# THE EVALUATION OF THE MORTARS IN THE HISTORICAL BUILDINGS IN OTTOMAN EMPIRE

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## ABSTRACT

Mortars and plasters used in historical buildings provide important helpful information about the building technology of their historical period and they are as important as historical documents. Therefore, the evaluation analysis of the original mortar and plaster during the restoration should be made based on a scientific base. The work may require to include scholars with various professions such as art historians, restorators, physicians, chemists, biologists, engineers, and architects within the same team during the analysis process from time to time. However, method determination practices that shall be used in application on the subject matter have not been standardized. In addition, it is not possible to utilize all the experiments and the standards that check and control the quality of binding products and new materials applied to mortar and plaster analysis of historical buildings. The purpose of mortar and plaster analysis of historical buildings is not to make quality control of the material used, but to determine the physical, chemical, and mechanical properties. Therefore, it is required to provide the information that explains the current conditions of the material as well as the factors that have led to the formation of the current situation of the material used in the buildings. This work evaluates the material properties of some mortars used in historical buildings in the Ottoman Empire and supplies a guide for the determination of the construction techniques in the Ottoman Empire.

**Keywords:** Mortars, Byzantine, Land Walls, Density

## 1. INTRODUCTION

Mortars and plasters used in historical buildings provide important helpful information about the building technology of their historical period and they are as important as historical documents. Therefore, the evaluation analysis of original mortar and plaster during the restoration should be made based on a scientific base. The work may require to include scholars with various professions such as art historians, restorators, physicians, chemists, biologists, engineers and architects within the same team during the analysis process from time to time.

However, method determination practices that shall be used in application on the subject matter have not been standardized. In addition, it is not possible to utilize all the experiments and the standards that check and control the quality of binding products and new materials applied on mortar and plaster analysis of historical buildings. The purpose of mortar and plaster analysis of historical buildings is not to make a quality control of the material used, but to determine the physical, chemical and mechanical properties. Therefore, it is required to provide the information that explains the current conditions of the material as well as the factors that have led to the formation of the current situation of the material used in the buildings [1].

The properties and characteristics of the mortars mostly depend on the volume of the binder component. There is the reason for which its evolution with time has been much related to the development of artificial cementitious material. So with the consolidation of the Roman civilization, the use of lime mortars was generalized and extended. Since the 18th century, hydraulic binder begun to permanently replace the lime. These new materials hardened more quickly and developed higher mechanic strength. In 19th century, the invention of Portland cement revolutionized the world of building materials,

completely displacing the use of lime in all types of civil and military constructions.

With the purpose of modifying and/or improving some of the properties of the mortars, traditionally they have been mixed, some different products or additional constituents. These products have evolved during mixture. At the beginning, the admixtures were composed of natural substances (blood, egg, fig juice, pig grease, manure etc.).

Since a long time ago, mortars as construction element have had a double mission, on one hand to make the connection between other materials (fundamentally rocks and bricks) and on the other hand to cover and protect the surfaces of columns, walls and facades. It is obvious that these functions are vital for the conservation of the monument and they reveal the importance of these materials in the historical heritage.
Some characteristics of the mortars (mainly those related with the heterogeneous composition and high porosity) can affect its durability by making them easily attachable for external agents and so to contribute to the instability of materials in contact with them [2].

In our country, we encounter Khorasan mortar with varying mixture ratios in buildings from Byzantine, Seljuk and Ottoman periods. This type of mortar is as strong as concrete and is made by binding lime together with varying proportions of river sand and brick pieces/powder that are used as aggregates. Khorasan mortar has been widely used in Ottoman buildings especially in those that belong to the 15th century and in the period that follows. In 18th and 19th centuries, lime mortar, named as “royal mortar” which was made of Italian pozzolan “poçlana”, has been used. Lime mortar is actually composed of non-hydraulic lime, which is resistant to water, combined with pozzolan. In this way hydraulic lime is formed which is hard and resistant to water at the same time. Hence, it is also known as Khorasan concrete in history. Lime mortar made out of pozzolan and brick pieces have been named by the Romans as “opus cementicium” and they have continued to survive until today. In addition, these mortars have served to improve the cement technology of today. Towards the 20th century, the hydraulic quality of cement and its feasible use has been combined with positive features like low stress, high deformation capacity and porosity of lime mortar and as a consequence, lime-cement mortar production has begun. The first step in the evaluation of mortar and plaster used in historical buildings is the accurate determination of the original material used and the reasons that have led to deterioration [3].

In this work; the historic mortars of different buildings of Byzantine and Ottoman era are explained and the properties of the historic mortars are evaluated and compared each other. The evaluation gives a brief information about the historic mortars for the restoration works and architectural studies.

## 2. METHODS AND ANALYSIS

Mortars containing brick or tile powder and lime are called as Khorasan mortar in the Ottoman and Cocciopenti in the ancient Roman time. From the results of the various analysis of the coating mortar, it was determined that these consisted primarily of strongly carbureted on lime to which pozzolanic aggregate had been added [4]. The purpose of another study was to trace a constitutive history by means of chemical and mechanical analysis of the mortar used [5]. The different binders and aggregates used, coming from different quarries, could this suggest the existence of various moments of construction with an expansion of the built structure.

Mortars constitute a significant structural, as well as aesthetic element of historic masonry after closely related to the longevity and durability. Their structure and properties usually differ according to the functional role (structural mortars, renders-plasters, flooring), the technology of each era and the availability of raw materials [6;7].

The analysis and characterization of old mortars is performed by many researches and various methods and tools have been proposed during the last decades, focusing in the physical, mineralogical, chemical and mechanical properties of mortars. The difficulty in understanding the properties of historic mortars could be attributed to the variety of raw material used for their production (clay, lime, pozzolan, gypsum, brick dust, different types of aggregates) which are met in a range of proportions. In addition, other parameters such as the application technique or the environmental conditions could

also influence their properties. This interrelated system results in facing a rather complex problem during the analysis of historic mortar.

Historic mortars are composite materials, comprised of hydraulic or aerial binding material or a mixture of binding materials, aggregates not always in crystalline form and additive passive or active, which react with the binding material and are modified during their setting, hardening and ageing, according to processes as yet not well known.
The Romans are credited with a large number of innovation in construction, including hydraulic cement, a mixture of volcanic ash and lime. Mortars of different types and composition, were widely known and used in ancient world and the lime mortar-putty was wide spread throughout the Roman and Byzantine Empires. In many cases, lime was used as a binder and for better plasticity. Mortars with crushed ceramics as aggregates were used by the Ottomans. These mortars, besides being suitable for building purposes were also preferred as a watertight layer on building mortars or to enhance the watertight aspects of a building mortar. Adding limestone o the mix has been known to enhance the mortar strength. Mortars with volcanic aggregates with or without limestone fragments, were used for most building components or on exterior surfaces in the Ottoman and Byzantine buildings, as was used in the unique dome structure mortars of the contemporary St. Sophia Museum in Istanbul. The better freeze-thaw resistance of the mortars prepared with limestone and volcanic aggregates is probably due to an appropriate pore structure and sufficient mechanical strength. Furthermore, the better water-proofing behavior of the mortars with the additive of fine crushed ceramic is believed to result from a denser pore structure of the mortar binder [8].

The compactness of the studied mortar group confirms that there were in the past traditional mortar technologies that remained unaltered for large historical periods. The properties of crushed brick mortar, for example do not show appreciable changes from Early-Age Byzantine to the late Ottoman period.

Roman mortars have been highly appreciated for their durability. However, the main technological properties of Ottoman mortars, such as the mechanical strength, durability and permeability are not sufficiently well known to enable correlations to be established with their microstructure.

**2.1 Results**
The different types of historic mortars were used in Early-Age Byzantine and Ottoman buildings. The properties of the historic mortars do not differ according to the Byzantine and Ottoman construction. Above; the characteristic properties of some Byzantine and Ottoman buildings are determined and evaluated.

The porosity of Early-Age Byzantine mortars changes between 37-48 % in the Byzantine palaces (Big Palace) in Figure 1. The mortar is resistant to the volume change due to the freezing of water in the pores of the mortar. The unit weight is 1,32-1,61 gr/cm3. The binder/aggregate ratio is between 1/3 and 1/4. Early-Age Byzantine mortars are hydraulic mortars. This property supplies the pozzolanic activity and high strength of the mortar. The pozzolanic property depends on the brick pieces and powder or the pozzolans. The brick pieces increase the mechanical strength and the pozzolanic hydraulic reactions. The brick pieces were mostly used in Roman and Byzantine mortars. The maximum aggregate grain size of Early Byzantine mortars is 4 mm. The compressive strength of the mortars changes between 6-8 MPa [9].

**Figure 1.** Big Palace of Byzantine

The porosity of Early-Age Byzantine religious building (Hagia Sophia in Figure 2). mortars changes between 32-48 %. The unit weight is 1,23-1,66 gr/cm3. The water absorption of mortars by weight is 19-42 %. The binder/aggregate ratio is between 1/2 and 1/4. This ratio is the same as the other Byzantine buildings. The maximum aggregate grain size of

Early Byzantine mortars is 4 mm. The compressive strength of the mortars changes between 3-6 MPa [10].

**Figure 2.** Hagia Sofia

The porosity of Early-Age Byzantine defense walls (Figure 3) mortars changes between 28-52 %. The unit weight is 1,14-1,90 gr/cm3. The water absorption of mortars by weight is 13-50 %. The binder/aggregate ratio is between 1/2 and 1/4. This ratio is the same as the other Byzantine buildings. The maximum aggregate grain size of Early Byzantine mortars are 4 mm. The compressive strength of the mortars changes between 3-6 MPa [11].

**Figure 3.** Istanbul Land walls

In the research of Ottoman mosques, Lala Pasa and Ibrahim Pasa Mosque are investigated in Figure 4. The porosity of Ottoman mosques mortars changes between 31,3-39,1 %. The unit weight is 1,96-2,23 gr/cm3. The water absorption of mortars by weight is 9,6-12,4 %. The binder/aggregate ratio is between 1/2 and 1/5. The compressive strength of the mortars changes between 12,4-15,3 MPa [12].

**Figure 4.** Lala Pasa Mosque (left) and Ibrahim Pasa Mosque

The porosity of Ottoman bath mortars changes between 38 %. The unit weight is 1,7 gr/cm3. The binder/aggregate ratio is between 1/2 and 1/3. The maximum aggregate grain size of bath mortars is 1 mm [13].

The porosity of Ottoman palace (North Africa in Figure 5) mortars changes between 35-39 %. The unit weight is 1,54-1,67 gr/cm3. The water absorption of mortars by weight is 24-29 %. The maximum aggregate grain size of bath mortars is 1 mm [3]. The porosity of Ottoman palace mortars (Turkey) changes between 29-46 %. The unit weight is 1,55-1,95 gr/cm3. The water absorption of mortars by weight is 14-22 %. The maximum aggregate grain size of bath mortars is 1 mm [14].

**Figure 5.** Ottoman monuments of "Ghar El Melh" (Tunisia)

## 3. CONCLUSIONS

As a result of the evaluation, the porosity, the water absorption and the maximum grain size of Ottoman mortars are less than the Early-Age Byzantine mortars and also the density and the strength of Ottoman mortars are more than the Early-Age Byzantine mortars. Although the structure of the Ottoman and Early-Age Byzantine mortars are approximately the same, the characteristic properties of the Ottoman mortars are better. In Ottoman mortars, the broken bricks, as appropriate pozzolanic materials, were mostly used. The bricks used as aggregates in the mortars and plasters have good pozzolanicity mainly derived from their amorphous clay mineral dissociation products. Therefore, using the hydraulic binding material supply the high strength and characteristic properties. In the beginning, the Ottoman mortars inspired from the Byzantine mortars and then the Ottomans mortars enhanced with new technologies and have better characteristic properties. Therefore, nowadays, the Ottoman buildings are still with their magnificent construction.

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