordj Moussa), the samples are coded MJBM for jointing mortars and MFBM for coating mortars:

- MJBM: Its color is light pink. It it consists of very fine sand particles and dirt and shows the presence of whitish lime particles of lime of various sizes. With a naked eye, one can also easily see a given number of pores and grains of a larger grain size in a reddish-brown colour.

- MFBM: Its color is pink- yellowish. It consists of big sand particles and grains of a larger grain.
size in a black-brown colour. It is brittle to the touch.

A petrographic analysis of the samples through the microscopic observation of the thin plates of the mortar samples permitting the identification of certain minerals that make up the mortar (Table.1)

<table>
<thead>
<tr>
<th>Samples</th>
<th>Observation of the samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qasbah MJQ</td>
<td></td>
</tr>
<tr>
<td>Imperial Caste (Bordj Moussa) MJBM</td>
<td></td>
</tr>
<tr>
<td>Qasbah MFQ</td>
<td></td>
</tr>
<tr>
<td>Imperial Caste (Bordj Moussa) MFBM</td>
<td></td>
</tr>
</tbody>
</table>

Table.1. Microscopic observation of the sample

3.1. Methods

We chose the complementary analysis techniques, in order to carry out the chemical and mineralogical characterisation of the collected mortar samples. The advantages of this procedure are that the different results directly provide us a great deal of information. By combining the results of physical, mineralogical and chemical analysis, we have been able to identify the elements that compose them and check the first findings, giving us a better insight to the materials.

3.1.1: Physical analysis

Physical analysis enables us to identify the specific and apparent densities, as well as the percentage (%) of humidity, porosity and water absorption, according to French standards NF P18-558; NF P94-050; NF P18 554.

3.1.2 Mineralogical analysis

Its purpose is to identify minerals and theirs dosage for a quantitative estimate. This study was conducted using X-ray diffraction.

3.1.3. Chemical analysis

The chemical composition of Ottoman mortars was determined by X-ray fluorescence, using the principle of standard NF P 15-467. The loss on ignition is determined at 1000 °C, under the provisions of standard EN 1744-1.

Historical studies pertaining to the Ottoman period refer to the possibility of using natural hydraulic lime in the composition of some mortars, hence the importance of calculating the hydraulic index, in order to verify this hypothesis.

The hydraulic index (HI) is calculated using equations (1) (Boynton, 1980).

\[
HI = \frac{\text{Al}_{203\%} + \text{Fe}_{203\%} + \text{Si}_{102\%}}{\text{Ca}_0\% + \text{Mg}_0\%}
\]

3.2. Results

3.2.1. Physical properties

The results obtained from the physical analysis, are summarised in Table.2. They show that for jointing mortars, the highest value of apparent density is 1.28 g / cm³ and the corresponding value of the specific density is 1.98 g / cm³.

The highest value of apparent density, for coating mortars is 1.53 g / cm³ and the higher value of their specific density is 2.13 g/cm³.

All the samples of jointing and coating mortars have a lower percentage of water absorption and porosity.
Table 2. Results of physical analysis

3.2.2 Mineralogical composition

The results of the XRD mineralogical analysis reported in Table 3, revealed the presence of significant amounts of quartz and calcite. For jointing mortars, the amount of quartz was around 18% for the jointing mortars, while sample MFBM of coating mortars has a quartz amount around 26.5%.

The calcite amount varies between 33% for MJQ and 61% for MJBM, while sample of coating mortars MFBM has a quartz amount around 59%.

The mineralogical composition of the jointing mortars MJQ reveals the presence of gypsum, with amount of 16%, while it is found that very low contents in the other samples, they vary between 01 and 02%.

Furthermore, in all samples, the existence of Muscovite, Albite and Feldspars has been found, in amounts that vary between 6% to 6.5% for Muscovite, 2.5% to 15% for Albite.

Table 3. Results of mineralogical analysis

The results of the XRD mineralogical analysis reported in Table 4, revealed a totally different and atypical mineralogical composition in the sample MFQ. Besides Calcite, quartz and Magnesite (periclase) the presence of Portlandite, Lavendulan and Krautite is noted.

Table 4. Results of mineralogical analysis of MFQ

This mineralogical composition could not be quantified, but the reading of the crystallographic radio diagram of the sample, allows observing fine and resolute peaks of
calcite and quartz, but also of Lavandulan, of Portlandite, and of Krautite.

3.2. Chemical composition

The chemical analysis results are provided in Table 5. These results show that the most important component of the various mortar samples is CaO with rates ranging from 23.67% for MJQ to 36.40% for MJBM, while they range slightly higher for coating mortars, with 34.56% for MFQ and 45.53% for MFQ.

The SiO2 content is also important, however, in a lower percentage than the SiO2 rates. They range between 22.11% to 29.22% for jointing mortars and 14.58% to 27.01% for coating mortar.

We have also noted the combinations of oxides SiO2, Al2O3 and Fe2O3 for all samples are insignificant and the values for their hydraulic index are low.

3. Conclusion

The military forts of the city of Bejaia have the same constructive typology. They have the walls in earthen rammed with brick facing or mixed structure. The walls are very thick and can reach 2m50, which responds to the defensive character of these buildings.

The materials used (bricks, rubble and mortars) have differences in their dimensions, colors and even textures.

The composition of these mortars is done according to specific proportions of the various components: the most important component, as regards quantity, is calcite, followed by quartz, and finally, although in smaller quantities, some additives, such as crushed bricks and clay materials.

The proportions between these main components range from two parts to four parts lime for one part sand (2:4 / 1).

The mortars of the Bejaia forts, which have a higher proportion of calcite and are enriched with gypsum, have a low hydraulic index, confirming the dolomitic nature of the lime used in their manufacture.

All of these results have enabled us to see the similarities of the mortar components, their respective proportions, and their physical properties, despite the diversity of buildings, which leads us to say that there was a common knowledge in the city of Bejaia.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Levels (contents) (%)</th>
<th>HI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SiO2</td>
<td>Al2O3</td>
</tr>
<tr>
<td>Quasbah MJQ</td>
<td>29.22</td>
<td>7.80</td>
</tr>
<tr>
<td>Bordj Moussa MJ BM</td>
<td>22.11</td>
<td>4.71</td>
</tr>
<tr>
<td>Quasbah MFQ</td>
<td>14.58</td>
<td>3.21</td>
</tr>
<tr>
<td>Bordj Moussa MFBM</td>
<td>27.01</td>
<td>06.58</td>
</tr>
</tbody>
</table>

Table 5. Results of chemical analysis
References


Mallinowski , R (1982). Durable préhistorique ancient mortars and concretes, Nordic Concrete Research, in transportation research board, décembre, p22.


S. H. T. A. 1H891 ou Article 8, Section 1, Carton 1, Bougie, Colonel Lemercier, Rapport sur la place de Bougie, 12 nov. 1833.

S. H. A. T : 1H891, Les fortifications

S.H.A.T: Art 8, sect. 1, Bougie, carton n° 1, Vivien, Mémoire sur la place de Bougie, 1 juin 1834.

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