Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Cement and Concrete Research 35 (2005) 1555–1565
Cement and Concrete Research

Lime pozzolana mortars in Roman catacombs: composition, structures and restoration

Sergio Sánchez-Moral[a,*], Luis Luque[a], Juan-Carlos Cañaveras[b], Vicente Soler[c], Javier Garcia-Guinea[a], Alfredo Aparicio[a]

[a]Museo Nacional de Ciencias Naturales (CSIC), C/ José Gutiérrez Abascal 2, E-28006 Madrid, Spain
[b]Universidad de Alicante, Departamento de Ciencias Tierra and Medio Ambiente, E-03080 Alicante, Spain
[c]Instituto de Productos Naturales y Agrobiologia de Canarias, Avda, Astrofisico Francisco Sanchez 3, E-38206 La Laguna, Tenerife, Spain

Received 21 April 2003; accepted 19 August 2004

Abstract

Analyses of microsamples collected from Roman catacombs and samples of lime–pozzolana mortars hardened in the laboratory display higher contents in carbonated binder than other subaerial Roman monuments. The measured environmental data inside the Saint Callistus and Domitilla catacombs show a constant temperature of 15–17 °C, a high CO_2 content (1700 to 3500 ppm) and a relative humidity close to 100%. These conditions and particularly the high CO_2 concentration speed-up the lime calcitization roughly by 500% and reduce the cationic diffusion to form hydrous calcium aluminosilicates. The structure of Roman catacomb mortars shows (i) coarser aggregates and thicker beds on the inside, (ii) thin, smoothed, light and fine-grained external surfaces with low content of aggregates and (iii) paintings and frescoes on the outside. The observed high porosity of the mortars can be attributed to cracking after drying linked with the high binder content. Hardened lime lumps inside the binder denote low water/mortar ratios for slaking. The aggregate tephra pyroclasts rich in aluminosilicate phases with accessorial amounts of Ba, Sr, Rb, Cu and Pb were analysed through X-ray diffraction (XRD), electron microprobe analysis (EMPA) and also by environmental scanning electron microscopy (ESEM) to identify the size and distribution of porosity. Results support procedures using local materials, special mortars and classic techniques for restoration purposes in hypogeal backgrounds.

Keywords: $CaCO_3$; $Ca(OH)_2$; Mortar; Aggregate; Pozzolan; Microcracking; Crystal size; Curing

1. Introduction

Lime–pozzolana mortars cover large surfaces of Roman catacomb walls and are usually painted with frescoes (Fig. 1a). In the eastern part of Rome, outside the ancient walls, Saint Callistus and Domitilla are two of the oldest catacombs excavated in volcanic tuff. Saint Callistus is famous for the popes' tombs of the second century AD. These important archaeological–architectural heritages attract thousands of tourists. Many wall surfaces of Saint Callistus and Domitilla catacombs are made of volcanic rock dated to the middle Pleistocene originating from the Colli Albani volcanic district. Corridors are often partially covered with bricks making up the structural arches, walls and domes. Many cubicles containing family or communal tombs were dug as squared dome shapes and covered with mortar and stuccoes (Fig. 1b). Mortar prevents failure of the soft substrate and provides a clean, plain, light surface to be decorated with religious paintings and symbols. The catacombs were built from the second to the eighth century AD, and the main part of the decorated mortar originates from the first stages of the catacomb use.

The excellent properties of lime–pozzolana mortars, such as high strength, insolubility and hardening even under water, were known to the ancient Roman builders since the third century BC. Significant Roman monuments, such as

* Corresponding author.
E-mail address: ssmilk@mncn.csic.es (S. Sánchez-Moral).

0008-8846/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconres.2004.08.009

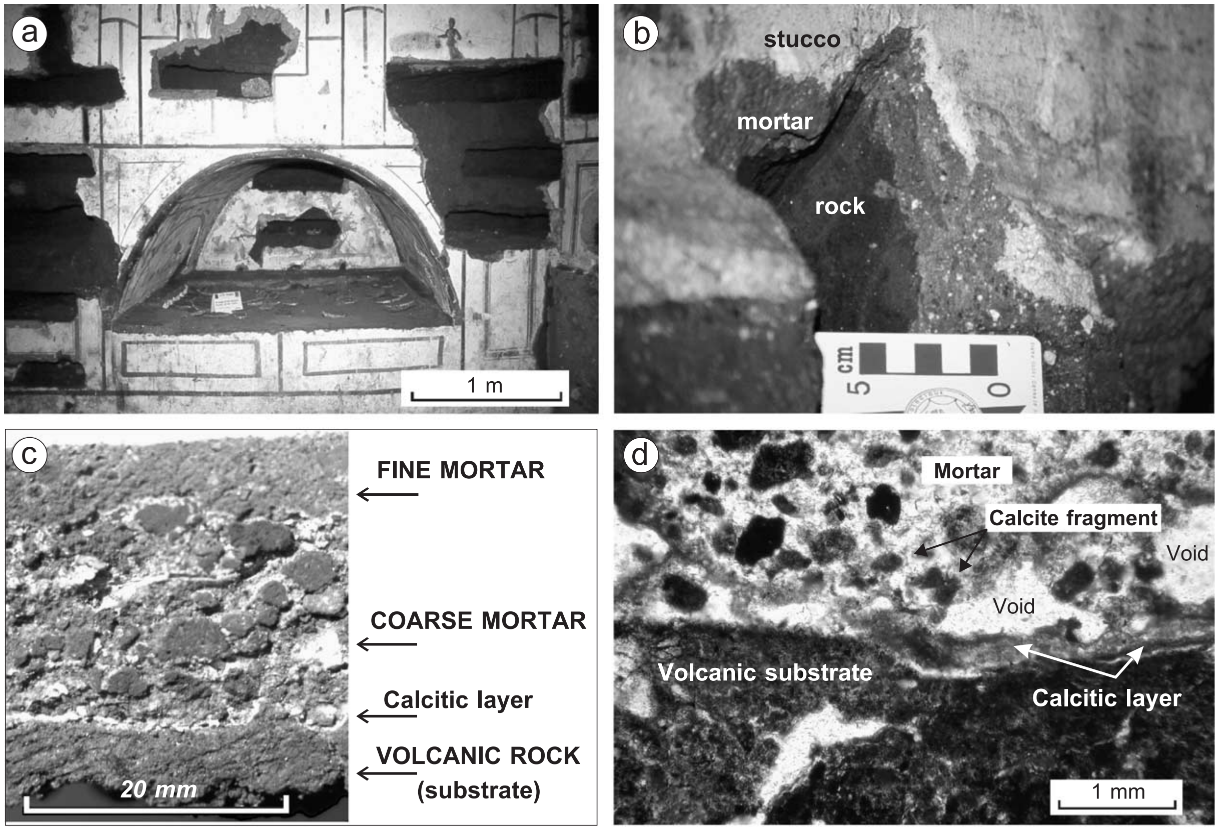

Fig. 1. (a) Aspect of walls in a cubicle covered by mortar and painted frescoes in the Saint Callistus catacomb (Rome). (b) Section showing the volcanic substrate overlaid by thin layers of mortar and stucco. (c) Section of individual sample showing coarse and fine aggregate inside the mortar beds and pure calcite in the mortar substrate interface. (d) Thin section of both the volcanic substrate and the mortar with two thin calcite layers overcoating the substrate.

the Pantheon, Roman Baths or Coliseum in Rome, were built using Roman concrete called "Opus Caementicium" in the first century AD [1]. The structural and physical–chemical characterization of the lime–pozzolana mortars used in building and the determination of the prevailing microenvironmental conditions could provide enough information to formulate new specific mortars for restoration purposes, using original neighbouring raw materials. The region of Rome is volcanic in nature, and the hills of the City consist of a relatively soft and light volcanic material known as tuff. In different places, it has slightly different textures and colours (grey, brown, and black are typical), but it is always lighter than lava, very coarse-grained with numerous small cavities. Unfortunately, recent restorations using inadequate materials incompatible with the original bedding mortar may cause permanent damage [2]. The use of physically–chemically suitable mortar, aesthetically compatible, must help restoration works [2–5]. Detailed studies on historical mortars sampled in the Roman catacombs may contribute to understanding the aspects of missing traditional techniques.

The aim of this work is to determine the chemical and mineralogical composition, texture, structure and properties of lime–pozzolana mortars from Roman catacombs. The research concentrated on three aspects of research: (i) studying microsamples collected from the wall catacombs by optical microscopy, environmental scanning electron microscopy (ESEM), electron microprobe (EM), X-ray diffraction (XRD), ICP-AES, atomic absorption spectroscopy (AAS), porosimetry, etc.; (ii) performing original experiments of lime–pozzolana hardening under X-ray diffraction with thermal control; and (iii) measuring the environmental data inside catacombs (RH values, CO_2 concentration, temperature, pH and chemical composition of infiltration waters).

2. Method and techniques

2.1. Environmental data

Microclimatic parameters were measured by installing a monitoring system consisting of microsensor instruments, a PC-based data logger system and a signal-conditioning unit inside Saint Callistus catacomb. Microsensors installed on air/floor/lamps measured temperature (measurement accuracy 0.01 °C), air relative humidity (0.1%), air CO_2 concentration (2.8 ppm) and ^{222}Rn concentration (pylon AB5 scintillometer with a diffusion detector). Automatic recording of data every 2 min was performed during 6