JAUHS is an international journal published by the Institute of Architecture and Urban Studies, Blida University. Algeria

JAUHS

Journal of Architecture, Urbanism, and Heritage Studies

CHARACTERIZATION OF BRICKS FROM THE OTTOMAN PERIOD IN ALGIERS (ALGERIA) THROUGH THEIR PHYSICAL AND CHEMICAL PROPERTIES

Naima ABDERRAHIM MAHINDAD *1

[1] University Blida1, Institute of Architecture and urban planning, Saad Dahleb, Blida , Algeria, Laboratory ETAP, mahindad_naima@univ-blida.dz

Keywords
Algiers
Ottoma period
Terracotta
bricks
Characterization,

Abstract

In traditional and historical Algerian architecture, there are many monuments built with terracotta bricks. Although Algeria has a very rich heritage park, our interest mainly focuses on the terracotta bricks used in buildings from the Ottoman period, in Algiers and in particular, these used in the Citadel of Algiers, the Casbah and villa Mahieddine. This study allows us to determine the physical and mechanical properties of a selection of bricks and identify their mineralogical composition. The results of these studies showed that the bricks of the Ottoman period are sand-lime bricks and their resistance to mechanical stresses is related to the firing temperature of the bricks and the nature of the raw material.All these elements influence the physical and mechanical characteristics of the terracotta bricks. These results allow the manufacture of bricks intended for the restoration of historic buildings, more compatible with old materials.

1. Introduction

1.1. Introduction

Knowing the characteristics of materials is an important source of information for understanding the historical and archaeological evolution of bricks used in building in ottoman period in Algiers.

The bricks intended for the restoration of historic buildings must be compatible with the characteristics of the materials that they are intended to replace [1]. It is important that the material used during the restoration and/or reconstruction operations, has the same morphological and physical characteristics, so that the new material does not differ too much from the old one [2].

In recent decades, research on masonry binders has essentially focused on the characterization of the materials used in historic buildings [3].

This new line of research opened a sphere towards new knowledge and perception of materials, through a scientific and analytical approach. [4].

In the case of Algeria, studies relating to historical materials are extremely rare and cover only a portion of its historical and archaeological heritage: The majority of studies have focused on ancient mortars for its repair and restitution, while terracotta bricks have been very little studied. Bricks of the Ottoman period in Algeria were studied through an unpublished literature exploited in the works of Chergui [5] and that of Foufa [6], and which consist of the Ottoman period archives. Doctoral theses have apprehended the study of the physical and mechanical characteristics of bricks and especially their influences. Adding they were interested in the improvement of the qualities of mortars and concretes as we have seen in the study of the mechanical and thermal properties of bricks. [7].

The aim of this study is to characterize of ancient terracotta bricks, used in previously selected Ottoman constructions. The objective is to identify their mineralogical composition and physical and mechanical properties, as well as its production techniques.

The aim of this study is to characterize of ancient terracotta bricks, used in previously selected Ottoman constructions. The objective is to identify their mineralogical composition and physical and mechanical properties, as well as its production techniques. The results obtained are compared to various historical studies.

1.2. Presentation of the historical buildings studied

In view of the diversity of Ottoman buildings, as regards their use and geographical location, we have limited our research to the most representative buildings, as regards their function and geographic location, in order to target a more comprehensive sampling of the teracotta bricks used during this period. The buildings selected as part of this study are:

1- The Citadel of Algiers: it is the pillar of Ottoman power, which consists of various structures, such as a palace and the mosque of Dey, Beys Palace, the Summer Pavilion, Hammam of Dey, the Janissaries quarter, the Skifa [a monumental door], The casemates (The pillboxes) and the powder house. All of the above were built between the sixteenth and eighteenth centuries. Within this palatial complex, we have chosen two buildings from these samples, the powder house and the Casemates (The pillboxes).

2- Villa Mahieddine : This is a Fahs house (a house in the countryside). This villa was mostly used during the summer; it was built between the sixteenth and seventeenth century.

3- House of the Casbah of Algiers: The Medina, which constitutes the Ottoman city, contains most of the houses and dwellings of that time. These houses were built between the sixteenth and eighteenth centuries.

2. Material and Method

2.1. Materials

We choose four brick samples from the above listed sites. These bricks show the visual changes as regards their colours and textures). All samples are presented in “Figure 1”.

1- The powder magazine

The powder magazine brick sample, codified BR1, was taken from the exterior wall of the west facade of the building.

The bricks have a compact structure, these bricks are soft and brittle by hand, they have a porous appearance with small white grains of variable dimensions. The dimensions of the bricks are mostly 27 cm long by 12 cm wide and 3.8 cm thick.

2- The Casemate

The sample of bricks BR2, taken from the Casemates are compact and have a semi-soft consistency that is not very brittle by hand. The dimensions of these bricks are generally 28 cm long by 13 cm wide and 3.5 cm thick.

3- Villa Mahiedine

These samples of bricks BR3 have a very compact appearance, they are semi-hard, they have a porous appearance and are not brittle by hand. Their dimensions vary from 24 to 26 cm long, to 10 to 11 cm wide and 3.3 cm thick.

4- **House of the Casbah of Algiers**

These samples of bricks have a very compact appearance, are not brittle by hand, and have a semi-hard structure. With some ready variations the dimensions of the bricks are 21 cm long by 10 cm wide and 3 cm thick.

Buildings	Location	samples	Description
powder magazine BR1			- Compact appearance, - Tender - Hand friable - Porous aspect - Dotted with white grains - Colour: copper yellow to copper orange - Dimension: 27X12X3.8 (cm)
the Casemates BR2			-Compact appearance, - Semi Tender - Little friable by hand - Orange-red colour with small white grains Dimension : 28×13X3.5 (cm)
Villa Mahieddine BR3			-Very compact appearance, - Half duration - not brittle by hand. - Porous aspect. - Yellow- orange colour Dimension : 26 ×12X3, 3 (cm)
The Casbah of Algiers BR4			-Very compact appearance, - Bricks are half hard - Not brittle by hand. - Porous aspect. - Red-orange colour - Dimension: 21×10X3 (cm)

Figure. 1. Location and description of samples.

2.2. Methods

We chose the complementary analysis techniques; in order to carry out the chemical and mineralogical characterization of the collected bricks samples [8], 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.

1- petrographic analysis

The petrographic study of the different samples of the selected materials is carried out according to the protocol adopted in geology for the study of the different types of rock [9]. This methodology has been applied in petrographic studies carried out on archaeological materials such as, the work carried out on the characterization of the types of dough used in Roman constructions and covers [10]. It is based on a reading at two macroscopic and microscopic scales.

2- 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.

Determining the concentration of free lime (CaO) is done via the sucrose method, according to NF EN 459-2. Determining the concentration of free lime (CaO) is based on dissolving the sample in demineralised Water, which is then titrated with hydrochloric acid (HCl), diluted to 5%, and using phenolphthalein as indicator, hence, we can quantify the amount of free lime (CaO) expressed as a percentage.

3- Mineralogical analysis

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

4- Mechanical analysis

This test was performed in the laboratory of the Research Materials and Environment (eg LMMC) research unit, M 'Hamed Bougara University, Boumerdes. We calculated the compressive and flexural strength of the different samples.

3. Results

3.1. Petrographic analysis.

All the results of the petrographic study are summarized in "Figure 2".

The BR1 sample (powder magazine) has a carbonate matrix whose colour varies from coppery yellow to coppery orange, see brown for some grains. It has the Dolomitic and micritic texture combined with iron oxide with more than 10% of grains not joined in a carbonated mud. The texture is heterogeneous, with grains of different sizes and different nature. The grains are subangular and rounded, in large proportion in the matrix, greater than 30% of the dough. There is a large amount of monocrystalline and polycrystalline quartz, clay (kaolinite and illite) and micas. The matrix has a dissolution porosity of almost 10%.

The matrix of BR2, is carbonate of orange-red colour and completely oxidized. It has the texture of a wackston limestone with more than 30% of grains not joined in a carbonated mud. The texture is more or less homogeneous, with grains of different sizes and different nature. The grains are subangular and rounded, in large proportion in the matrix, greater than 30% of the dough. We note the presence of often polycrystalline quartz grains, feldspars, iron oxide and micas mainly biotite. The matrix has a dissolution porosity of almost 10%.

The matrix of sample BR3 is yellow-orange, carbonated and oxidized in parts (red), the texture of which is compact and homogeneous. It contains grains of monocrystalline quartz, calcite and foraminifers, with practically more than 10% of very fine grains, consisting of fine sand with dispersed subangular sand. The matrix is very compact with very low porosity.

The matrix of sample BR4 is red-orange, carbonated, the texture of which is compact and homogeneous in appearance. It has the appearance of a micrite with less than 10% very fine grains (mudstone). It is an oxidized rock with probably the presence of hematite, nodules of carbonate nature, bioclasts (micritized bivalves, uniserized foraminifera and benthic and sometimes completely oxidized), clay in very small proportions. The quartz grains are monocrystalline. The matrix is very compact with a reduced shrink porosity.

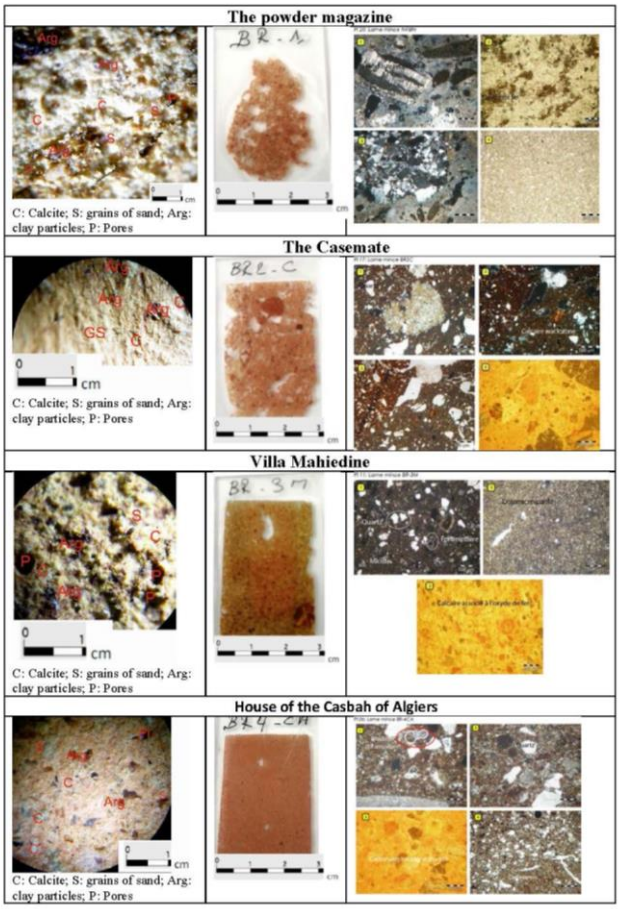


Figure 2. Microscopic observation and identification of minerals in brick samples N. Abderrahim (Mahindad / Y. Habrouche)

3.2. Physical analysis

The physical analyzes focused on the calculation of the apparent and specific densities, the total porosity and the open porosity as well as the water absorption and the humidity rate.

From the results reported in "Table 1", it appears that the water absorption varies from 18.15% for the BR4 sample from the house of Casbah of Algiers and 20.35% for the BR1 Powder magazine sample, which is equivalent to a total porosity, which varies from 30.04% to 32.35%. The percentage of open porosity of the different samples varies from 27.04% to 28.21%.

The water absorption varies from 18.15% for the BR4 sample from the house of Algiers Casbah and 20.25% for the BR1 sample from the powder magazine.

Table 1. Physical properties of mortars.

Samples	Apparent density (g/cm3)	Specific density specific (g/cm3)	Total Porosity (%)	Open porosity ouverte %	Absorption of water Ab (%)	Humidity (%)
BR1	1,38	2,04	32, 35	28,21	20,25	0,91
BR2	1,32	1,92	31,25.	27,18	19,78	5,24
BR3	1,43	2,05	30,24	27,12	19,04	1,25

In addition, we were able to determine the hardness of the bricks compared to the Mohs scale, as shown in “Table 2”.

Table 2. Mohs' hardness of brick samples

Samples	Sample crossed out by	Classification	Specification
BR1	Apatite	4	Tender
BR2	Apatite	4	Tender
BR3	Feldspar	5	Half-hard
BR4	Feldspar	5	Half-hard

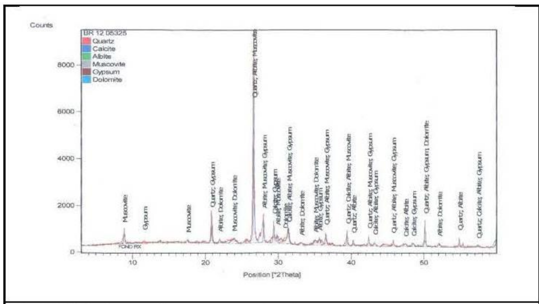
3.3. Mineralogical analysis

The mineralogical analysis of the bricks samples studied made it possible to obtain the results presented in “Table 3".

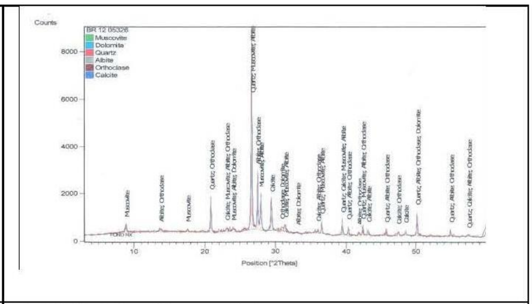
Table 3. Mineralogical composition of brick samples

Materials	Samples			
	BR1	**BR2**	**BR3**	**BR4**
Quartz	31,5	36,5	44	44,5
Albite	16,5	16	10	10
Orthoclase	-	14,5	10	5
Gypsum	1	-	-	3
Calcite	17	23	20	22,5
Dolomite	09	4,5	6	7
Muscovite	20	2	5	3
Hematite	-	-	3	-
Other	5	3,5	2	5

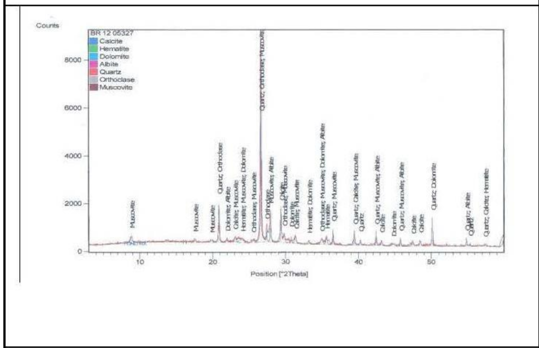
The mineralogical analysis of the different samples as we can see in theXRD diagrams, presented in “Figure 3”., shows that all the samples analysed consist of quartz which is from the group of silicates, in large proportion between 31.5% and 44.5%, as well as calcite In proportions up to 23%. The other components are in a smaller proportion apart from Muscovite which is present for a rate of 20% in the BR1 sample, moreover the Albite is found in close proportions in all the samples and vary by 10% for BR3 and BR4, at 16% for BR1 and BR2. We note the presence of Dolomite in a smaller proportion. This composition allows us to certify that the clay used for the manufacture of bricks is a limestone clay but which present certain differences from one sample to another.



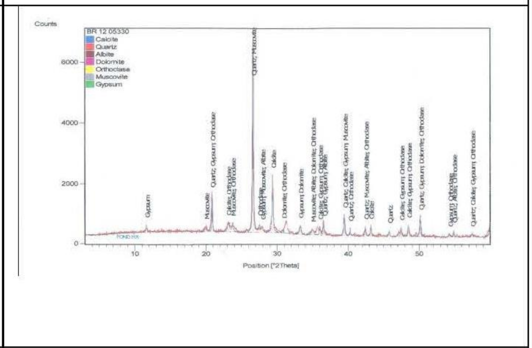
A. BR1 (powder magazine)



B. BR2 (The Casemate)



C. BR3 (Villa Mahiedine)



D. BR4 (House from Casbah of Algiers)

Fig. 3. The XRD Diagrams of the different bricks samples from the city of Algiers (CETIM)

3.4. Mechanical analysis

The mechanical tests of the bricks removed focused on compression and bending tests, according to the protocol shown in “Figure 4”.

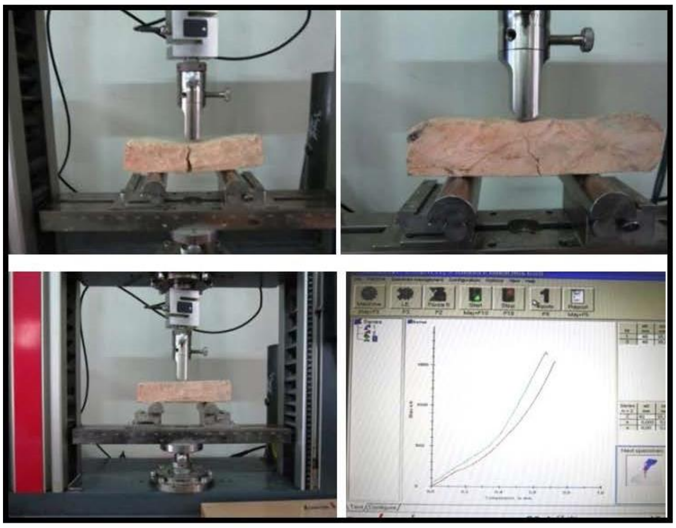


Figure 4. Compression test process (N.Mahindad)

The mechanical tests relating to the compressive and flexural strength and shown in Table 4, have shown that all of the bricks samples have an average compressive strength which does not exceed 9 MPa, while the average value of the compressive strength must be between 8 to 12 MPa The greatest compressive strength was found in the BR2 sample (8.33 MPa), while the lowest value was recorded for the BR1 sample (4.46

MPa). Furthermore, from the results obtained, we note that the flexural strength is lower than the compressive strength and it varies from 4.02MPa to 6.32MPa.

Table 4. Results of mechanical tests on brick samples

Samples	Compression (MPa)	flexural strength (MPa)
BR1	4,46	4,42
BR2	8,33	6,32
BR3	5,73	4,02
BR4	6,84	5,13

4. Discussion

The results of the physical tests show that the total porosity varies from 30.04% to 32.35%. The average of the open porosity contents of the different samples is 27.43%. The maximum value of porosity was recorded for the BR1 sample (powder magazine), it is 28.21%.

The humidity rate differs from one sample to another. These rates are related to the environment of the building where the sample was taken. The humidity is quite high for all the samples. It is noted that the highest humidity level is at the Casemate level with 5.24%, where the brick sample was taken in a confined space and poorly exposed to the sun, while the lowest rate is at the level of the powder magazine with 0.91%. The powder magazine space is a space dedicated to the manufacture of powder, so we are in an isolated and dry environment.
The Casbah sample also has a high humidity rate of 2.12%, and a water absorption capacity of 18.15%. This site is confined and the buildings very little exposed to the sun, which increases the humidity in the environment.
The mineralogical analysis by diffraction shows that the essential components of the bricks analyzed are quartz and calcite in significant proportions. This composition allows us to conclude that the clay used for the manufacture of bricks is a marly limestone clay, therefore, we are in the presence of silica-limestone bricks. The bricks show differences in other components, such as Muscovite which is found in large proportion at the powder magazine level (20%) and the orthoclase which is present in three samples BR2, BR3 and BR4 in considerable proportion varying from 5 to 14.5%.

The color of the bricks is a function of several factors including the ferruginous nature of the clay, the firing temperature, the firing level and the atmosphere of the oven. Thus, certain mineralogical components can influence the nuances of the color, in particular the iron oxide, which one can find in hematite, which is present only in the BR3 sample (Villa Mahieddine).

The mineralogical analyzes highlight some variations in the mineralogical compositions of the different samples studied. In addition, the petrographic analysis allowed us to identify more precisely the grains of sand, the additives, some figurative elements like organic matter and also some alteration or oxidation reactions.

The different samples are made of monocrystalline or polycrystalline quartz but have differences in terms of the figurative elements they contain, thus the samples BR1 and BR2 contain white micas (muscovite) for the first and black (biotite) for the second of which the origin may be the granite found near the Bâb Azzoun gate, while the BR3 and BR4 samples contain bioclasts and foraminifers.

Components that allow us to group the manufacturing pastes of the bricks studied two by two. It turns out that the bricks BR1 and BR2 have pastes whose compositions are close but present differences in terms of their structures, which lead us to assume that the raw material comes from the same or similar deposits, probably red marl or yellowish and which occupies the plateaus, the plains and the valley bottoms which border the city of Algiers. The difference in texture could be explained by the implementation in the manufacture of bricks and in particular the mixing, which when it is poorly executed reveals a heterogeneous structure.

The bricks BR3 and BR4 have different textures but there are similar figurative elements, in particular the bioclasts, which allows us to advance that the clay used, comes from the marly clay mass found near the quarry of hydraulic works, near the city of Algiers.

The bricks BR3 and BR4 have different textures but there are similar figurative elements, in particular the bioclasts, which allows us to advance that the clay used, comes from the same marly clay mass.

In correlation with the petrographic descriptions, it can be noted that the samples with dark matrices, in particular BR2 and BR4, which are orange-red to red-brown in color, have better compressive and bending strengths than the color samples clearer, namely BR1 and BR3. This state of affairs could be explained by the firing conditions of the bricks, given that among the criteria for determining the color of the bricks, in addition to the ferruginous nature of the clay, there is the firing temperature, the level and the atmosphere of the oven.

5. Conclusion

In conclusion, we can retain the following points in relation to the characterization of the different samples of the bricks of the buildings dating from the Ottoman period of the city of Algiers.

The different samples of bricks studied are sand-lime bricks. the clays used come from marl clay formations specific to the site, since the deposits are generally close to the built monuments.

Nevertheless, in view of the geological specifications of each region, such as muscovite and orthoclase, the origin of which may be the granite or sand found in samples from the city of Algiers and the gypsum found in shale or limestone, with which, gypsum can be associated. These various minerals can be considered as intentional additions to the composition of the bricks as a degreaser aimed at improving the characteristics of the clay used.

The compressive strengths of all the bricks samples taken have a compressive strength, which approximates the minimum admissible values. The greatest values of the compressive strength were recorded for the samples whose color of the matrix is darker, which allows us to deduce that the resistance of the bricks to mechanical stresses is related to the firing temperature of the bricks and the nature of the raw materials which influence the physical and mechanical characteristics of the materials

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