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An investigation of Roman mortar technology through the petrographic analysis of archaeological material

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Abstract

This paper studies Roman mortars to demonstrate that petrographic analysis provides valuable information on ancient mortar technology. Facts on lime technology relating calcination and slaking were obtained through petrographic analysis. The analysis also revealed the composition and origin of raw materials, pozzolanic additions and mortar hydraulicity. The results were contrasted with ancient Roman technology records including Cato, Pliny, Vitruvius, Palladius and Faventinus. The binders' petrofabric suggests a high reactivity and water retention capacity and a low shrinkage for the lime. These agree with the long slaking and soft burning advised by the Romans. The strong binder cohesion and perfect aggregate-binder bond of most mortars together with the presence of aggregate-binder reaction denotes a high reactivity for the lime which also agrees with soft burning. The mortars were probably made with a non-hydraulic or feebly-hydraulic lime and their hydraulicity is mainly due to the addition of pozzolans (ceramics). These agree with Roman authors consistently advising to use a pure carbonate rock for lime making. The pozzolanic additions are probably responsible for the good durability of the mortars.

Keywords: Mortar technology; Lime; Petrographic analysis; Hydraulicity; Pozzolan; $Ca(OH)_2$; Roman mortar

1. Introduction

This paper demonstrates that petrographic analysis of historic mortars provides fundamental information on mortar technology. The results arising from petrographic examination can be used today to fabricate quality repair mortars compatible with their adjacent masonry [1]. Samples of Roman mortars ranging in age from 100 BC to 500 AD were analysed with a petrographic microscope and the results compared to Roman records on mortar technology. The petrographic microscope is an important tool in geology and archaeometry which can be used to identify sources of raw materials and to attribute stone artefacts to their geological source [2]. It is also an essential tool in building material science in order to study the composition, size and shape of mineral grains and matrices; their relationships and arrangement; their decay and the presence of pores, cracks, cements and directional textures [3]. The technology of lime production determines the durability and properties of a lime mortar. For example, calcination and slaking are very important operations in the manufacture of building limes as they govern properties such as lime reactivity, shrinkage, density and water retention capacity, which in turn determine workability, plasticity and carbonation speed [4]. It has been demonstrated that underwater storage following slaking of quicklime improves plasticity and workability of limes due to particle size reduction and morphology changes [5]. Long slaking has also been associated to an increase in the water retention capacity of lime thus facilitating carbonation therefore enabling development of an early strength and improving mortar durability. The nature of the raw materials also determine the properties of and

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durability of mortars. For example, the presence of magnesian lime and/or reactive aggregate can impart a hydraulic set and therefore determine the quality of a mortar [6].

2. Materials and methods

Twenty six mortars ranging from 1500 to over 2000 years in age, originating from thirteen structures from six different locations in La Rioja, Spain, were analysed. The mortars fulfilled different functions within the built fabric. The samples were dated by archaeologists 'in situ' by means of archaeological methods. Fragments were selected for thin section preparation and petrographic analysis. Table 1 includes details of the samples. Given the age of the mortars and their limited availability, especial care was taken during thin section preparation in order to preserve the material. The mortars were pre consolidated by impregnation in a resin under vacuum. Thin sections were then cut with oils to avoid damaging water-soluble minerals in the mortars. They were polished to the standard thickness of 20 μm, covered with a glass slip and examined with a petrographic microscope incorporating eye pieces of 2, 10, 20 and 40 magnifications using both natural and polarised light.

3. Results and discussion

3.1. Petrofabric of lime binders vs. lime making technology

Petrographic analysis evidenced that the mortars studied, especially plasters and renders, possessed homogeneous, cohesive binders displaying a strong binder-aggregate bond and an absence of over-burned and under-burned lime particles. The lime binders are fine-grained rarely displaying fractures. These features can be observed in Figs. 1–4. Evidence of aggregate-binder reaction was found in several mortars and the presence of ceramic fragments acting as pozzolans was also recorded (see Figs. 1–4). Petrographic analyses revealed that approximately 85% of the mortars studied display unweathered binders which continue fulfilling their role.

In the mortars analysed, the fine-grained lime binders possess a high specific surface. In addition, the absence of binder cracks indicates a low shrinkage. The lime's high specific surface and low shrinkage suggest that the raw limestone was soft-burned. According to Boynton [4], lower burning temperatures and/or shorter burning duration (soft burning) yield the desirable soft-burned, highly reactive limes of low shrinkage and density and high porosity whereas a high burning temperature and long calcining

Table 1
Characteristics of the mortars studied

Sample or sample group	Mortar type/function	Age	Function of the structure holding the mortar
Geographical Location: Contrebia Leukade, Aguilar del Río Alhama, La Rioja., Spain			
RCL1	Pointing ashlar masonry of tufa and sandstone	Early Roman empire I-II c. AD	Tower of defensive city wall
RCL2			Column of city wall doorway
RCL3			City wall, lower ashlar courses
RCL4			
Geographical location: Mantible Bridge, Fuenmayor, La Rioja., Spain			
RM1	Pointing sandstone ashlar masonry	Early Roman empire I–II c. AD	Bridge over the Ebro river, part of the Roman road connecting the Pyrinees with the interior of Iberia
RM2	Bedding sandstone ashlar masonry		
Geographical location: Calahorra City, La Rioja., Spain			
RC1	Grouting a mosaic	Pre-dates late Roman empire (IV c. AD)	Paving a room
RC2	Decorated plaster	Early Roman empire I to II c. AD	Back / interior yard
RC3	Plaster	Early Roman empire I to III c. AD	Monumental construction
RC4	Render		Large pool in thermal baths
RC5	Plaster		Part of a thermal complex
Geographical location: Tirgo Town, La Rioja., Spain			
RT1	Rendering mortar	Late Roman empire IV–V c. AD	Pool in a garden or thermal bath
RT2			
Geographical location: Varea Town, La Rioja., Spain			
RV1	Render	Late Roman empire IV c. AD	Possible living space
RV2	Plaster		
RV3	Revestimiento		Craftwork establishment
RV4	Decorated plaster	Early Roman empire I to III c. AD	Possible living space
Geographical location: Inestrillas Town, La Rioja., Spain			
I1	Pavement	Celtic I c. B.C. (Romanization in progress)	Man–made caves. A possible private dwelling with a defensive character