Journal of Cultural Heritage 14S (2013) e73–e76

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Characteristics of bricks used in the domes of some historic bath buildings

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ARTICLE INFO

Article history:
Received 30 October 2012
Accepted 5 November 2012
Available online 18 February 2013

Keywords:
Historic brick
Composition
Firing temperature
Durability
Conservation

ABSTRACT

In this study, characteristics of bricks used in the domes of some historic bath buildings dated to 15th century in İzmir were determined in order to indicate the properties of repair bricks that will be used in the conservation works of the domes. For this purpose, their basic physical properties, elemental and mineralogical compositions, firing temperatures and microstructural properties were determined by using XRF, XRD, SEM-EDS and TGA analysis. Analysis results indicated that the bricks are of low density, high porosity and were produced from raw materials containing low amounts of calcium poor clays fired at low temperatures (< 900 °C). They are mainly consisted of small pores with $r < 5\ \mu m$ that make the bricks more susceptible to salt crystallization and freeze-thaw cycles. Although the bricks were fired at low temperatures and susceptible to salt crystallization and freeze thaw cycles, the structural systems of the domes remained without losing their integrity due to the moderate climatic conditions of İzmir. Repair bricks that will be used in the conservation works of the domes should be compatible with the original ones and produced from calcium poor clays by firing at low temperatures.

1. Introduction

The materials used in the construction of Ottoman baths were stones, bricks and binding materials. Rubble and cut stones were the main materials of wall systems where bricks were generally used in superstructure components such as arches, vaults and domes. Binding materials used in the construction of both walls and domes were lime mortars. Interior and exterior surfaces of the domes were covered with brick-lime plasters called *cocciopesto* that prevented water penetration to the structure. In previous studies, characteristics of mortars, plasters and stones used in the construction of some historic bath buildings dated to 15th century in İzmir were determined [1–3]. In this study, raw materials and production technologies of bricks used in the domes of same buildings were determined.

Bricks are manufactured by first removing coarse stones from the natural clay source before mixing with water. The plastic mixture is then shaped, dried and heated at temperatures greater than 600 °C [4]. Some changes occur in mineralogical, chemical and physical properties of raw materials of bricks during heating. Heating destroys the crystal structure of clay and pozzolanic amorphous substances like metakaolin are formed when the heating temperature is between 450 and 800 °C depending on the type of clay mineral [5]. At temperatures over 800 °C, pozzolanic activities are lost and high temperature mineral phases such as mullite and cristobalite are formed [6]. For Ca-rich clays, gehlenite formed at 800 °C, diopsite formed at 850 °C, wollastonite formed at 1050 °C; and for Ca-poor clays, hematite formed at 850 °C are important mineral phases formed at different heating temperatures [7].

Mineralogical transformations during heating result in changes in the pore structure of bricks [4,8]. At firing temperatures around 800 °C, in bricks produced from Ca-rich clays, calcite ($CaCO_3$) is decomposed and calcium oxide (CaO) is formed. In the presence of water, calcium oxide returns into portlandite ($Ca(OH)_2$), and portlandite transforms into calcite again as a result of its reaction with CO_2. These reactions generate a considerable increase in volume and formation of fissures that generally known as "lime blowing" in the brick structure [4,8]. For bricks produced from Ca-poor clays, porosity slightly reduces at this temperature. At firing temperatures below 900 °C, pores smaller than 1 μm predominate in both types of bricks [4]. At firing temperatures around 900 °C, pore size distribution remains almost unchanged in Ca-rich bricks while the amount of pores bigger than 7 μm significantly increase in Ca-poor bricks [4]. The most significant increment in the amount of larger pores and the lowest porosity is obtained at firing temperatures around 1000 °C in Ca-poor bricks and at firing temperatures around 1100 °C in Ca-rich bricks [4].

Shaping method (molding, pressing, extrusion) used during manufacturing is another factor that affects the porosity of bricks [9]. But, to evaluate the effect of shaping method to porosity is

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1296-2074/$ – see front matter
http://dx.doi.org/10.1016/j.culher.2012.11.030

Fig. 1. Düzce Bath in Seferihisar-İzmir.

much more complicated since such some other factors such as firing temperature, firing speed also need to be taken into account [9].

Total porosity and pore sizes of bricks are important factors that affect the durability and mechanical resistance of bricks [4,10]. Bricks with high porosity and high amounts of small pores ($r < 1\ \mu m$) are more susceptible to salt crystallization and freeze-thaw cycles [4,10,11]. Changes in porosity due to salt crystallization and freeze-thaw cycles reduce the mechanical resistance of bricks over time [4,12].

This study aims to determine the properties of bricks used in the domes of some historic bath buildings dated to 15th century in order to indicate the characteristics of repair bricks that will be used in the conservation works of domes.

2. Experimental methods

In this study, basic physical properties, mineralogical and chemical compositions, firing temperatures, microstructural properties and pozzolanic activities of bricks used in the domes of four Ottoman bath buildings, which are Hersekzade, Kamanlı, Düzce and Ulamış baths located in İzmir, were investigated (Fig. 1).

Bulk density and porosity, which are the main physical properties of bricks, were determined by using standard test methods [13]. Mineralogical compositions were determined by X-ray diffraction analyses (Philips X-Pert Pro X-ray Diffractometer). Firing temperatures of bricks were determined in relation to their mineralogical compositions. Elemental compositions were identified by using X-ray fluorescence analyses (XRF) carried out on a Spectra IQ II spectrometer. Microstructures were determined by Philips XL 30S FEG Scanning Electron Microscope (SEM) coupled with X-Ray Energy Dispersive System (EDS). Weight losses between 200-600°C due to the loss of chemically bound waters and between 600 and 900°C due to the loss of CO_2 during decomposition of calcium carbonate were determined by using Shimadzu TGA-21. The pozzolanic activity of the bricks was identified by measuring the differences in electrical conductivities (mS/cm) before and after the addition of powdered brick (less than 53 μm) into saturated calcium hydroxide solution [14].

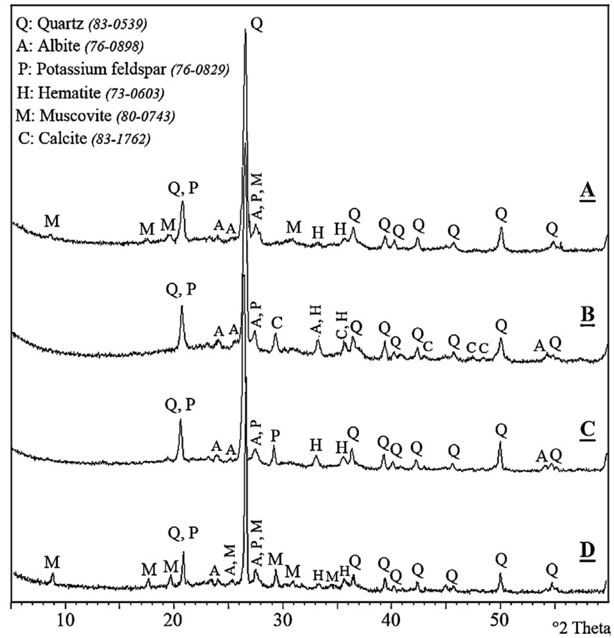

Fig. 2. XRD patterns of bath bricks (A: Hersekzade, B: Kamanlı, C: Düzce, D: Ulamış).

3. Results and discussions

3.1. Basic physical properties

All bricks are of low density and high porosity. Density and porosity values of bricks are between 1.7 and 1.8 g/cm^3 and 33 and 37%, by volume, respectively. These values were almost in the same ranges with other bricks used in domes of some historic buildings in Anatolia [15]. The use of light bricks in the domes may be attributed to provide structural stability [16].

3.2. Mineralogical and elemental compositions

XRD analysis indicated that bricks are mainly composed of quartz (SiO_2), albite ($Na(AlSi_3O_8)$), potassium feldspar ($KAl_2Si_2O_5(OH)_4$) and muscovite ($KAl_2(AlSiO_3O_{10})(F,OH)_2$) (Fig. 2).

XRF analysis results revealed that bricks are composed of high amounts of SiO_2, Al_2O_3, Fe_2O_3, and low amounts of Na_2O, K_2O, MgO and CaO (Table 1). The presence of low amounts of Ca in their composition reveals that calcium poor clay was used in the manufacturing of the bricks.

The bricks were found as non-pozzolanic according to the pozzolanic activity measurements carried out by measuring the differences in electrical conductivities (mS/cm) before and after addition of powdered bricks (less than 53 μm) into saturated calcium hydroxide solution [14]. In this method, bricks were accepted as pozzolanic if the difference between two measurements is bigger than 1.2 mS/cm. Electrical conductivity differences of the examined bricks ranging from 0.2–0.7 mS/cm reveals that examined bricks are not pozzolanic. These results show that amount of clay

Table 1
Percent elemental composition of the bricks identified by XRF.

Samples	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5
Her.	62.66	18.81	6.34	2.19	1.01	0.32	2.72	0.84	0.04
Kam.	65.07	15.77	6.27	1.73	3.08	0.39	2.54	0.66	0.06
Duz.	69.09	15.12	6.87	1.65	0.57	0.31	1.96	0.71	0.08
Ula.	59.87	18.72	6.97	2.55	2.34	0.32	3.09	0.80	0.14

Her.: Hersekzade; Kam.: Kamanlı; Duz.: Düzce; Ula.: Ulamış.