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CHARACTERIZATION OF BRICKS USED IN THE EXTERNAL CASING OF ROMAN BATH WALLS "GADARA-JORDAN"

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ABSTRACT

The use of sub-soil materials have been used in buildings long time ago, for more than 10,000 years. This study investigates the different characteristics of brick units used in one of the Roman baths in Gadara archaeological site. This is achieved by studying the raw materials and the different technological measurements of brick units: shapes, dimensions and visual description. Moreover, it studies the construction techniques and deterioration problems, by using some scientific techniques and analytical procedures such as EDX for defining the elemental and chemical characteristics of brick samples, Polarizing microscope and XRD for studying the mineralogical components, in addition to the use of SEM that was used for studying the morphological characteristics of the samples. Furthermore, this study determines the different physical, mechanical and thermal properties of the collected samples according to different scientific techniques and standard tools such as digital camera, magnifying glass and mechanical sieves. The results of the study prove that the brick units are divided into two types cubit square and rectangular shapes which are used as external casing layers. They are characterized by homogeneous chemical characteristics and different visual appearances according to the firing degrees and firing conditions (oxidizing or reduction). On the other hand the differences of these physical properties play specific roles in the deterioration cycles, and their mechanisms affect the brick units. Finally, the study provides a definition of the effective methods, materials and preservation measurements for restoring and maintaining the investigated monument.

KEYWORDS: Brick, External Casing, Deterioration Problems, EDX, XRD, SEM

RESEARCH OBJECTIVE

The objective of this study is to show the different characteristics of ancient bricks used as an external casing, and to study the relationships among these characteristics and different deterioration forms affecting one of the oldest brick buildings in Jordan

1. INTRODUCTION

Bricks are one of the oldest building materials known to man (Baradan, 1990). The use of sub-soil materials in building was a large subject along eras (Harrison, 1990). Soil, mixed with water and various additives, has been used as a building material for more than 10000 years and is still used. Where more than ⅓ of the world's population is still living in adobe and similar structures (Sumanov, 1990). The brickwork has attracted considerable interest over the years, through using different types of bricks that have been divided according to different criteria depending on fabric, dimensions, regularity of shape and appearances (Warren, 1999). In addition to the presence of other factors that resulted from manufacturing effects such as sharpness of arises, smoothness of faces and bottom surfaces as well as the presence or absence of such features as sunken margins, pressure marks and forge. Fired or burned bricks have been used on a large scale (to a large extent) in buildings from the very beginning of the third millennium B.C. when a facing of fired clay bricks was used in the great Ziggurats Ur in about 2100 BC. In later times the Romans and the Byzantines brought fired clay brick to a state of fine achievements. (Weaver, and matero, 1997). In Jordan, for example, there are some Roman and Byzantine archaeological structures that were mainly constructed by fired bricks.

The aim of this study is to evaluate the different chemical characteristics and physical properties of brick unit used in the construction of one of the most important archaeological buildings situated in Gadara and to assess its deterioration forms. Moreover, the study aims to know and choose the suitable materials and methods that will be used in the contrive steps of new brick unites for reconstruction purpose.

1.1 Historical Overview of the Case Study

The site of Gadara is located in northern Jordan, 28 km. northwest of Irbid city on a flat plateau of Limestone dropping steeply to the north, south and west from altitude of 350m. above sea level (Nielsen, et. al., 1989). Unfortunately, there is no single study, before this one that took into consideration the characteristics of fired brick as an important building material in Jordan. Some earlier studies mentioned, without giving details, that bricks were used as construction or decorative materials in different sites. For example, it was mentioned that the fired brick was used in Qasr Mshatta (that was built during the Ummayyad period) where natural stones were employed for the exterior walls and brick for the interior walls (Cresswell 1958).

The Roman bath in Gadara (Fig. 1-a) was excavated in 1977-1983 by Danish archaeologists who had no evidences indicating when it was built. This building is located about 50m. west of the central-plan church. (Weber, 1988). It is considered one of the most important archaeological buildings located in this area. The main building of the bath was

30m wide and 50m long. It was built on a steep slope. It consists of different rooms and open spaces, such as a changing room, a warm room, a sauna room, a hot room and other services room (Fig. 1 -b). The bath came to an end by a destruction caused by an earthquake at around 400 AD. Furthermore, in the first half of the 7th century AD., the bath was used as a habitation or perhaps for industrial purposes. It was ultimately destroyed by the great earthquake of eighth century AD. (Russell, 1985)

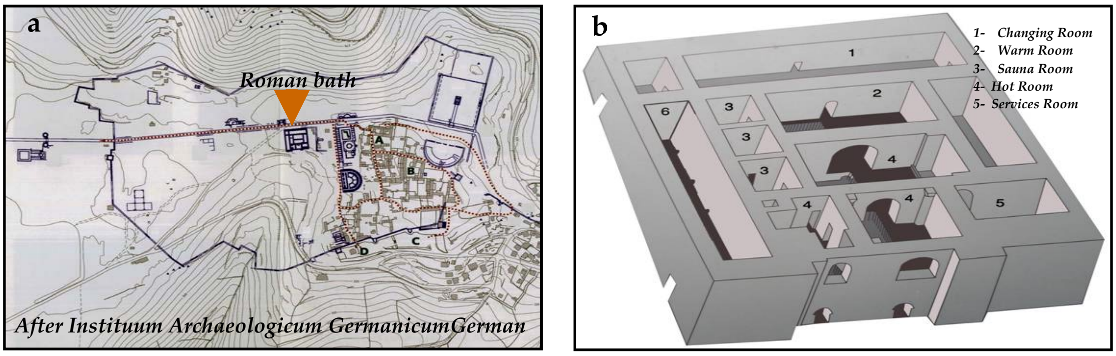
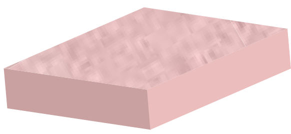
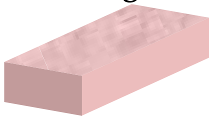


Fig. 1 a, b: Site plan and general overview of the roman bath in Umm Qais

1.2 Raw Materials Used

Red bricks are used as an external casing to cover limestone ground and walls in different sites of bath. Brick units are cemented by mud mortar and characterized by decayed and disintegrated surfaces in addition to contamination by different deterioration products such as gray hard crusts, black cement layers, biological colonization, fly ashes and soil particles. Technically speaking, scientific and analytical studies were done to evaluate the different shapes and dimensions of this brick to realize different relations between it as one of essential building materials and different deterioration mechanisms. All results are listed in the table 1.

Table 1: Measurements of burned bricks used in Roman bath in Gadara

Dimensions	**Dimensions**		
	Length	*Width*	*Height*
Cubit square 	25 cm ± 0.15 mm	25 cm ± 0.30 mm	3.4 cm ± 0.21 mm
Rectangular 	24.4 cm ±.1 mm	12.4 cm ± .1 mm	3.3 cm ± 0.11 mm

1.3 Brick as a Casing Technique

Fired brick was used as a building material in different techniques such as a course building by diagonal and horizontal layering (Harrison, 1990). These techniques were varied either in their height or shapes to create different architectural features such as walls, foundations, domes, complex series of arches and vaults (David Moore, 2002). They were stuck with some types of mortar that transformed directly after drying to compose a monolithic construction, (Kholucy, 1990). So, it is important to understand how each of the discrete brick systems was designed to react with the different deterioration and disintegration factors, where the potential damage is not easily detectable (Grrison, 1990) Through different historical, technical observations and structural analyses of our case study it could be said that the brick units were used as external casing layers to cover the essential walls of the bath with height of about 1.83m, in addition to the ground of warm and sauna rooms to prevent the leakage of water vapor and to maintain the internal temperature, (Fig. 2).

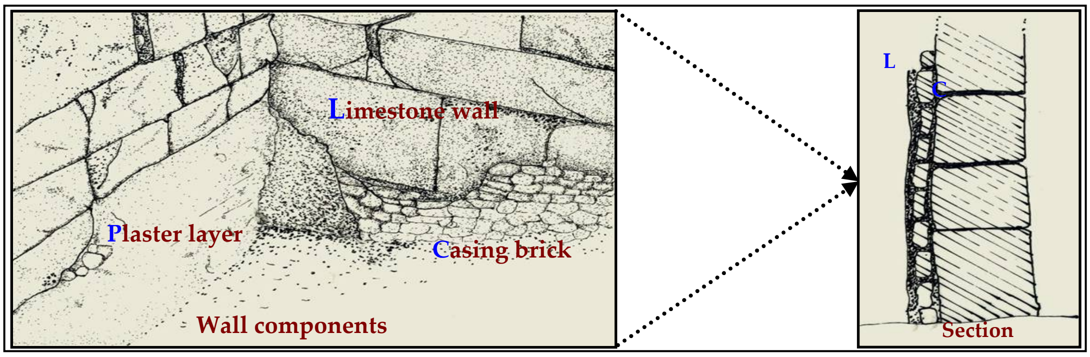


Fig. 2: The brick unites used as an external casing on the bath walls

1.4 Condition Assessment

The decay of the building materials such as stones, bricks and mortars is a complex phenomenon (Sarkar, 1992). It takes place through various deterioration mechanisms (Collepardi, 1990); mostly due to external and internal deterioration factors. All of these mechanisms lead to the creation of different deterioration forms such as leaching, dissolution and cracks, (Bityukova and Limberg, 2005). In addition to the appearance of other deterioration aspects as salt efflorescence, staining of the exterior walls and spread of an unpleasant smell throughout the building (Ignatavičius, 2005). Bricks suffer from several factors of weathering processes like other porous building materials especially when buried in a salty ground (Karpuz and Pasamethouglu, 1992), (Fassina, 1988b). All of these factors lead to several mechanisms of deterioration. Some of these mechanisms and changes are minor and imperceptible; some are so fundamental. Those original materials are barely recognizable, some changes are intentional and controlled, as in the processes of manufacturing; some are unintended and largely uncontrolled as in deterioration and disintegration and finally some of them are accepted or welcomed (Pye, 2001).

Mostly, the main cause of brick buildings decay, apart from the occurrence of natural disasters like earthquakes and floods, is the effects of human factors that include poor maintenance and abandonment (Michon, 1990)(Gale, 1997). The different deterioration forms affecting the brick artifacts are considerably varied due to the variation in their chemical composition, the nature and quantity of impurities brick contain (Plenderleith and Werner, 1989). From this point of view it could be said that our case study was affected by several deterioration processes. These processes affected both bath brick structures and brick units. These processes are also mainly due to four causes which could be summarized as follows:

- The aggressive environmental situations in the study area (i.e. effects of air temperature, wind blown and rain off moisture) (El-Gohary and Al-Shorman, 2006).
- The properties of the brick (i.e. the relation between the natural hazards and physical, and mechanical properties, in addition to differentiation of chemical characteristics)
- The improper details, specification and workmanship (i.e. strange additives, impurities insufficient preparing and manufacturing steps)
- Finally the effects of use and the improper maintenance (i.e. unsuitable design, building techniques defects and wrong conservation works).

After evaluating and assessing all environmental conditions, dominated meteorological parameters "Air temperature, RH and Wind blown" and other deterioration factors dominating in the study area it could be claimed that there are three essential mechanisms affecting the archaeological site owing to chemical, physical and biological actions. All of these mechanisms lead to the creation of several deterioration forms which can be concluded as follows:

- **Category A:** Resulted essentially from the effect of ***physical mechanisms*** affecting ***bath walls*** that lead to create different deterioration forms such as in *unequal settlement*, *collapsing of internal architectural features* and *general instability*, (Fig. 3).

Fig. 3: Some *physical* deterioration forms affecting the brick structure

- **Category B:** Contains different deterioration aspects resulted essentially from the effects of ***chemical deterioration mechanisms*** affecting the brick units such as sap root staining, *bees burrowing* and *bird accumulations*, (Fig. 4).

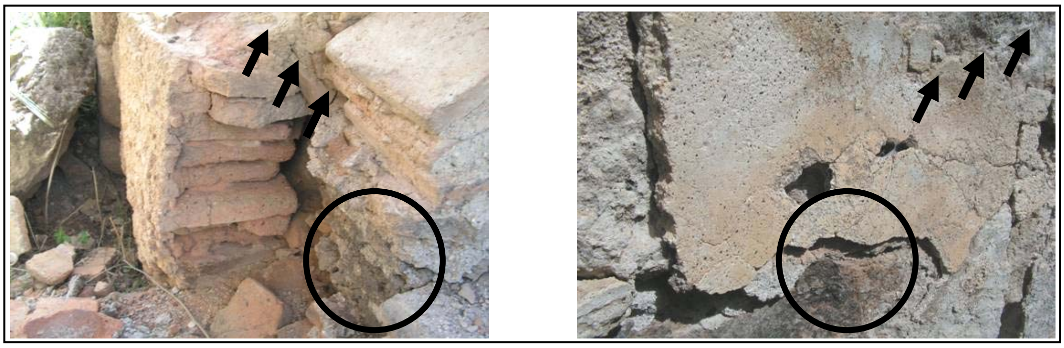


Fig. 4: Some *chemical* deterioration forms affecting the brick structure

- **Category C:** Includes the ***biological mechanisms*** affecting both the joints and plaster layers which lead to several deterioration appearances such as *salt crystallization, poor carbonation of mortars, wearing out of mortar components and water saturation*, (Fig. 5)**.**

Fig. 5: Some *biological* deterioration forms affecting the brick structure

2. EXPERIMENTAL STUDIES

Several kinds of laboratory tests can be performed when further information is required either to identify materials; measure their properties (Fitch, 1997), or to evaluate their deterioration states (Pye and Cronyn, 1988). From this point of view some red brick samples and different surfaces accumulations, table 2 were collected from different points at the site and submitted to analytical studies by chemical, physical and mechanical tools such as polarizing microscope which serve for the mineral identification.

This is done by investigating the different optical characteristics of sample components and XRD which serve for the mineral components (Fitzner, et al, 1994) in addition to other techniques such as EDX, SEM and some computer programs.

Table 2: Description and different characteristics of the collected samples

Samples	*Samples details and visual observations*			
	Kind	*Altitude*	*Place and Direction*	*Samples description*
1	Fragment	180 cm	North interior wall	Some sample used for EDX, XRD, petrographic description and SEM studies
2	Fragment	90 cm	Western interior wall	
3	Fragment	120 cm	Southern interior wall	
4	Fragment	ground	Eastern interior wall	
5 -17	Random fragments from interior walls and different altitude for defining physical properties			

2.1 Visual Examinations

Scientific digital camera (Pentax-K100 D super with magnifying glass) and mechanical sieves numbers (2.5, 1, 0.5 mm) were used for identifying and describing the visual features of brick samples "Color and Texture". The different results indicate that the samples are characterized by different surfaces features such as ***color*** which is divided into 3 types, light to dark reddish, dark yellowish and black to brown according to firing degree, and the position of brick units in the kiln. Moreover, the ***texture*** of the samples vary from coarse, (i.e. most of the non clay minerals have a grain size higher than $^1/_{16}$ mm , such as sand) to fine grains in which most of the non-clays, made of grains, have a grain size finer than $^1/_{16}$ mm, such as silt (Fig. 6).

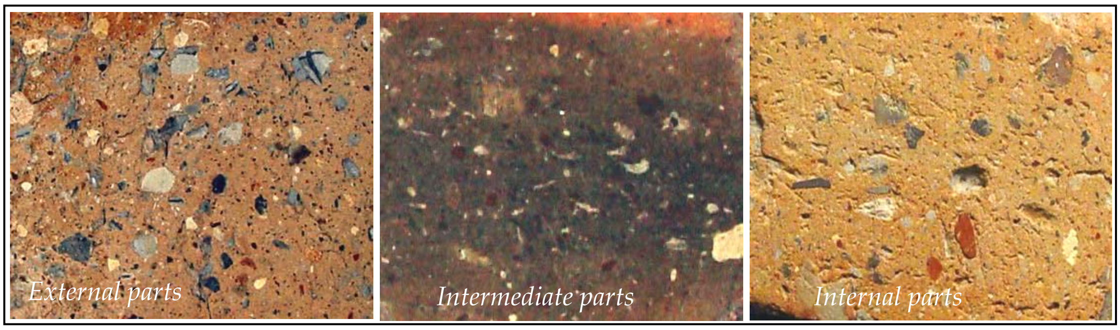


Fig. 6: Different colors and texture features of brick samples

2.2 Polarizing Microscope Examinations

Polarizing microscope is a principal method of identifying minerals in archaeological materials through petrographic analysis. It is closely related to petrology and deals with the origin, occurrence and, structure of minerals. (Rice, 1987). Some brick samples were prepared according to Lewis and McConchie, 1994, and investigated by *Leica DLMSP polarizing microscope* to identify the studied samples and their texture. Photomicrographs were obtained using a camera attached to the microscope and the relative abundance of each constituent was determined using *Prior Model G point counter*. The results showed that all used materials are related to the local Jordanian materials which had been used along time both in brick and pottery manufacture particularly clay materials. All of these materials are characterized by amorphous or glassy structure. Furthermore, all of the samples include some none clay minerals, such as, ***Calcite*** **(Limestone fragments)** as primary and regular grains with 7-10 %. ***Grog*** **(Pottery fragments)** finest grains characterized by sub-rounded to sub-angular shape. In addition there are 1-3 % ***Fine Quartz*** grains, "*free crystalline silica*", 1% angular shape ***Chert*** and less than 1% ***Plagioclase***. Furthermore**,** the samples also contain 1% ***Olivine*** and 1% ***Pyroxene*** "characterized by cleavage index", in addition to some alteration products such as ***Iddingsite*** and some additive minerals mostly lower than the matrix clay, (Fig. 7-a, b, c, d, e, f).

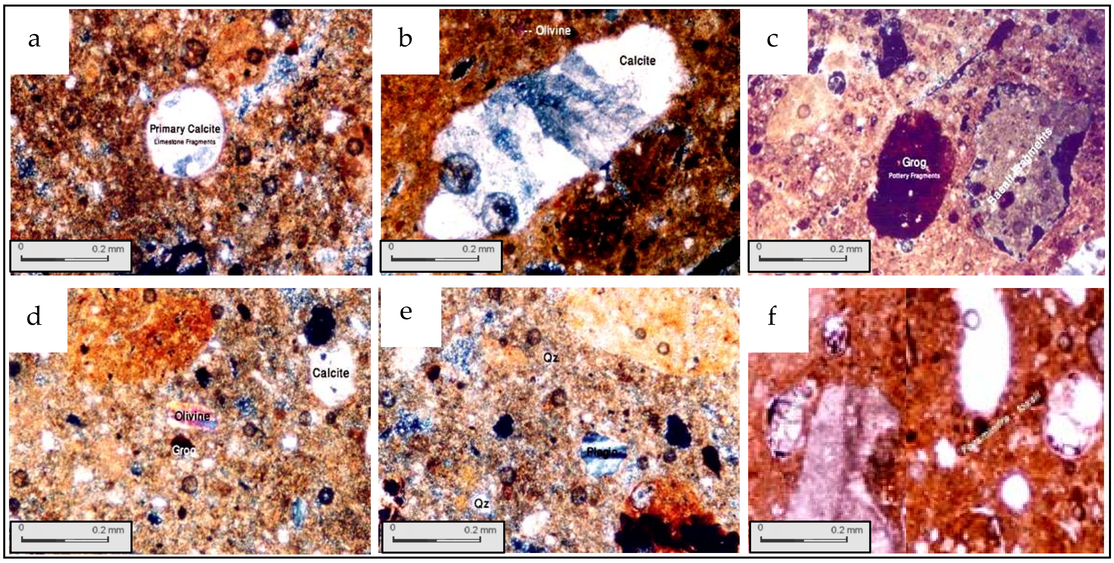


Fig. 7 (a, b, c, d, e, f): Polarizing micrographs of different optical features of red brick samples

2.3 Morphological Description by Scanning Electron Microscope "SEM"

The Stereo-scan or SEM is one of the most scientific tools used in the material investigations (Brothwell, 1971) through scanning highly focused electron beam over the target area and observing the generated secondary electrons that reflect and define the morphological features of the samples (Mcalister, 1996). SEM model FEI Quanta 200 was used to achieve this target. All obtained observations indicate that the brick body contains different surface features, such as the wide distribution deteriorated crusts and corroded quartz grains with the presence of some large voids and macro-pores, as well as, some disintegration aspects in each grain (Fig. 8-a), in addition to the presence of some organic and inorganic residues and vesicular remains characterized by combustible materials such as vegetables matters and straw (Fig. 8-b). Also, some powdered and sieved charcoal, organic chips, limestone grains and portray fragments were present (Fig. 8-c).

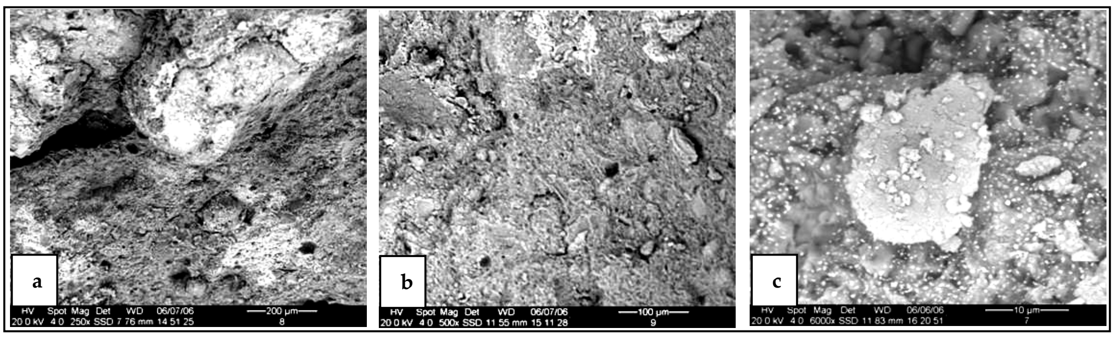


Fig. 8 (a, b, c): SEM micrographs showing different morphological features of red brick samples

2.4 Chemical and Mineralogical Characteristics

The chemical and mineralogical analysis of building materials are necessary to assess the grade of their components and their alteration products.

2.4.1 Elemental investigations by "EDX technique"

EDX Energy dispersive X–ray spectrometer is a powerful tool for studying the mineral distribution and more precisely the effect of the elements on this distribution. (Lini, et al., 2006). It is one of the various techniques that are used to determine the concentrations of inorganic elements (Cook and Martin, 1988). EDX analytical unit attached with FEI Quanta 200 SEM was used to identify the elemental composition of the samples.

The results proved that the investigated samples are divided into 3 groups (a, b and c) according to the effect of firing temperatures degree, the changing of essential ratio of the clay mineral elements, as well as the position and the direction of brick units in the kiln (***a***) high fired surface, (***b***) medium fired surface and (***c***) low fired surface".

All of these results are shown in (Fig. 9- a, b, c)

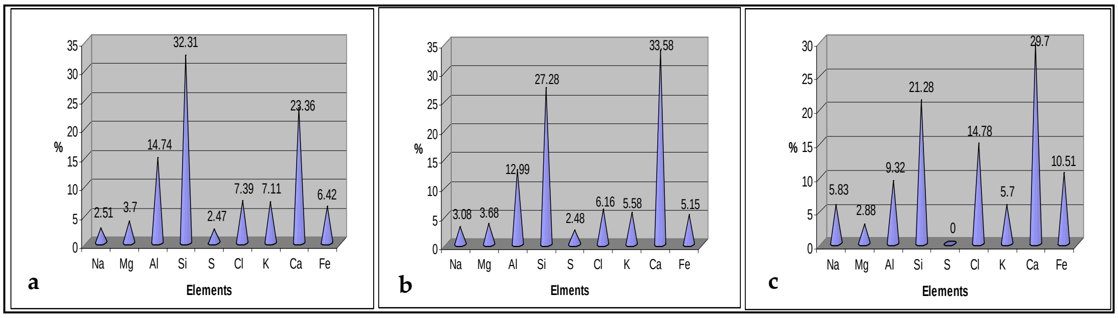


Fig. 9: Different analytical results of brick samples by EDX technique

2.4.2 Mineralogical investigations by "XRD technique"

X- Ray Diffraction technique has always been considered a powerful tool for detecting the mineralogical crystalline compounds which are present either in building materials (Moriconi, et al., 1994), fired materials characterization (Zussman, 1977) or in weathering surface crusts (El-Gohary, 2004$_b$). Accordingly, different samples of fired bricks were collected from the site and analyzed using XRD model 6000-Shimazu X ray diffractometer to identify the microcrystalline phases present in these samples. The analytical data showed that the samples could be divided into 3 main categories: the 1st category represents the outer surface facing directly the firing source, (Fig. 10-a) the 2nd category represents the outer surface of brick far away from the firing source, (Fig. 10-b) and the 3rd category represents the core of the brick, (Fig. 11).

The analyzed samples contain different types of crystalline minerals such as ***Calcite***, ***Quartz***, ***Witherite*** and ***Halite***, in addition to ***amorphous structures*** in the clay mineral zone.

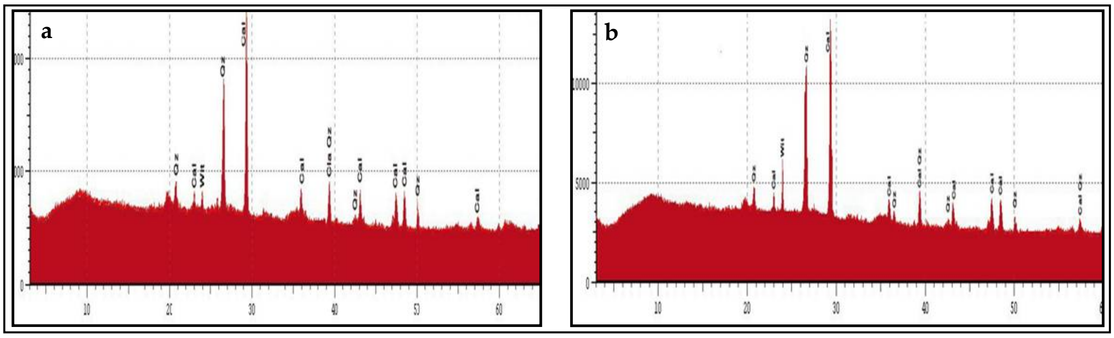


Fig. 10: XRD pattern of outer surface a facing directly the firing source and b far away from the direct firing source

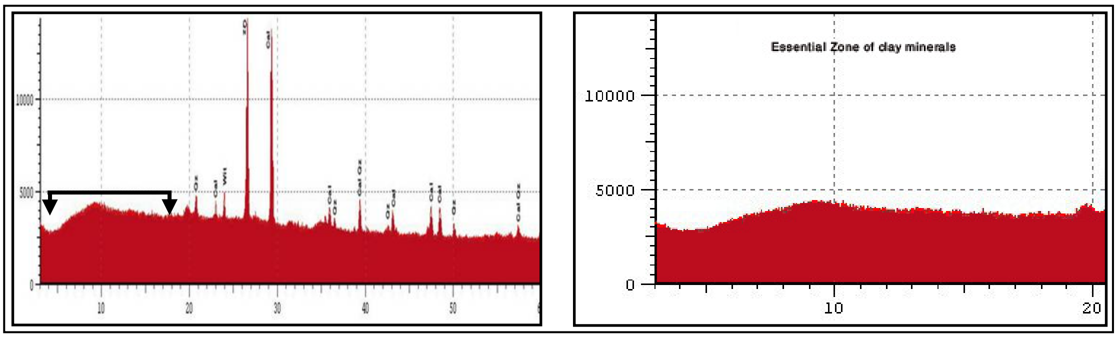


Fig. 11: XRD pattern of the core of brick (intensity vs 2θ)

2.5 Physical Properties

Different physical properties have a great influence on the engineering behavior of building structures and their materials (stone, brick, mortar and plaster) (Bajare and Svinka, 2000) (El-Gohary, 2004a). Some of these properties are mostly related to each other and depend directly on the presence of pores, grain types and cement materials as well as mineralogical composition. Furthermore, it is well known that the porosity of the burnt brick (pore size, shape and position) depends ultimately upon the size and shape of the particles in the clay body (Grimshaw, 1971).

In addition, porosity depends on the raw materials and firing temperature. This firing temperature vitrifies brick materials and decreases their pore space which depends on extreme resistance to moisture movement of the very small intervening space (Warren, 1999). Affected samples were randomly collected from the main body of the path walls. They were mechanically cleaned by coarse and soft brushes and they were prepared to testing procedures.

Density, Porosity, Saturation degree and Water-up-take of brick samples were evaluated according to the procedures recommended by *RILEM, 1980 Tests No. I.1 and I. (A1)2* in order to assess different relationships between them and the impact of environmental weathering affecting the alteration of the brick structure through using different tools and computer programs according to the following formulas:

- **σabs** = M1/ (M1-M3) in g/cm^3
- **σapp** = M1/(M2-M3) in g/cm^3
- **ϱ** = (M2-M1)/(M2-M3)*100 in vol

%, where:

σ_{abs} is absolute density, σ_{app} is apparent density, ϱ is porosity, **M1** is dry weight, **M2** is wet weight and **M3** is hydrostatic weight. The obtained results are showing in figures (12), (13), (14), (15).

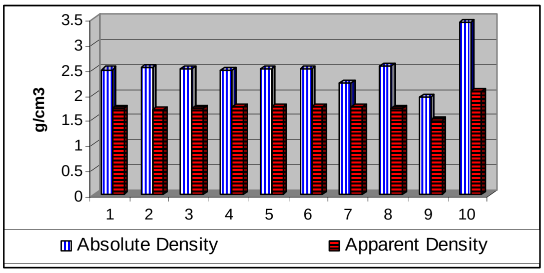


Fig. 12: The differences in *density* index "absolute and apparent" of the samples

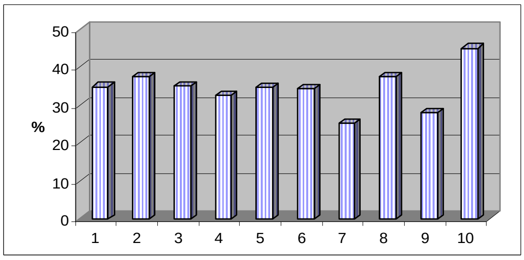


Fig. 13: The differences in *porosity* index of the samples

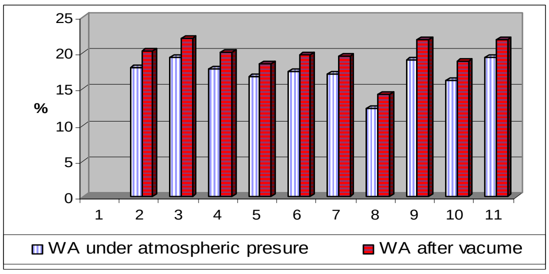


Fig. 14: The differences in *water uptake index* "under AP and after V" of the samples

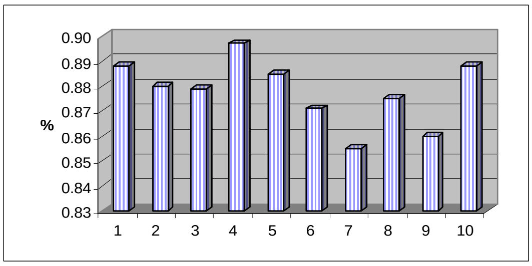


Fig. 15: The differences in *water saturation coefficient* of the samples

3. RESULTS EVALUATION AND DISCUSSION

The study proved that there is a noticeable difficulty in discussing the different chemical characteristics and physical properties of brick structure. This difficulty is essentially due to the effects of several deterioration forms that are attributed to the effects of deterioration cycles dominating in the study area, as well as the effects of manufacturing processes. In addition to the diversity of the inorganic and organic material used to produce the brick. These different relations are fully presented and explained as follows:

3.1 Visual Examinations

According to Fig. (6), the color variation from light to dark (Warren, 1999) may be due to the arrangement of bricks in the kiln, where the exposed parts being burnt to a light color and the parts resting against each others to a dark color. These variations depend on the quantity and quality of the raw materials, and on how a particular kiln or clamp was fired, in addition to the firing conditions of different parts of a kiln. Consequently, visual features of brick units indicate that they are noticeable variable colors such as ***dark reddish*** on external part of the brick facing directly the firing source, and ***Light reddish*** or ***dark yellowish*** characterizing the other part of brick units are due to the semi reduction conditions during the firing processes, while ***black, brown and red*** in the core middle part of the samples are attributed to the oxidizing conditions. On the other hand, the sample texture varies from ***coarse***, ***intermediate*** to ***fine*** which are particularly due to several reasons such as preparing and mixing of raw materials, as well as firing degree and firing conditions, in addition to the type and the appearances of different grains "raw materials" used in the brick manufacturing, or partly to the culture and tradition dominating at that time. Finally they are due to the deterioration factors affecting the brick units.

3.2 Polarizing Microscope Examinations

As previously shown in Fig. (7- a, b, c, d, e, f), the amorphous or glassy structure characterizing the investigated samples is due to the breaking down of the clay minerals, which were changed directly to dark materials that were said to be isotropic, as reported before by Hodges (1976). The decomposition of clay minerals and the loss of their crystallographic structure (to become amorphous) starts at a temperature of about 550 ^{o}C (in the case of Kaolinite) and about 750 ^{o}C (in most of other clays)..After that, the vitrification process will take place at a temperature higher than 900 ^{o}C (Todor, 1979). In the case of our samples, the clay groundmass is completely amorphous, which agrees with the indications of the presence of calcite. This is why no clay could be detected by the XRD, although very limited vitrification could be rarely detected, which can be attributed to the flux effect of some alkalis such as sodium and potassium. On the other hand it can be said that the presence of ***Calcite*** **(**Limestone fragments**)** as primary and regular grains is due to the firing degree less than ***800 ^{o}C***. Once the firing degree reaches ***800 ^{o}C*** or above, $CaCo_3$ will decompose and CaO may react with the clay forming calcium silicate (*Wollastonite*), which is characterized by a pale or white color (Rice, 1987). These grains mostly resulted from some fossils activities *particularly Foraminifera, or from* the fragments of limestone which were added as a flux for reduction of the firing temperature during manufacturing the brick. ***Grog*** **(**Pottery fragments**)**, the finest grains with subrounded to sub-angular shape, are present as a direct result of adding these fragments during brick making in order to improve some of its physical properties and to prevent or reduce the shrinkage index. The presence of ***Fine Quartz grains*** "*free crystalline silica*" is mainly due to the fact that quartz is the most common and abundant inclusion in the most fired clay bodies and play an important role in determining some structural properties such as shrinkage, porosity and strength. (Rice, 1987). On the other hand the presence of both angular grains of ***Plagioclase*** and ***Chert*** are ascribed to the addition of some local raw materials such as stone fragments. Furthermore, ***Olivine*** and ***Pyroxene*** essentially result from adding some of the basaltic fragments spread in the study area during the production processes.

3.3 SEM Morphological Descriptions

As shown above through SEM photomicrographs figures (8-a, b, c), all observed deteriorated forms indicate that the brick body was highly affected by some aggressive factors of deterioration especially wind erosion and groundwater actions as well as aggressive actions of rainfall (El-Gohary, 2004a). In addition, some different disintegration aspects especially black hard crusts (Some fly ashes cemented by black cement mortar) had been attributed to the synergetic effects between different sources of water and dust particles (Fassina, 1988a). Furthermore, it could be seen that the presence of some large voids, macropores and some disintegration aspects (corrosion forms in the most quartz grain) are essentially attributed to the loss of cohesive index of the cement materials because of leaching actions resulted from either rain water or ground water which finally may change the grains from angular and sub-angular to rounded and sub-rounded (El-Gohary, 2000). Within the same context it could be said that the presence of inorganic and organic residues, vesicular remains and other combustible materials may be present as a direct result of varied firing temperatures and quantity of air currents containing different types of pollutants (Bell, et al, 1996), as well as some powdered and sieved charcoal, organic chips, limestone grains and portray fragments that resulted from adding some local materials during the firing processes.

3.4 Elemental Investigations by "EDX technique"

As previously shown in Fig. (9-a, b, c) the investigated samples are divided into 3 categories according to the effect of firing temperature where ***category a*** characterizes the completely fired surface facing directly the firing source, ***category b*** characterizes the moderately fired surface facing indirectly the firing source and ***category c*** characterizes the slightly fired surface mostly representing the brick core. All of essential element ratios of the clay mineral (Na, Mg, Al, Si and Ca) were altered because of the degree and the time of firing in addition to the position of brick units facing the fire in the kiln (directly or indirectly). Also, it could be noticed that ***Si*** element as a major component in the brick samples is increasing according to the firing ratio (***32.31 in sample a***), (***27.28 in sample b***) and (***21.28 in sample c***). That is to say, the percentage of Si increases as a direct result of decomposition and decreasing of clay minerals which lose their crystallographic structure and become amorphous in the firing process.

3.5 Mineralogical Investigations by "XRD technique"

As presented before in XRD charts figures (10-a, b) (11), the samples contain 2 major minerals: Calcite and Quartz. ***Calcite*** ($CaCO_3$) is a major mineral resulted from adding limestone fragments during the brick making processes as a flux, or from using lime as sticking mortar, or as a direct result of water migration, Bajare and Svinka, (2000). It may be also due to the carbonation cycle affected lime mortar layers. On the other hand, the presence of ***Quartz*** (SiO_2) is ascribed to the use of some sand particles as an additive material in brick manufacturing. It may be also formed by rising the temperature, which leads to the driven off water of crystallization and carbonization of some organic compounds in an exothermic reaction. Consequently aluminum silicate will be dehydrated leading to the formation of SiO_2. Meanwhile, clays convert to amorphous metakaolin (Warren, 1999). Furthermore, ***Witherite*** ($BaCO_3$) as a trace mineral is similar to aragonite and occurs nearly in sedimentary rocks and results from alteration of some mineral as anglesite or barites (Deer, et al, 1975). Also, it mostly occurs through some effects of some inherent materials migrated from the ground water characterizing the study area. As emphasized by Petrakis, (1988) ***Halite*** (Na Cl) originated from different sources as rocks, soils or resulted from different chemical effects and drying cycles (Abdel Hady, 1995). It is one of the most serious soluble salts affecting the archeological materials which can occur both during burial time and after excavation. It plays an important role in determining the amount, the shape and the grade of deterioration. In our case, Halite exists as a trace salty material resulted from the soil that characterizes the study area. Its low amount is essentially ascribed to its high solubility index, and the effect of the alternative cycles of dissolving and crystallization; and vice versa depend on its equilibrium RH of this salt (75, 3% in 25°C). This result agrees with the results presented by Arnold (1981). Finally, the presence of amorphous structures in the investigated samples is due to the clay minerals themselves and is particularly difficult to analyze. Imperfections in crystalline structure affect their diffraction characteristics, (Grim, 1968; and Kingery, 1974).

3.6 Physical Properties

The corrosion of porous building materials does not only occur on the weathering surface, but also under the surface in the pore spaces, which represents the preferred affected area for physio-chemical and biological weathering processes. According to figures (12), (13), (14) and (15) all the studied samples have apparent density ranges between 1.48 and 2.06 g/cm^3 and between 1.95 and 3.43 g/cm^3 for the absolute density. The samples have a high total porosity between 25.17 and 45.04 %. Consequently, brick porosity is important; it, in addition to the chemical and mineralogical influencing factors influence movement of water, water vapour, and migration of salt solutions in building materials. Furthermore, the inner zone of building materials, being attacked chemically, is a function of porosity Von Plewh-Leisen, et al, (1994), Efes, (1979), Ordaz and Espert, (1985), Fitzner, (1988), Fitzner, (1990). Therefore, porosity seems to be the most important physical property affecting the deterioration cycle of building materials particularly under the effect of water and gases, Robertson, (1982), Mertz, (1991). In most of the cases, the more porous building materials are the stronger facing the deterioration cycles than the dense ones. Whereas the denser type is almost unaffected (Snethlage, 1985). From this point of view, it could be concluded that the porosity, pore size, and pore shape of burnt brick are controlled by many factors, among which the initial firing temperature, shape and size of additives are the most important (Grimshaw, 1971, Warren, 1999).

CONCLUSION

The study reported here shows that the Roman brick buildings in Jordan containing different types, shapes and dimensions such as rectangular and cubit square units. The characteristics that define these bricks units are many and varied. This may be due to the presence of some variables such as firing temperatures, materials used, manufacture processes and dominated conditions. The deterioration phenomena affecting the brick units owing essentially to some physical and chemical events, such as air temperature, wind blown and rain off moisture, leaching out, salt crystallization and thermal changes, in addition to the properties of brick itself. All of these mechanisms led to the creation different deterioration forms such as unequal settlement, collapsing of internal architectural features, sap root staining, bees burrowing, bird accumulations, poor carbonation of mortars, wearing out of mortar components and water saturation.

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