PLASTER CHARACTERISTICS OF
ÇİNİLİ HAMAM
BUILT BY MİMAR SİNAN IN İSTANBUL

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ABSTRACT

PLASTER CHARACTERISTICS OF ÇİNİLİ HAMAM BUILT BY MİMAR SİNAN IN İSTANBUL

In this study, horasan and lime plasters of Zeyrek Çinili Bath (16^{th} c.) in İstanbul built by Mimar Sinan, considered as the master architect of the Ottoman Empire, were investigated to determine application techniques of plasters, basic physical properties, raw material compositions, microstructural properties and hydraulicity of plasters, mineralogical, chemical compositions of binders, pozzolanic activities of crushed brick aggregates by using standard test methods, binocular microscope, XRD, SEM-EDS and TGA.

Multilayered plaster application on the wall surfaces of the inner spaces of the bath was classified as lower level and upper level plasters. The lower level plasters are composed of two horasan plaster layers. The first layer is rough while the second layer is fine. Glazed tiles are adhered on the second layer of the horasan plasters by glazed tile adhesives. Hence, all horasan plasters are original and not repaired.

The upper level plasters are composed of a horasan plaster layer with one or two lime plaster layers. The plasters of domes are consisted of a rough horasan plaster layer with one fine lime plaster layer.

Horasan plasters used in all spaces of the bath have no significant differences in their physical properties, mineralogical, chemical compositions, microstructural properties, pozzolanicity and hydraulicity. Horasan plasters are high porous and low dense materials. The layers of horasan plasters used in the bath are well adhered to each other. Brick aggregates of horasan plasters have good puzzolanic properties. Hence, most of the horasan plasters are hydraulic.

ÖZET

MİMAR SİNAN TARAFINDAN İSTANBUL'DA İNŞA EDİLEN ÇİNİLİ HAMAMIN SIVA ÖZELLİKLERİ

Bu çalışmada, Osmanlı İmparatorluğu'nun usta mimarı olarak anılan Mimar Sinan tarafından İstanbul'da inşa edilen Zeyrek Çinili Hamam'ın (16.yy) horasan ve kireç sıvaları, sıvaların uygulama teknikleri, fiziksel özellikleri, hammadde kompozisyonları, mikroyapısal özellikleri ve hidroliklikleri, bağlayıcıların mineralojik ve kimyasal kompozisyonları, agrega olarak kullanılan tuğla kırıklarının puzolanik aktiviteleri belirlenmesi için standart test metodları, binoküler mikroskop, XRD, SEM-EDS ve TGA kullanılarak incelenmiştir.

Hamam iç mekanlarının duvar yüzeylerindeki çok katmanlı sıva uygulama tekniği, alt seviye ve üst seviye sıvalar olarak sınıflandırılmıştır. Alt seviye sıvalar iki horasan sıva katmanından oluşur. İlk katman kaba sıva iken ikinci katman ince sıvadır. Çiniler horasan sıvaların ikinci katmanı üzerine çini yapıştırma harcı ile yapıştırılmıştır. Dolayısıyla, tüm horasan sıvalar orjinal ve onarım görmemiş durumdadır.

Üst seviye sıvalar bir horasan sıva katmanı ve bir ya da iki kireç sıva katmanından oluşmaktadır. Kubbelerin sıvaları bir kaba horasan sıva katmanı ile bir ince kireç sıva katmanından oluşmaktadır.

Hamamın tüm mekanlarında kullanılan horasan sıvaların fiziksel özellikleri, mineralojik, kimyasal kompozisyonları, mikroyapısal özellikleri, puzolaniklikleri ve hidroliklikleri önemli farklılıklar göstermemektedir. Horasan sıvalar çok gözenekli ve düşük yoğunluklu malzemelerdir. Hamamda kullanılan horasan sıvaların katmanları birbirine iyi yapışmış durumdadır. Horasan sıvaların tuğla agregaları iyi puzolanik özelliklere sahiptir. Dolayısıyla, horasan sıvaların birçoğu hidroliktir.

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CHAPTER 1

INTRODUCTION

1.1. Subject and Aim

Conservation studies of historic buildings and monuments must be done by safeguarding their architectural, aesthetic and historic values. Historic buildings bear witness to traditions, craftsmanships, materials, technologies etc. and they are inseparable from the history. Hence, interventions on historical building materials must be carried out by safeguarding them for future generations[1].

Brick-lime plasters are important materials of the historic buildings that protect structure of the building from damp and fire. Crushed bricks or tiles used in production of brick-lime plasters were named as “Horasan” in Turkey.

Horasan plasters made by mixing of lime and crushed bricks as aggregates are one of the most common and important building materials of the historic aqueducts, bridges and bath buildings due to their hydraulicity, durability and high mechanical strength. In the conservation works, basic physical properties, raw material compositions, mineralogical, chemical and microstructural properties of horasan plasters must be known in order to prepare new horasan plasters for the purpose of conservation.

Zeyrek Çinili Bath is one of the first and largest Ottoman bath buildings built by Mimar Sinan in İstanbul. The bath is among the most outstanding examples of Ottoman architecture. In addition, the bath is a significant monument because it reached to the present day by preserving original material characteristics. However, any information about characteristics of the original plasters and their application of the bath had not been documented. The aim of this study is the determination of the characteristics of plasters used on the walls and domes of the bath in accordance with spaces, levels, and layers and also understanding the material technology of the horasan plasters of the buildings designed by Mimar Sinan.

[1] The Venice Charter, http:// http://www.icomos.org/charters/venice_e.pdf

1.2. Limits of the Study

Internal walls of the Zeyrek Çinili Bath were coated with horasan and lime plaster layers. In this thesis, characteristics of the plasters taken from ılıklık (warm area), sıcaklık (hot area) and halvet spaces of the men’s and women’s sections of the bath were investigated in order to determine their basic physical properties, raw material compositions, mineralogical, chemical and microstructural properties, pozzolanic activities and hydraulic properties. In addition, plasters from the domes of soyunmalık (changing area) of the men’s and women’s sections were examined. The characteristics of the plasters from the walls of soyunmalık and the domes of ılıklık, sıcaklık and halvet spaces were not investigated due to difficulties to collect samples from domes and too many interventions carried out on the walls of the soyunmalık.

1.3. Organization of the Study

Organization of the study is comprised of collection of samples, analysis and interpretation. Plaster samples were collected from the interior wall surfaces of ılıklık, sıcaklık and halvet spaces of the bath and also from the dome of soyunmalık. Layers of plasters and their application techniques were documented by photographs from field survey and drawings which were studied by using AutoCAD and Photoshop software programs.

In the analyses part of the study, basic physical properties, raw material compositions of the plasters and pozzolanic activities of the crushed brick aggregates were determined by standart test methods. Mineralogical compositions were defined by using X-ray diffraction (XRD) and chemical compositions were defined by Scanning Electron Microscope (SEM) equipped with X-Ray Energy Dispersive System (EDS). Thermo Gravimetric Analyzer (TGA) were used for determination of hydraulicity. Scanning Electron Microscope and binocular microscope were used for determination of microstructural properties and application techniques of plasters.

Results of the laboratory studies were discussed and compared with the results of analyses of other plasters used in some Ottoman bath buildings. Results were interpreted to determine characteristics of plasters and application techniques.

CHAPTER 2

ZEYREK ÇİNİLİ BATH AND PLASTERS

In this chapter, historical background, spatial characteristics, construction technique and materials of Zeyrek Çinili Bath and plasters used in historic buildings, raw materials of historic plasters and crushed fired clay products used in historic buildings were given.

2.1. Zeyrek Çinili Bath

Mimar Sinan who is considered as the master architect of Ottoman Empire built hundreds of buildings in the 16th century including mosques, madrasahs, palaces, caravansaries, tombs, schools, hospitals, bridges, aqueducts and public baths.

The number of the baths designed by Mimar Sinan is not known exactly. According to old documents, the baths were listed as nearly 59 baths. Also, 45 of these baths were built in İstanbul (Önge 1988). Zeyrek Çinili Bath is one of the remarkable Ottoman baths built by Mimar Sinan. The bath is a significant monument because it reached to the present day by preserving most of its authenticity. It is located on İtfaiye Street in Zeyrek Kırkçeşme District in Fatih, İstanbul (Figure 2.1).

Figure 2.1. Location of Zeyrek Çinili Bath
(Source: Google earth image-25.05.2015)

Zeyrek Çinili Bath has called different names like Hayrettin Paşa bath, Kaptanpaşa bath, Tezgahçılar and Zeyrek Çinili bath (Koçu 1944). At the present time, it is mostly called as Çinili bath due to the fact that İznik glazed tiles were used on the interior walls of the bath (Yetkin 1988).

2.1.1. Historical Background

Zeyrek Çinili Bath was built by Mimar Sinan to generate revenue for the Barbaros Hayrettin Pasha madrasah and tomb (Figure 2.2). Although the construction year was not recorded exactly, according to some sources, the bath was built between 1540 and 1546 (Yetkin 1993, Önge 1988). In another source, the construction year was given between 1534 and 1546 (Koçu 1944).

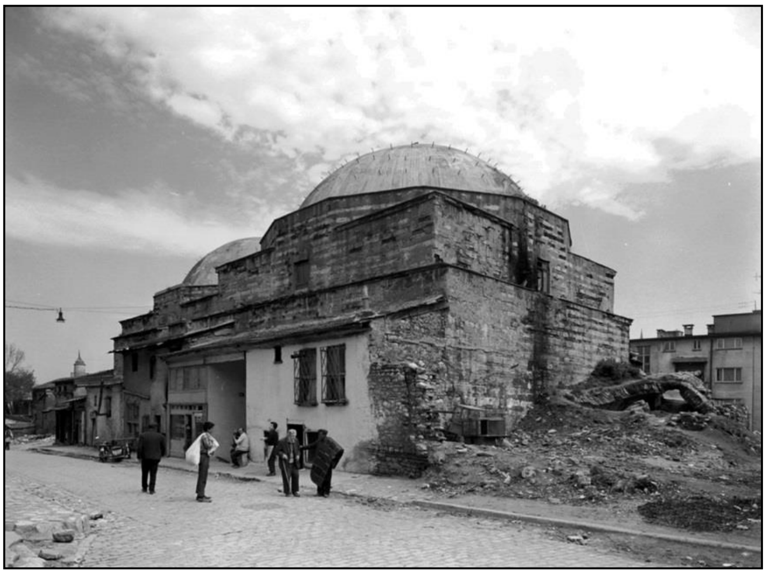


Figure 2.2. Zeyrek Çinili Bath
(Source: Eski İstanbul Fotoğrafları Arşivi)

Çinili bath was affected from several disasters until today. In 1782 and 1833, the bath was damaged because of the devastating fires known as Cibali fires. After the 7th Cibali fires happened in 1782, the bath was started to use as a military saddlery (Koçu 1944). In 1833, the bath was severely damaged by the 8th Cibali fires and then it was not used for years. In this period, glazed tiles of the bath were damaged and removed (Koçu 1944). In addition, a domed and marble columned portico in front of the entrance of men's section was damaged by the result of the fires and was removed (Yetkin 1993).

As a result of these fires, the bath lost its waqf property and was transferred to personal ownership. The bath was repaired by Ali Bey between 1833 and 1850 and started to use as public bath again (Koçu 1944) (Figure 2.3, 2.4).

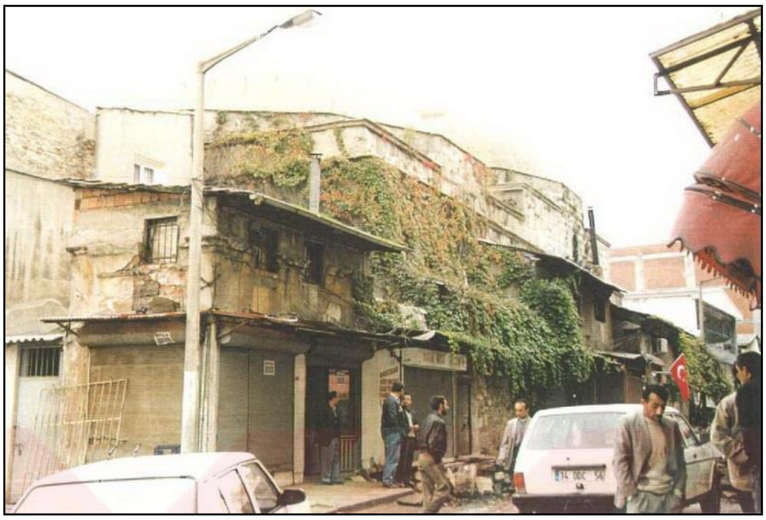


Figure 2.3. Zeyrek Çinili Bath, northwest elevation
(Source: Ertuğrul 2002)

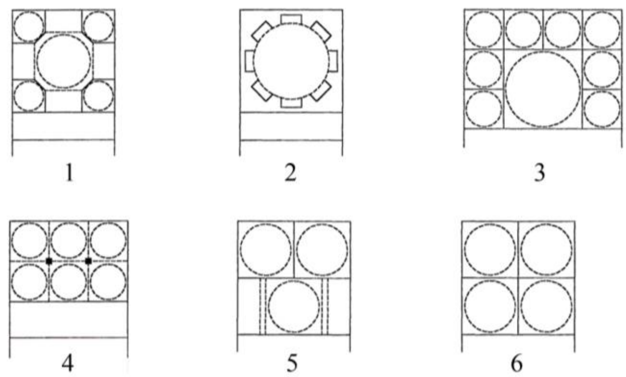
Figure 2.4. Zeyrek Çinili Bath, northwest elevation
(Source: KA.BA 2012)

At the present day, restoration works of Zeyrek Çinili bath have been proceeded (Figure 2.5). Extensive researches and multidisciplinary studies were carried out for the restoration works. Hence, unqualified additions and layers were removed such as ceramic covering on the northwest wall surfaces, marble floor covering on the slab of men’s sıcaklık and cement based covering on the walls and domes. A few of original pieces of the glazed tiles were found and recorded (Kabaoğlu 2013).

Figure 2.5. Zeyrek Çinili Bath, southwest elevation, 2015

2.1.2. Spatial Characteristics

The Ottoman bath plans were categorized according to organization of sıcaklık spaces by Eyice (1960). Thus, Zeyrek Çinili Bath has cross plan with halvet spaces on the corners as plan type 1 (Figure 2.6).



1. Cross planned sıcaklık with halvet spaces on the corners
2. Star-shaped planned sıcaklık type
3. Square planned sıcaklık with halvets around the sıcaklık
4. Multi-domed plan type
5. Central domed rectangular planned sıcaklık with two halvets
6. The plan type has same size soyunmalık, sıcaklık and halvets

Figure 2.6. Ottoman bath plan types
(Source: Ertuğrul 2002)

Zeyrek Çinili bath was built as a typical double bath consisting of men’s and women’s sections. These sections were built symmetrically with the same plan organization. Each of the sections has a ‘’soyunmalık’’ (changing area), a ‘’ılıklık’’ (warm area) and a ‘’sıcaklık’’ (hot area). Hot and cold water reservoirs and külhan are situated on the behind of the sıcaklık spaces. The entrances of the bath are provided from the northwest separately to the men’s and women’s sections (Figure 2.7).

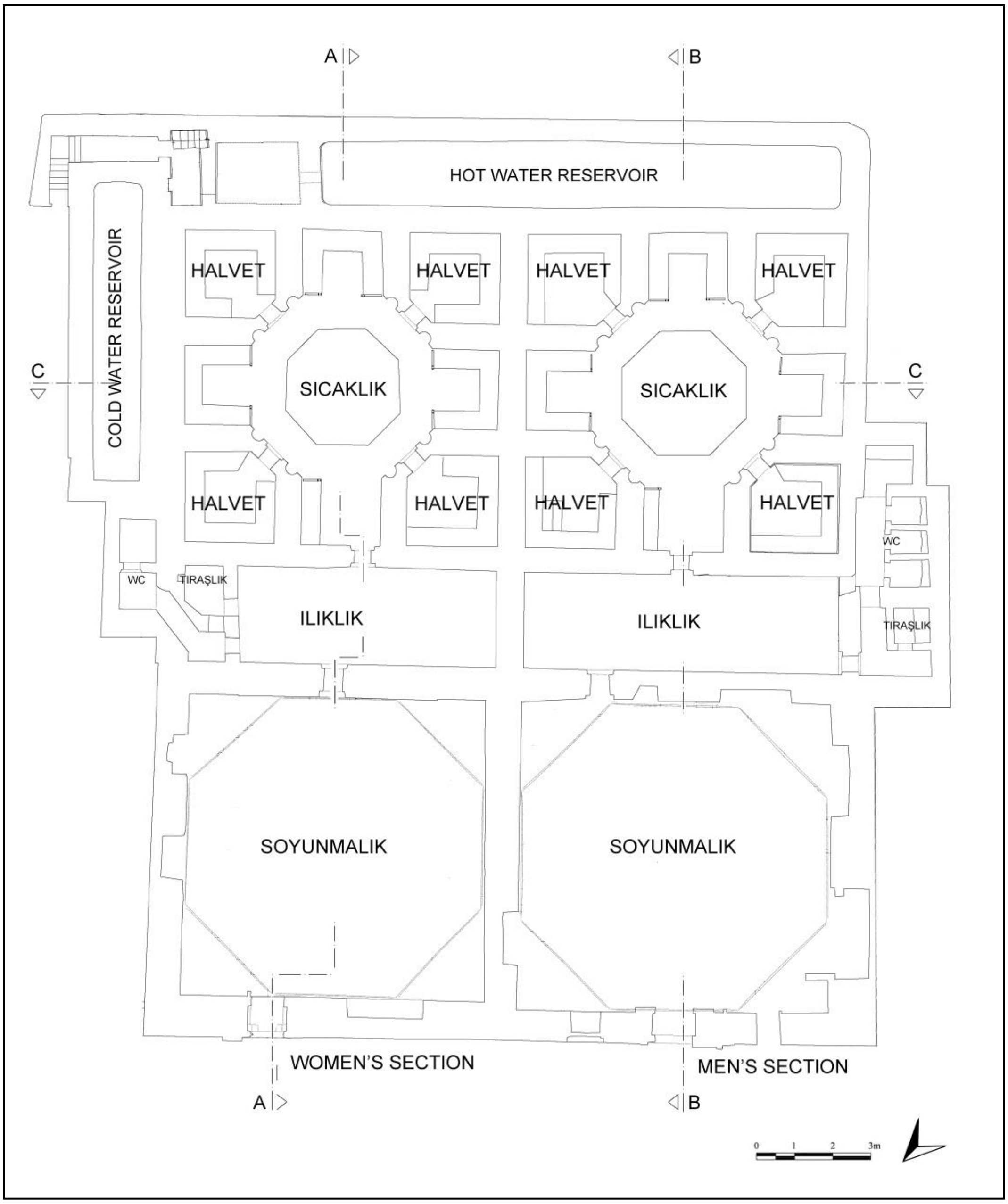


Figure 2.7. Plan of Zeyrek Çinili Bath
(Source: KA.BA)

The soyunmalık which is entered from the outside as the first space is square planned, covered with a large dome (Figure 2.8). Wooden two-storey galleries consisting of changing rooms were added to soyunmalık and also a marble fountain was placed at the middle of the soyunmalık of Men's section in the 19th century (Koçu 1944).

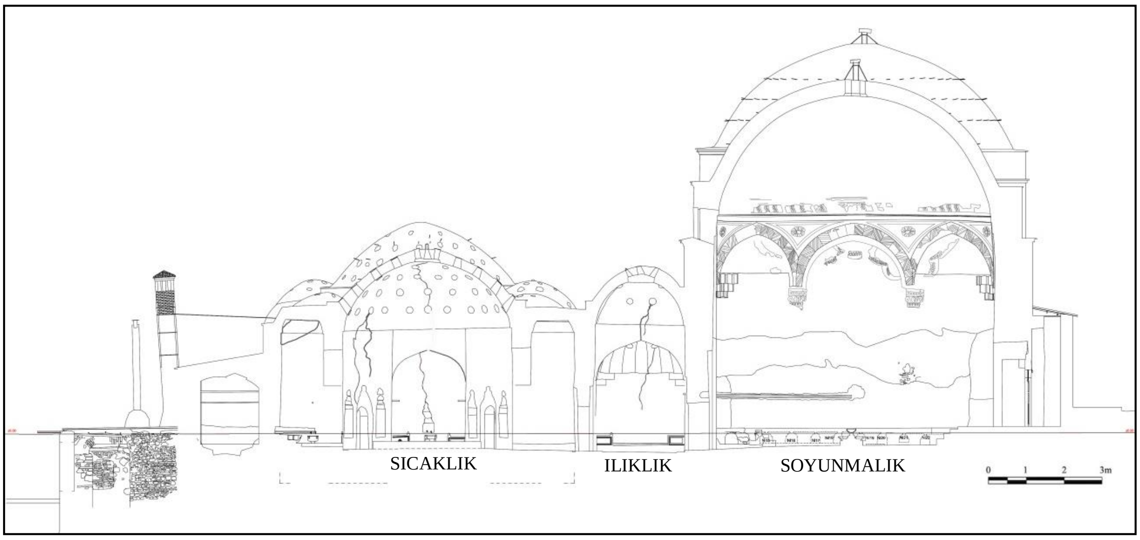


Figure 2.8. Section A-A of Zeyrek Çinili Bath
(Source: KA.BA)

The ılıklık is located on the between of soyunmalık and sıcaklık as a transition space. It has smaller area than soyunmalık and sıcaklık. This space is rectangular planned and connected to service rooms like toilets and shaving rooms (Figure 2.9).

(a) (b)

Figure 2.9. Northeast elevation (a) and southwest elevation (b) of ılıklık of Zeyrek Çinili Bath

The sıcaklık space which is square planned has four halvet rooms on the corners and four iwans on between of them. Two niches with muqarnas are situated on sides of halvet entrances. An octagonal marble slab is placed on the centre of the sıcaklık (Figure 2.10).

Figure 2.10. Sıcaklık of Zeyrek Çinili Bath

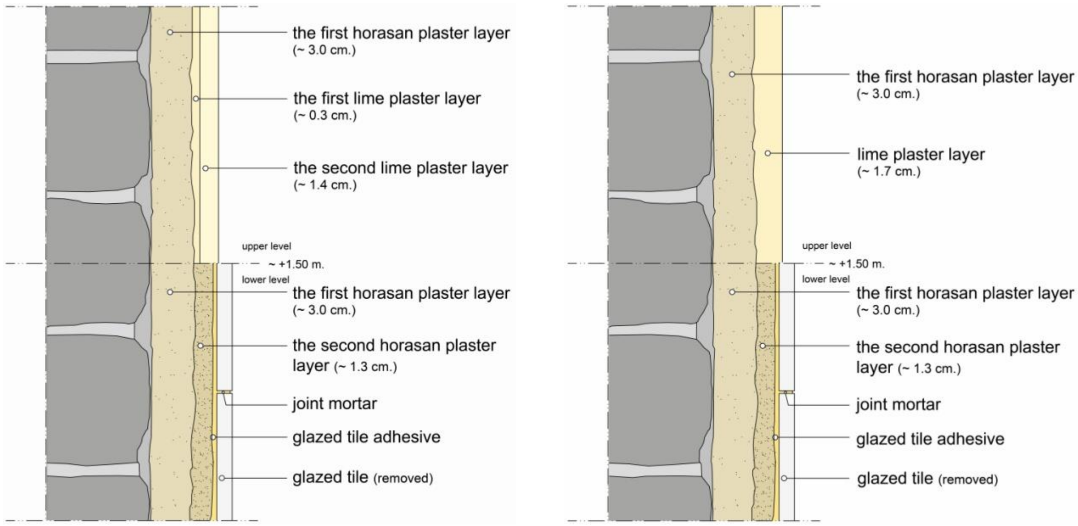
2.1.3. Construction Technique and Materials

Walls of the bath building were constructed with rubble stone, cut stone and brick in the masonry system. Exterior walls of the bath were nearly 100 cm and two rows of brick and stone.

Domes of the bath building were constructed with brick and mortar as binding material. Soyunmalık space was covered a large dome provided by squinchs at the corners. Although men’s and women’s sections of the bath were constructed as nearly as same, the dome of men’s soyunmalık was built as higher than the dome of women’s soyunmalık (Aru 1949). Ilıklık space was covered a barrel vault with two semi domes. Sıcaklık space was covered a large dome on the centre. Four halvet rooms were covered by domes and four iwans were covered by vaults.

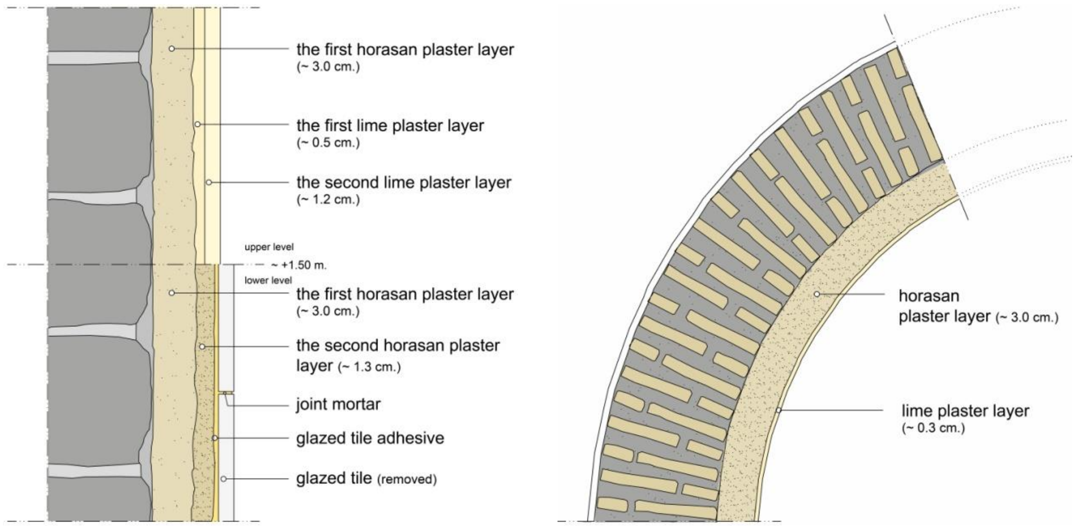
Walls and domes were plastered on the interior. However, the walls were not plastered and the domes were lead covered on the exterior. The plasters on the wall surfaces of the interior spaces of the bath were classified as lower level plasters and upper level plasters. The lower level plasters were consisted of a rough horasan plaster layer and a fine horasan plaster layer. Glazed tiles were adhered on the fine horasan plaster layer by glazed tile adhesive (Figure 2.11, 2.12). These glazed tiles which can be visible on some parts of the interior walls of the bath are blue, white coloured, geometric, floral patterned and hexagon, square shaped.

The upper level plasters were consisted of a rough horasan plaster layer with one or two fine lime plaster layers. The plasters of the domes of men's and women's soyunmalık spaces were consisted of a rough horasan plaster layer and a lime plaster layer (Figure 2.11, 2.12)



(a) (b)

Figure 2.11. Plaster layers of ılıklık (a) and sıcaklık (b) of Zeyrek Çinili Bath



(a) (b)

Figure 2.12. Plaster layers of halvet (a), soyunmalık's dome (b) of Zeyrek Çinili Bath

2.2. Plasters Used in the Historic Buildings

Plasters and renders are protective elements applied on structural components of buildings. They provide protection to surface structure of buildings against water and moisture penetration, salt crystallization, wetting-drying and freezing-thawing cycles and biological growths. They also support fire resistance, modify sound absorption and improve thermal and sound insulation. They show high resistance against impact damages and they can be easily repaired (Seeley 1995, Watts 2001).

In addition to their protection function, they also provide an aesthetic finishing and a regular, smooth surface which is proper to painting or decoration. Their use on the surface structure of buildings is based on their raw material compositions and environmental conditions (Seeley 1995, Watts 2001).

In this part, knowledge of raw materials of plasters used in historical buildings and plasters used in historic buildings that produced by crushed fired clay products (bricks, roof tiles, etc.) and lime was explained.

2.2.1. Raw Materials of Historic Plasters

The main raw materials of historic plasters are mud, gypsum, lime, aggregates and fibrous organic materials.

The use of mud plasters have been known since ancient times. Mud plasters are produced by adding water to mixed clay, sand, silt and fibrous materials. They support thermal insulation to buildings and therefore they are convenient materials to provide protection against hard climate conditions (Pearson 1994).

Gypsum was used as a lubricant for setting of stone blocks by the Egyptians. The use of gypsum mortars have been for over 4000 years at the Middle East. Gypsum plaster is generally used interior spaces of the building due to having high solubility against to water (Livingston et. al. 1991). Gypsum plasters is produced by heating gypsum rocks ($CaSO_4$. 0.5 H_2O) at between 135 - 175 °C and so transforming it to calcium sulphate hemihydrate (CaSO4.½H2O) (Reaction 2.1). When water is added, hemihydrate transforms to gypsum and gives solidity to mass of gypsum (Reaction 2.2).

$$CaSO_4 \,.\, 2\,H_2O + \text{Heat} \rightarrow CaSO_4 \,.\, ½\,H_2O + 1.5\,H_2O \qquad (2.1)$$

$$CaSO_4 . ½H_2O + 1.5\,H_2O \rightarrow CaSO_4 \,.\, 2\,H_2O \qquad (2.2)$$

The use of lime as a binder known since Roman times is obtained from limestones. Vitruvius, a Roman architect who lived in 1st century BC, remarked characteristics of limestone in the producing of historic mortars and plasters (Vitruvius 1960). Limestones can be categorized depends on their origin, texture, mineralogical and chemical compositions (Eckel 1928). Finding a suitable limestone quarry and carrying them to kilns is the beginning of lime manufacture.

The lime production is comprised of calcination, slaking and carbonation stages (Figure 2.13).

$$\underset{\text{(Limestone)}}{CaCO_3} \xrightarrow{\textit{Calcination}} \underset{\text{(Quicklime)}}{CaO} \xrightarrow{\textit{Slaking}} \underset{\text{(Lime)}}{Ca(OH)_2} \xrightarrow{\textit{Carbonation}} \text{Lime Plaster}$$

Figure 2.13. The lime production stages

Calcination of limestone is the first process of lime production that provides transformation from calcium carbonate ($CaCO_3$) to calcium oxide (CaO) with releasing carbon dioxide gas (CO_2) (Reaction 2.3). Calcination temperature of limestone is not more than 900 °C with an environment containing 100 % CO_2 and under 760 mm. Hg pressure (Boynton 1980).

$$\text{Calcium Carbonate } (CaCO_3) + \text{Heat} \rightarrow \text{Quicklime } (CaO) + CO_2 \qquad (2.3)$$

The second process is slaking carried out by adding water to quicklime in order to obtain lime ($Ca(OH)_2$) (Reaction 2.4). In Roman times, it was considered that lime should be stored for many years to provide a good plasticity (Boynton 1980). Also, Vitruvius recommended that lime should be kept for several years to complete its slaking (Vitruvius 1960).

$$\text{Quicklime } (CaO) + H_2O \rightarrow \text{Lime } (Ca(OH)_2) + \text{Heat} \qquad (2.4)$$

Carbonation is the hardening process of slaked lime which occurs by absorbing of carbon dioxide (CO_2) from air and evaporation of water (Reaction 2.5). Carbonation of lime is related to amount of water, carbon dioxide concentration and permeability of lime (Van Balen and Van Gemert 1994).

$$\text{Slaked Lime } (Ca(OH)_2) + CO_2 \rightarrow \text{Calcium Carbonate } (CaCO_3) + H_2O \quad (2.5)$$

Lime plaster is produced by mixing of aggregates with lime. Aggregates are mainly classified as inert and pozzolanic aggregates (Boynton 1980). Inert aggregates are composed of inactive silicates and aluminates and they don't react with lime. Pozzolanic aggregates are consisted of active silicates and aluminates and they react with lime.

Pozzolanic aggregates can be categorized as natural and artificial. Natural pozzolans have generally a volcanic origin such as volcanic dust and ash. Artificial pozzolans like bricks and tiles are mainly manufactured by heating materials rich in clays at temperatures between 600-900 °C (Cowper 1998).

Lime plasters can be classified as non-hydraulic and hydraulic. Non-hydraulic lime plasters are manufactured by result of the mixing inert aggregates with pure lime. Non-hydraulic lime plasters are hardened by the carbonation of lime. Hydraulic lime plasters are manufactured by result of the use of hydraulic lime or mixing of pozzolanic aggregates with pure lime. Hydraulic lime plasters are hardened by the carbonation of lime and the reaction between pozzolans and lime.

2.2.2. General Characteristics of the Crushed Fired Clay products Used In Plasters of the Historic Buildings

Crushed fired clay products (bricks, roof tiles) were used in the production of plasters of the historic buildings, especially in the wet spaces of the buildings. The mortars and plasters obtained from mixture of lime and crushed bricks as artificial pozzolans enable setting in water and high mechanical strength (Lea 1940).

Crushed bricks were named as “Cocciopesto” in Roman (Massazza and Pezzuoli 1981), “Horasan” in Turkey, “Surkhi” in India (Spence 1974), “Homra” in Arabic countries (Lea 1940). The earliest use of crushed brick aggregates to obtain lime plasters was found in the constructions from 3000 B.C (Moropoulou et al. 2005). Their use as plasters in the cisterns was found in the period of Solomon’s Kingdom (Baronio et al. 1997b). Later usage was found in Greece (Moropoulou et al. 2005). In the Roman period, the use of crushed bricks was more evident. Cocciopesto mortars were used as aggregates in wall plastering, in floor covering and in mortar of the structural components like arches and foundations (Matias et al. 2014). In the Ottoman period, crushed bricks were used as aggregates in lime plasters and mortars especially in the bath buildings and cisterns.

Crushed brick aggregates are produced by heating raw materials containing clay minerals between 450 and 800 °C. In these temperature intervals, the crystal structures of the clays are destroyed and the pozzolanic amorphous materials are formed. Pozzolanic amorphous materials are mainly aluminosilicates that react with lime to produce calcium silicate hydrate and/or calcium aluminate hydrate. For instance, if kaolinite (Al_2O_3. $2SiO_2$. $2H_2O$) is heated between 450 and 800 °C, the amorphous metakaolin (Al_2O_3. $2SiO_2$) is formed (Reaction 2.6). This substabces react with lime ($Ca(OH)_2$) in the presence of water to form calcium silicate hydrate ($3CaO.2SiO_2.7H_2O$) and tetracalcium aluminate hydrate ($4CaO.Al_2O_3.19H_2O$) (Reaction 2.7).

$$\underset{\text{Kaolinite}}{Al_2O_3.2SiO_2.2H_2O} \rightarrow \underset{\text{Metakaolin}}{Al_2O_3.2SiO_2} + 2H_2O \tag{2.6}$$

$$\underset{\text{Metakaolin}}{Al_2O_3.2SiO_2} + \underset{\text{Lime}}{7Ca(OH)_2} + \underset{\text{Water}}{19H_2O} \rightarrow \underset{\substack{\text{Tetracalcium}\\\text{aluminate hydrate}}}{4CaO.Al_2O_3.19H_2O} + \underset{\substack{\text{Calcium silicate}\\\text{hydrate}}}{3CaO.2SiO_2.7H_2O} \tag{2.7}$$

These products by the result of these formations give the hydraulic character to the mortars and plasters (Reaction 2.6, 2.7).

The use of artificial pozzolans manufactured by heating materials rich in clays at temperatures between 600-900 °C induce a reaction between mixture of silica and alumina with calcium hydrate. This pozzolanic reaction is mainly depending on the amount of clays (Böke et al. 2004). Moreover, many features such as the temperature and the duration of the heat treatment, the amount and type of original clays, the particle size distribution and specific surface and the chemical reactions involved may affect this reaction (Matias et al. 2014).

Determination of the characteristics of lime plasters and mortars produced by using crushed brick aggregates became an important subject in order to define the essential characteristics of the intervention plasters and mortars which will be used in the conservation of the historic buildings. Hence, extensive studies had been carried out on crushed brick aggregates, lime plasters and mortars. In the recent studies, physical properties, raw material compositions, hydraulic and pozzolanic properties of horasan mortars and plasters used in some historic buildings were determined and their results are given as below.

Physical properties of horasan plasters and mortars used in historic bath buildings were identified according to their densities and porosities by several studies (Böke et al. 2004, Uğurlu 2005, Özkaya 2005, Kurugöl and Güleç 2012).

Density and porosity values of horasan plasters used in Ördekli Bath in Bursa, Saray and Beylerbeyi Baths in Edirne were determined by Böke et al. (2004). Consequently, density and porosity values of horasan plasters of Ördekli Bath were 1.4 g/cm^3 and 43% averagely. Density and porosity values of horasan plasters were 1.6 g/cm^3 and 32% for Saray Bath and were 1.7 g/cm^3 and 26% for Beylerbeyi Bath (Böke et al. 2004).

Density and porosity values of horasan plasters used in some Ottoman Baths in rural areas of İzmir were determined by Uğurlu (2005). Accordingly, density and porosity values of horasan plasters of Düzce Bath were found between 1.3-1.6 g/cm^3 and 31-48 % averagely. Density and porosity values of horasan plasters were found between 1.1-1.5 g/cm^3 and 40-57 % for Hersekzade Bath and were found between 1.1-1.7 g/cm^3 and 32-54 % for Kamanlı Bath. In addition to horasan plasters, density and porosity values of lime plasters were found between 1.3-1.7 g/cm^3 and 24-41 % for Düzce Bath; and 1.3 g/cm^3 and 40 % for Hersekzade Bath; and 1.3-1.8 g/cm^3 and 29-45 % for Kamanlı Bath (Uğurlu 2005).

Density and porosity values of horasan plasters used in Serapis temple (Bergama/Turkey) from the Byzantine period were found 1.3 g/cm^3 and 48% averagely by Özkaya (2005). Density and porosity values of lime mortar samples taken from Yoros Castle in the Byzantine period were found between 1.55–1.83 g/cm3 and 28–35% by Kurugöl and Güleç (2012).

Raw material compositions of horasan plasters and mortars were described according to their lime/aggregate ratios (Böke et al. 2004, Uğurlu 2005, Özkaya 2005, Kurugöl and Güleç 2012, Moropoulou et al. 1995, Maravelaki-Kalaitzaki et al. 2003, Moropoulou et al. 2000).

Lime/aggregate ratios of horasan plasters of Ördekli Bath were found between 2:3 to 1:1 by weight. Lime/aggregate ratios of horasan plasters were found between 1:1 to 3:1 for Saray Bath and were found between 2:3 to 1:1 for Beylerbeyi Bath (Böke et al. 2004). According to Uğurlu (2005), lime/aggregate ratios of horasan plasters of Düzce Bath were between 2:3 to 3:2 by weight. Lime/aggregate ratios of horasan plasters of Hersekzade and Kamanlı baths were between 2:3 to 1:1 and 2:3 to 3:2 by weight.

Raw material compositions of horasan plasters used in Serapis temple from the Byzantine period were determined (Özkaya 2005). Their lime/aggregate ratios were around 1:2.6 by weight.

Raw material compositions of horasan mortars used in some historic buildings from Byzantine period such as Hagia Sophia (İstanbul) (Moropoulou et al. 1995), Yoros Castle (İstanbul) (Kurugöl and Güleç 2012) and some historic buildings in different regions such as in Rhodes (Moropoulou et al. 1995), in Crete (Maravelaki-Kalaitzaki et al. 2003) and some churches, cathedrals in Kiev (Moropoulou et al. 2000) were determined. The analysis results indicated that the horasan mortars have 1:4 to 1:2 in volume binder/aggregate ratios.

Hydraulic characteristics of horasan plasters and mortars were described by lots of studies (Böke et al. 2004, Uğurlu 2005, Özkaya 2005, Uğurlu 2012, Moropoulou et al. 1995, Robador et al. 2010, Silva et al. 2006, Kurugöl and Güleç 2012, Kramar et al. 2011, Rai and Dhanapal 2015).

Results of the analysis indicated that horasan plasters used in some Ottoman bath buildings located in Bursa and Edirne (Böke et al. 2004), in İzmir (Uğurlu 2005) had hydraulic properties.

Horasan plasters and mortars used in Serapis temple (Özkaya 2005), in ancient cities of Aigai (Manisa) and Nysa (Aydın) (Uğurlu 2012), in ancient Byzantine buildings (Moropoulou et al. 1995), in water channel of Mérida (Spain) (Robador et al. 2010), in historical town of Mertola (Silva et al. 2006), in Yoros Castle from Byzantine period (Kurugöl and Güleç 2012) were hydraulic. Besides, hydraulic properties of mortars collected from Kyme (Turkey) were investigated (Miriello et al. 2011). Hydraulicity values of mortars were found between 0.11 and 0.23. The results showed that the mortars collected from Kyme had hydraulic properties.

Most of the mortars from Yoros Castle were found hydraulic due to addition of pozzolanic brick dust and tuff aggregates into the mortars (Kurugöl and Güleç 2012). Cocciopesto mortars from ancient cities of Aigai (Manisa) and Nysa (Aydın) were hydraulic due to the use of pozzolanic crushed brick aggregates in their production depended on their raw materials of high silica content and low firing temperatures (< 950°C) (Uğurlu 2012). Several crushed brick mortars and plasters were collected from ancient Byzantine buildings and thermal analysis were carried out. Results of the analyses indicated that those type of mortars and plasters were hydraulic due to calcium silicate formations at the crushed brick-lime interfaces (Moropoulou et al. 1995).

Silva et al. (2006) also analyzed four types of mortars including horasan mortars from historical town of Mertola. They found hydraulic reaction products not only in the lime-brick interface but also throughout the lime binder due to completely blended bricks aggregates in the lime.

Robador et al. (2010) studied the hydraulic characteristics of mortars and coatings of the viridarium water channel of hydraulic structures of Augusta Emerita (Mérida, Spain). The channel was covered with two hydraulic mortars and a finishing coating. Lime was used as binder and the siliceous aggregates composed of quartz, mica and feldspars were used in the preparation of mortars and coatings. Ceramic fragments composed of quartz, mica, iron oxides, anorthite and an amorphous phase; aluminium iron silicates were added to the mortar to improve its hydraulic properties.

Kramar et al. (2011) investigated the properties of mortars collected from bath complex of the Roman villa rustica from an archeological site near Mošnje (Slovenia). In this study, they examined the mortar layers of the mosaics, wall paintings and mortar floors. They observed brick fragment aggregates in the mortars. Analysis of brick aggregate–binder interfaces revealed various types of hydraulic reaction products.

Rai and Dhanapal (2015) studied the engineering properties of old masonry materials and new mortars being used for renovation of the Lucknow monuments (18th century). This monument was built by using thin burnt-clay bricks (Lakhauri) and lime-crushed brick aggregate (surkhi) mortars. In that study mechanical properties of bricks were found high. The lime-surkhi mortars were found as lime-rich with binder to aggregate ratio of approximately 1:2 to 3 by volume. The renovation mortars indicated poor hydraulic property in comparison with lime-surkhi mortar determined by thermal analysis.

Determination of the use of crushed bricks as aggregates in the mortars and plasters was an important subject for conservation studies. Hence, a number of studies were conducted on measuring the pozzolanicity of heat treated clays and their effects on the lime mortars and plasters (Böke et al. 2004, Uğurlu 2005, Böke et al. 2006, Stefanidou et al. 2014, Baronio and Binda 1997a).

Böke et al. (2004) and Uğurlu (2005) studied the characteristics of crushed brick aggregates used in horasan plasters of the Ottoman bath buildings. According to these studies, crushed brick aggregates used in horasan plasters were pozzolanic.

Böke et al. (2006) investigated the characteristics of bricks as aggregates in the mortars used in the domes of the Ottoman bath buildings. They found that the bricks used as aggragates in the mortars were pozzolanic due to use of high amounts of clay minerals and low firing temperature.

Stefanidou et al. (2014) investigated physico-mechanical, chemical and microstructural characteristics of structural mortars and plasters of cisterns and baths from Roman, Byzantine and Ottoman period in Greece to find their functionality. They found that mortars and plasters are coherent and dense due to the pozzolonic reactions between siliceous and brick aggregates with lime.

Baronio and Binda (1997a) studied the pozzolanicity of bricks and clays, and also characterized their chemical and mineralogical compositions. They concluded that most clays show pozzolanicity when heated high temperatures. They also investigated the pozzolanicity of the bricks manufactured in Italy in the 1990s. Based on the results, they have low pozzolanicity because of too high heating temperature or low amount of clays in the compositions of bricks.

According to some recent studies, the most effective temperature for ideal pozzolanicity was found 650 °C for kaolinite and 930 °C for illite (He et al. 1995), temperatures between 730°C - 850 °C at longer heating time (Al-Rawas et al. 1998), at nearly 700 °C (Chakchouk et al. 2006), temperatures between 500 °C and 700 °C (Budak et al. 2010).

Faria-Rodrigues (2004) analysed the raw materials mixed of kaolinite with some illite and other phyllosilicates with quartz and traces of feldspar. This mixture was heated at 800°C and 600°C for 3.5 hours and at 700°C for 30 minutes. Heat treated clays were tested with the EN 196-5 (CEN. EN 196-5, 2011) standard test. They concluded that the mixture heated at 800°C for 3.5 hours showed the highest pozzolanicity.

Velosa (2006) investigated the pozzolanic reactivity of ‘‘brick dust’’ obtained from industrial unfired paste by heating at temperatures 750 °C, 950 °C and 1100 °C. Results showed that the most suitable temperature was 750 °C for pozzolanic reactions.

Teutonico et al. (1994) studied on mortars contained brick aggregates heated at nearly 950 °C moderate. They observed that compressive strength of the mortars increased due to use of brick aggregates heated at lower temperatures.

Cortina and Dominguez (2002) investigated the effects of a type of ceramic waste heated at 1300 °C and 1000 °C (chamotte) to the lime mortars. The results of the analyses indicated that smaller ceramic particles heated at 1000°C provided higher lime mortar strength.

Chemical compositions of horasan plasters are described by several studies (Uğurlu 2012, Kurugöl and Güleç 2012). Results of these analysis indicated that horasan plasters and mortars used in Yoros Castle were composed of high amounts of CaO, SiO_2, Al_2O_3 and low amounts of Fe_2O_3, MgO, Na_2O with other oxides (Kurugöl and Güleç 2012). Horasan plasters used in some Ottoman bath buildings were composed of high amounts of CaO, SiO_2, Al_2O_3 and low amounts of Fe_2O_3, MgO, Na_2O (Uğurlu 2012).

On the other hand, gypsum (SO_3) was detected on the results of chemical compositions of horasan plasters by some studies (Bertolini et al. 2013, Böke and Akkurt 2003).

Bertolini et al. (2013) examined the cocciopesto mortars of basilica (4th-5th century) of San Lorenzo in Milan in order to determine dating and documenting of the construction techniques used in different historical ages. Results indicated that the binders were mainly magnesian limes although there were significant differences in their microstructures. In the Roman period, hydraulic cocciopesto mortars were used due to structural necessity. The detection of gypsum in many samples indicated its use as intentionally.

Böke and Akkurt (2003) examined original and historic repair brick–lime plasters from Saray bath in Edirne to characterize their technology. They found that the original one was structurally sound while the repair one was deteriorated despite being in the same environment. This difference was investigated by comparing their raw material compositions and the pozzolanic activities of the brick powders used in the plasters. Although the results showed no significant differences, ettringite crystals were found to be responsible for its deterioration due to addition of gypsum in the mixture of plaster.

In this thesis, characteristics of horasan and lime plasters used in Zeyrek Çinili Bath (16^{th} c.) as an outstanding example of Ottoman architecture built by Mimar Sinan in İstanbul were determined. Basic physical properties and raw material compositions of plasters, mineralogical and chemical compositions of fine plaster matrices, microstructural properties, pozzolanic activities of crushed brick aggregates and hydraulic properties and also application techniques of plasters were identified.

CHAPTER 3

CHARACTERIZATION OF PLASTERS

In this study, basic physical properties, raw material compositions, mineralogical and chemical compositions of fine plaster matrices, microstructural properties, pozzolanic activities of crushed brick aggregates and hydraulic properties of plasters collected from Zeyrek Çinili Bath were determined by using standard test methods, XRD, SEM-EDS, TGA and binocular microscope.

3.1. Collection of Samples

Horasan and lime plaster samples were collected from the interior wall surfaces of ılıklık, sıcaklık and halvet spaces and from the domes of soyunmalık of the men's and women's sections of the bath (Figure 3.1-3.8).

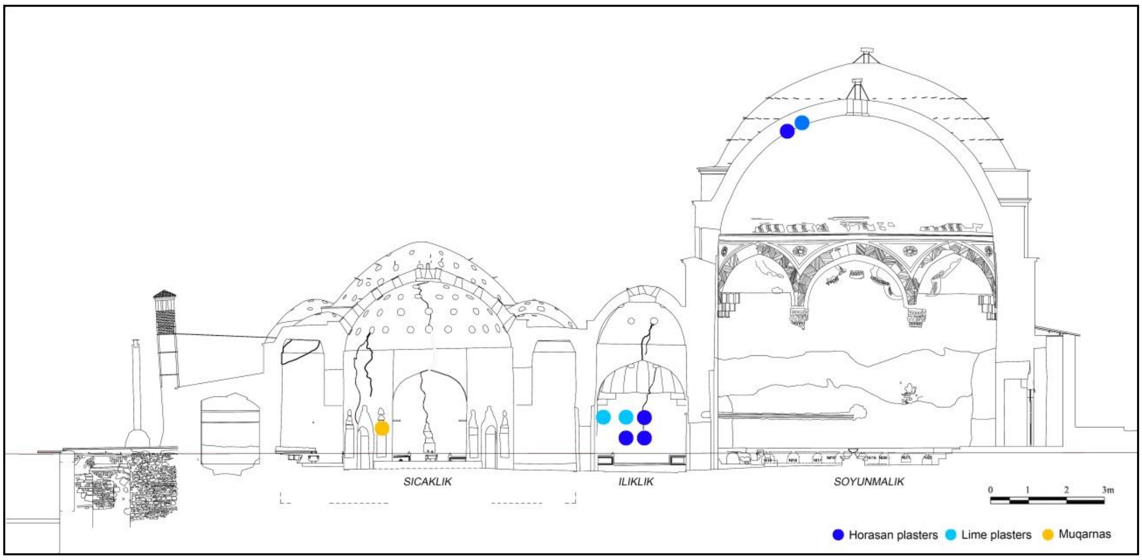


Figure 3.1. Section A-A of Zeyrek Çinili Bath showing where the samples were collected (Source: KA.BA 2015)

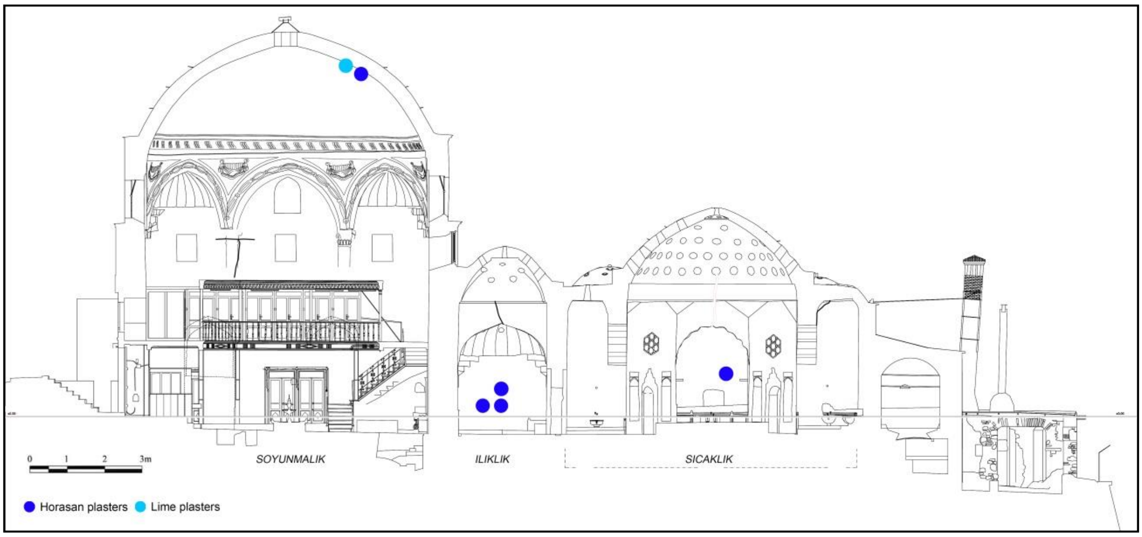


Figure 3.2. Section B-B of Zeyrek Çinili Bath showing where the samples were collected (Source: KA.BA 2015)

16 samples were collected from the men’s section of the bath. 6 samples were from lower level and 6 samples were from upper level. 2 samples were taken from niche mortar and glazed tile adhesive. 2 samples were taken from the dome of men’s soyunmalık space. 16 samples were collected from women’s section of the bath. 6 samples were from lower level and 6 samples were from upper level. 2 samples were taken from a muqarnas and joint mortar of the glazed tiles. 2 samples from the dome of women’s soyunmalık space were taken (Figure 3.3-3.8).

(a) (b)

Figure 3.3. Sıcaklık space of the men’s section (a) and women’s section (b) showing where the samples were collected

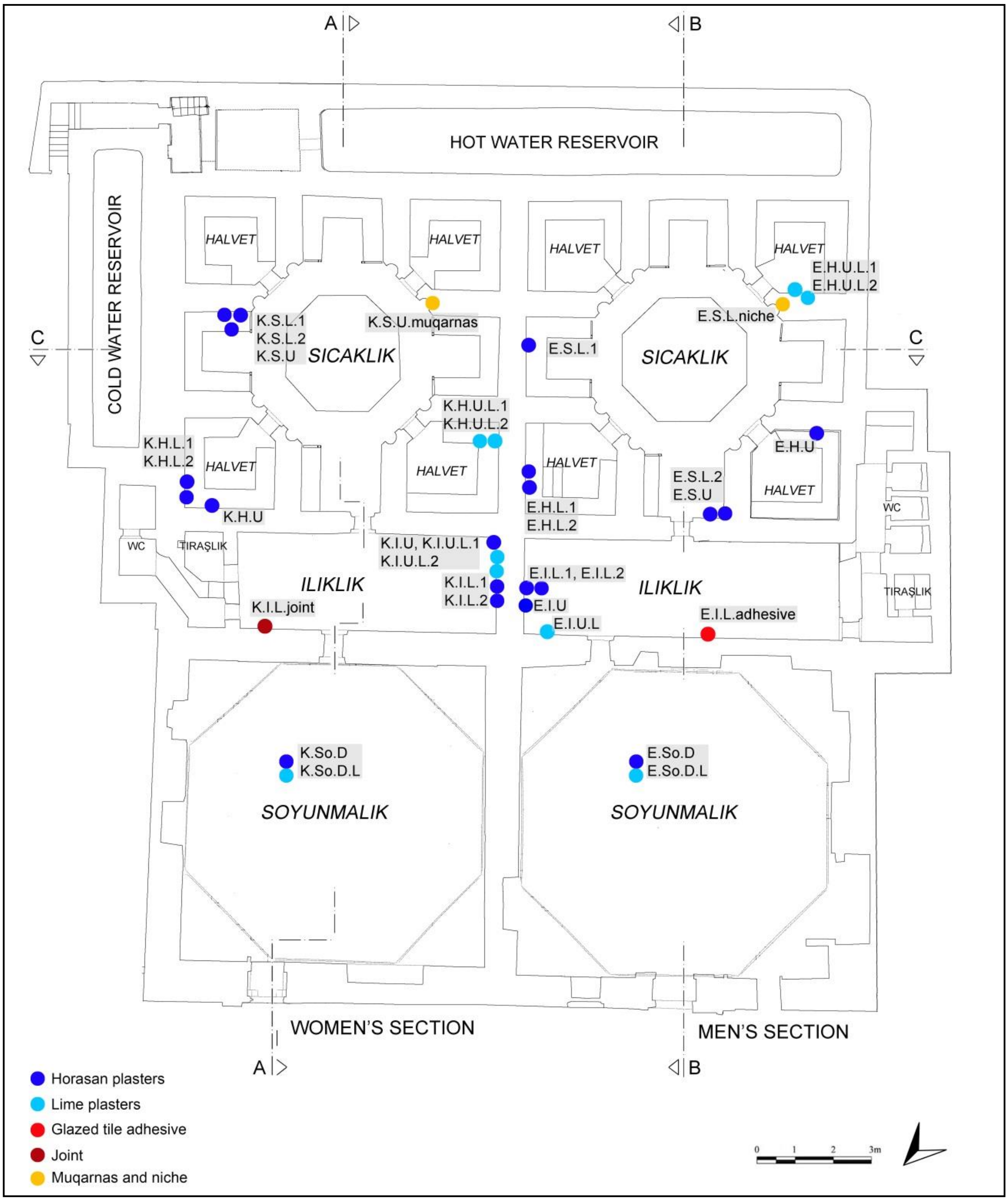


Figure 3.4. Zeyrek Çinili Bath showing where the samples were collected (Source: KA.BA 2015)

Figure 3.5. Ilıklık space showing horasan plasters attached glazed tiles

Figure 3.6. Ilıklık space showing where the samples were collected

Figure 3.7. Sıcaklık space showing where the samples were collected

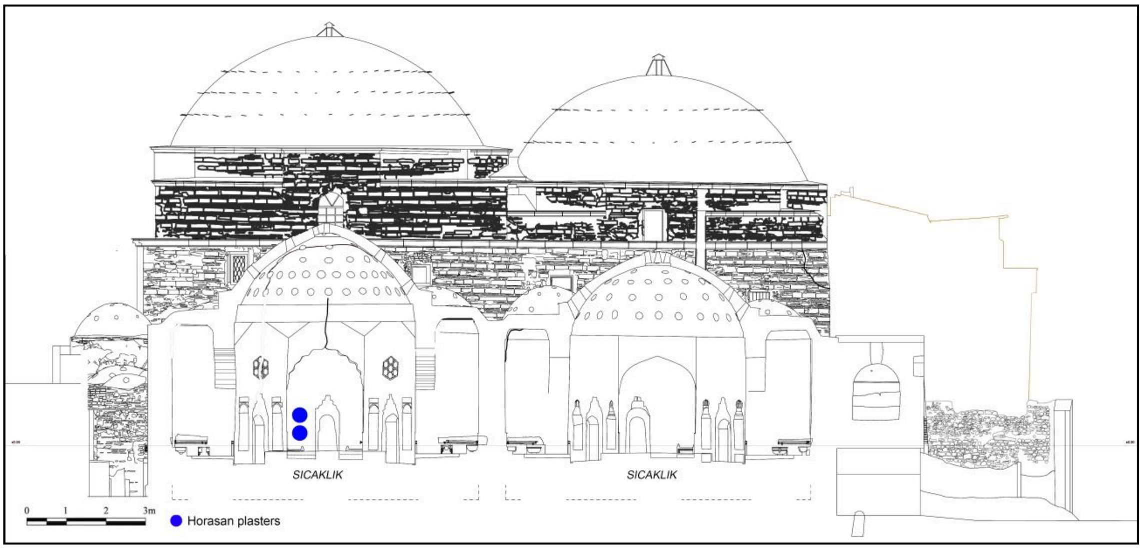


Figure 3.8. Section C-C of Zeyrek Çinili Bath showing where the samples were collected (Source: KA.BA 2015)

Sample codes were labelled in accordance with their sections, spaces, levels, layers and type of plasters. Accordingly, first letter indicates the section of the bath (E: Erkekler, K: Kadınlar) while the second letter indicates the space or the architectural element (So: Soyunmalık, I:Ilıklık, S:Sıcaklık, H:Halvet, D:Dome). Third letter shows the level of the sample (L: Lower, U: Upper). The fourth letter indicates the lime plaster samples (L: Lime plaster). Horasan plasters are not indicated by any letter. The fourth one can be a word instead of a letter if the samples were collected from specific points (adhesive: glazed tile adhesive, joint: joint mortar, niche: niche mortar, muqarnas). The final letter indicates the layer of the plaster (1: The bottom layer of horasan plaster, 2: The upper layer of horasan plaster) (Table 3.1, 3.2)

Table 3.1. Table showing definitions of the samples collected from men’s section

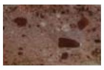
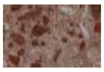
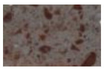
ZEYREK ÇİNİLİ BATH	MEN'S SECTION		DEFINITION
	sample	code	
ILIKLIK		E.I.L.1	First layer of the horasan plaster collected from the lower level of the ılıklık
		E.I.L.2	Second layer of the horasan plaster collected from the lower level of the ılıklık
		E.I.U	Horasan plaster collected from the upper level of the ılıklık
		E.I.U.L	Lime plaster collected from the upper level of the ılıklık
		E.I.L.adhesive	Glazed tile adhesive collected from the lower level of the ılıklık.
SICAKLIK		E.S.L.1	First layer of the horasan plaster collected from the lower level of the sıcaklık
		E.S.L.2	Second layer of the horasan plaster collected from the lower level of the sıcaklık
		E.S.U	Horasan plaster collected from the upper level of the sıcaklık
		E.S.L.niche	Horasan plaster collected from the niche on the lower level of the sıcaklık
HALVET		E.H.L.1	First layer of the horasan plaster collected from the lower level of the halvet
		E.H.L.2	Second layer of the horasan plaster collected from the lower level of the halvet
		E.H.U	Horasan plaster collected from the upper level of the halvet
		E.H.U.L	Lime plaster collected from the upper level of the halvet
SOYUNMALIK (dome)		E.So.D	Horasan plaster collected from the dome of the soyunmalık
		E.So.D.L	Lime plaster collected from the dome of the soyunmalık

Table 3.2. Table showing definitions of the samples collected from women’s section

ZEYREK ÇİNİLİ BATH	WOMEN'S SECTION		DEFINITION
	sample	code	
ILIKLIK		K.I.L.1	First layer of the horasan plaster collected from the lower level of the ılıklık
		K.I.L.2	Second layer of the horasan plaster collected from the lower level of the ılıklık
		K.I.U	Horasan plaster collected from the upper level of the ılıklık
		K.I.U.L	Lime plaster collected from the upper level of the ılıklık
		K.I.L.joint	Joint mortar of the glazed tiles collected from the lower level of the ılıklık
SICAKLIK		K.S.L.1	First layer of the horasan plaster collected from the lower level of the sıcaklık
		K.S.L.2	Second layer of the horasan plaster collected from the lower level of the sıcaklık
		K.S.U	Horasan plaster collected from the upper level of the sıcaklık
HALVET		K.H.L.1	First layer of the horasan plaster collected from the lower level of the halvet
		K.H.L.2	Second layer of the horasan plaster collected from the lower level of the halvet
		K.H.U	Horasan plaster collected from the upper level of the halvet
		K.H.U.L	Lime plaster collected from the upper level of the halvet
		K.H.U. muqarnas	Lime plaster collected from the muqarnas on the upper level of the halvet
SOYUNMALIK (dome)		K.So.D	Horasan plaster collected from the dome of the soyunmalık
		K.So.D.L	Lime plaster collected from the dome of the soyunmalık

3.2. Determination of Application Techniques of Plasters of the Interior Spaces

Field surveys were implemented for observation in the bath and collecting plaster samples. Then, pre-laboratory studies were carried out and sections of plaster samples were examined by binocular microscope and SEM to define their application techniques.

3.3. Determination of Basic Physical Properties of Plasters

RILEM standard test methods were applied to determine bulk densities and porosities of plaster samples (RILEM 1980). The ratio of the mass to its bulk volume of the sample is density and the ratio of the pore volume to the bulk volume of the sample is porosity.

Two parallel samples were used to determine their densities and porosities. First of all, samples were dried in an oven at 40ºC at least for 24 hours and then they were weighed by using a precision balance (AND HF-3000G) to record their dry weights (M_{dry}). Afterwards, they were wholly placed within distilled water in a vacuum oven and saturated (Lab-Line 3608-6CE Vacuum Oven). The samples after being saturated, their saturated weights (M_{sat}) were measured and then Archimedes weights (M_{arch}) of sample with hydrostatic weighing in distilled water were determined by using precision balance. After all, for calculation of bulk densities (D) and porosities (P) of the plaster samples, the dry, saturated and Archimedes weights were used in the following formulas given below:

$$D\ (g/cm^3) = M_{dry} / (M_{sat} - M_{arch}) \tag{3.1}$$

$$P\ (\%) = [(M_{sat} - M_{dry}) / (M_{sat} - M_{arch})] \times 100 \tag{3.2}$$

where;

D = Density (g/cm^3)

P = Porosity (%)

M_{dry} = Dry weight (g)

M_{sat} = Saturated weight (g)

M_{arch} = Archimedes weight (g)

M_{sat}-M_{dry} = Pore volume (g)

M_{sat}- M_{arch} = Bulk volume (g)

3.4. Determination of Raw Material Compositions of Plasters

Lime-aggregate ratio and particle size distribution of aggregates of the samples were determined by dissolving of the carbonated lime in dilute hydrocholoc acid. In this procedure, two parallel plaster samples were dried in an oven at 60°C and weighed ($M_{samp.}$) by a precision balance. Then, these samples were left in the dilute (5%) hydrochloric acid solution. After whole of the carbonated lime were dissolved, aggregates were filtered and washed with distilled water until all chlorine ions removes. They were weighed by using a precision balance (M_{agg}). Then, the following formulas were carried out to determine ratios of acid soluble and insoluble parts.

$$\text{Insoluble \%} = [(M_{sam} - M_{agg}) / (M_{sam})] \times 100$$

$$\text{Acid Soluble \%} = 100 - \text{Insoluble \%}$$

M_{sam} = Dry weight of the sample (g)

M_{agg} = Dry weight of the aggregates (g)

In order to determine exact lime ratio of the plasters, the lime ($Ca(OH)_2$) used in the preaparation of the plasters were used. Lime/aggregate ratio was calculated by the following these formulas:

$$\underbrace{Ca(OH)_2}_{74g} + \underbrace{CO_2}_{44\,g} \rightarrow \underbrace{CaCO_3}_{100g} + H_2O \quad \text{(Molecular weights)}$$

$$\text{Aggregate \%} = (100 \times \text{Insoluble}) / [((\text{Acid Soluble \%} \times M.W._{Ca(OH)2}) / M.W._{CaCO3}) + \text{Insoluble \%}]$$

$$\text{Lime \%} = 100 - \text{Aggregate \%}$$

$M.W._{CaCO3}$ = Molecular weight of $CaCO_3$ which is 100.

$M.W._{Ca(OH)2}$ = Molecular weight of $Ca(OH)_2$ which is 74.

Particle size distributions of aggregates were determined by sieve analysis using an Retsch AS200 analytical sieve shaker. The sieve sizes were 53 μm, 125 μm, 250 μm, 500 μm, 1180 μm and 2360 μm.

3.5. Determination of Mineralogical and Chemical Compositions of Fine Plasters Matrices

Mineralogical compositions of fine plaster matrices (less than 63 micron called binders) were determined by X-ray Diffraction (XRD) analysis using a Philips X-Pert Pro X-ray Diffractometer with CuKα radiation in the 5-70º range.

Chemical compositions of plasters were determined by Philips XL 30-SFEG Scanning Electron Microscope (SEM) equipped with X-Ray Energy Dispersive System (EDS). The powdered plaster samples with particle size less than 53μm were pressed into pellets under about 10 tons/cm^2 pressure and these pellet samples were examined.

3.6. Determination of Microstructural Properties of Plasters

Microstructural properties were determined by a Philips XL 30-SFEG Scanning Electron Microscope (SEM) and a binocular microscope.

3.7. Determination of Pozzolanic Activities of the Crushed Bricks Used as Aggregates

Pozzolanic activities of the crushed bricks used as aggregates were measured by using electrical conductivity method (Luxan et al. 1989).

Firstly, saturated calcium hydroxide solution ($Ca(OH)_2$) was prepared and was measured its electrical conductivity. Secondly, aggregates less than 53μm size were mixed with saturated calcium hydroxide solution (5 g/200ml), stirred for two minutes and measured its electrical conductivity. Finally, difference between two measurements (ΔEC in mS/cm) was calculated and this was showed pozzolanic activity values of the crushed brick aggregates. If the EC is over 2 mS/cm, it was accepted that the aggregates have good pozzolanicity (highly energetic pozzolan) (Luxan et al. 1989).

3.8. Determination of Hydraulicity of Plasters

The hydraulic character of plasters was determined by thermogravimetric analysis (Shimadzu TGA-21). The samples were heated in the temperature range of 200-900°C and their weight losses were measured. During the heating, loss of hygroscopic (adsorbed) water was mainly defined at 200ºC, loss of chemically bound water of hydraulic components was defined at 200 to 600ºC and loss of carbon dioxide gas depending on decomposition of calcium carbonates was defined at 600ºC to 900ºC.

If the ratio of CO_2/chemically bound water (H_2O) of plasters is between 1 and 10, the plasters could be considered as hydraulic (Bakolas et al. 1998).

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, results of the experiments carried out to determine application techniques of plasters of the interior spaces, basic physical properties and raw material compositions of plasters, mineralogical and chemical compositions of fine plaster matrices, microstructural properties, pozzolanic activities of crushed brick aggregates and hydraulic properties of plasters were given and discussed.

4.1. Application Techniques of Plasters of the Interior Spaces

Plasters applied on the wall surfaces of the inner spaces of the bath can be classified as lower level and upper level plasters. The lower level plastering on the wall surfaces were extended to 1.5 m height from the floor surfaces and the upper level plastering were extended along the wall surfaces from 1.5 m height. These levels are distinguished clearly due to their colors, layers and traces of glazed tiles (Figure 4.1).

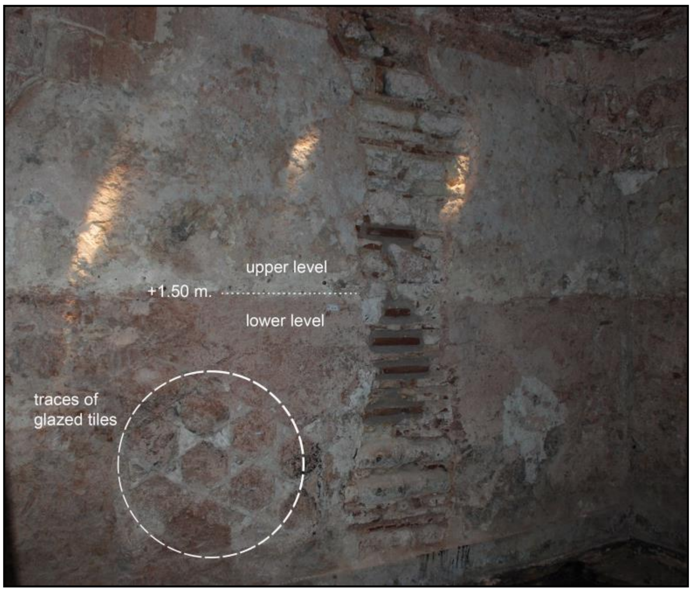


Figure 4.1. The image from ılıklık space of the bath showing levels and traces of the glazed tiles on the wall surface

The lower level plasters were consisted of two horasan plaster layers. The first layer of the lower level horasan plasters was rough while the second layer was fine. The thickness of the first layer was about 3.0 cm and the second layer was nearly 1.3 cm. Glazed tiles were adhered on the second layer of the horasan plasters by glazed tile adhesive (Figure 4.2, 4.3 and 4.4).

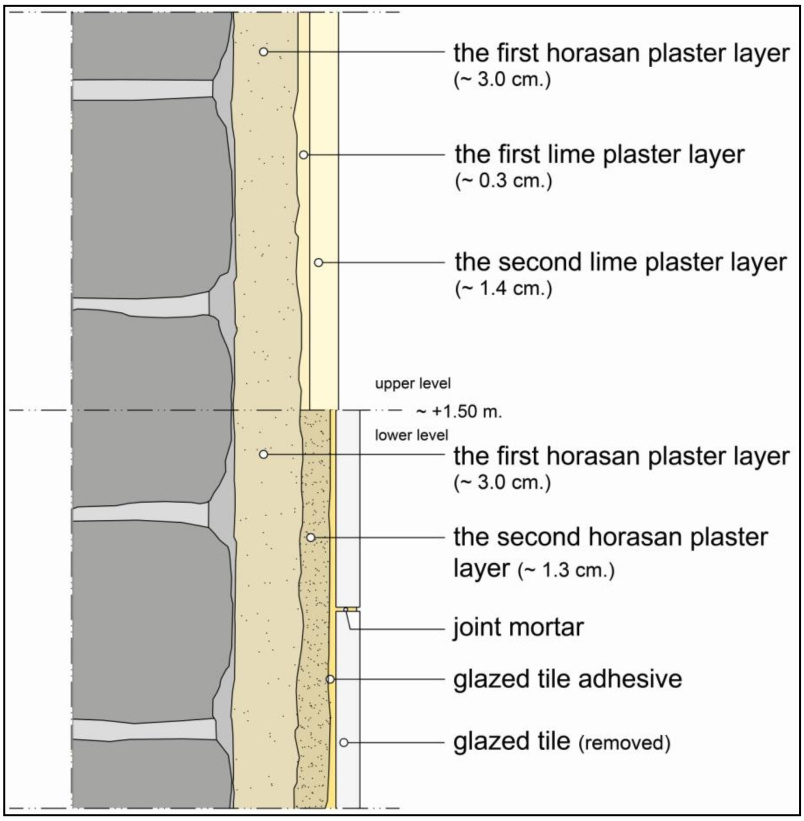


Figure 4.2. Plaster layers of ılıklık spaces

The upper level plasters were consisted of a rough horasan plaster layer with one or two fine lime plaster layers. The thickness of the upper level horasan plaster was about 3.0 cm. The thickness of the first and the second layer of the lime plasters were nearly 0.3 and 1.4 cm on the wall surfaces of the ılıklık space and were about 0.5 and 1.2 cm on the wall surfaces of the halvet space (Figure 4.2 and 4.4). The upper level plasters of the sıcaklık spaces had one lime plaster layer on the horasan plaster and thickness of this lime plaster layer was about 1.7 cm (Figure 4.3).

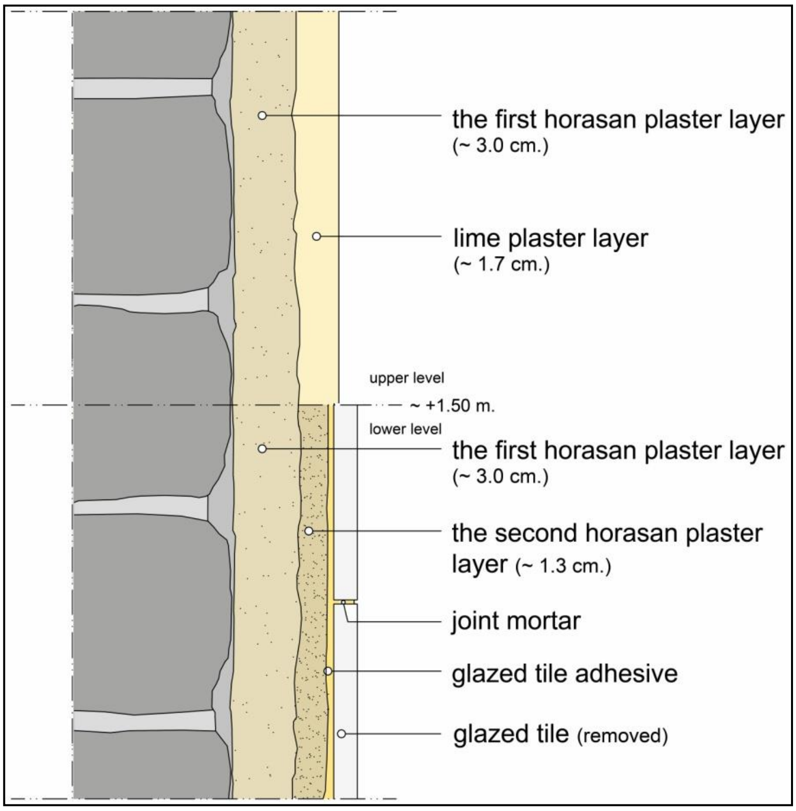


Figure 4.3. Plaster layers of sıcaklık spaces

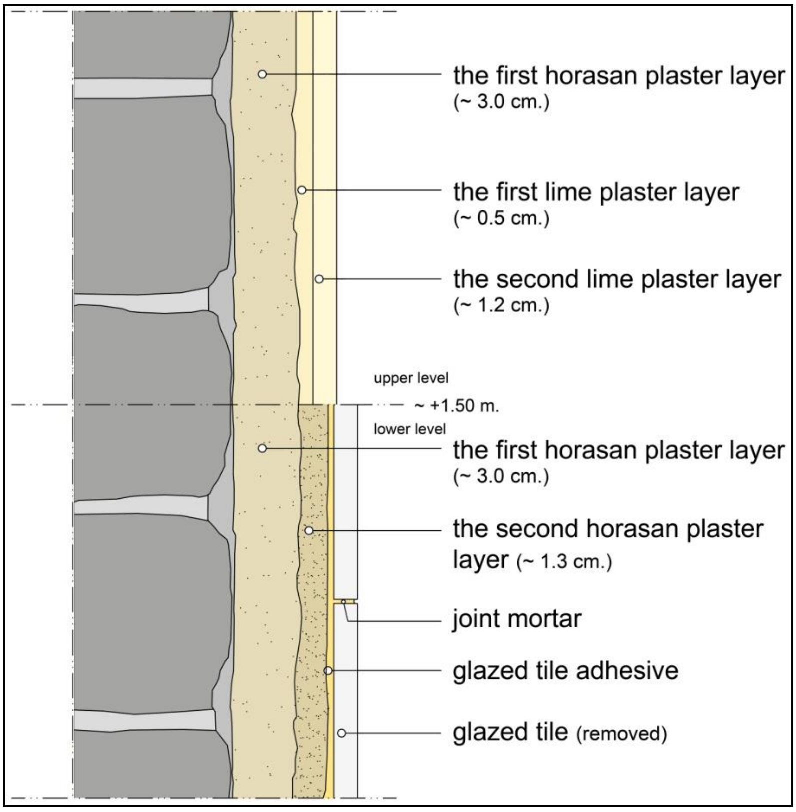


Figure 4.4. Plaster layers of halvet spaces

Multilayered plaster application together with the use of glazed tiles is an uncommon technique for the Ottoman bath buildings. Generally, a thin pinkish finishing layer is observed on horasan plaster layers of the other Ottoman baths. However, this finishing layer was not found on the walls of Zeyrek Çinili Bath. This indicated that glazed tiles were applied on the horasan plaster layers as a decorative finishing layer and this application technique is a rare example of the bath buildings of Ottoman Empire.

The plasters collected from the domes of men's and women's soyunmalık spaces were consisted of a rough horasan plaster layer with one fine lime plaster layer. The thickness of the horasan plaster was about 3.0 cm and the the lime plaster was about 0.3 cm (Figure 4.5).

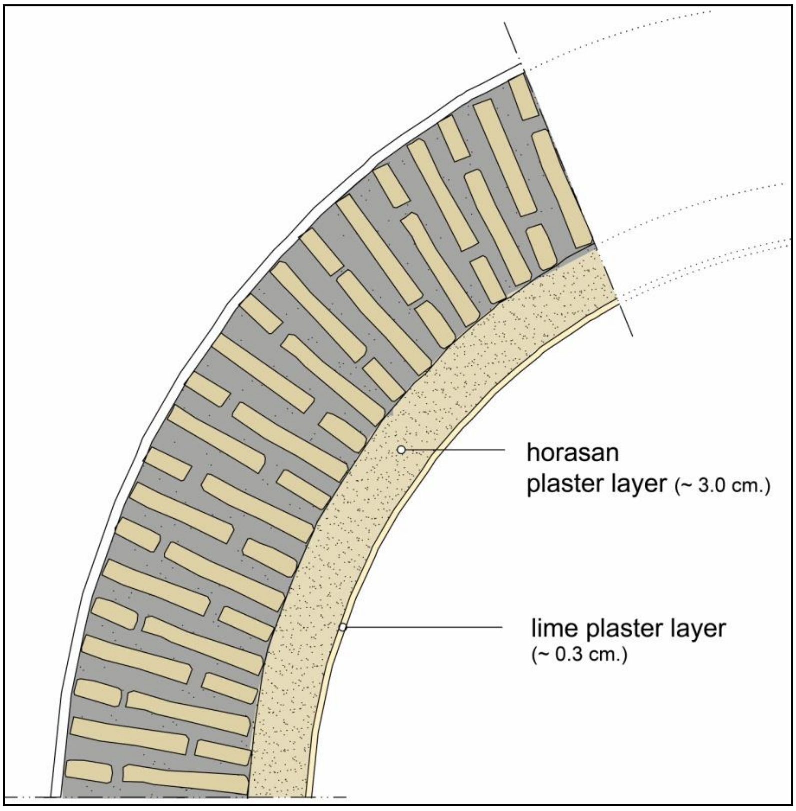


Figure 4.5. Plaster layers of domes of soyunmalık

Layers of horasan and lime plasters and interfaces between the layers were determined by using binocular microscope (Figure 4.6, 4.8, 4.9) and SEM-EDS (Figure 4.7).

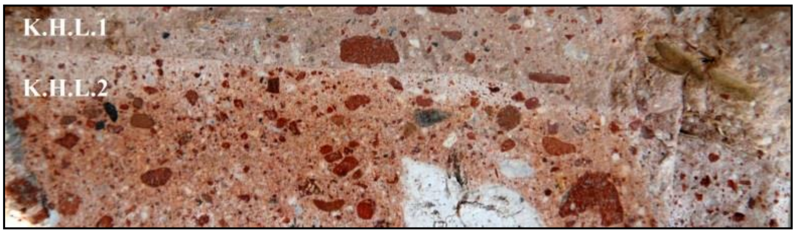
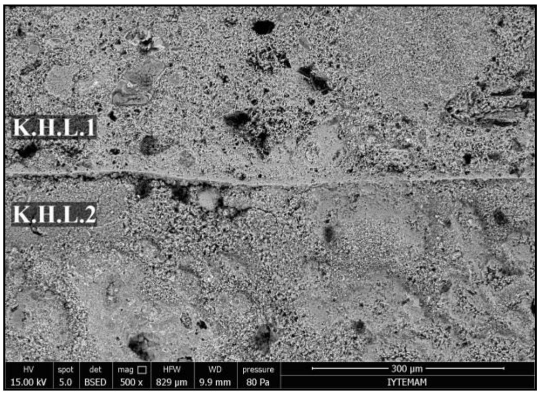
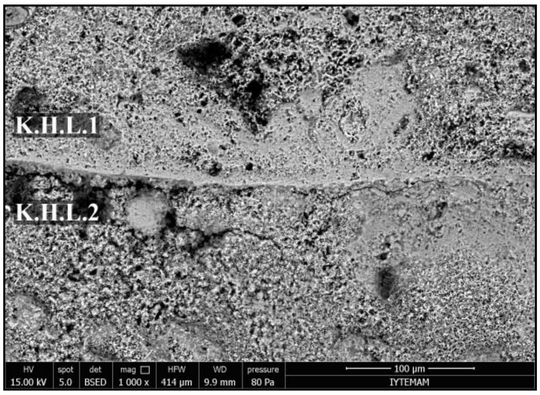


Figure 4.6. Interfaces between horasan plaster layers from the lower level

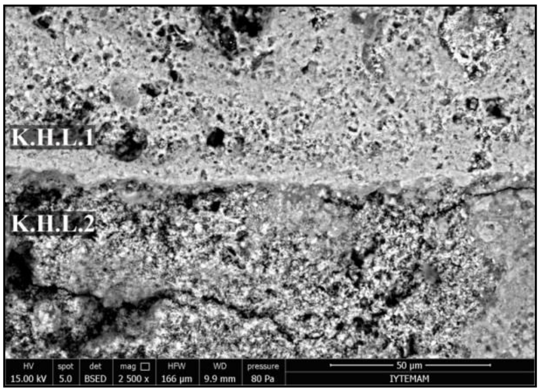
SEM and binocular analysis indicated that layers of horasan plasters of lower levels were well adhered to each other and distinguishable due to their appearances and a distinct line between each of plaster layers (Figure 4.6, 4.7). This distinct line was observed clearly due to the fact that second layers of plasters were applied after the first layers were dried on the wall surfaces. This multilayered plaster technique could be executed for protecting the wall from water effects.



(a)



(b)



(c)

Figure 4.7. BSE images showing the interfaces between horasan plaster layers from the lower level at magnifications of 500 (a), 1000 (b), 2500 (c)

Binocular analysis showed that horasan plaster and lime plaster layers of the upper level had a strong adhesion between each of plaster layers (Figure 4.8).

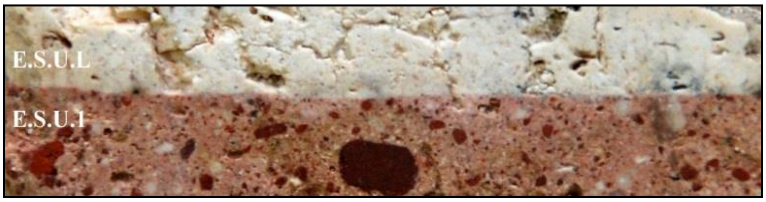


Figure 4.8. Interfaces between horasan and lime plaster layer from the upper level

On the other hand, binocular analysis indicated that lime plaster layers of the upper level had a weak adhesion. Also, a clear difference between their textures was observed (Figure 4.9). The bottom lime plaster layer was fine and the upper was rough. It showed that these lime layers can be originated from the repair of the bath.

Figure 4.9. Lime plaster layers from the upper level

4.2. Basic Physical Properties of Plasters

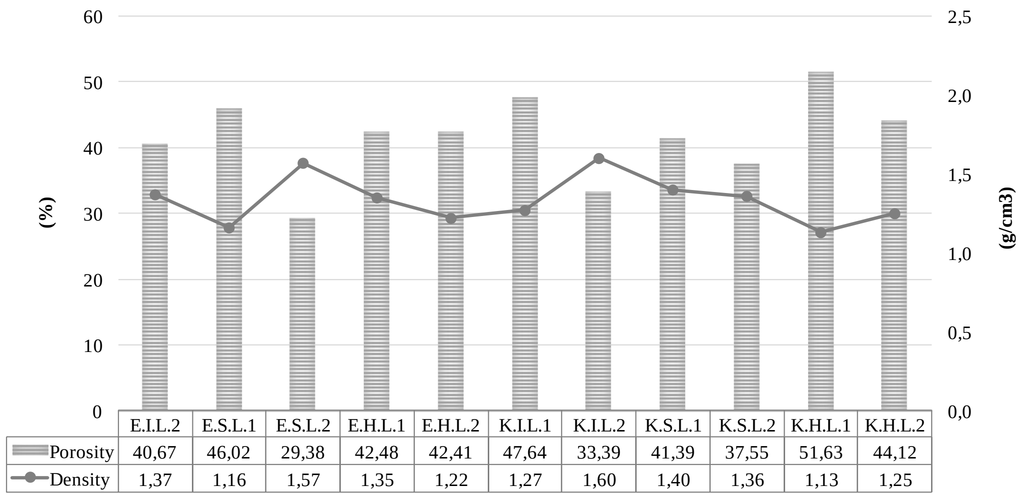
The one of the main physical properties of the materials are density and porosity. In this study, density and porosity values of plasters were determined.

Density and porosity values of the lower level horasan plasters of the bath varied between 1.1-1.6 g/cm^3 and 29-52 % by volume respectively (Figure 4.10). Density and porosity values of the upper level horasan plasters were in the range of 1.1-1.4 g/cm^3 and 31-56 % (Figure 4.11).

Horasan plasters of the men's section had density and porosity values vary between 1.1-1.6 g/cm^3 and 29-56 % respectively (Figure 4.12). Similarly, horasan plasters of the women's section had their values vary between 1.1-1.6 g/cm^3 and 33-52 % (Figure 4.13).

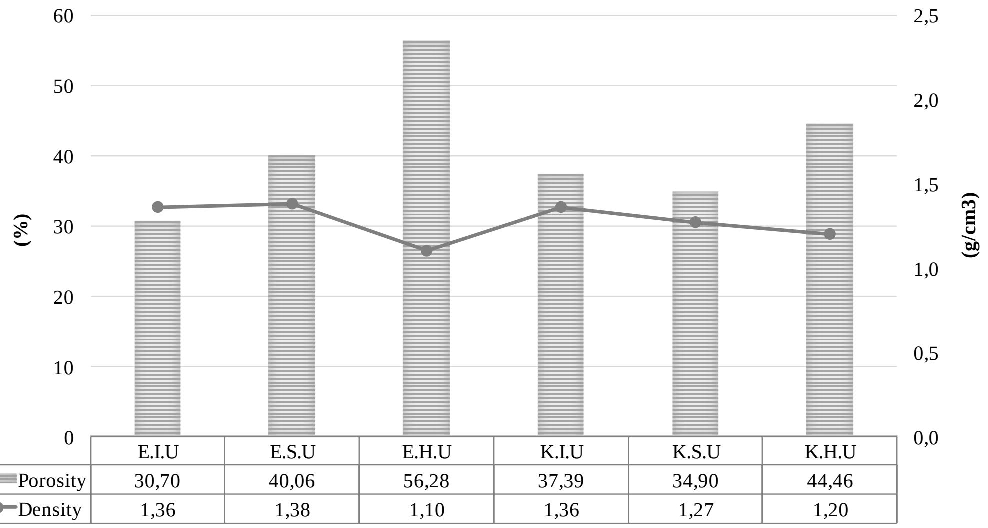
Lime plasters of the men’s section had density and porosity values range between 1.4-1.6 g/cm^3 and 33-41 % respectively and lime plasters of the women’s section had their values range between 1.1-1.5 g/cm^3 and 38-52 % (Figure 4.14).

Based on these results, the density and porosity values of horasan plasters collected from lower and upper levels of all spaces were nearly in the same ranges. Accordingly, the density and porosity values of horasan plasters used in the men’s and women’s sections were almost similar to each other. In addition, the density and porosity values of lime plasters of the bath were in the similar ranges. These density and porosity values indicated that horasan plasters and lime plasters used in the bath are low dense and high porous materials.



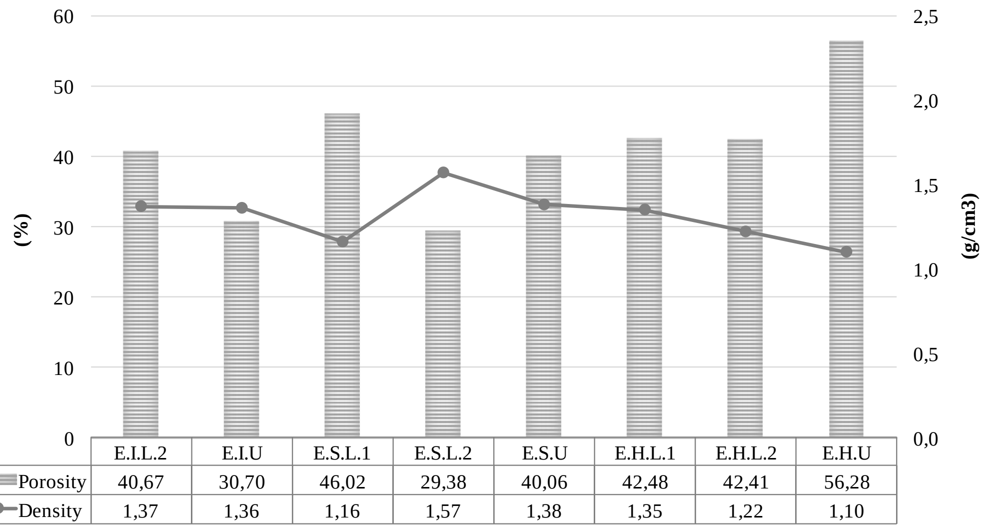
	E.I.L.2	E.S.L.1	E.S.L.2	E.H.L.1	E.H.L.2	K.I.L.1	K.I.L.2	K.S.L.1	K.S.L.2	K.H.L.1	K.H.L.2
Porosity	40,67	46,02	29,38	42,48	42,41	47,64	33,39	41,39	37,55	51,63	44,12
Density	1,37	1,16	1,57	1,35	1,22	1,27	1,60	1,40	1,36	1,13	1,25

Figure 4.10. Density and porosity values of the lower level horasan plasters



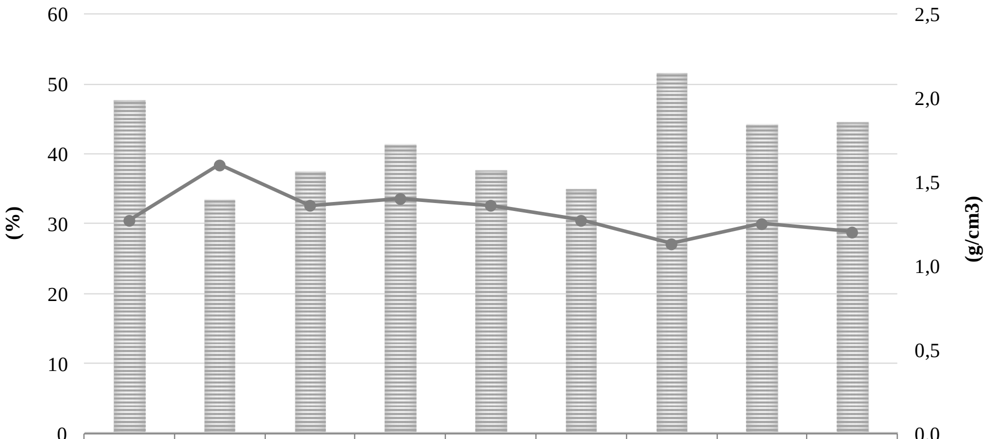
	E.I.U	E.S.U	E.H.U	K.I.U	K.S.U	K.H.U
Porosity	30,70	40,06	56,28	37,39	34,90	44,46
Density	1,36	1,38	1,10	1,36	1,27	1,20

Figure 4.11. Density and porosity values of the upper level horasan plasters



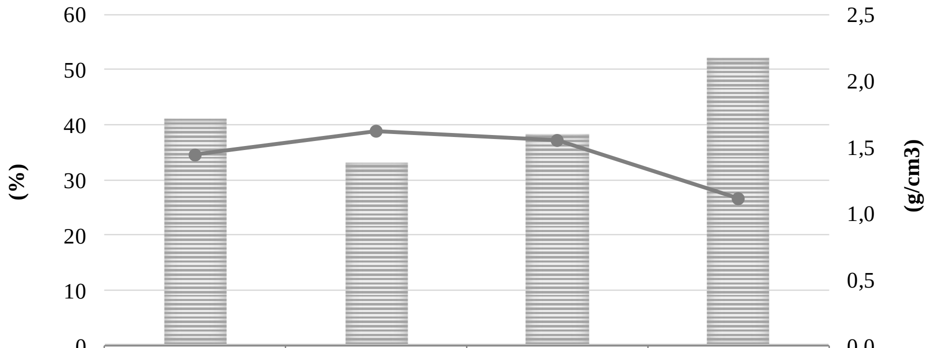
	E.I.L.2	E.I.U	E.S.L.1	E.S.L.2	E.S.U	E.H.L.1	E.H.L.2	E.H.U
Porosity	40,67	30,70	46,02	29,38	40,06	42,48	42,41	56,28
Density	1,37	1,36	1,16	1,57	1,38	1,35	1,22	1,10

Figure 4.12. Density and porosity values of horasan plasters of men’s section



	K.I.L.1	K.I.L.2	K.I.U	K.S.L.1	K.S.L.2	K.S.U	K.H.L.1	K.H.L.2	K.H.U
Porosity	47,64	33,39	37,39	41,39	37,55	34,90	51,63	44,12	44,46
Density	1,27	1,60	1,36	1,40	1,36	1,27	1,13	1,25	1,20

Figure 4.13. Density and porosity values of horasan plasters of women’s section



	E.I.U.L.2	E.H.U.L.2	K.I.U.L.2	K.H.U.L.2
Porosity	41,10	33,03	38,21	52,00
Density	1,44	1,62	1,55	1,11

Figure 4.14. Density and porosity values of lime plasters of men’s and women’s sections

In previous studies, nearly similar density and porosity values of horasan and lime plasters used in several Ottoman baths were estimated (Uğurlu 2005, Böke et al. 2004). As a result of these studies, horasan plasters collected from lower and upper levels of the baths were almost same. Accordingly, the density and porosity values of horasan plasters used in these baths were averaged for each case. In the following tables, average values of density and porosity values of horasan plasters (Table 4.1) and lime plasters (Table 4.2) used in the Ottoman baths were given.

Table 4.1. Comparison of density and porosity values of horasan plasters

Name	Location - Year	Density (g/cm3)	Porosity (%)
Zeyrek Çinili Bath	İstanbul - 16th c.	1,3	41
Düzce Bath	İzmir - 16th c.	1,5	42
Hersekzade Bath	İzmir - 15th c.	1,3	47
Kamanlı Bath	İzmir - 15th c.	1,4	42
Ördekli Bath	Bursa - 15th c.	1,3	45
Beylerbeyi Bath	Edirne - 15th c.	1,7	26
Saray Bath	Edirne - 14th c.	1,6	33

Table 4.2. Comparison of density and porosity values of lime plasters

Name	Location - Year	Density (g/cm3)	Porosity (%)
Zeyrek Çinili Bath	İstanbul - 16th c.	1,4	41
Düzce Bath	İzmir - 16th c.	1,5	39
Hersekzade Bath	İzmir - 15th c.	1,4	40
Kamanlı Bath	İzmir - 15th c.	1,5	37

Based on these results, the density and porosity values of horasan and lime plasters used in the Ottoman bath buildings were almost in the same ranges. These results indicated that horasan and lime plasters of the baths located in different regions were produced by using similar raw materials and preparation techniques.

Horasan and lime plasters used in several historic buildings had similar density and porosity values. Density and porosity values of horasan plasters and mortars used in Serapis temple (Özkaya 2005) and Yoros Castle (Kurugöl and Güleç 2012) from the Byzantine period were nearly in the same ranges.

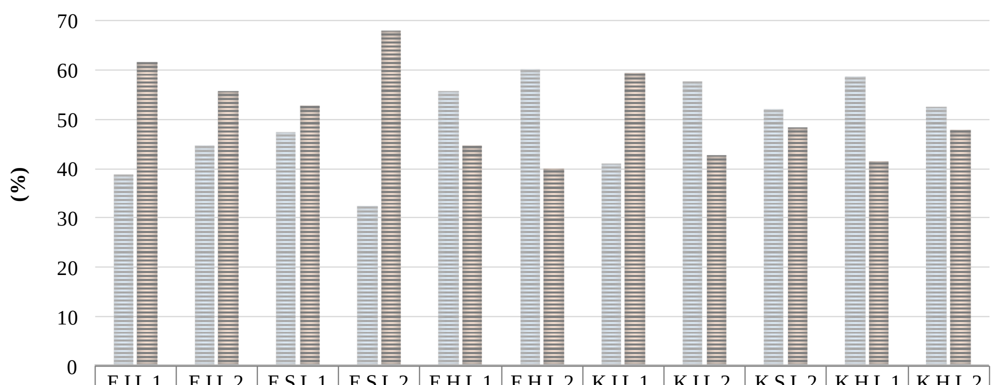
4.3. Raw Material Compositions of Plasters

Horasan plasters are mainly composed of carbonated lime and brick aggregates. In this study, percent of lime and aggregate and particle size distribution of aggregates were determined.

Horasan plasters had percent of lime and aggregate values vary between 32.2-67.8 % - 60.0-40.0 % by weight. Percent of lime and aggregate values of the lower level horasan plasters of the bath varied between 32.2-67.8 % - 60.0-40.0 % by weight (Figure 4.15). Percent of lime and aggregate values of the upper level horasan plasters ranged between 33.7-66.3 % - 48.4-51.6 % (Figure 4.16).

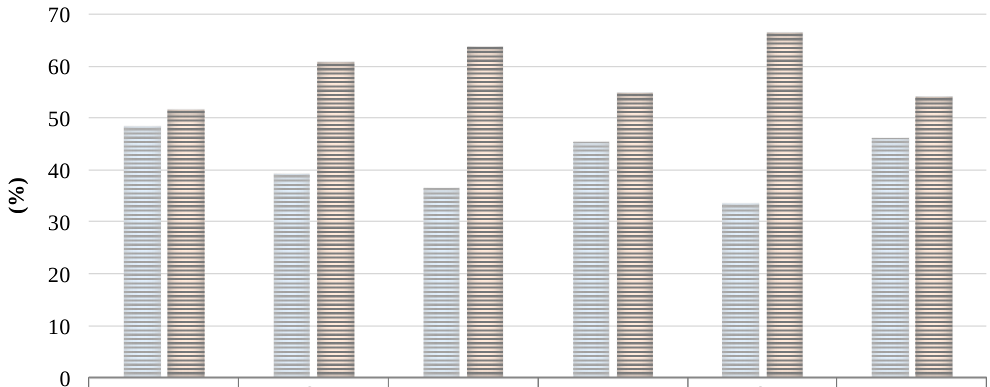
Horasan plasters of the men’s section had percent of lime and aggregate values range between 32.2-67.8 % - 60.0-40.0 % by weight (Figure 4.17). Horasan plasters of the women’s section had percent of lime and aggregate values range between 33.7-66.3 % - 58.5-41.5 % (Figure 4.18).

These values showed that percent of lime and aggregate values of lower and upper level horasan plasters were in the similar ranges. Also, horasan plasters of men’s and women’s sections had similar percent of lime and aggregate values.



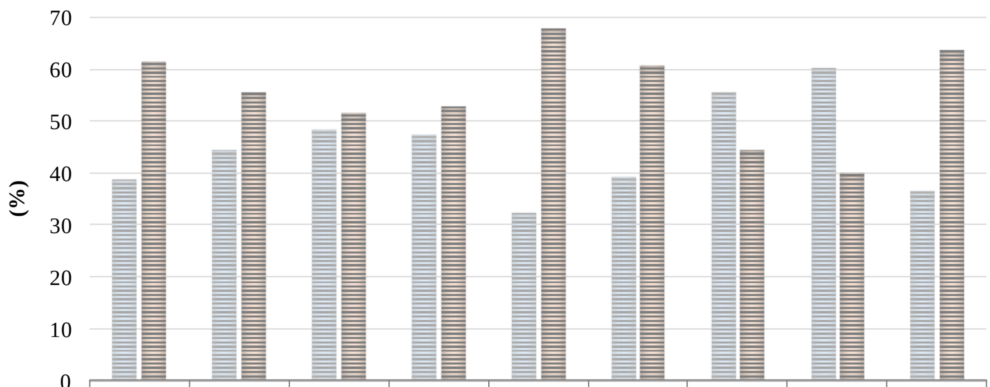
	E.I.L.1	E.I.L.2	E.S.L.1	E.S.L.2	E.H.L.1	E.H.L.2	K.I.L.1	K.I.L.2	K.S.L.2	K.H.L.1	K.H.L.2
Lime	38,7	44,5	47,3	32,2	55,5	60,0	40,9	57,5	51,8	58,5	52,3
Aggregate	61,3	55,5	52,7	67,8	44,5	40,0	59,1	42,5	48,2	41,5	47,7

Figure 4.15. Percent of lime and aggregate values of lower level horasan plasters



	E.I.U	E.S.U.	E.H.U	K.I.U.	K.S.U.	K.H.U.
Lime	48,4	39,3	36,5	45,3	33,7	46,0
Aggregate	51,6	60,7	63,5	54,7	66,3	54,0

Figure 4.16. Percent of lime and aggregate values of upper level horasan plasters



	E.I.L.1	E.I.L.2	E.I.U	E.S.L.1	E.S.L.2	E.S.U.	E.H.L.1	E.H.L.2	E.H.U
Lime	38,7	44,5	48,4	47,3	32,2	39,3	55,5	60,0	36,5
Aggregate	61,3	55,5	51,6	52,7	67,8	60,7	44,5	40,0	63,5

Figure 4.17. Percent of lime and aggregate values of horasan plasters of men’s section

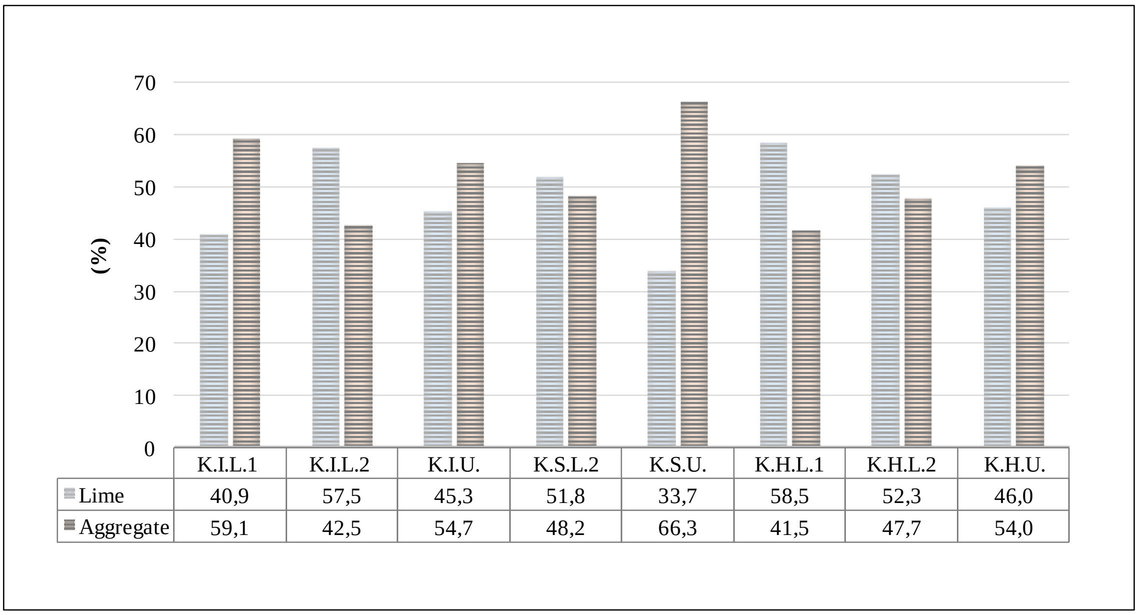


Figure 4.18. Percent of lime and aggregate values of horasan plasters of women's section

According to previous studies by Uğurlu (2005) and Böke et al. (2004), average values of percent of lime and aggregate values of plasters used in the Ottoman bath buildings were given in the following table (Table 4.3). These values indicated that percent of lime and aggregate values of horasan plasters of the baths were nearly 45-55 % - 58-42 % by weight.

Table 4.3. Comparison of percent of lime and aggregate values of horasan plasters

Name	Location - Year	Lime (%)	Aggregate (%)
Zeyrek Çinili Bath	İstanbul - 16th c.	52	48
Düzce Bath	İzmir - 16th c.	51	49
Hersekzade Bath	İzmir - 15th c.	51	49
Kamanlı Bath	İzmir - 15th c.	46	54
Ördekli Bath	Bursa - 15th c.	49	51
Beylerbeyi Bath	Edirne - 15th c.	45	55
Saray Bath	Edirne - 14th c.	58	42

Based on these results, percent of lime and aggregate values of plasters used in the Ottoman bath buildings were almost in the same ranges. Besides, plasters and mortars used in Serapis temple (Özkaya 2005), Yoros Castle (Kurugöl and Güleç 2012), Hagia Sophia (Moropoulou et al. 1995) and some historic buildings in different regions such as in Rhodes (Moropoulou et al. 1995), in Crete (Maravelaki-Kalaitzaki et al. 2003) and some churches, cathedrals in Kiev (Moropoulou et al. 2000) had similar percent of lime and aggregate values.

The particle size distribution of the horasan plaster samples showed that aggregates which had particle sizes 500 µm. were the main fraction of the total aggregates. This main fraction used in horasan plasters of the men's section and women's section was in the range of 16-40 % and 8-32 % (Figure 4.19).

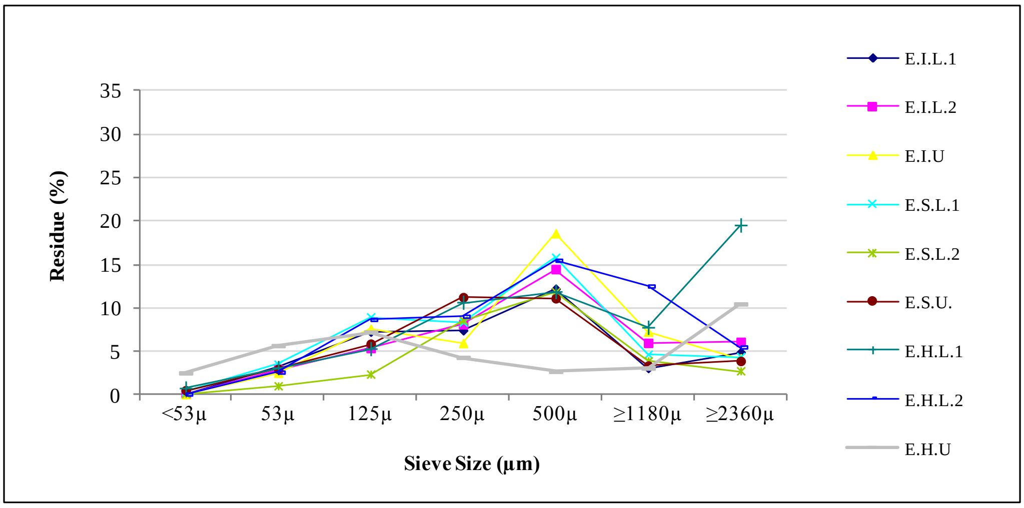


Figure 4.19. Particle size distributions of horasan plasters of men's section

Aggregates used in horasan plasters of the men's section composed of particle sizes 500 µm ranged between 16-40% and particle sizes between 500-1180 µm ranged between 17-26%. Aggregates used in horasan plasters of the women's section which had particle sizes 500 µm. were in the range of 8-32% and particle sizes between 500-1180 µm were in the range of 14-24% (Figure 4.20).

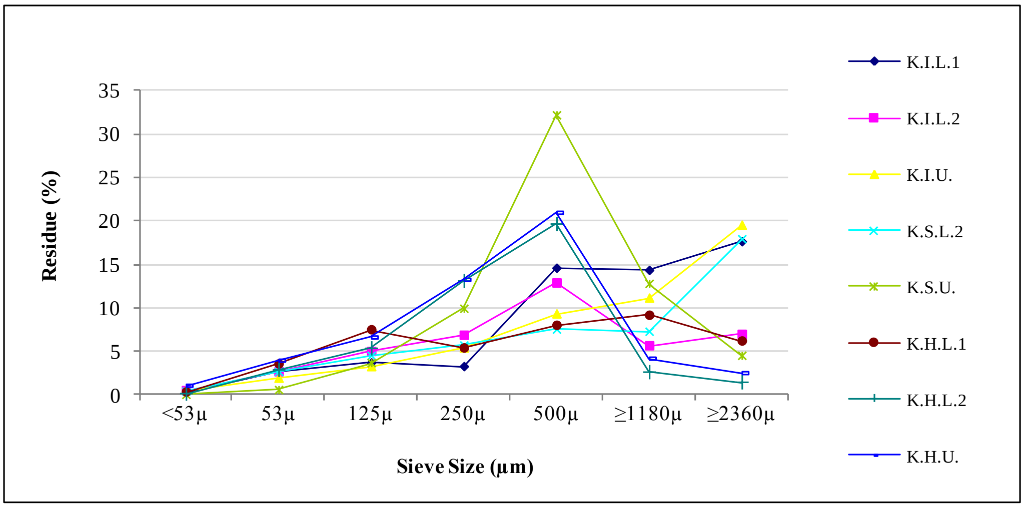
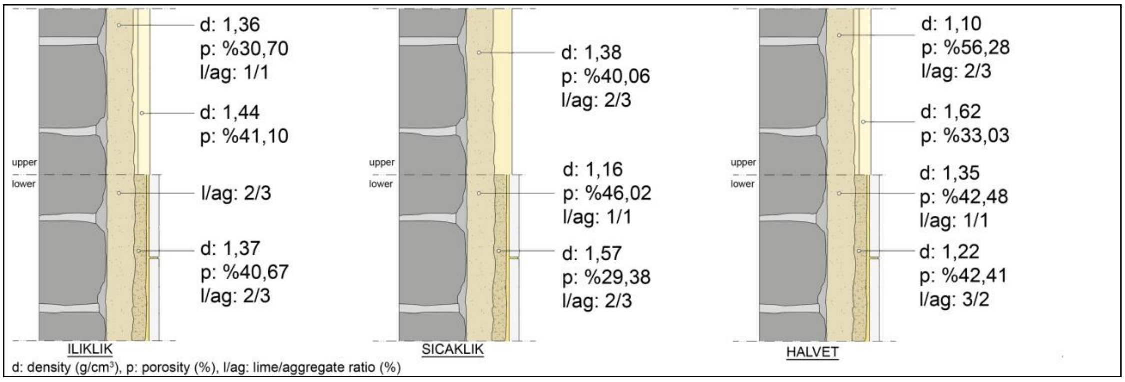
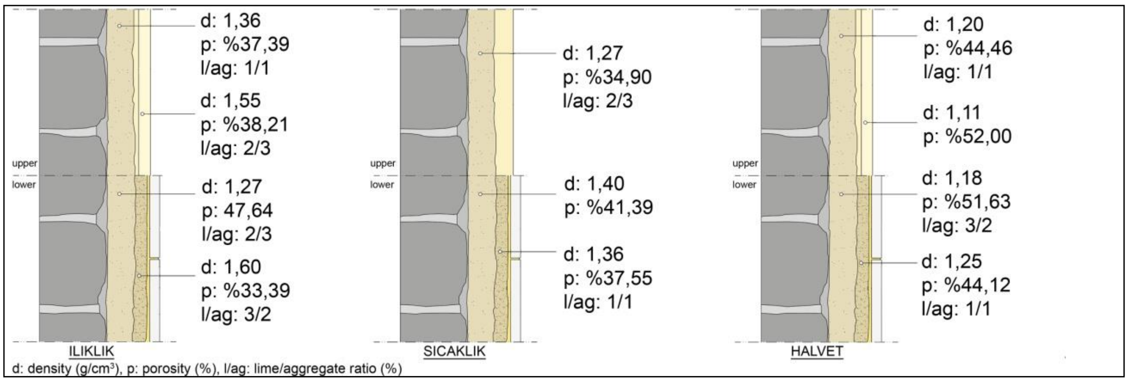


Figure 4.20. Particle size distributions of horasan plasters of women's section

All results of the experiments to determine basic physical properties and raw material compositions of the horasan and lime plasters were given in the following figure (Figure 4.21).



(a)



(b)

Figure 4.21. Density, porosity values and lime/aggregate ratios of plasters of men's (a) and women's (b) sections

4.4. Mineralogical and Chemical Compositions of Fine Plaster Matrices

Mineralogical and chemical compositions of fine plaster matrices were determined by XRD and SEM-EDS analyses.

4.4.1. Mineralogical Compositions of Fine Plaster Matrices

XRD analysis was applied to determine mineralogical compositions of fine horasan plasters, lime plasters and dome plasters, glazed tile adhesives, joint mortar, niche mortar and muqarnas matrices.

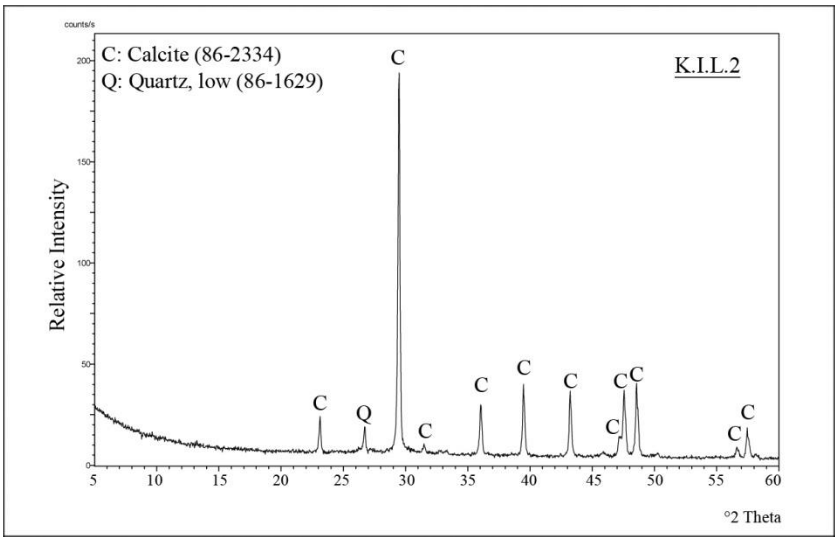
4.4.1.1. Mineralogical Compositions of Horasan Plasters

XRD analyses results indicated that horasan plasters were mainly consisted of calcite (C: $CaCO_3$), quartz (Q: SiO_2) and albite (A: ($Na(AlSi_3O_8)$)). Calcite was originated from carbonated lime, while quartz and other silicieous minerals were from brick powders.

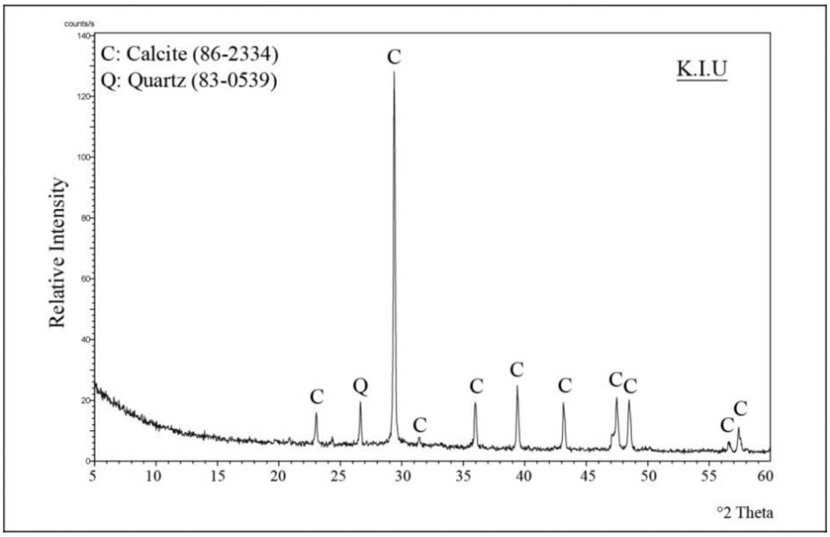
Minerals determined on XRD patterns of horasan plaster samples were given in the following table (Table 4.4). XRD patterns of horasan plaster samples from ılıklık, sıcaklık and halvet spaces of the men's and women's sections were given in the figures (Figure 4.22 - 4.27).

Table 4.4. Mineralogical compositions of horasan plasters determined by XRD results

Sample code	Minerals determined on XRD patterns
E.I.L.1	C, Q, A.H
E.I.L.2	C, Q
E.I.U	C, Q, A
E.S.L.1	C, Q, A.C.L
E.S.L.2	C, Q.L
E.S.U	C, Q, A
E.H.L.1	C, Q
E.H.L.2	C, Q
E.H.U	C, Q
K.I.L.2	C, Q, A
K.I.U	C, Q
K.S.L.2	C, Q
K.S.U	C, Q, A
K.H.L.1	C, Q
K.H.L.2	C, Q, A
K.H.U	C, Q, A
C: Calcite, Q: Quartz, A: Albite, A.H: Albite high, A.C.L: Albite calcian low	

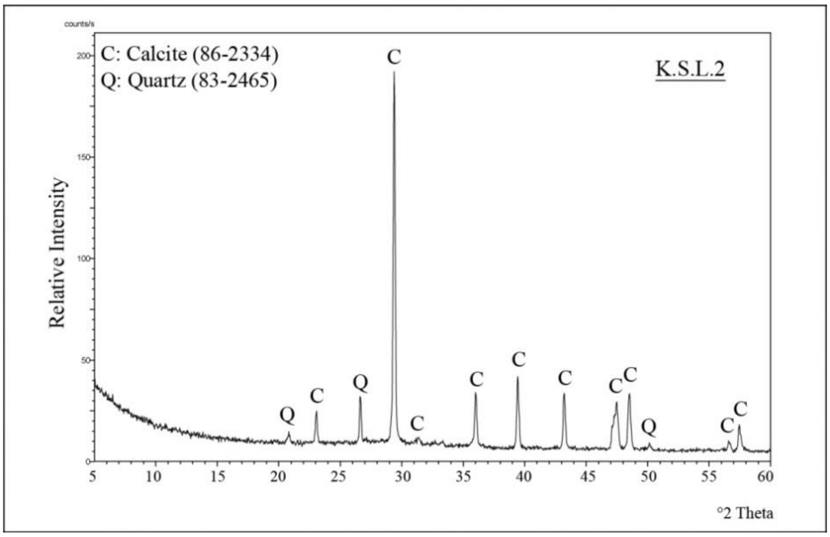


(a)

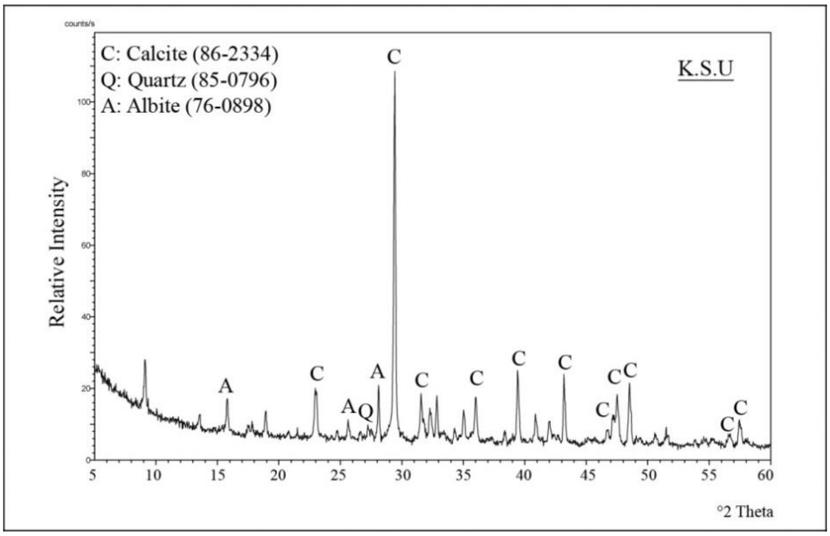


(b)

Figure 4.22. XRD patterns of horasan plaster samples from lower level (a) and upper level (b) of ılıklık space of the women's section

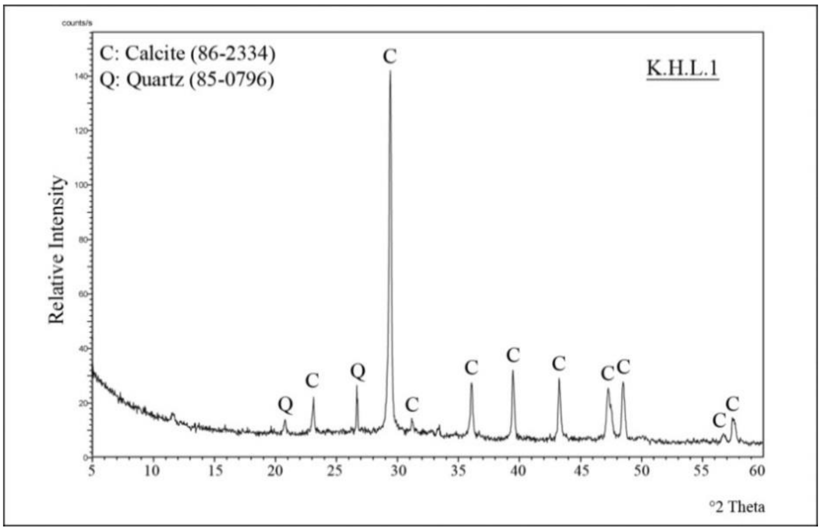


(a)

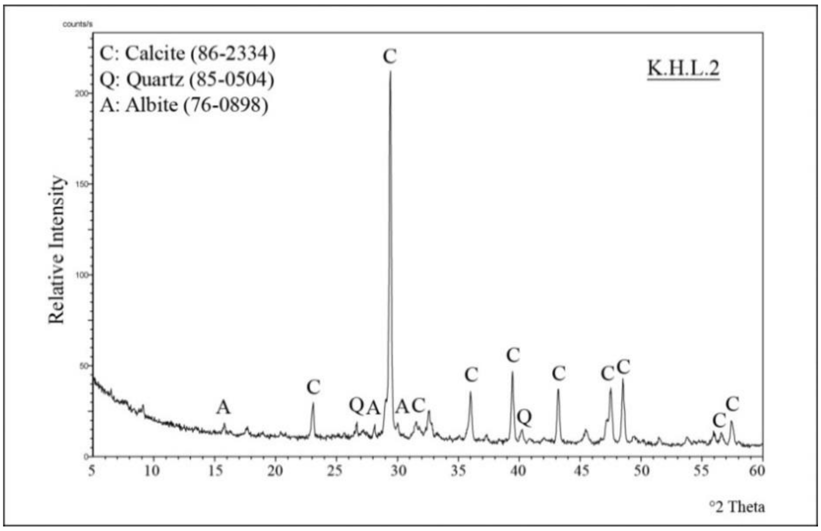


(b)

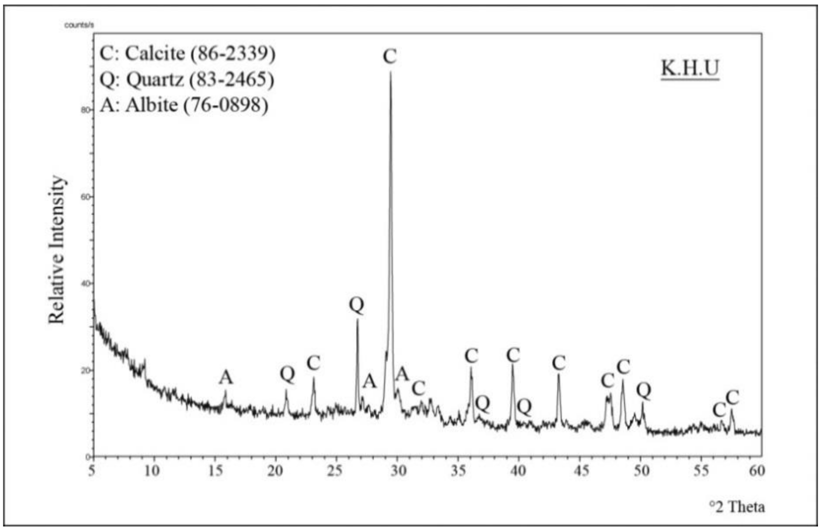
Figure 4.23. XRD patterns of horasan plaster samples from lower level (a) and upper level (b) of sıcaklık space of the women's section



(a)

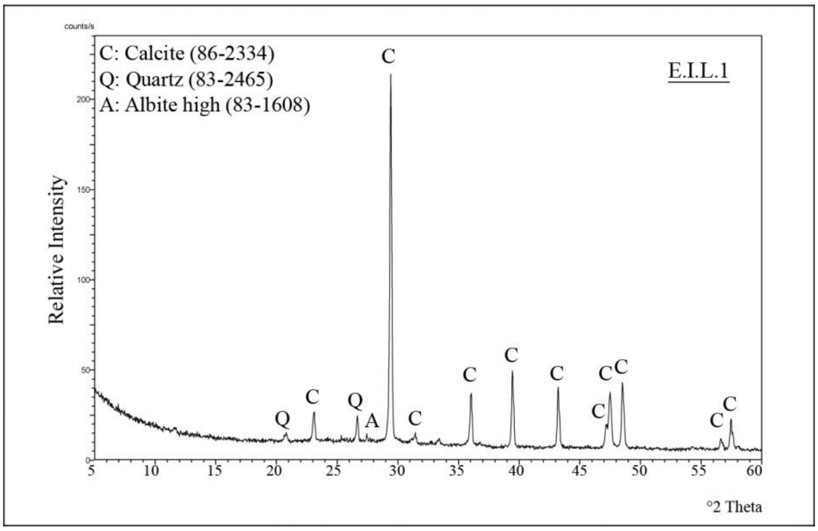


(b)

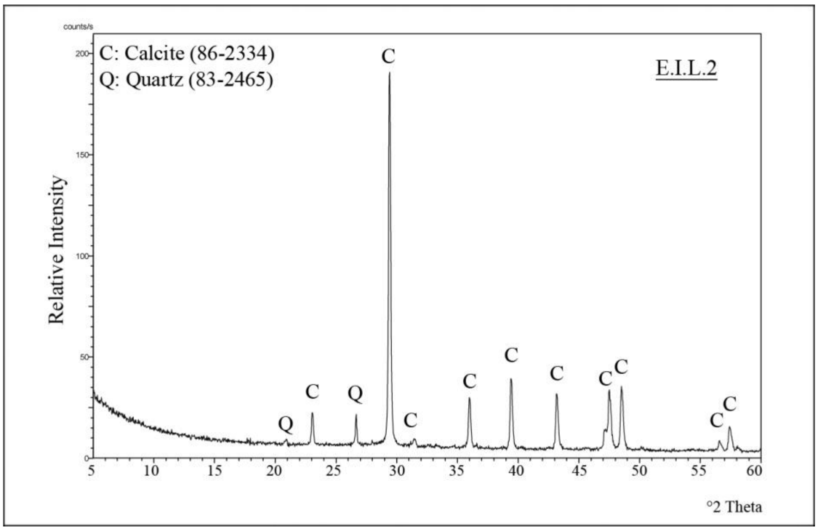


(c)

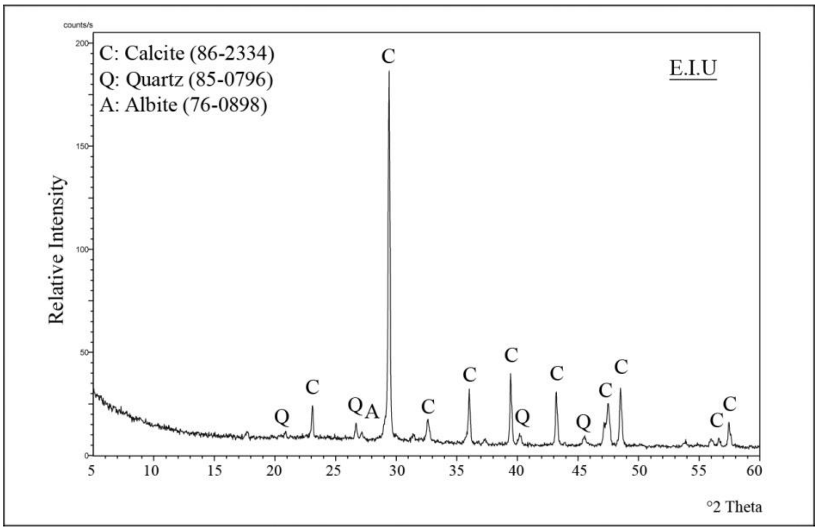
Figure 4.24. XRD patterns of horasan plasters from lower level (a), (b) and upper level (c) of halvet space of the women's section



(a)

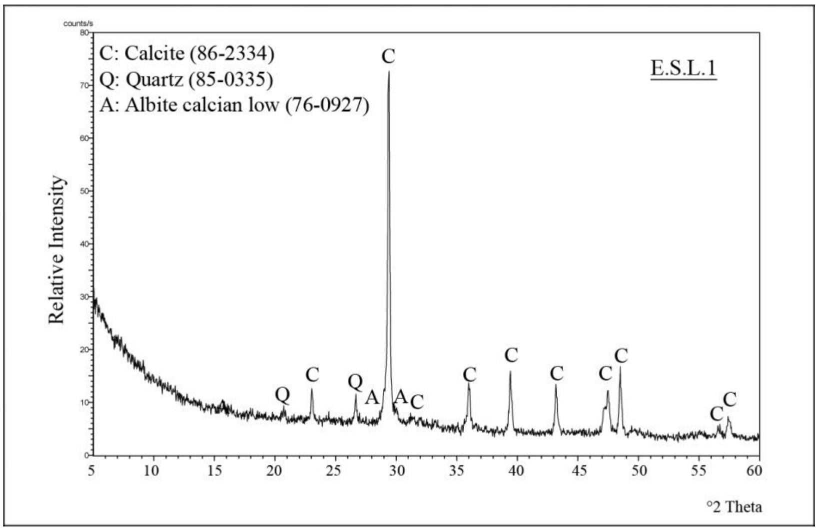


(b)

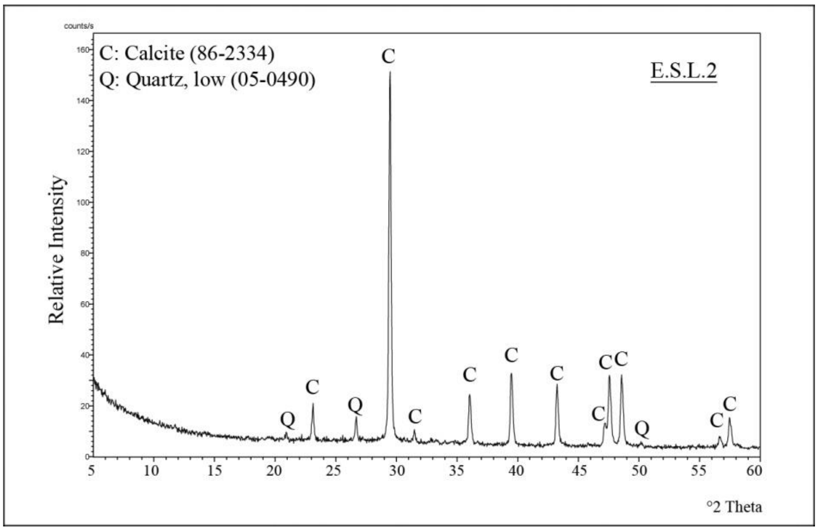


(c)

Figure 4.25. XRD patterns of horasan plaster samples from lower level (a), (b) and upper level (c) of ılıklık space of the men's section



(a)



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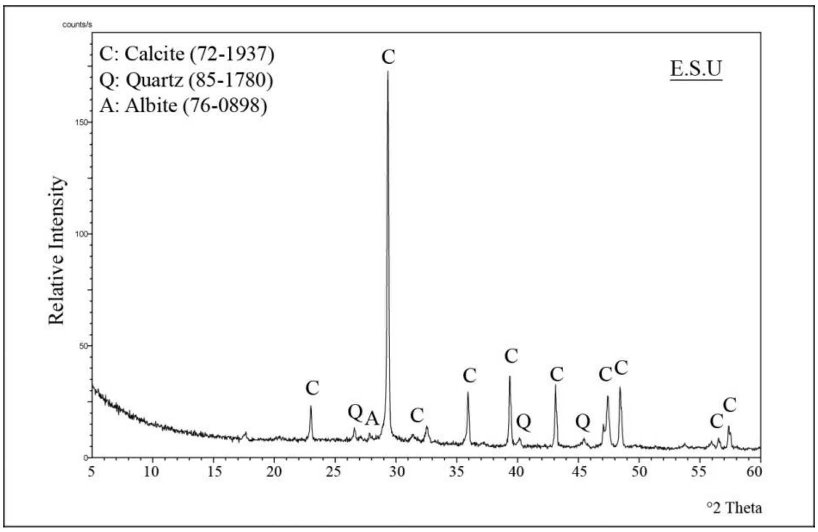
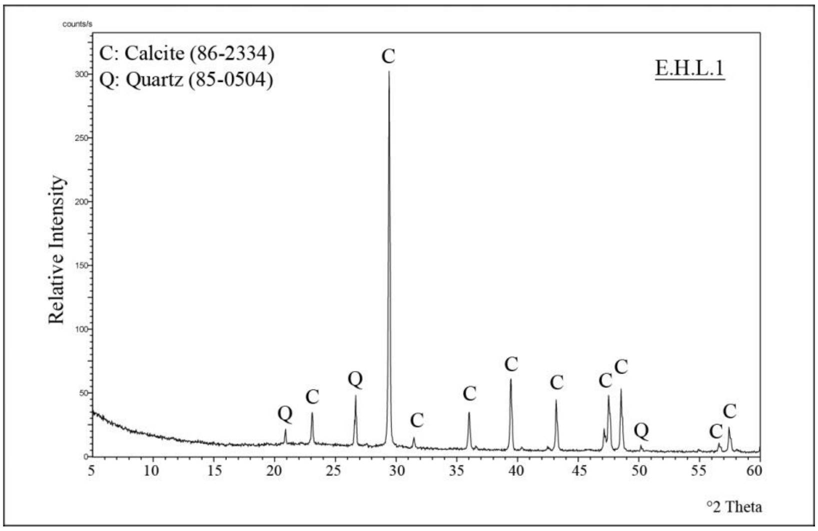
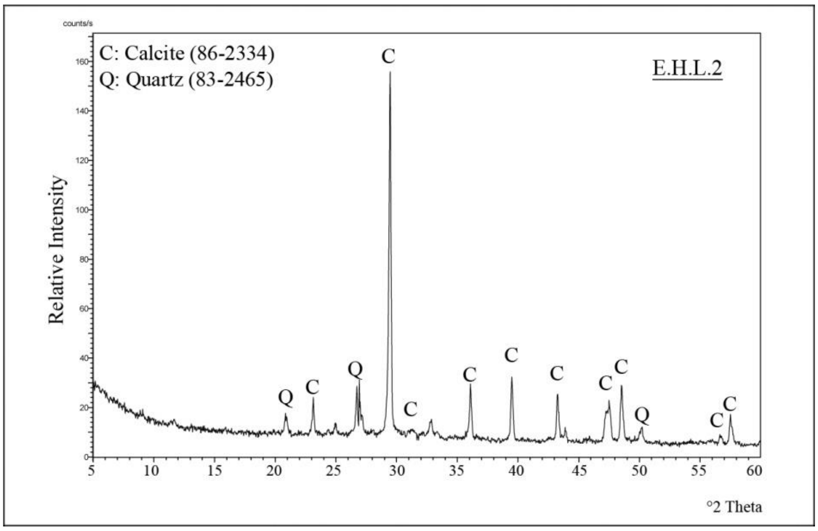


(c)

Figure 4.26. XRD patterns of horasan plaster samples from lower level (a), (b) and upper level (c) of sıcaklık space of the men’s section



(a)



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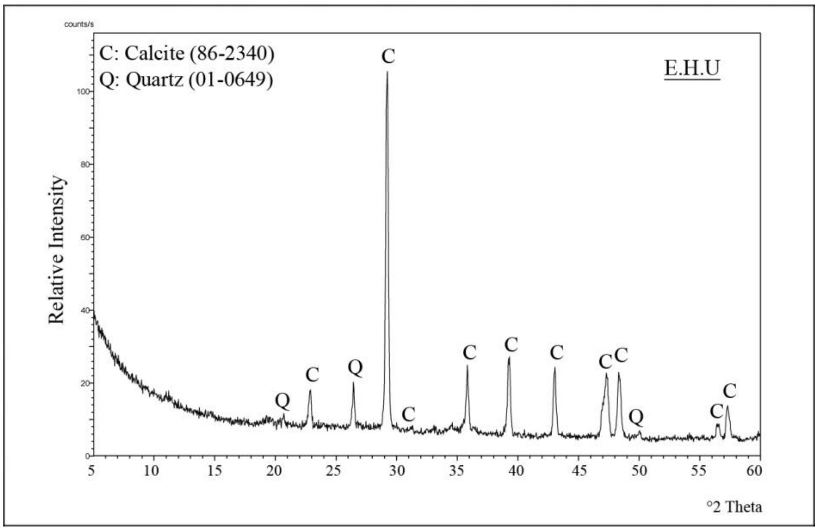


(c)

Figure 4.27. XRD patterns of horasan plaster samples from lower level (a), (b) and upper level (c) of halvet space of the men’s section

In previous studies, similar mineralogical compositions were observed for horasan plasters used in several Ottoman bath buildings (Uğurlu 2005, Böke et al. 2004) (Table 4.5).

Table 4.5. Comparison of mineralogical compositions of horasan plasters from different Ottoman bath buildings

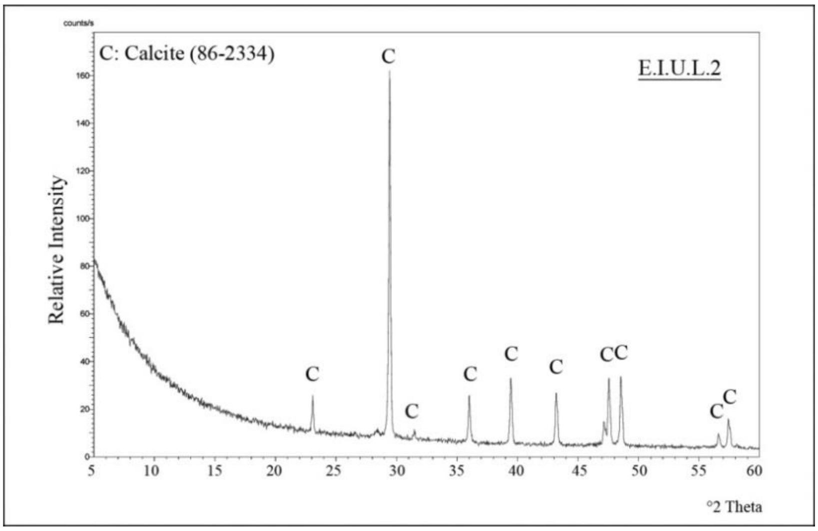
Name	Location - Year	Mineralogical Composition
Zeyrek Çinili Bath	İstanbul - 16th c.	Calcite, Quartz, Albite, Gypsum
Düzce Bath	İzmir - 16th c.	Calcite, Quartz, Albite
Hersekzade Bath	İzmir - 15th c.	Calcite, Quartz, Albite
Kamanlı Bath	İzmir - 15th c.	Calcite, Quartz, Albite
Ördekli Bath	Bursa - 15th c.	Calcite, Quartz, Feldspar
Beylerbeyi Bath	Edirne - 15th c.	Calcite, Quartz, Feldspar
Saray Bath	Edirne - 14th c.	Calcite, Quartz, Feldspar

4.4.1.2. Mineralogical Compositions of Lime Plasters

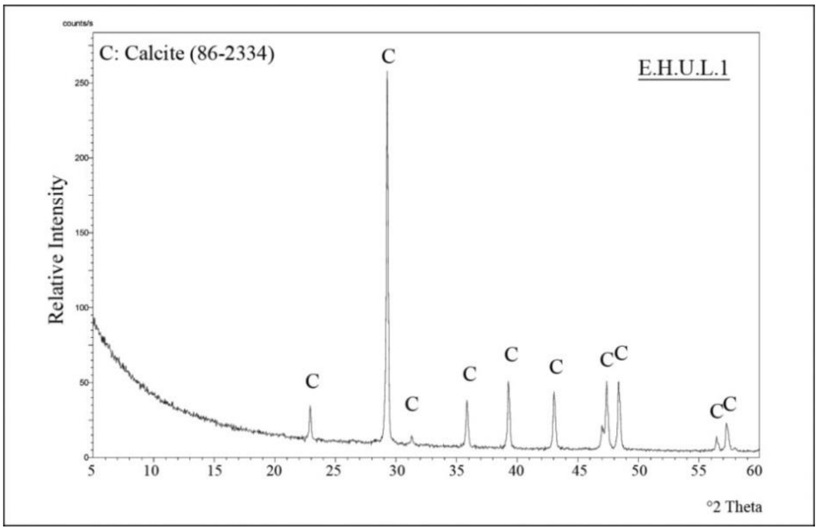
XRD analyses revealed that lime plasters were mainly consisted of calcite (C: $CaCO_3$) (Table 4.6, Figure 4.29 and 4.30). These results indicated that plasters were produced from pure lime. Furthermore, magnesite peaks were determined by the result of XRD applied on the lime plaster sample from women's halvet space (K.H.U.L.2) (Figure 4.26). This can be explained by the use of magnesian lime as different from the others.

Table 4.6. Mineralogical compositions of lime plasters determined by XRD results

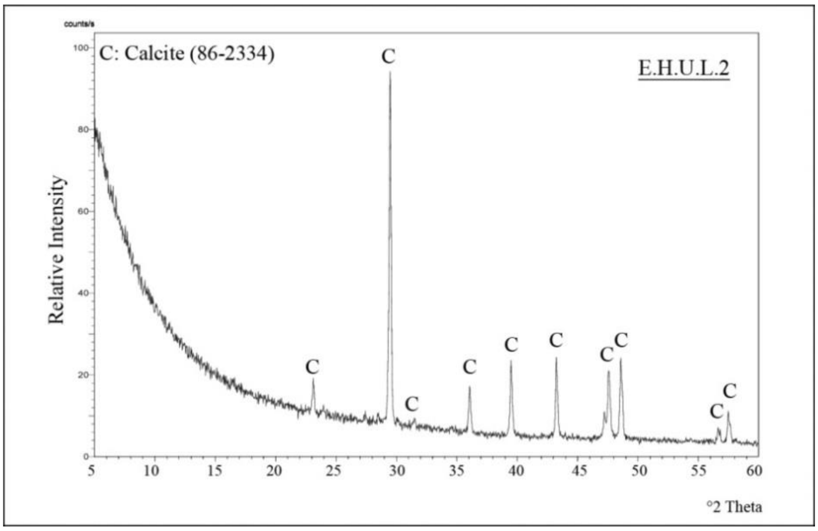
Sample code	Minerals determined on XRD patterns
E.I.U.L.2	C
E.H.U.L.1	C
E.H.U.L.2	C
K.I.U.L.2	C
K.H.U.L.2	C, M
C: Calcite, M: Magnesite	



(a)

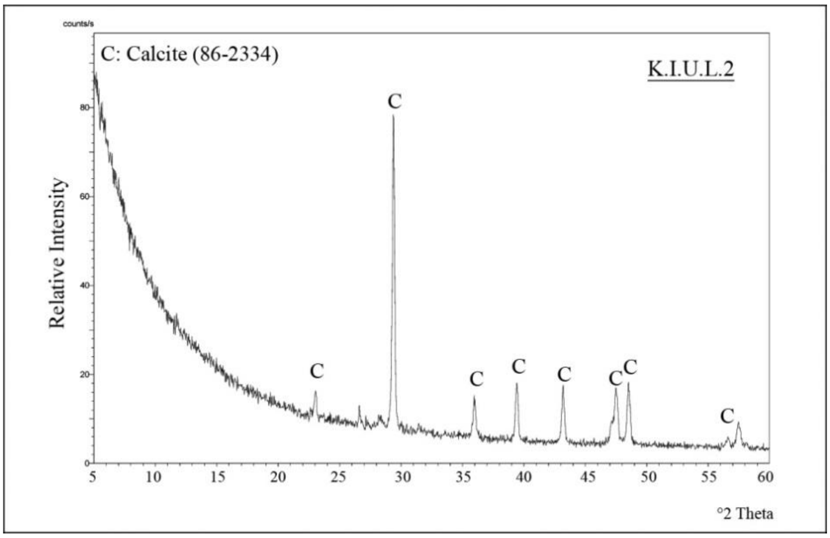


(b)

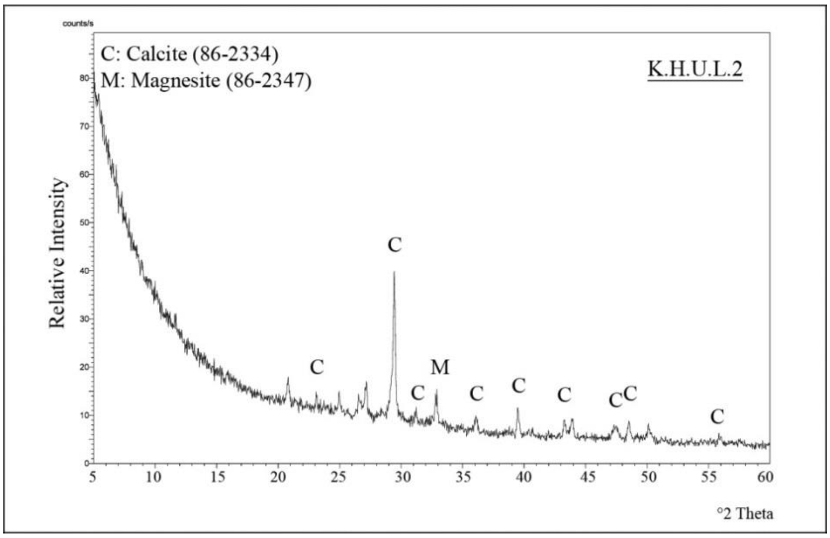


(c)

Figure 4.28. XRD patterns of lime plasters from ılıklık (a) and halvet (b), (c) of the men's section



(a)



(b)

Figure 4.29. XRD patterns of lime plaster samples from ılıklık (a) and halvet (b) of the women's section

In previous studies, nearly similar mineralogical compositions were observed for lime plasters used in several Ottoman bath buildings (Uğurlu 2005, Böke et al. 2004). General mineralogical compositions of lime plasters used in the Ottoman baths were given in the following table (Table 4.7).

Table 4.7. Comparison of mineralogical compositions of lime plasters from different Ottoman bath buildings

Name	Location - Year	Mineralogical Composition
Zeyrek Çinili Bath	İstanbul - 16th c.	Calcite, Magnesite
Düzce Bath	İzmir - 16th c.	Calcite
Hersekzade Bath	İzmir - 15th c.	Calcite
Kamanlı Bath	İzmir - 15th c.	Calcite
Ördekli Bath	Bursa - 15th c.	Calcite
Beylerbeyi Bath	Edirne - 15th c.	Calcite
Saray Bath	Edirne - 14th c.	Calcite

4.4.1.3. Mineralogical Compositions of Dome Plasters

Dome plasters taken from men's and women's soyunmalık were consisted of two layers; bottom layer was horasan plaster and upper one was lime plaster. The mineralogical compositions of these layers were determined by XRD.

XRD analysis showed that horasan plasters of the domes of the men's and women's soyunmalık were composed of calcite (C: $CaCO_3$), quartz (Q: SiO_2) and albite (A: ($Na(AlSi_3O_8)$)) (Table 4.8, Figure 4.30).

Table 4.8. Mineralogical compositions of plasters from domes determined by XRD results

Sample code	Minerals determined on XRD patterns
E.So.D	C, Q, A
K.So.D	C, Q, A
E.So.D.L	C, G
K.So.D.L	C, G
C: Calcite, Q: Quartz, A: Albite, G: Gypsum	

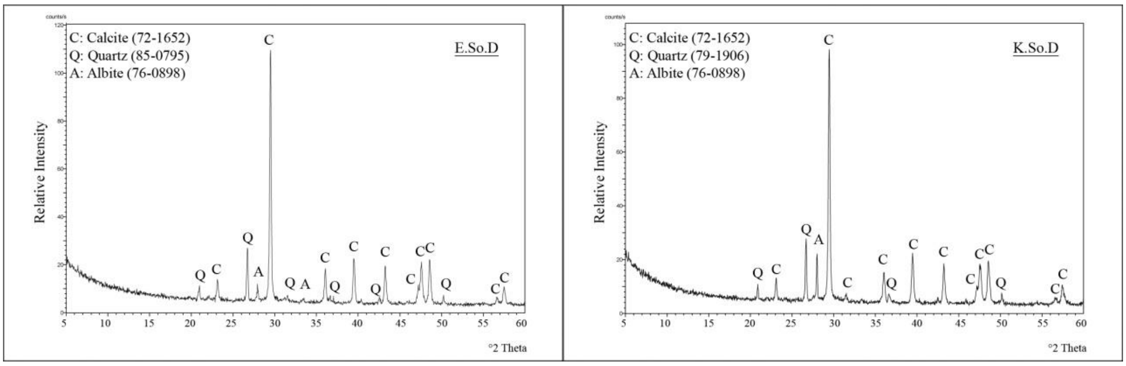


Figure 4.30. XRD patterns of horasan plasters from domes of the men’s and women’s soyunmalık

On the other hand, mainly calcite peaks were observed on the XRD patterns of lime plasters from domes of the men’s and women’s soyunmalık (Table 4.8, Figure 4.31). Although calcite (C: $CaCO_3$) peaks were clearly determined, minor gypsum peaks were also determined by the XRD analysis of the lime plaster from men’s soyunmalık dome (E.So.D.L). This can be explained that the domes of men’s and women’s soyunmalık had different lime plaster contents from each other.

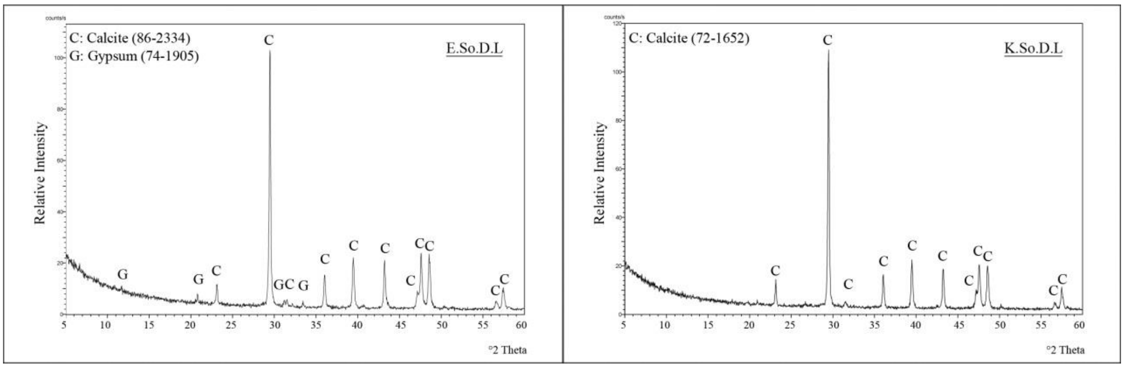


Figure 4.31. XRD patterns of the lime plasters from domes of the men’s and women’s soyunmalık

4.4.1.4. Mineralogical Compositions of Glazed Tile Adhesive

Glazed tile adhesive were collected by observing traces of glazed tiles on the wall surfaces. Based on XRD analyses, glazed tile adhesive was found to be composed of mainly gypsum. This indicated that glazed tiles were attached on the horasan plasters by using gypsum as adhesive. Minor peaks of calcite (C: $CaCO_3$) have also been observed (Figure 4.32). It can be explained by the impurities from the sampling.

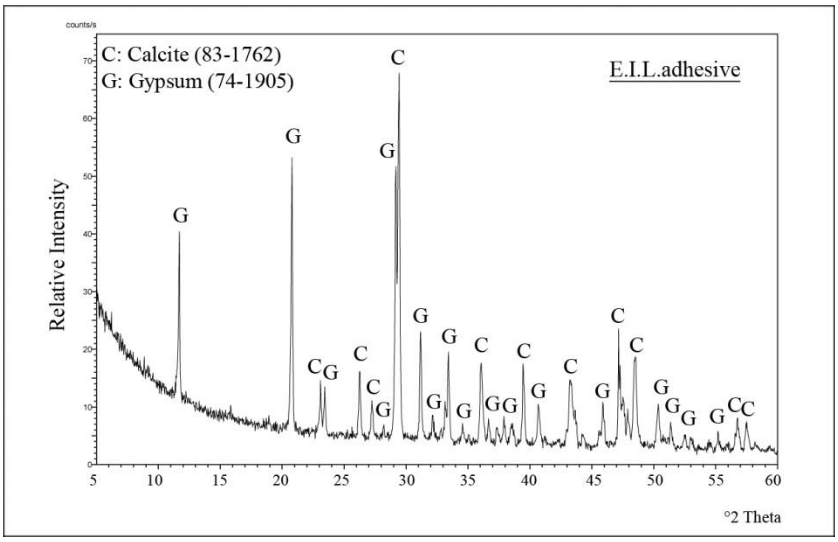


Figure 4.32. XRD patterns of glazed tile adhesive

4.4.1.5. Mineralogical Compositions of Joint Mortar

Joint mortar of the glazed tiles was mainly composed of calcite (C: $CaCO_3$) and quartz (Q: SiO_2) (Figure 4.33). Although gypsum was determined by the XRD results of the glazed tile adhesives, it was not observed on the results of the joint mortars. This could be explained by the solubility of gypsum. Since joint mortars were exposed to water much, gypsum was not used due to high solubility in water.

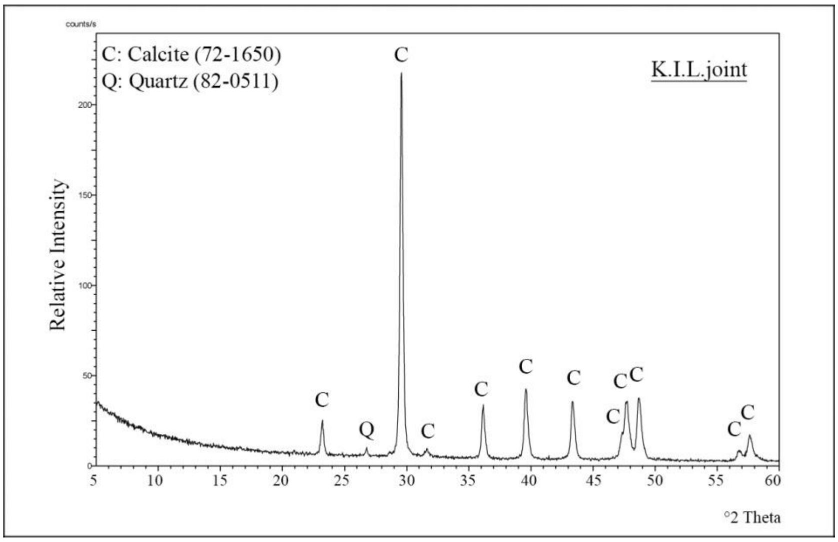


Figure 4.33. XRD patterns of joint mortar of the glazed tiles

4.4.1.6. Mineralogical Compositions of Muqarnas and Niche Mortar

Additionally, plaster collected from muqarnas of the women's halvet and niche mortar of the men's sıcaklık were investigated by XRD. The plaster collected from muqarnas was composed of mainly calcite (C: $CaCO_3$) (Figure 4.34). Niche mortar was composed of calcite (C: $CaCO_3$) and quartz (Q: SiO_2) (Figure 4.35).

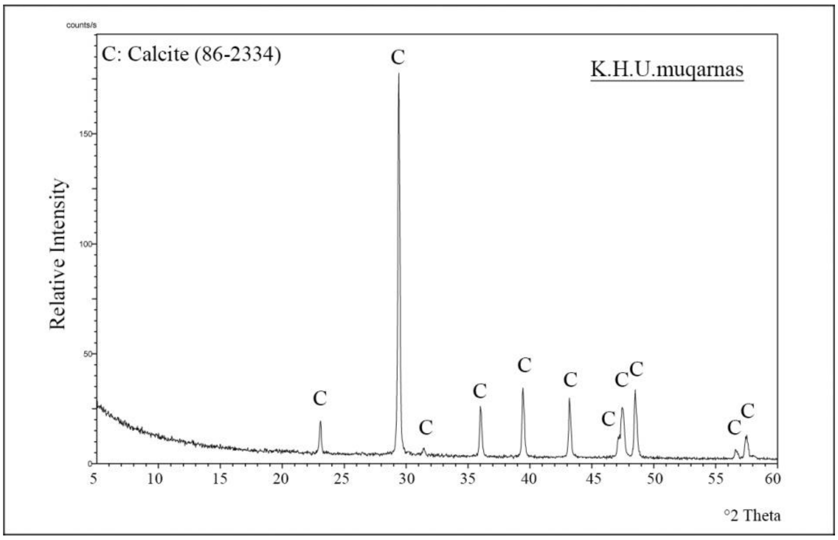


Figure 4.34. XRD pattern of the lime plaster collected from muqarnas

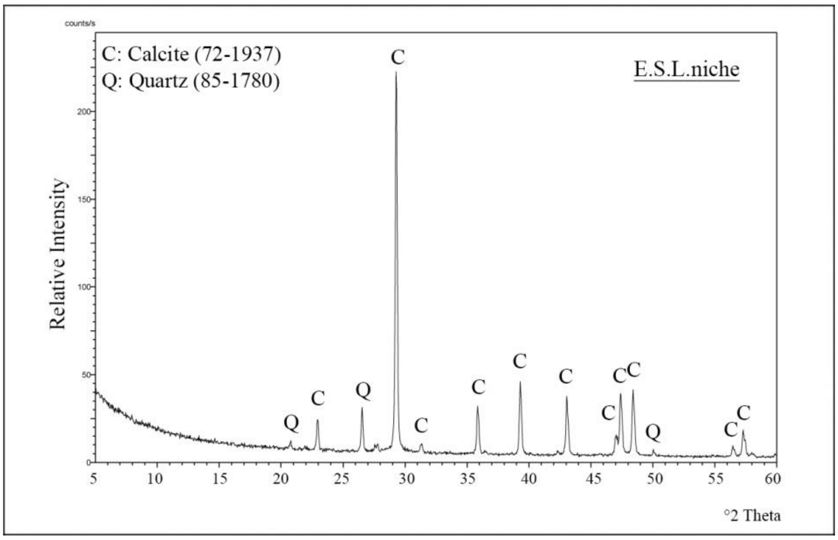


Figure 4.35. XRD pattern of the horasan plaster collected from niche mortar

4.4.2. Chemical Compositions of Plasters

Chemical compositions of horasan plasters, lime plasters and dome plasters were determined by using SEM-EDS. The analysis was carried out for three different areas of each pellet samples. Then their average values were calculated and given in the following tables (Table 4.9 - 4.12).

4.4.2.1. Chemical Compositions of Horasan Plasters

Chemical compositions analysis of horasan plasters showed that horasan plasters were composed of high amounts of CaO (48,5 %), SiO_2 (33,3 %), Al_2O_3 (8,34 %) and low amounts of FeO (2,74 %), MgO (2,6 %), SO_3 (2,25 %), K_2O (0,67 %) and Na_2O (0,28 %) (Table 4.9, 4.10). Presence of mainly CaO was resulted from carbonated lime and SiO_2 and Al_2O_3 were resulted from brick powders.

Based on the results, SO_3 is detected in all horasan plaster samples in the amounts ranged between 0,55 – 3,55 % (Table 4.9, 4.10). This may show the use of gypsum addition in the lime binder to provide quick setting. On the other hand, presence of gypsum addition can cause deterioration of plasters due to humid and hot conditions of the bath (Böke and Akkurt 2003). However, most of the horasan plasters were in good condition. It may be originated from protection of glazed tiles. One horasan plaster sample had high amount SO_3 (10,5 %) due to most probably repairment of the bath.

Table 4.9. Chemical compositions (%) of horasan plasters of men's section

Sample	CaO	MgO	SiO_2	Al_2O_3	FeO	Na_2O	K_2O	SO_3
E.I.L.1	44,31±0,88	1,98±0,07	36,03±0,65	10,29±0,57	3,44±0,27	0,57±0,04	1,23±0,07	2,15±0,17
E.I.L.2	60,44±0,44	1,83±0,16	25,75±0,36	6,78±0,26	2,24±0,16	0,69±0,10	1,57±0,14	0,69±0,10
E.I.U	47,11±0,13	1,54±0,05	38,08±0,20	8,45±0,15	2,33±0,06	0,55±0,05	0,65±0,01	1,30±0,05
E.S.L.1	44,69±0,48	2,22±0,15	35,85±0,15	10,04±0,62	3,93±0,10	0,19±0,01	0,58±0,06	2,48±0,14
E.S.L.2	54,57±0,85	4,14±0,27	29,20±0,61	7,72±0,16	2,41±0,11	0,17±0,13	1,24±0,03	0,55±0,04
E.S.U	50,68±0,70	1,35±0,06	36,86±0,50	6,74±0,11	2,01±0,09	0,55±0,12	0,84±0,05	0,96±0,16
E.H.L.1	41,71±0,61	1,26±0,04	48,19±0,80	6,58±0,11	1,13±0,03	0,16±0,06	0,70±0,04	0,25±0,19
E.H.L.2	42,94±0,64	3,19±0,11	37,67±0,45	9,99±0,29	3,05±0,14	0,16±0,05	0,41±0,05	2,59±0,13
E.H.U	36,95±1,87	9,92±0,20	41,40±1,40	7,66±0,33	2,88±0,14	0,20±0,02	0,31±0,06	0,68±0,04

Table 4.10. Chemical compositions (%) of horasan plasters of women's section

Sample	CaO	MgO	SiO_2	Al_2O_3	FeO	Na_2O	K_2O	SO_3
K.I.L.1	57,61±0,6	1,36±0,04	30,17±0,36	7,38±0,11	2,13±0,01	-	0,19±0,03	1,13±0,17
K.I.L.2	53,19±0,36	1,32±0,07	31,0±0,18	8,59±0,35	3,01±0,07	0,03±0,06	0,13±0,05	2,73±0,20
K.I.U	53,30±0,4	2,06±0,12	30,75±0,28	9,28±0,13	2,82±0,10	0,54±0,11	0,62±0,04	0,64±0,07
K.S.L.2	46,62±0,11	3,41±0,23	32,39±0,52	10,15±0,46	3,41±0,17	0,51±0,08	1,55±0,07	1,96±0,19
K.S.U	55,73±0,66	2,71±0,07	22,03±0,35	6,82±0,31	2,02±0,28	0,05±0,05	0,17±0,01	10,47±0,19
K.H.L.1	38,76±7,99	2,55±0,03	25,43±5,59	7,23±1,54	2,59±0,60	-	0,33±0,01	3,55±0,77
K.H.L.2	54,26±0,74	1,23±0,03	30,42±0,88	7,88±0,31	2,61±0,18	0,13±0,03	0,29±0,12	3,19±0,34
K.H.U	43,25±0,39	1,96±0,01	36,05±0,49	10,19±0,18	4,61±0,18	0,28±0,03	0,61±0,17	3,05±0,28

4.4.2.2. Chemical Compositions of Lime Plasters

Chemical compositions analysis of lime plasters indicated that lime plasters contained high amounts of CaO (71,4 %) and low amounts of SiO_2 (17,8 %), Al_2O_3 (3,8 %), MgO (3,6 %), SO_3 (2,04 %), FeO (0,75 %), K_2O (0,25 %) and Na_2O (0,16 %) (Table 4.11). This showed that pure lime was highly used in preparation of lime plasters. In addition, the results of chemical composition analysis showed that the first layer of lime plaster sample from the men's halvet had high amounts of gypsum (5,64 %) (E.H.U.L.1).

Presence of gypsum addition provides quick setting. However, this can cause deterioration of plasters due to solubility of gypsum in humid and hot conditions of the bath. Some of the lime plasters were deteriorated. It may be originated from gypsum addition.

Table 4.11. Chemical compositions (%) of lime plasters

Sample	CaO	MgO	SiO_2	Al_2O_3	FeO	Na_2O	K_2O	SO_3
E.I.U.L.2	79,24±2,18	2,37±0,38	14,09±1,34	2,91±0,34	0,52±0,03	0,21±0,05	0,27±0,05	0,40±0,07
E.H.U.L.1	44,29±1,32	2,99±0,07	35,68±1,25	9,15±0,15	1,64±0,06	0,13±0,08	0,48±0,05	5,64±0,18
E.H.U.L.2	78,14±0,61	4,06±0,38	12,69±0,48	2,29±0,10	0,94±0,17	0,09±0,08	0,23±0,07	1,57±0,14
K.I.U.L.2	75,64±4,37	6,45±1,59	13,88±1,87	2,16±0,47	0,41±0,16	0,21±0,17	0,12±0,04	1,14±0,45
K.H.U.L.2	79,85±3,10	2,56±0,63	12,89±0,52	2,58±0,56	0,28±0,03	0,19±0,11	0,17±0,11	1,48±0,43

4.4.2.3. Chemical Compositions of Dome Plasters

Chemical composition of horasan and lime plasters taken from the domes of the men's and women's soyunmalık were given in the following table (Table 4.12)

Results of chemical composition analysis showed that horasan plasters from the domes were composed of high amounts of CaO (64,8 %), SiO_2 (21 %) and low amounts of Al_2O_3 (6,24 %), FeO (2,73 %), Na_2O (1,8 %), MgO (1,7 %), K_2O (0,9 %) and SO_3 (0,82 %). On the other hand, lime plasters from the domes were composed of mainly CaO (83,4 %). These results revealed that the lime plaster from the men's soyunmalık dome (E.So.D.L.) contained high amounts of SO_3 (6,27 %) (Table 4.12). This can be explained that the men's soyunmalık dome has been repaired.

Table 4.12. Chemical compositions (%) of dome horasan and lime plasters

Sample	CaO	MgO	SiO_2	Al_2O_3	FeO	Na_2O	K_2O	SO_3
E.So.D	65,26±1,18	2,33±0,12	19,52±0,74	5,96±0,18	2,66±0,27	2,19±0,11	0,70±0,09	1,37±0,14
K.So.D	64,32±0,57	1,09±0,04	22,47±0,56	6,52±0,27	2,79±0,07	1,42±0,05	1,11±0,06	0,28±0,08
E.So.D.L	82,26±4,98	2,52±0,74	3,56±1,18	0,94±0,59	2,02±0,79	2,28±1,29	0,16±0,18	6,27±0,48
K.So.D.L	84,52±1,05	1,09±0,32	8,83±0,44	2,66±0,12	0,32±0,12	1,83±0,20	0,36±0,11	0,40±0,07

4.5. Microstructural Properties of Horasan and Lime Plasters

Bonding between brick aggregates and lime of horasan plasters and microstructural properties of lime plasters were investigated by using SEM-EDS.

4.5.1. Bonding between Brick Aggregates and Lime of Horasan Plasters

Bonding between brick aggregates and lime of horasan plasters were examined by SEM-EDS analysis to understand how aggregates and lime mixed during the preparation of horasan plaster.

Horasan plasters had homogeneous characteristics. Brick-lime interfaces were shown without microcracks. This revealed that brick and lime were adhered strongly to each other (Figure 4.36).

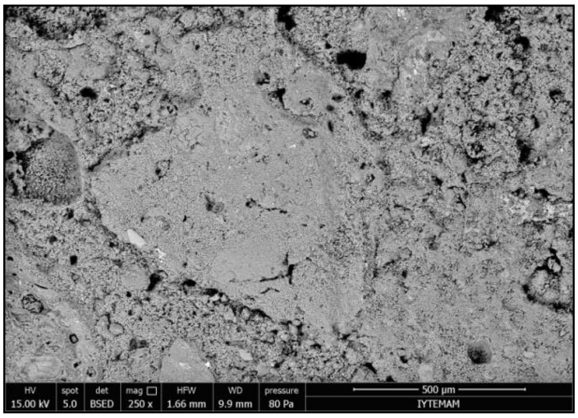
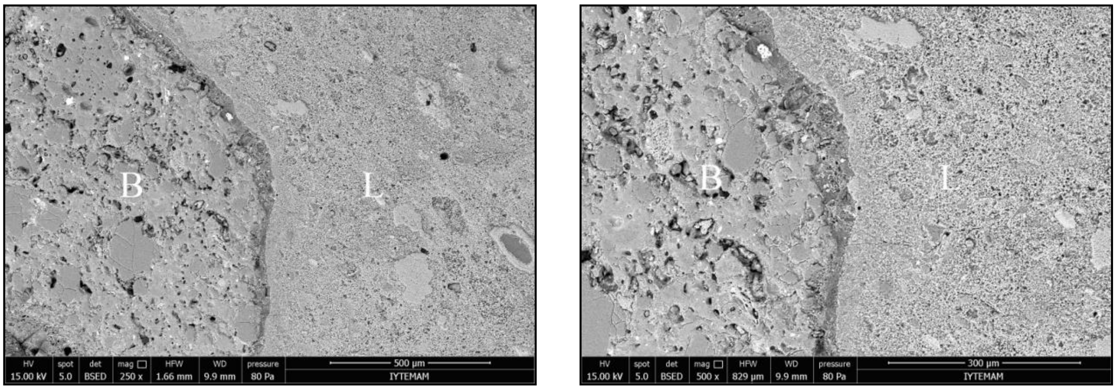


Figure 4.36. BSE image of the second horasan plaster layer (K.H.L.2) at magnification of 250x

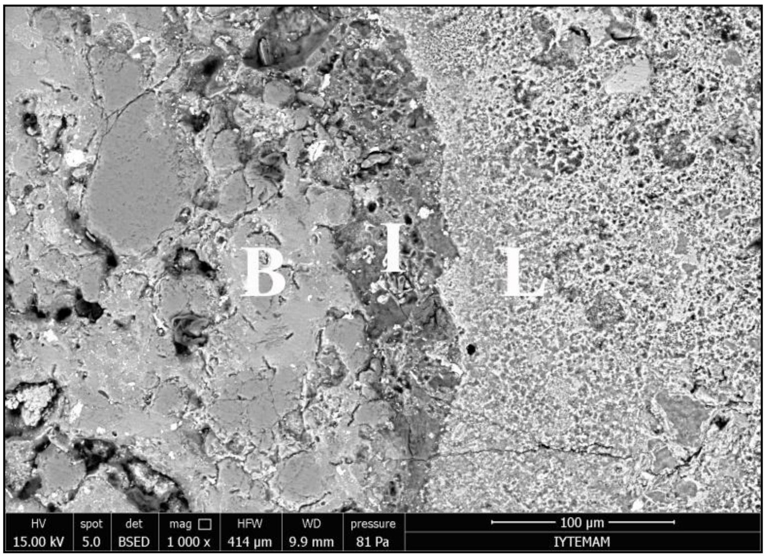
Microstructural analyses showed that lime binder was adhered well to the brick aggregates. Interfaces between brick aggregates and lime, named as “reaction rim”, were composed of hydraulic products by forming of reaction between brick aggregates and lime (Figure 4.37).



(a) (b)

Figure 4.37. BSE images of the first horasan plaster layer (K.H.L.1) at magnifications of 250 (a), 500 (b)

The result of chemical composition of the crushed brick aggregates (B), interface (I) and lime matrix (L) indicated that they were composed of high amounts of CaO, SiO_2 and Al_2O_3 (Figure 4.38). CaO decreased and SiO_2 increased from lime matrix to brick aggregate. Interface was composed of 27.73% CaO, 16.36% Al_2O_3, 44.92% SiO_2. This may show that the existence of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH) formations as a result of reaction between brick aggregates and lime. These hydraulic products provide hydraulic properties to horasan plaster.



(a)

Oxides	Wt. %
Na_2O	1.45
MgO	0.89
Al_2O_3	10.39
SiO_2	75.75
K_2O	1.29
CaO	6.24
TiO_2	0.59
FeO	3.39
Total	100.0

(B)

Oxides	Wt. %
Na_2O	0.29
MgO	1.86
Al_2O_3	16.36
SiO_2	44.92
SO_3	0.35
K_2O	0.43
CaO	27.73
TiO_2	1.50
FeO	6.57
Total	100.0

(I)

Oxides	Wt. %
MgO	0.84
Al_2O_3	4.47
SiO_2	23.19
SO_3	0.70
CaO	69.53
FeO	1.26
Total	100.0

(L)

Figure 4.38. BSE image of the first horasan plaster layer (K.H.L.1) at magnifications of 1000x (a) and chemical composition (%) of the crushed brick aggregates (B), interface (I) and lime matrix (L)

The elemental compositions of a brick aggregate and lime binders were determined by SEM-EDS (Figure 4.39). The result of the elemental composition indicated that they were rich in calcium (Ca), silica (Si), and alumina (Al) elements. Ca content decreased and Si content increased from the lime matrix to the brick aggregate.

Reaction rim was shown to be composed of calcium (Ca), silica (Si), and alumina (Al) elements. This may indicate the existence of CSH and CAH formations.

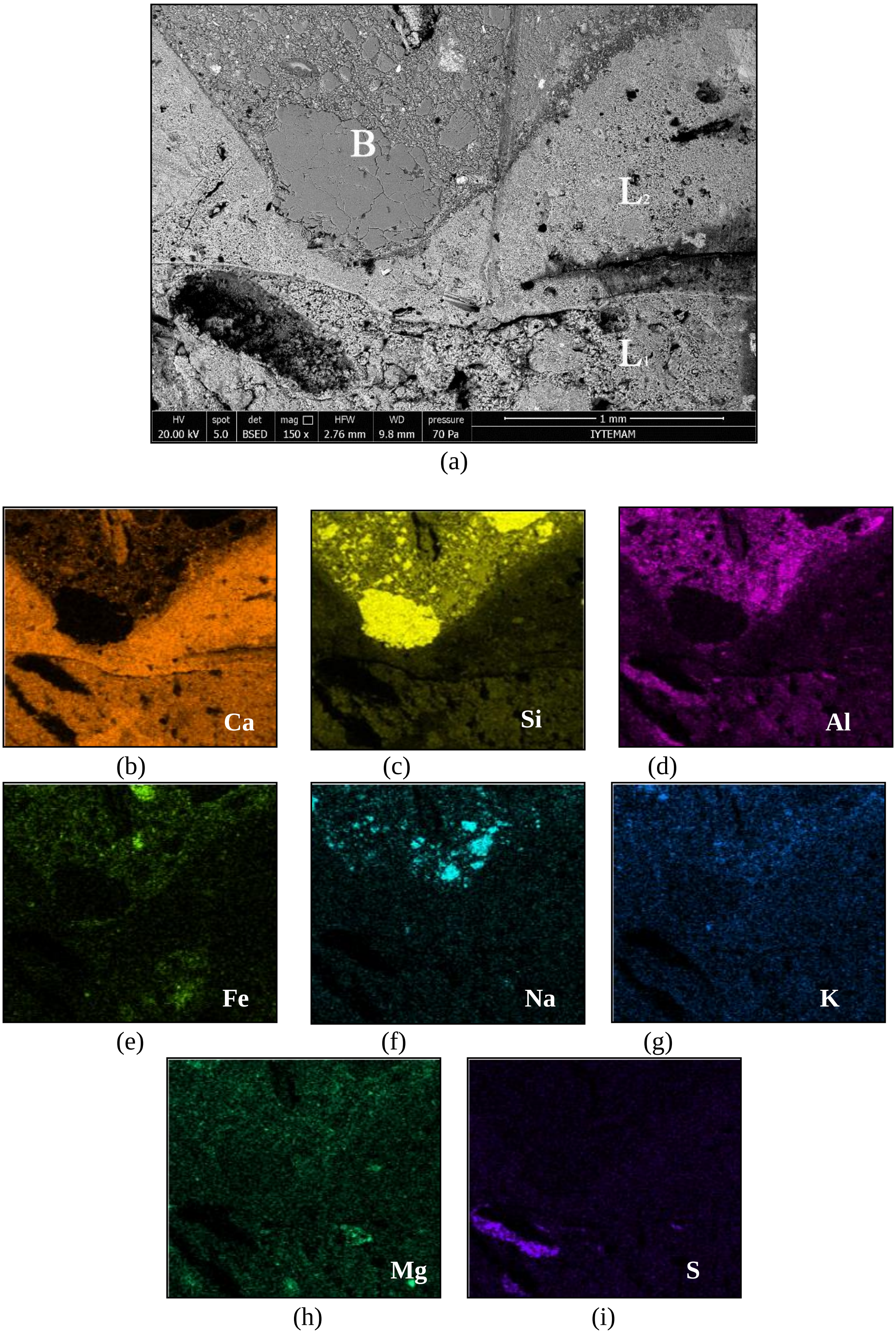
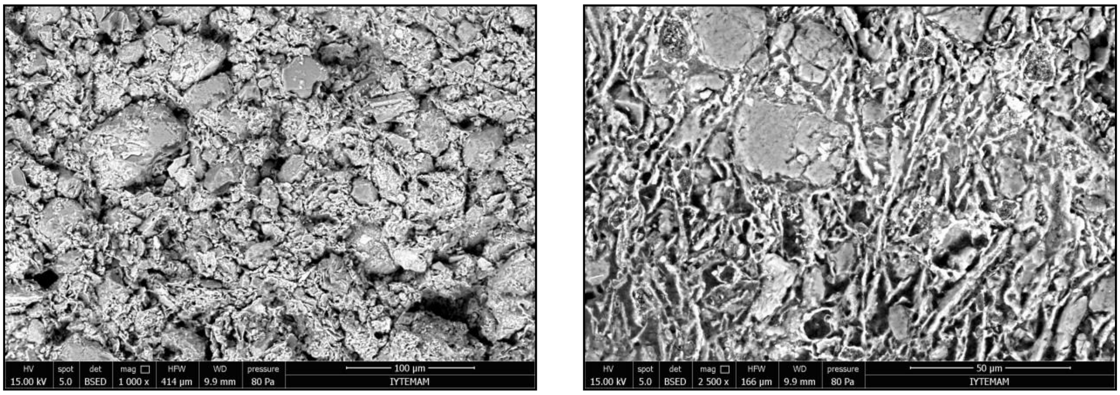


Figure 4.39. BSE image (a) of a brick aggregate (B) and lime matrix (L_1) of the first layer horasan plaster (K.H.L.1) and lime matrix (L_2) of the second layer (K.H.L.2) and elemental mapping images showing Ca (b), Si (c), Al (d), Fe (e), Na (f), K (g), Mg (h) and S (i)

SEM analysis revealed that brick aggregates of the horasan plasters had a porous microstructure (Figure 4.40). In the pores of the brick aggregates, precipitated micritic calcite crystals were observed (Figure 4.41). Precipitation of these calcite crystals were formed by the dissolution of carbonated lime in the humid and hot conditions of the bath.

These porous brick aggregates considered as ideal materials to provide durability of plasters due to the fact that they may prevent deterioration by the result of dissolution and precipitation of carbonated lime (Böke et al. 2004).



(a) (b)

Figure 4.40. BSE image showing fragments of the brick aggregates of the horasan plasters at magnifications of 1000 (a), 2500 (b)

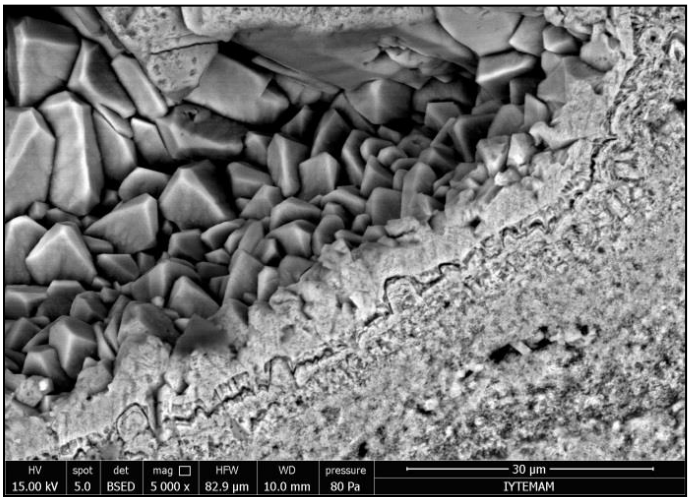


Figure 4.41. BSE image of precipitated calcite crystals in the pores of the brick aggregates of the horasan plaster (K.H.U) at magnification of 5000x

4.5.2. Microstructural Characteristics of Lime Plasters

SEM-EDS analyses revealed that lime plasters were produced from pure lime. Lime plasters were composed of one or two lime layers. However, another layer was observed on SEM image based on the deposition of calcite layers formed by the dissolution and precipitation of carbonated lime due to humid and hot conditions of the bath (Figure 4.42).

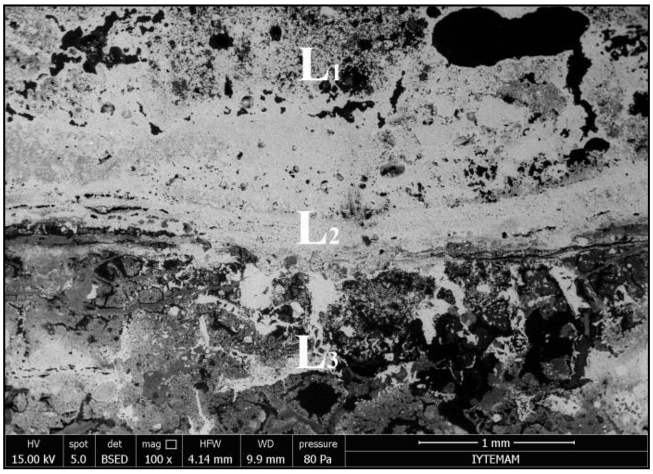


Figure 4.42. BSE image of the deposition of calcite layers due to dissolution and precipitation of lime plaster (K.H.U.L) at magnification of 100x

Deterioration was detected on lime plasters due to humid and hot conditions of the bath. They were porous and easily crumble (Figure 4.43).

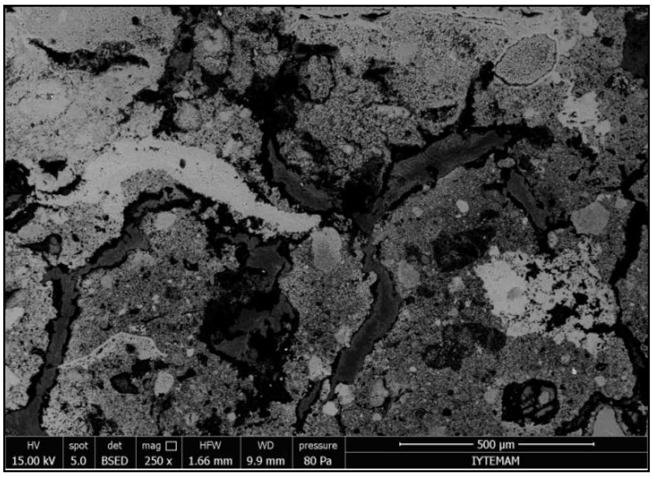


Figure 4.43. BSE image showing deterioration of the lime plaster (K.H.U.L) at magnification of 250x

4.6. Pozzolanic Activities of Crushed Brick Aggregates

Pozzolanic activities of the crushed brick aggregates were measured by using electrical conductivity method. In this analysis, saturated calcium hydroxide solution ($Ca(OH)_2$) was prepared and was measured its electrical conductivity. Then, aggregates less than 53µm size were mixed with saturated calcium hydroxide solution (5 g/200ml), stirred for two minutes and then measured its electrical conductivity. Finally, their difference (ΔEC in mS/cm) was determined. If the electrical conductivity difference is more than 2 mS/cm, it was revealed that the aggregates have good pozzolanicity (highly energetic pozzolan) (Luxan et al. 1989).

Results of the electrical conductivity analysis indicated that their electrical conductivity differences were vary between 1.80-5.50 mS/cm. Most of the crushed brick aggregates of the horasan plasters had good puzzolanic activities. One of the crushed brick aggregates (E.S.L.2) had not pozzolanic activities and two of the crushed brick aggregates (E.H.U, K.H.L.2) had weak pozzolanic activities (Figure 4.44).

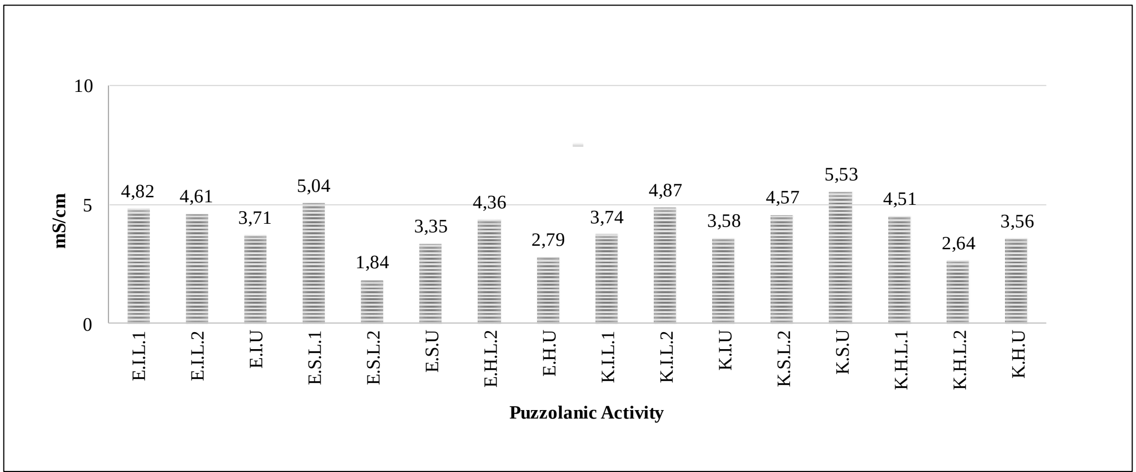


Figure 4.44. Pozzolanicity values of crushed brick aggregates

According to previous studies by Uğurlu (2005) and Böke et al. (2004), averages of the pozzolanicity values of the crushed brick aggregates of horasan plasters used in several historic Ottoman bath buildings were ranged between 3,9-7,5 mS/cm (Table 4.13). Hence, all crushed brick aggregates used in horasan plasters of these baths were pozzolanic.

Table 4.13. Comparison of average pozzolanicity values of brick aggregates used in horasan plasters

Name	Location - Year	Electrical conductivity differences (mS/cm)
Zeyrek Çinili Bath	İstanbul - 16th c.	3,9
Düzce Bath	İzmir - 16th c.	5,4
Hersekzade Bath	İzmir - 15th c.	6,1
Kamanlı Bath	İzmir - 15th c.	4,6
Ördekli Bath	Bursa - 15th c.	7,5
Beylerbeyi Bath	Edirne - 15th c.	6,1
Saray Bath	Edirne - 14th c.	4,4

4.7. Hydraulicity of Horasan Plasters

Hydraulic characteristics of the horasan plasters were determined by using thermogravimetric analysis and their values were given (Table 4.14, Figure 4.45).

In this analysis, the samples were heated and their weight losses were recorded at 200°C, 600°C and 900°C. These weight losses were originated from loss of hygroscopic (adsorbed) water at 200ºC, loss of chemically bound water of hydraulic components between 200ºC - 600ºC and loss of carbon dioxide gas depending on decomposition of calcium carbonates between 600ºC - 900ºC. If the ratio of CO_2/chemically bound water (H_2O) of plasters is between 1 and 10, these plasters could be considered as hydraulic (Bakolas et al. 1998).

Results of the analysis indicated that nearly all of the horasan plasters had hydraulic character. The CO_2/H_2O ratios of the horasan plasters varied between 1.59-6.19 (Table 4.14). These results indicated hydraulic property of horasan plasters. Hydraulic character of horasan plasters may be due to the use of pozzolanic aggregates. Three horasan plaster samples (E.I.L.2, E.S.L.2, E.H.L.2) had CO_2/H_2O ratios higher than 10 and they could be non hydraulic. One of these horasan plasters had non pozzolanic crushed brick aggregates. Although two of the horasan plasters had pozzolanic crushed brick aggregates, they were non hydraulic. This may be showed that their crushed brick aggregates were inadequate for hydraulicity (Table 4.14, Figure 4.45).

Table 4.14. H_2O percents, CO_2 percents and CO_2/H_2O ratios of horasan plasters

Sample	H_2O (%)	CO_2 (%)	CO_2 /H_2O
E.I.L.1	7,44	11,79	1,59
E.I.L.2	1,16	23,61	20,41
E.I.U	4,75	17,76	3,74
E.S.L.1	5,14	14,32	2,79
E.S.L.2	1,35	22,13	16,42
E.S.U	4,10	17,82	4,35
E.H.L.1	4,06	17,03	4,20
E.H.L.2	1,53	24,61	16,04
K.I.L.1	0,98	3,56	3,65
K.I.L.2	3,48	21,57	6,19
K.I.U	4,49	19,10	4,25
K.S.L.1	4,12	14,35	3,49
K.S.U	5,71	14,18	2,48
K.H.L.1	5,17	16,09	3,11
K.H.L.2	5,48	17,91	3,27
K.H.U	5,52	11,52	2,09

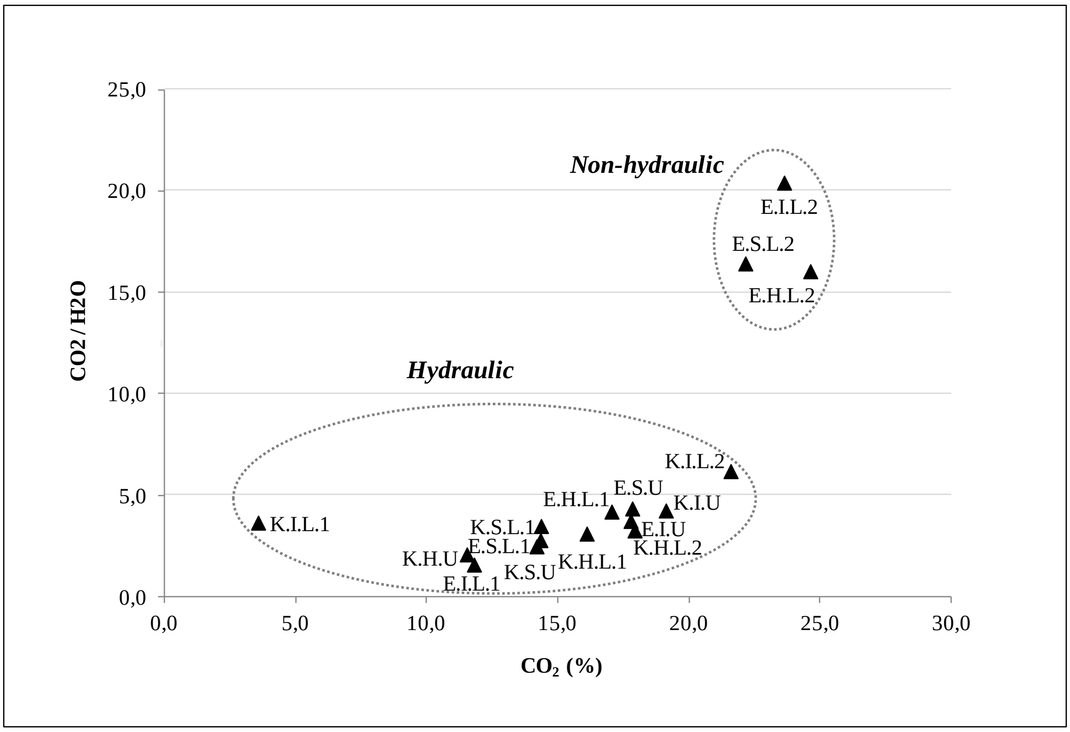


Figure 4.45. Hydraulicity (CO_2/H_2O) versus CO_2 % of plasters

4.8. General Evaluation of Plasters Used in Zeyrek Çinili Bath

Horasan plasters used in all spaces of the bath have significant similarities in their physical properties, mineralogical, chemical compositions, microstructural properties, pozzolanic activities of the crushed brick aggregates and hydraulicity. Analysis results of all horasan plasters of the bath according to their spaces, levels and layers were given (Figure 4.46).

- Horasan plasters are low dense and high porous materials. Density and porosity values of horasan plasters varied between 1.1-1.6 g/cm^3 and 29-56 % by volume respectively.
- Horasan plasters are mainly composed of carbonated lime and brick aggregates. Lime/aggregate ratios of horasan plasters of the bath vary between 2/3 – 3/2 by weight. Aggregates with particle sizes 500 µm. constitued the main fraction of the total of aggregates within the horasan plasters.
- Horasan plasters were mainly consisted of calcite (C: $CaCO_3$), quartz (Q: SiO_2) and albite (A: ($Na(AlSi_3O_8)$)). Calcite was originated from carbonated lime, while quartz and other silicieous minerals were from brick powders.
- Pozzolanicity values of brick aggregates of horasan plasters were vary between 1.80-5.50 mS/cm. Most of the crushed brick aggregates of the horasan plasters (more than 2 mS/cm) had good pozzolanic activities. Hydraulic character of plasters may be attributed to the use of pozzolanic brick aggregates.
- Hydraulicity values of horasan plasters were vary between 1.6-20.4. Nearly all of the horasan plasters (between 1 and 10) had hydraulic character.

Lime plasters of the bath according to their spaces, levels and layers were also given (Figure 4.46). Analysis results of all lime plasters of the bath were nearly same.

- Lime plasters have low density and high porosity values. Density and porosity values of lime plasters ranged between 1.1-1.6 g/cm^3 and 33-52 % by volume respectively.
- Lime plasters were mainly consisted of calcite (C: $CaCO_3$). Hence, lime plasters were produced from pure lime. One of the lime plasters (K.H.U.L.2) may have been produced from magnesian lime due to presence of magnesite peaks on the XRD result.

Characteristics of dome plasters of soyunmalık spaces of the bath were determined by several methods (Figure 4.46).

- Horasan plasters of the domes were composed of calcite (C: $CaCO_3$), quartz (Q: SiO_2) and albite (A: ($Na(AlSi_3O_8)$)). Calcite was originated from carbonated lime, while quartz and other silicieous minerals were from brick powders.
- Lime plasters of the domes were composed of mainly calcite (C: $CaCO_3$). However, minor gypsum peaks were also detected on the XRD patterns of lime plasters from the men’s soyunmalık dome (E.So.D.L). This may indicate that men’s soyunmalık dome had been repaired.

Characteristics of glazed tile adhesive and joint mortar collected by observing traces of glazed tiles on the wall surfaces were determined (Figure 4.46).

- Glazed tile adhesives were composed of mainly gypsum. This indicated that glazed tile adhesives were used on the horasan plaster layer for attachment of glazed tiles to the wall. Also, minor peaks of calcite (C: $CaCO_3$) have been observed. It could be explained by the impurities from the sampling.
- Joint mortar of the glazed tiles were mainly composed of calcite (C: $CaCO_3$) and quartz (Q: SiO_2). Gypsum was not observed on the XRD patterns of the joint mortars. Joint mortars were exposed to water more than glazed tile adhesives. Thus, gypsum was not used due to high solubility in water.

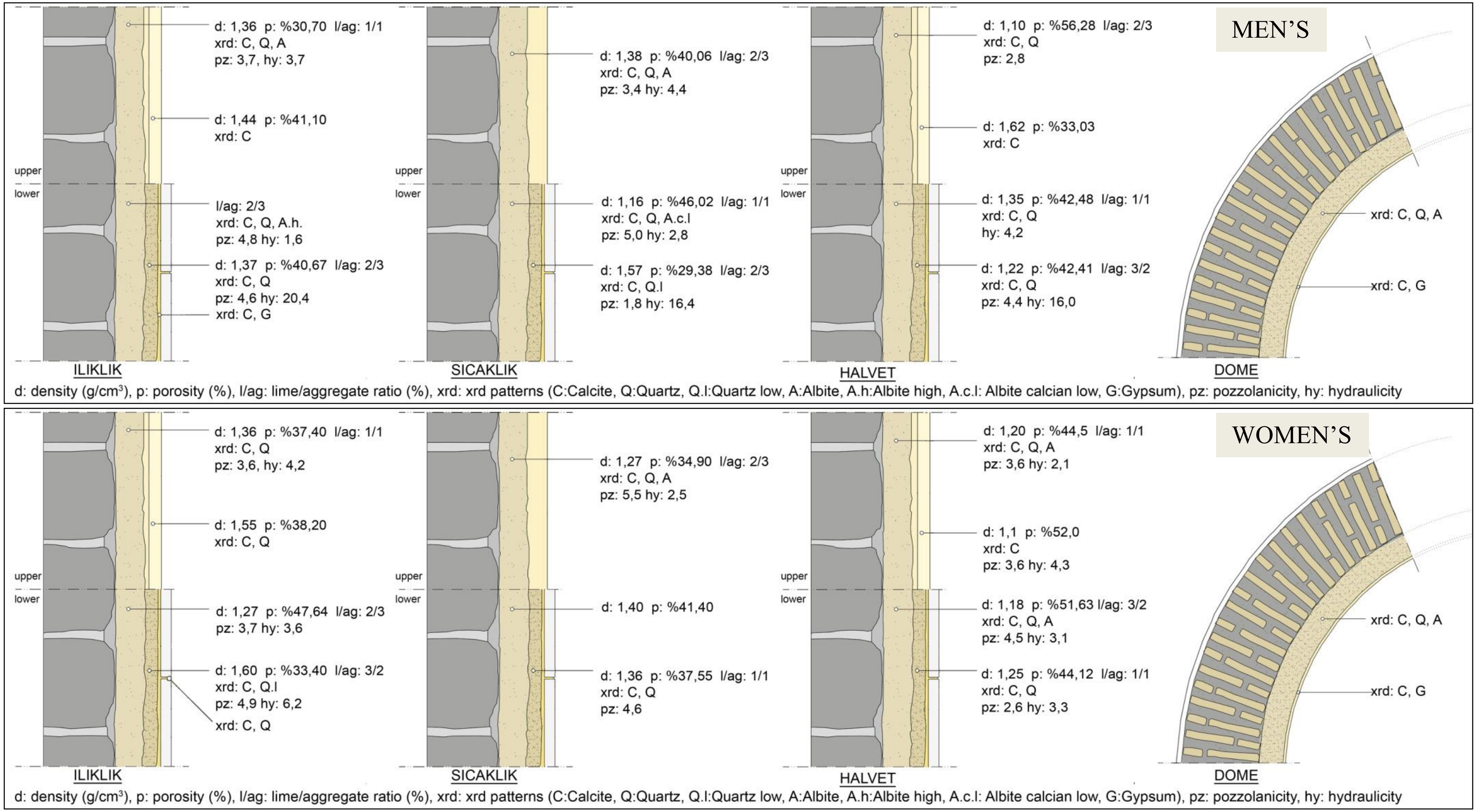


Figure 4.46. Basic physical properties, raw material compositions, mineralogical compositions, pozzolanicity and hydraulicity values of the plasters

CHAPTER 5

CONCLUSIONS

In this study, the characteristics of the plasters used in Zeyrek Çinili Bath as an outstanding example of Ottoman architecture built by Mimar Sinan in İstanbul were determined by using several methods.

Horasan and lime plasters were used in the interior spaces of Zeyrek Çinili Bath. Plaster application technique were not different according to spaces of the bath. Multilayered plaster application was used in all spaces of the bath. This multilayered plaster application on the wall surfaces of the inner spaces of the bath can be classified as lower level and upper level plasters. These two levels are distinguishable clearly from each other due to their colors, layers and traces of glazed tiles. The lower level plasters on the wall surfaces are extended to 1.5 m height from the floor surfaces of the bath and the upper level plasters are extended along the wall surfaces from 1.5 m height.

The lower level plasters are composed of a rough horasan plaster on the wall surface and a fine horasan plaster applied on the rough plaster. The layers of horasan plasters used in the bath are well adhered to each other. The fine horasan plaster layer is less porous than the rough one. Since the lower level of the wall is exposed to water much, this multilayered horasan plaster technique is carried out to protect the wall from water entries.

Glazed tiles are adhered on the second layer of the horasan plasters by glazed tile adhesives. All lower level horasan plasters were taken from beneath the traces of glazed tiles on the wall surfaces. Hence, all horasan plasters are original and not repaired. On the other hand, multilayered plaster application together with the use of glazed tiles is a rare example of Ottoman baths.

The upper level plasters are consisted of a rough horasan plaster layer with one or two lime plaster layers. All horasan plasters of the bath have similar properties. Thus, the upper level horasan plasters are original like lower level horasan plasters. The layers of lime plasters of the upper level are weak adhered to each other. Lime plaster layers can be formed due to repair of the bath.

The plasters of the domes of men's and women's soyunmalık are composed of a rough horasan plaster layer with one fine lime plaster layer. Lime plasters from women's soyunmalık dome are mainly composed of carbonated lime. However, the lime plasters from men's soyunmalık dome contains gypsum with carbonated lime. This can be explained that the men's soyunmalık dome has been repaired.

Lime plasters are porous and low dense. Lime plasters applied on upper level of the bath are mainly composed of carbonated lime. These plasters were obtained from pure lime. Lime plasters were deteriorated due to humid and hot conditions of the bath. Presence of high amounts of gypsum in some samples may indicate repair of the bath.

Horasan plasters used in all spaces of the bath have no significant differences between their physical properties, mineralogical, chemical compositions, microstructural properties, pozzolanic activities of the crushed brick aggregates and hydraulicity.

Horasan plasters manufactured by using lime and crushed brick aggregates are high porous and low dense materials. Horasan plasters of the bath have different size and amount brick aggregates. The strong adherence between brick aggregates and lime is observed due to their fine mixing. Porous brick aggregates are considered as ideal materials to provide durability of plasters due to hot and humid conditions of the bath.

Most of the horasan plasters are hydraulic. Brick aggregates of nearly all horasan plasters have good pozzolanic properties. Hydraulic character of horasan plasters may be due to the use of pozzolanic aggregates.

All horasan plasters of the bath contain gypsum. The use of gypsum addition in the lime binder provides quick setting. Also, gypsum can cause deterioration of plasters due to humid and hot conditions of the bath. However, most of the horasan plasters were in good condition. It may be originated from protection of glazed tiles.

Glazed tile adhesives are mainly composed of gypsum. However, the joint mortars of the glazed tiles are composed of carbonated lime due to prevent water penetration to the glazed tile adhesives.

Determination of plaster characteristics of Zeyrek Çinili Bath which is a remarkable cultural asset is significant since it should be considered as a part of documentation of such an important historic building constructed by Mimar Sinan as well as being a part of historic traditions, craftsmanships etc. Also, this study indicated that plaster characteristics of the Zeyrek Çinili Bath located in the capital of Ottoman Empire and Ottoman Baths located in Bursa, Edirne and in rural areas of İzmir were similar. Hence, this revealed that horasan plaster production technologies were traditional and widespread in the Ottoman period.

REFERENCES

Al-Rawas, A., Hago, A., Corcoran, T., Al-Ghafrial, K. (1998). Properties of Omani Artificial Pozzolana (sarooj). *Applied Clay Science, 13,* 275-292. doi:10.1016/j.conbuildmat.2014.09.028

Aru, K.A. (1949). *Türk Hamamları Etüdü*. (PhD Thesis). İstanbul Teknik Üniversitesi, İstanbul.

Bakolas, A., Biscontin, G., Moropoulou, A., Zendri, E. (1998). Characterization of Structural Byzantine Mortars by Thermogravimetric Analysis. *Thermochimica Acta, 321*(1-2), 151-160.

Baronio, G. and Binda, L. (1997a). Study of the Pozzolanicity of Some Bricks and Clays. *Construction and Building Materials, 11*(1), 41-46.

Baronio, G., Binda, L., Lombardini, N. (1997b). The Role of Brick Pebbles and Dust in Conglomerates Based on Hydrated Lime and Crushed Bricks. *Construction and Building Materials, 11*(1), 33-40.

Bertolini, L., Carsana, M., Gastaldi, M., Lollini, F., Redaelli, E. (2013). Binder Characterisation of Mortars Used at Different Ages in the San Lorenzo Church in Milan. *Materials Characterization*, *80*, 9-20. doi:10.1016/j.matchar.2013.03.008.

Boynton, R.S. (1980). *Chemistry and Technology of Lime and Limestone* (2nd Edition). New York: John Wiley & Sons.

Böke, H. and Akkurt, S. (2003). Ettringite Formation in Historic Bath Brick-Lime Plasters. *Cement and Concrete Research 33*(9), 1457-1464.

Böke, H., Akkurt, S., İpekoğlu, B., Uğurlu, E. (2006). Characteristics of Brick Used as Aggregate in Historic Brick-lime Mortars and Plasters. *Cement and Concrete Research 36*, 1115-1122.

Böke, H., İpekoğlu, B., Akkurt, S., Uğurlu, E. (2004). Tarihi Yapıların Onarımlarında Kullanılacak Horasan Harç ve Sıvalardaki Puzolanik Malzemelerin Özellikleri. *TÜBİTAK Projesi*, *Proje No: 102I025 (İÇTAG – I674).*

Budak, M., Akkurt, S., Böke, H. (2010). Evaluation of Heat Treated Clay for Potential Use in Intervention Mortars. *Applied Clay Science 49*, 414-419. doi: 10.1016/j.clay.2009.11.031

CEN. EN 196-5, (2011). Methods of Testing Cement. Part 5: Pozzolanicity Test for Pozzolanic Cement, Brussels (Belgium), CEN.

Chakchouk, A., Samet, B., Mnif, T. (2006). Study on the Potential Use of Tunisian Clays as Pozzolanic Material. *Applied Clay Science 33*, 79-88.

Cortina, M.G. and Dominguez, L.D. (2002). Aired-lime and Chamotte Hydraulic Mortars. *Material Construction 52*, 65-76.

Cowper, A.D. (1998). *Lime and lime Mortars* (First published in 1927 for the Building Research Station by HM Office). London: Donhead Publishing Ltd.

Eckel, E.C. (1928). *Cements, Limes and Plasters*. New York: John Wiley & Sons.

Ertuğrul, A.D. (2002). *Mimar Sinan'ın İstanbul'daki Mevcut Hamamları*. (M.Sc. Thesis). İstanbul Technical University, İstanbul.

Eski İstanbul Fotoğrafları Arşivi. (2016). *Zeyrek Çinili Hamam.* Retrieved from http://eski.istanbulium.net/post/128846326218/zeyrek-cinili-hamam (accessed June 20, 2016)

Eyice, S. (1960). İznik'de Büyük Hamam ve Osmanlı Devri Hamamları Hakkında Bir Deneme. *Tarih Dergisi 11*(15), 108-120.

Faria-Rodrigues, P. (2004). *Mortars for Old Masonry Renders-The Influence of Binders.* (Ph.D. Thesis). NOVA University of Lisbon, Lisbon.

He, C., Osbaeck, B., Makovicky, E. (1995). Pozzolanic Reactions of Six Principal Clay Minerals: Activation, Reactivity Assessments and Technological Effects. *Cement and Concrete Research 25*(8), 1691-1702.

ICOMOS International Council on Monuments and Sites. (2015). The Venice Charter. (1964). Retrieved from http://www.icomos.org/charters/venice_e.pdf (accessed June 20, 2016)

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Kabaoğlu, C. (2013). Çinili Hamam Projesi. *Kargir Yapılarda Koruma ve Onarım Semineri V Bildiri Kitabı*. 177-191.

Koçu, R.E. (1944). Çinili Hamam. *İstanbul Ansiklopedisi 7*, 4014-4019.

Kramar, S., Zalar, V., Urosevic, M., Körner, W., Mauko, A., Mirtic, B., Lux, J., Mladenovic, A. (2011). Mineralogical and Microstructural Studies of Mortars from the Bath Complex of the Roman Villa Rustica near Mosnje (Slovenia). *Materials Characterization 62*, 1042-1057. doi:10.1016/j.matchar.2011.07.019.

Kurugöl, S. and Güleç, A. (2012). Physico-Chemical, Petrographic, and Mechanical Characteristics of Lime Mortars in Historic Yoros Castle (Turkey). *International Journal of Architectural Heritage: Conservation, Analysis, and Restoration 6*(3), 322-341. doi:1080/10.15583058.2010.540072.

Lea, F.M. (1940). Investigations on Pozzolanas (Technical Paper). *Building Research 27,* 1-63.

Livingston, R., Tinsae, A.W., Chaturbahai, A. (1991). *The Use of Gypsum Mortar in Historic Buildings, Structural Repair and Maintenance of Historic Buildings.* 157-165. Southampton, UK: Computational Mechanics Publications

Luxan, M.P., Madruga, F., Saavedra, J. (1989). Rapid Evaluation of Pozzolanic Activity of Natural Products of Conductivity Measurement. *Cement and Concrete Research 19,* 63-68. doi: 10.1016/0008-8846(89)90066-5.

Maravelaki-Kalaitzaki, P., Bakolas, A. and Moropoulou, A. (2003). Physico-chemical study of Cretan ancient mortars. *Cement and Concrete Research 33*, 651-68.

Massazza, F. and Pezzuoli, M. (1981). Some Teachings of a Roman Concrete Mortars, Cement and Grouts Used in the Conservation of Historic Buildings. *Proceedings of Symposium in Rome*, 219-245.

Matias, G., Faria, P., Torres, I. (2014). Lime Mortars With Heat Treated Clays and Ceramic Waste: A Review. *Construction and Buiding Materials 73,* 125-136.

Mertens, G., Elsen, J., Brulet, R., Brutsaert, A., Deckers, M. (2009). Quantitative Composition of Ancient Mortars from the Notre Dame Cathedral in Tournai (Belgium). *Materials Characterization 60*, 580-585.

Miriello, D., Bloise, A., Crisci, G.M., Apollaro, C. and La Marca, A. (2011). Characterisation of archaeological mortars and plasters from kyme (Turkey). *Journal of Archaeological Science 38,* 794-804.

Moropoulou, A., Bakolas, A., Anagnostopoulou, S. (2005). Composite Materials in Ancient Structures. *Cement & Concrete Composites 27*, 295-300.

Moropoulou, A., Bakolas, A., Bisbikou, B. (1995). Characterization of Ancient, Byzantine and Later Historic Mortars by Thermal and X-ray Diffraction Techniques. *Thermomica Acta 269/270*, 779-795.

Moropoulou, A., Çakmak, A.S., Lohvyn, N. (2000). Earthquake Resistant Construction Techniques and Materials on Byzantine Monuments in Kiev. *Soil Dynamics and Earthquake Engineering 19*, 603-615.

Önge, M.Y. (1988). *Anadolu Türk Hamamları Hakkında Genel Bilgiler ve Mimar Koca Sinan'ın İnşa Ettiği Hamamlar*. 403-428. Mimarbaşı Koca Sinan, Yaşadığı Çağ ve Eserleri. İstanbul: Vakıflar Genel Müdürlüğü Yayınları.

Özkaya, A.Ö. (2005). *Properties of Roman bricks and mortars used in Serapis Temple in Bergama.* (M.Sc. Thesis). İzmir Institute of Technology, İzmir.

Pearson, G. (1994). *Conservation of Clay and Chalk Buildings*. Dorset: Donhead Publishing Ltd.

Rai, D.C. and Dhanapal, S. (2015). Mineralogical and Mechanical Properties of Masonry and Mortars of the Lucknow Monuments Circa the 18th Century. *International Journal of Architectural Heritage: Conservation, Analysis, and Restoration 9*, 300-309. doi:10.1080/15583058.2013.780109.

RILEM. (1980). Tests Defining the Structure. *Materials and Construction 13*(73).

Robador, M.D., Perez-Rodriguez, J.L., Duran, A. (2010). Hydraulic Structures of the Roman Mithraeum House in Augusta Emerita, Spain. *Journal of Archaeological Science 37*, 2426-2432. doi:10.1016/j.jas.2010.05.003.

Silva, A.S., Paiva, M., Ricardo, J., Salta, M., Monteiro, A.M., Candeias, A.E. (2006). Characterisation of Roman Mortars from the Archaeological Site of Tróia (Portugal). *Materials Science Forum 514-516*, 1643-1647. doi: 10.4028/www.scientific.net/MSF.514-516.1643.

Seeley, I. H. (1995). *Building Technology* (Fifth Edition). 206-212. Basingstoke, Hampshire: The Macmillan Press Ltd.

Spence, R. (1974). Lime and Surkhi Manufacture in India. *Appropriate Technology 1*(4), 6-8.

Stefanidou, M., Pachta, V., Konopissi, S., Karkadelidou, F., Papayianni, I. (2014). Analysis and characterization of hydraulic mortars from ancient cisterns and baths in Greece. *Materials and Structures 47*(4), 571-580. doi: 10.1617/s11527-013-0080-y.

Teutonico, J.M., McCaig, I., Burns, C., Ashurst, J. (1994). The Smeaton Project-Factors Affecting the Properties of Lime Based Mortars. *Bulletin of the Association for Preservation Technology 25*, 32-49.

Uğurlu, E. (2005). *Characterization of Horasan Plasters from Some Ottoman Baths in İzmir*. (M.Sc. Thesis). İzmir Institute of Technology, İzmir.

Uğurlu, E. (2012). *Characteristics of Roman Mortars Produced from Natural and Artificial Pozzolans in Aigai and Nysa.* (PhD Thesis). İzmir Institute of Technology, İzmir.

Uğurlu, E. and Böke, H. (2009). The use of brick–lime plasters and their relevance to climatic conditions of historic bath buildings. *Construction and Building Materials 23*, 2442-50.

Van Balen, K. and Van Gamert, D. (1994). Modelling Lime Carbonation Shrinkage of Lime and Hydrated Cement. *Materials and Structures 27*, 393-398.

Velosa, A. (2006). Lime Mortars with Pozzolans for Old Masonry Coating (in Portuguese). (Ph.D. Thesis). Aveiro University, Aveiro, Portugal.

Vitruvius. (1960). *The Ten Books on Architecture*. New York: Dover Publications.

Watts, A. (2001). *Modern Construction Handbook,* New York: Springer-Verlag Wien.

Yetkin, Ş. (1993). Çinili Hamam. *Türkiye Diyanet Vakfı İslam Ansiklopedisi 8,* 337. İstanbul: Türkiye Diyanet Vakfı İSAM.

Yetkin, Ş. (1988). *Mimar Sinan'ın Eserlerinde Çini Süsleme Düzeni*. 479-498. Mimarbaşı Koca Sinan, Yaşadığı Çağ ve Eserleri. İstanbul: Vakıflar Genel Müdürlüğü Yayınları.

APPENDIX A

BASIC PHYSICAL PROPERTIES OF PLASTERS

Table A.1. Basic physical properties of plasters collected from men's section of Zeyrek Çinili Bath

Sample	Dry Weight (g)	Saturated Weight (g)	Archimedes Weight (g)	Density (g/cm^3)	Porosity (%)
E.I.L.1	8,15	12,33	4,56	1,05	53,80
E.I.L.2	36,03	46,69	20,48	1,37	40,67
E.I.U.1	4,17	5,14	2,00	1,33	30,89
E.I.U.2	4,94	6,02	2,48	1,40	30,51
E.I.U				1,36	30,70
E.I.U.L.1	23,28	28,18	13,64	1,60	33,70
E.I.U.L.2	3,84	5,29	2,30	1,28	48,49
E.I.U.L				1,44	41,10
E.S.L.1.1	40,24	56,37	20,97	1,14	45,56
E.S.L.1.2	17,47	24,38	9,51	1,17	46,47
E.S.L.1				1,16	46,02
E.S.L.2	65,93	78,25	36,32	1,57	29,38
E.S.U.1	13,95	17,78	7,23	1,33	36,92
E.S.U.2	27,73	36,16	16,70	1,43	43,20
E.S.U				1,38	40,06
E.H.L.1.1	13,00	15,56	7,55	1,62	31,96
E.H.L.1.2	12,31	18,40	6,91	1,07	53,00
E.H.L.1				1,35	42,48
E.H.L.2.1	3,75	5,05	2,15	1,29	44,83
E.H.L.2.2	0,97	1,31	0,46	1,14	40,00
E.H.L.2				1,22	42,41
E.H.U.1	2,23	3,31	1,24	1,08	52,17
E.H.U.2	1,18	1,82	0,76	1,11	60,38
E.H.U				1,10	56,28
E.H.U.L	8,91	10,73	5,22	1,62	33,03

Table A.2. Basic physical properties of plasters collected from women's section of Zeyrek Çinili Bath

Sample	Dry Weight (g)	Saturated Weight (g)	Archimedes Weight (g)	Density (g/cm^3)	Porosity (%)
K.I.L.1	3,23	4,44	1,90	1,27	47,64
K.I.L.2.1	15,20	17,97	8,83	1,66	30,31
K.I.L.2.2	13,59	16,80	8,00	1,54	36,48
K.I.L.2				1,60	33,39
K.I.U.1	40,40	48,22	20,74	1,47	28,46
K.I.U.2	23,60	32,28	13,54	1,26	46,32
K.I.U				1,36	37,39
K.I.U.L.1	7,63	9,41	4,58	1,58	36,85
K.I.U.L.2	2,84	3,58	1,71	1,52	39,57
K.I.U.L				1,55	38,21
K.S.L.1.1	4,34	5,46	2,43	1,43	36,96
K.S.L.1.2	2,44	3,26	1,47	1,36	45,81
K.S.L.1				1,40	41,39
K.S.L.2.1	14,33	18,72	7,82	1,31	40,28
K.S.L.2.2	11,25	14,04	6,03	1,40	34,83
K.S.L.2				1,36	37,55
K.S.U.1	37,22	47,44	18,44	1,28	35,24
K.S.U.2	90,09	114,88	43,15	1,26	34,56
K.S.U				1,27	34,90
K.H.L.1.1	13,15	19,67	7,48	1,08	53,49
K.H.L.1.2	7,47	10,63	4,28	1,18	49,76
K.H.L.1				1,13	51,63
K.H.L.2.1	11,20	14,88	6,00	1,26	41,44
K.H.L.2.2	24,23	33,42	13,78	1,23	46,79
K.H.L.2				1,25	44,12
K.H.U.1	11,36	15,17	5,96	1,23	41,37
K.H.U.2	19,60	27,58	10,80	1,17	47,56
K.H.U				1,20	44,46
K.H.U.L.1	4,64	6,82	2,65	1,11	52,28
K.H.U.L.2	3,19	4,69	1,79	1,10	51,72
K.H.U.L				1,11	52,00

APPENDIX B

LIME/AGGREGATE RATIOS OF PLASTERS AND PARTICLE SIZE DISTRIBUTIONS OF AGGREGATES

Table B.1. Lime/aggregate ratios of plasters and particle size distributions of aggregates collected from men's section of Zeyrek Çinili Bath

Sample	Lime (%)	Aggregate (%)	Aggregate size distribution (%)						
			<53µ	53µ	125µ	250µ	500µ	≥1180µ	≥2360µ
E.I.L.1	61,32	38,68	0,05	3,12	7,22	7,38	12,17	3,04	4,87
E.I.L.2	55,55	44,45	0,07	2,88	5,34	8,07	14,42	5,93	6,05
E.I.L	58,43	41,57	0,06	3,00	6,28	7,72	13,29	4,49	5,46
E.I.U.1	50,24	49,76	0,07	3,89	7,64	6,16	19,00	7,92	2,41
E.I.U.2	52,92	47,08	0,00	1,08	7,47	5,66	18,08	6,51	5,94
E.I.U	51,58	48,42	0,03	2,49	7,56	5,91	18,54	7,21	4,17
E.S.L.1	52,71	47,29	0,36	3,47	8,92	8,31	15,78	4,63	4,36
E.S.L.2	67,78	32,22	0,10	0,99	2,34	8,56	11,83	3,87	2,72
E.S.U.1	61,42	38,58	0,43	3,70	6,90	10,89	11,02	2,29	2,90
E.S.U.2	59,96	40,04	0,54	2,17	4,77	11,49	11,10	4,36	4,80
E.S.U	60,69	39,31	0,49	2,93	5,84	11,19	11,06	3,32	3,85
E.H.L.1.1	41,13	58,87	0,52	2,94	5,37	11,05	12,66	6,79	18,41
E.H.L.1.2	38,80	61,20	0,94	3,23	5,18	10,18	11,02	8,67	20,58
E.H.L.1	39,96	60,04	0,73	3,08	5,27	10,61	11,84	7,73	19,49
E.H.L.2.1	40,33	59,67	0,09	4,34	8,16	10,18	22,14	9,03	3,78
E.H.L.2.2	48,62	51,38	0,00	0,79	9,11	7,82	8,73	15,91	7,15
E.H.L.2	44,47	55,53	0,04	2,57	8,63	9,00	15,43	12,47	5,46
E.H.U.1	54,99	45,01	4,72	9,43	9,54	4,68	1,24	3,22	11,44
E.H.U.2	72,08	27,92	0,23	1,80	4,83	3,85	4,07	2,84	9,38
E.H.U	63,54	36,46	2,48	5,62	7,19	4,26	2,66	3,03	10,41

Table B.2. Lime/aggregate ratios of plasters and particle size distributions of aggregates collected from women's section of Zeyrek Çinili Bath

Sample	Lime (%)	Aggregate (%)	Aggregate size distribution (%)						
			<53µ	53µ	125µ	250µ	500µ	≥1180µ	≥2360µ
K.I.L.1	40,85	59,15	0,30	2,68	3,68	3,25	14,57	14,32	17,62
K.I.L.2.1	50,98	49,02	0,59	2,91	5,69	8,02	17,82	5,81	6,68
K.I.L.2.2	63,95	36,05	0,40	2,41	4,29	5,70	7,94	5,49	7,25
K.I.L.2	57,47	42,53	0,49	2,66	4,99	6,86	12,88	5,65	6,96
K.I.U	45,34	54,66	0,54	1,91	3,25	5,39	9,31	11,13	19,53
K.S.L.2.1	50,99	49,01	0,40	2,41	4,29	5,70	7,94	5,49	7,25
K.S.L.2.2	52,56	47,44	0,59	2,91	5,69	8,02	17,82	5,81	6,68
K.S.L.2	51,78	48,22	0,49	2,66	4,99	6,86	12,88	5,65	6,96
K.S.U	33,66	66,34	0,00	0,56	3,64	9,91	32,16	12,78	4,50
K.H.L.1.1	58,27	41,73	0,54	3,81	6,45	4,90	7,47	11,62	6,02
K.H.L.1.2	58,78	41,22	0,13	3,32	8,54	5,89	8,54	6,70	6,38
K.H.L.1	58,53	41,47	0,33	3,56	7,49	5,40	8,00	9,16	6,20
K.H.L.2.1	51,34	48,66	0,20	2,79	5,09	9,18	23,66	3,62	1,65
K.H.L.2.2	53,33	46,67	0,09	2,98	5,61	17,03	15,66	1,61	1,24
K.H.L.2	52,34	47,66	0,15	2,88	5,35	13,11	19,66	2,61	1,44
K.H.U.1	50,19	49,81	1,88	5,36	7,52	12,05	15,39	3,76	2,96
K.H.U.2	41,78	58,22	0,22	2,50	5,68	14,41	26,51	4,57	2,04
K.H.U	45,99	54,01	1,05	3,93	6,60	13,23	20,95	4,17	2,50

APPENDIX C

CHEMICAL COMPOSITIONS OF PLASTERS

Table C.1. Chemical Compositions of plasters collected from women's section of Zeyrek Çinili Bath

Sample	CaO	MgO	SiO_2	Al_2O_3	FeO	Na_2O	K_2O	SO_3
K.I.L.1-2	58,19	1,36	29,88	7,26	2,14	0,07	0,16	0,93
K.I.L.1-3	56,99	1,40	30,57	7,44	2,12	0,02	0,21	1,25
K.I.L.1	57,59	1,38	30,23	7,35	2,13	0,05	0,19	1,09
K.I.L.2-1	53,28	1,38	31,02	8,43	3,07	0,00	0,12	2,71
K.I.L.2-2	53,49	1,34	31,17	8,34	3,04	0,00	0,09	2,54
K.I.L.2-2	52,79	1,24	30,82	8,99	2,93	0,10	0,19	2,94
K.I.L.2	53,19	1,32	31,00	8,59	3,01	0,03	0,13	2,73
K.I.U-1	53,75	2,11	30,43	9,15	2,79	0,41	0,67	0,69
K.I.U-2	52,97	2,14	30,88	9,29	2,93	0,62	0,60	0,56
K.I.U-3	53,18	1,92	30,93	9,40	2,73	0,59	0,59	0,67
K.I.U	53,30	2,06	30,75	9,28	2,82	0,54	0,62	0,64
K.I.U.L.2-1	76,16	6,09	13,63	2,10	0,48	0,21	0,08	1,26
K.I.U.L.2-2	79,73	5,07	12,14	1,73	0,52	0,04	0,12	0,63
K.I.U.L.2-3	71,03	8,18	15,86	2,66	0,23	0,37	0,16	1,52
K.I.U.L.2	75,64	6,45	13,88	2,16	0,41	0,21	0,12	1,14
K.S.L.2-1	46,65	3,19	32,77	9,89	3,24	0,48	1,61	2,17
K.S.L.2-2	46,49	3,65	32,60	9,89	3,40	0,60	1,47	1,89
K.S.L.2-3	46,71	3,40	31,79	10,68	3,58	0,44	1,58	1,82
K.S.L.2	46,62	3,41	32,39	10,15	3,41	0,51	1,55	1,96
K.S.U-1	55,02	2,65	22,42	7,05	1,98	0,06	0,18	10,64
K.S.U-2	56,32	2,79	21,89	6,46	1,76	0,10	0,18	10,49
K.S.U-3	55,85	2,69	21,77	6,94	2,32	0,00	0,16	10,27
K.S.U	55,73	2,71	22,03	6,82	2,02	0,05	0,17	10,47
K.H.L.1-1	47,88	3,20	31,87	9,00	3,28	0,00	0,33	4,43
K.H.L.1-2	32,99	2,21	21,94	6,34	2,16	0,00	0,45	3,03
K.H.L.1-3	35,42	2,24	22,47	6,34	2,33	0,00	0,22	3,19
K.H.L.1	38,76	2,55	25,43	7,23	2,59	0,00	0,33	3,55
K.H.L.2-1	55,05	1,20	29,45	7,57	2,58	0,16	0,42	3,57
K.H.L.2-2	53,58	1,25	31,17	7,87	2,81	0,10	0,26	2,95
K.H.L.2-3	54,15	1,25	30,63	8,19	2,45	0,12	0,18	3,04
K.H.L.2	54,26	1,23	30,42	7,88	2,61	0,13	0,29	3,19
K.H.U-1	42,91	1,95	36,30	10,38	4,54	0,25	0,71	2,96
K.H.U-2	43,18	1,97	36,37	10,15	4,48	0,31	0,71	2,83
K.H.U-3	43,67	1,95	35,48	10,03	4,81	0,28	0,42	3,36
K.H.U	43,25	1,96	36,05	10,19	4,61	0,28	0,61	3,05
K.H.U.L.2-1	82,37	2,23	11,74	2,12	0,25	0,10	0,10	1,08
K.H.U.L.2-2	80,80	2,16	12,44	2,42	0,31	0,16	0,29	1,42
K.H.U.L.2-3	76,39	3,28	14,48	3,21	0,28	0,31	0,11	1,94
K.H.U.L.2	79,85	2,56	12,89	2,58	0,28	0,19	0,17	1,48

Table C.2. Chemical Compositions of plasters collected from men's section of Zeyrek Çinili Bath

Sample	CaO	MgO	SiO_2	Al_2O_3	FeO	Na_2O	K_2O	SO_3
E.I.L.1-1	45,33	2,04	35,60	9,82	3,20	0,53	1,16	2,31
E.I.L.1-2	43,81	2,00	35,70	10,92	3,73	0,56	1,30	1,98
E.I.L.1-3	43,79	1,90	36,78	10,13	3,39	0,61	1,24	2,16
E.I.L.1	44,31	1,98	36,03	10,29	3,44	0,57	1,23	2,15
E.I.L.2-1	59,95	2,00	25,77	6,71	2,42	0,62	1,73	0,80
E.I.L.2-2	60,81	1,70	25,39	7,07	2,11	0,81	1,49	0,61
E.I.L.2-3	60,57	1,78	26,10	6,56	2,20	0,65	1,48	0,67
E.I.L.2	60,44	1,83	25,75	6,78	2,24	0,69	1,57	0,69
E.I.U-1	47,22	1,56	38,02	8,32	2,29	0,59	0,66	1,34
E.I.U-2	46,97	1,48	38,30	8,41	2,40	0,50	0,64	1,31
E.I.U-3	47,15	1,57	37,91	8,61	2,31	0,57	0,64	1,24
E.I.U	47,11	1,54	38,08	8,45	2,33	0,55	0,65	1,30
E.I.U.L.2-1	80,40	2,06	13,45	2,78	0,55	0,19	0,24	0,33
E.I.U.L.2-2	80,60	2,26	13,18	2,65	0,49	0,18	0,24	0,40
E.I.U.L.2-3	76,72	2,79	15,63	3,29	0,53	0,27	0,32	0,46
E.I.U.L.2	79,24	2,37	14,09	2,91	0,52	0,21	0,27	0,40
E.S.L.1-1	44,47	2,26	35,94	9,87	4,05	0,21	0,54	2,6
E.S.L.1-2	44,37	2,05	35,93	10,73	3,87	0,18	0,55	2,32
E.S.L.1-3	45,24	2,35	35,67	9,52	3,87	0,19	0,65	2,51
E.S.L.1	44,69	2,22	35,85	10,04	3,93	0,19	0,58	2,48
E.S.L.2-1	55,54	3,88	28,51	7,57	2,40	0,27	1,24	0,58
E.S.L.2-2	53,98	4,41	29,40	7,89	2,52	0,02	1,21	0,57
E.S.L.2-3	54,19	4,12	29,68	7,70	2,31	0,21	1,27	0,50
E.S.L.2	54,57	4,14	29,20	7,72	2,41	0,17	1,24	0,55
E.S.U-1	51,29	1,29	36,35	6,62	1,93	0,58	0,87	1,05
E.S.U-2	49,91	1,39	37,34	6,75	2,11	0,66	0,79	1,05
E.S.U-3	50,85	1,38	36,88	6,84	1,98	0,42	0,87	0,78
E.S.U	50,68	1,35	36,86	6,74	2,01	0,55	0,84	0,96
E.H.L.1-1	42,20	1,26	47,54	6,46	1,13	0,20	0,73	0,46
E.H.L.1-2	41,89	1,29	47,95	6,67	1,15	0,18	0,66	0,18
E.H.L.1-3	41,03	1,22	49,09	6,62	1,10	0,11	0,71	0,11
E.H.L.1	41,71	1,26	48,19	6,58	1,13	0,16	0,70	0,25
E.H.L.2-1	42,33	3,3	38,19	9,96	3,21	0,11	0,45	2,46
E.H.L.2-2	43,61	3,19	37,39	9,72	2,94	0,16	0,41	2,58
E.H.L.2-3	42,89	3,09	37,44	10,29	3,01	0,21	0,36	2,72
E.H.L.2	42,94	3,19	37,67	9,99	3,05	0,16	0,41	2,59
E.H.U-1	38,30	9,75	40,36	7,43	2,88	0,22	0,35	0,71
E.H.U-2	37,73	10,14	40,85	7,51	2,74	0,15	0,24	0,64
E.H.U-3	34,82	9,86	43,00	8,03	3,01	0,25	0,35	0,68
E.H.U	36,95	9,92	41,40	7,66	2,88	0,21	0,31	0,68
E.H.U.L.1-1	45,43	3,03	34,57	9,21	1,70	0,17	0,44	5,46
E.H.U.L.1-2	44,59	2,91	35,43	9,26	1,59	0,04	0,53	5,65
E.H.U.L.1-3	42,85	3,03	37,03	8,98	1,62	0,19	0,47	5,82
E.H.U.L.1	44,29	2,99	35,68	9,15	1,64	0,13	0,48	5,64
E.H.U.L.2-1	77,90	3,97	13,11	2,30	0,95	0,05	0,15	1,56
E.H.U.L.2-2	77,68	4,48	12,79	2,18	1,10	0,05	0,29	1,43
E.H.U.L.2-3	78,83	3,74	12,16	2,38	0,76	0,18	0,24	1,71
E.H.U.L.2	78,14	4,06	12,69	2,29	0,94	0,09	0,23	1,57

APPENDIX D

POZZOLANIC ACTIVITIES OF BRICK AGGREGATES

Sample	Electrical conductivity of $Ca(OH)_2$ (mS/cm)	Electrical conductivity of $Ca(OH)_2$ mixed with crushed bricks aggregates (mS/cm)	Difference in electrical conductivity (mS/cm)
E.I.L.1	7,98	3,16	4,82
E.I.L.2	7,97	3,36	4,61
E.I.U	7,99	4,28	3,71
E.S.L.1	7,87	2,83	5,04
E.S.L.2	7,96	6,12	1,84
E.S.U	7,79	4,44	3,35
E.H.L.1	8,07	3,45	4,62
E.H.L.2	8,13	3,77	4,36
E.H.U	7,85	5,06	2,79
K.I.L.1	7,97	4,23	3,74
K.I.L.2	7,92	3,05	4,87
K.I.U	7,86	4,28	3,58
K.S.L.2	7,85	3,28	4,57
K.S.U	7,85	2,32	5,53
K.H.L.1	8,01	3,5	4,51
K.H.L.2	7,98	5,34	2,64
K.H.U	7,98	4,42	3,56