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Characteristics of lime produced from limestone containing diatoms

Hasan Böke *, Özlem Çizer, Başak İpekoğlu, Elif Uğurlu, Kerem Şerifaki, Gülcan Toprak

Architectural Restoration Department, İzmir Institute of Technology, 35430 İzmir, Turkey

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Abstract

In this study lime binder used in stone and brick masonry mortars of some historic Ottoman baths was examined to understand whether the binders were hydraulic or not. For this purpose the mineralogical and elemental compositions and the microstructure of lime binder were determined by XRD, SEM–EDS and TGA analyses. The results indicate that the lime used in the brick dome mortars of Ottoman baths was hydraulic. Taking into account the kiln and fuel conditions of the 15th century, the possibility of obtaining hydraulic lime at relatively low temperature was examined. For this purpose limestone containing diatoms was heated at a relatively low temperature (850 °C), then slaked and carbonated. After heating and slaking, calcium silicate giving hydraulicity to the lime was indicated by XRD and SEM–EDS analyses. These results show that the production of hydraulic lime at a relatively low calcination temperature (850 °C) was possible with 15th century kilns.
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1. Introduction

Mortars used for bedding and jointing masonry units and rendering masonry surfaces are composed of binders and aggregates [1,2]. Historically, different types of binder materials have been used in the construction of masonry buildings. Mud mortars are the oldest documented mortars and were used in the construction of the first collective settlements in Mesopotamia 10,000 years ago [1]. Gypsum mortar is a binder long used in the brick vaults and arches due to its quick setting and high mechanical strength [1,3]. Lime mortars have been the most widely used in the construction of the buildings since their first known use in Egypt in 4000 BC [2,4].

Lime mortars can be classified as non-hydraulic and hydraulic. Non-hydraulic lime mortars are produced by mixing slaked lime with aggregates and harden by evaporation and carbonation of lime due to carbon dioxide in the air. Hydraulic lime mortars are produced either by mixing lime with pozzolans containing amorphous active silicates and aluminates or by developing hydraulic phases through the calcination of silica rich limestone directly quarried or synthetically mixed. Hydraulic lime mortars harden by evaporation, carbonation of lime and the reaction between lime and pozzolans or the hydraulic phases in the presence of water. This reaction produces calcium silicate hydrates and calcium aluminate hydrates, allow for setting under water and impart higher earlier strength to the hydraulic lime mortars [5]. For this reason, such mortars have been extensively used in the construction of foundations placed in waterlogged grounds and for drainage systems, cisterns, and bridges since ancient Greek period [1,2]. Romans successfully improved on masonry structures the use of hydraulic lime mortars produced by combining lime and pozzolans [1,2].

Determination of historic lime mortar characteristics became an important subject in the second half of the 20th century. The studies on historic lime mortars and plasters are compiled by Hansen et al. [6] in an extensive bibliography and provide a source for conservators and conservation scientists.

* Corresponding author. Tel.: +90 232 7507035; fax: +90 232 7507012.
E-mail address: hasanboke@iyte.edu.tr (H. Böke).

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Among the studies of historic lime mortars, the achievement of hydraulic properties of historic mortars is usually described as the process of mixing pozzolans with high calcium lime [7–12]. However, the possibility of the use of calcined hydraulic lime in historic mortars has not been thoroughly considered.

The first production of calcined hydraulic lime is documented around the second half of the 18th century [4]. This type of lime is obtained by the calcination of limestone with high amounts of clay substances, forming calcium and aluminum silicates at temperatures between 950 °C and 1250 °C. It was known that such temperatures could not be reached before the 18th century. Therefore the possibility of achieving the hydraulic properties of lime at relatively low temperatures through heating of limestone containing diatoms which are mainly composed of amorphous silica has not been taken into consideration.

In this study the hydraulic characteristics of lime mortars used in the walls and brick domes of some Ottoman baths are examined to determine whether hydraulicity of the mortars originates by mixing pozzolans with lime or by the use of hydraulic lime. The results of this study indicate that the lime used in the brick dome mortars of Ottoman baths was hydraulic. Taking into account the kiln conditions of the 15th century, the possibility of obtaining hydraulic lime at relatively low temperature was examined. For this purpose limestone containing diatoms was heated at a relatively low temperature (850 °C), then slaked and carbonated. After heating and slaking of limestone, formation of hydraulic products was indicated by XRD, SEM, EDS and TGA analyses.

2. Materials and method

The study is composed of two phases. First phase examines the general characteristics and the hydraulic properties of lime binders of the mortars used in the walls and brick domes of some Ottoman baths. Based on the findings of the first phase, second part of the study investigated the possibilities of obtaining hydraulic lime from limestone containing diatoms by calcining at relatively low temperature (850 °C).

2.1. Sampling of lime mortars

First phase of this study was to understand whether the lime binders used for masonry mortars of historic Ottoman bath constructions were hydraulic or not. Respectively, lime mortar samples were collected from the walls and domes of five historic Ottoman baths constructed in the

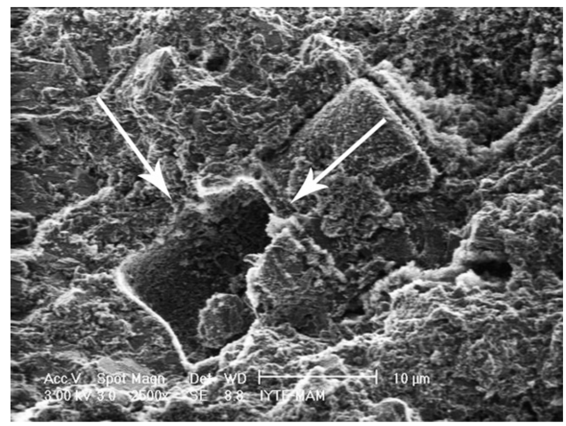

Fig. 1. SEM image of a cone shape diatom shown by arrow at the limestone aggregate.

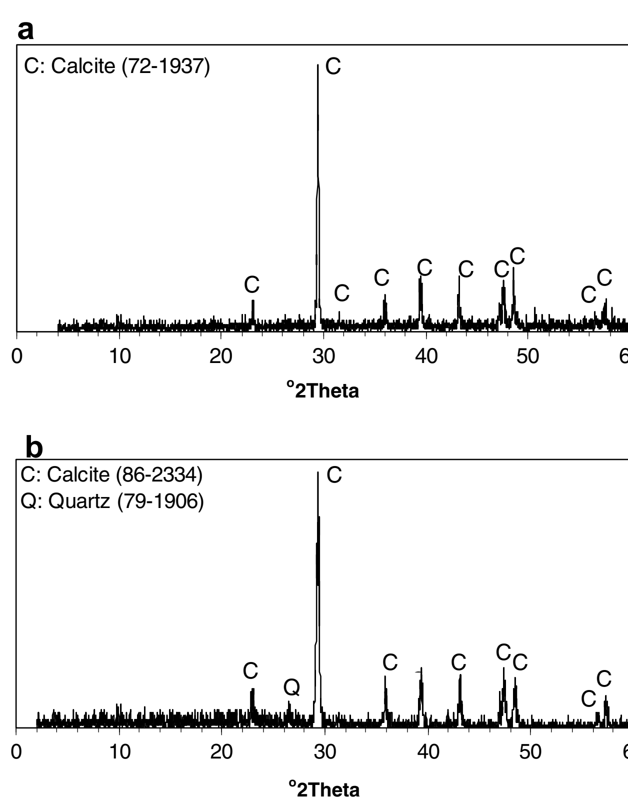

Fig. 2. Typical XRD patterns of white lumps in stone (a) and brick masonry (b) mortars.

Table 1
Density, porosity, uniaxial compressive strength (MPa) and lime aggregate ratio values of mortars

Sample	Density	Porosity	C.S. (MPa)	L/A
Se–S	1.52 ± 0.04	40.70 ± 1.56	–	0.7
Du–S	1.51 ± 0.03	41.85 ± 0.30	5.3 ±1.7	0.6
Ul–S	1.84 ± 0.03	26.82 ± 1.56	7.4 ± 4.7	0.3
He–S	1.50 ± 0.06	36.94 ± 5.89	9.7 ± 1.4	0.4
Ka–S	1.69 ± 0.04	32.80 ± 1.43	4.2 ± 0.5	0.7
Du–B	1.48 ± 0.08	38.60 ± 6.79	14.7 ± 4.5	0.4
Ul–B	1.72 ± 0.07	31.85 ± 2.33	21.0 ± 3.0	0.4
He–B	1.59 ± 0.04	35.07 ± 1.77	10.5 ± 2.6	0.3
Ka–B	1.40 ± 0.03	43.46 ± 1.14	8.8 ± 1.0	0.7

Se: Seferihisar bath; Du: Düzce bath; Ul: Ulamış bath; He: Hersekzade bath; Ka: Kamanlı bath; S: Stone masonry mortar; B: brick masonry mortar; C.S.: compressive strength; L/A: lime/aggregate.

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