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Original article

# Durability of bricks used in the conservation of historic buildings — influence of composition and microstructure

Kerstin Elert *, Giuseppe Cultrone, Carlos Rodriguez Navarro, Eduardo Sebastián Pardo

*Department of Mineralogy and Petrology, University of Granada, Fuentenueva S/N., 18002 Granada, Spain*

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**Abstract**

Differences in mineralogical and textural evolution during firing of calcareous and non-calcareous bricks are studied and correlated with their behaviour in hygric and weathering tests. Results reveal significant differences in the evolution of vitrification degree, porosity and pore size distribution. Such evolution depends mostly on raw clay composition and firing temperatures. A higher degree of vitrification and of compressive strength is displayed by calcareous rather than non-calcareous bricks at lower firing temperatures of between 700 and 900 °C. However, their resistance to salt crystallisation and freezing is not notably improved because of unfavourable pore size distribution and crack development. The latter are caused by the transformation of calcite into calcium oxide at around 800 °C, which reacts readily with moisture to form calcium hydroxide, thus leading to a volume increase (lime blowing). This problem can be avoided by closely controlling grain size and content of carbonates in the raw clays. High firing temperatures of 1100 °C in the case of calcareous clay and 1000 °C in the case of non-calcareous clay are required to produce durable bricks that remain unaltered upon weathering. The improved durability appears to be due to a more favourable pore size distribution and a reduction in porosity. Results from textural and hygric studies of the brick samples indicate that these parameters can to a significant extent be controlled by varying raw clay composition and firing temperature, thus making it possible to fabricate replacement bricks for particular conservation purposes. This paper addresses limitations regarding the interpretation of test results, as well as the lack of a systematic application of existing standards for evaluating the state of conservation of historic bricks and for establishing specifications for replacement bricks.



*Keywords:* Bricks; Clay mineralogy; Physico-chemical characteristics; Mechanical properties; Architectural conservation; Standard tests

## 1. Research aims

Brick masonry constitutes a significant part of the construction materials found in historic buildings. The level of decay in bricks differs widely, in many cases requiring partial replacements. The selection of compatible materials for the replacement of original bricks is crucial in order to avoid damage to the historical structure. This paper examines the influence of composition and firing temperature on the textural and microstructural evolution of calcareous and non-calcareous bricks. Textural and microstructural characteristics are correlated to hygric behaviour, strength and durability. The feasibility of manufacturing replacement bricks with specific properties suitable for particular conservation requirements is also assessed.

* Corresponding author.
*E-mail address:* kelert@ugr.es (K. Elert).


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## 2. Introduction

Bricks constitute an important part of the construction materials of historic buildings in Andalusia (Spain). Their mineralogical, chemical and physical characteristics, as well as the factors and mechanisms leading to their deterioration, have been extensively studied [1–4]. Raw materials and manufacturing parameters have been found to be of great importance to the quality and durability of bricks. Significant amounts of carbonates have been detected in many historic bricks, clearly identified as an original feature of the raw clay, for example, in the case of the Alhambra in Granada (Fig. 1) [1], and the Alcazaba in Loja [2]. Whether the selection of the calcareous clay was intentional or based on local availability is unknown, though the positive effect of carbonates on the properties of ceramics has been recognized since Roman times [5].

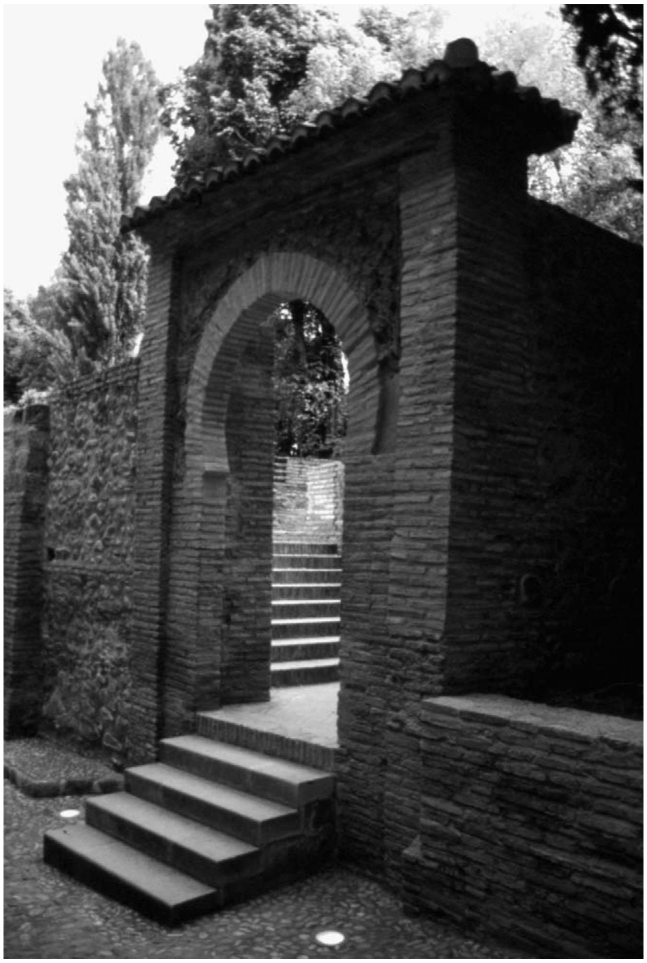

Fig. 1. Royal cemetery (Rauda) of the Alhambra. Analysis of brick samples performed by De la Torre López et al. [1] revealed the presence of calcite grains of primary origin.

Several researchers have studied the influence of clay composition on the quality of fired bricks, and have generally reported positive effects of moderate amounts of carbonates, which act as a flux [6]. It has been found that carbonates lead to a reduction in shrinkage and anisotropic behaviour and to an increase in compressive strength [5,7,8]. Tite and Maniatis [9] state that control of firing temperature would be less critical in the case of calcareous clays, since their morphology remains essentially unchanged over a wide range of temperatures. Furthermore, the oven atmosphere and the firing temperature have less of an effect on the final colour of calcareous than on non-calcareous bricks [5,10]. However, while the textural and mineralogical evaluation of calcareous and non-calcareous bricks is well documented, little has been published in the technical and conservation literature regarding the influence of raw material composition on hygric behaviour and durability upon weathering. Both properties are very important for the selection of replacement bricks.

Here we present a detailed examination of solid calcareous and non-calcareous bricks manually fabricated and fired in our laboratory at between 700 and 1100 °C. Differences in the evolution of vitrification degree, porosity and pore size distribution upon firing depending on the raw clay composition were evaluated. Textural and microstructural characteristics were correlated with the bricks' compressive strength and their performance in hygric and weathering tests. The results can be used to evaluate the suitability of the bricks as replacements for original masonry materials and to predict their performance once in place.

## 3. Materials and methods

Bricks were made of two locally available clays (Granada, Spain). One clay type (Viznar) contains significant amounts of calcite and dolomite, while the other (Guadix) has no carbonates. The granulometry of both clays shows no significant differences. Raw material was milled and sieved, discarding the fraction with a grain size of >1.5 mm. Bricks were fabricated manually using a clay to water ratio of 1:0.4 and were fashioned in wooden moulds (24.5 × 11.5 × 4 cm). Once dry, they were fired at between 700 and 1100 °C in an electric oven under oxidising conditions. Further details on the fabrication of the bricks are described elsewhere [11].

The mineralogical composition of clays and bricks was determined by powder X-ray diffraction (XRD, Philips PW 1710). A semiquantitative estimate of the vitreous phase content was performed considering the quartz content as constant. All other phases were scaled to this value: (vitreous phase) = 100% – Σ(all other mineral phases). Scanning electron microscopy (SEM, Zeiss DMS 950) and optical microscopy (OM) were employed to observe textural and microstructural features, as well as the vitrification evolution. Standard water behaviour tests were performed to determine the saturation coefficient [12] and the drying index [13]. Differing from the recommendations in the standard test, the evaporation curve was established in an environment of 50% relative humidity and 25 °C. The porosity accessible to water was calculated from water absorption data according to RILEM recommendations [14]. Pore size distribution was evaluated using mercury intrusion porosimetry (MIP, Micromeritics AutoPore III, Model 9420). Compressive strength was determined as described in UNE 67-026-86 [15]. In order to evaluate their decay behaviour, brick samples were exposed to 30 freeze–thaw cycles following UNE 67-028-84 specifications [16] and to 10 salt crystallisation cycles using sodium sulphate decahydrate ($Na_2SO_4 \cdot 10H_2O$) according to UNE 7136 specifications [17].

## 4. Results and discussion

### *4.1. Mineralogical composition and its influence on vitreous phase development*

XRD data reveal that Viznar clay contains significant amounts of calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$), while Guadix clay contains no carbonates. Mineralogical