COMPATIBILITY OF REPAIR MORTARS AT THE ARCHAEOLOGICAL SITE OF VILLA DOMIZIA ON GIANNUTRI ISLAND, ITALY.

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Abstract

Although it is widely recognised that a compatible approach is required in performing restoration works, a lack of knowledge still prevails concerning the choice of the parameters to take into account in the assessment of a sustainable level of compatibility of such actions.

The INCO-MED project PRODOMEA (Project on high compatibility technologies and systems for conservation and documentation of masonry works in archaeological sites in the Mediterranean area) has been expressly set up to produce a widely accessible system of information on conservation works carried out on masonry of archaeological sites located in the Mediterranean Basin. The final aim is to support future actions by suggesting methods and technologies of intervention that are compatible at different levels.

With this purpose, Roman archaeological sites were selected in Italy, Portugal, Jordan and Syria, in order to perform sampling and analysis of bedding and plastering mortars, both original and from restoration, aiming at assessing a correct compatibility approach.

The aim of the present work is to provide results obtained at one of the target sites, Villa Domizia on Giannutri Island (Italy). The characterization of the different types of mortars identified and the evaluation of the damage affecting the materials, alongside the identification of the natural and anthropogenic sources of deterioration, are presented.

The discussion of results will be performed in the framework of the compatibility approach developed within the PRODOMEA Project.

1. Introduction

Compatibility is a broad concept which has long been considered in the conservation of cultural heritage. However, few evaluations exist on archaeological sites and in historic buildings (1, 2, 3).
In the framework of the PRODOMEA Project (Project on high compatibility technologies and systems for conservation and documentation of masonry works in archaeological sites in the Mediterranean area) the compatibility approach is a fundamental criterion for the selection of the best conservation practices for archaeological sites. The approach aims to assess the compatibility of intervention actions at different levels according to four groups of parameters: physico-chemical, environmental, operational and socio-cultural.

The present work describes the compatibility study on specific properties, included among the physico-chemical and environmental parameters, at the Villa Domizia on Giannutri Island in Italy, one of the sites selected within the PRODOMEA project. While the physico-chemical parameters represent the characteristics of the materials and include the intrinsic factors determining the effective performance of the intervention action, the environmental criteria are related to external factors that interact with the material components.

2. Case study

Situated in the Northern Tyrrhenian Sea, the Island of Giannutri is the southernmost island of the Tuscan Archipelago. On the island are present important archaeological remains of the Roman period (from 50 BC to 100 AD). The archaeological area comprises a group of connecting buildings with different functions, located between Cala Maestra (western coast) and Cala Spalmatio (eastern coast). The western coast is the location of the Residential Quarter, a group of service posts (cistern and cryptoporto), a small thermal system, and the Harbour Quarter which includes “Le Stanze” and the “Darsena” archaeological sites (Fig. 1).

The site called “Le Stanze” consists of a small ancient harbour quarter and is composed of a complex of similarly sized, interconnecting rooms, located next to a vaulted structure and a cistern. The “Darsena”, located at the landing area of the ancient harbour of Cala Maestra, is characterized by a rectangular basin, obtained from digging into the calcareous rock (Fig. 2). The cutting of the natural rock is clearly visible, with the excavated materials being used in the building of the masonry (4).

Figure 1: Location of the Harbour Quarter and Residential Quarter archaeological sites on the western coast of Giannutri Island.
The archaeological area studied constitutes a good example of traditional building practices. In fact, ancient Roman masonry was mainly built using squared blocks of volcanic rocks (tuff), named *cubilia*, arranged in *opus reticolatum* bordered by bricks forming a *testaceum belt* (Fig. 2).

This technique was widely used in Roman masonry in central and central-southern Italy between the 1st century BC and 1st century AD, at the end of the Republican Age. Vitruvius considered it to be the most representative technique of his epoch (5).

Figure 2: Detail showing the *opus reticolatum* masonry with the *testaceum belt*

3. Materials and methods

3.1. Sampling

A preliminary survey at *Villa Domizia* was essential for ensuring an efficient planning and implementation of the sampling campaign. The recognition of the most suitable masonry for sampling led to the identification of mortars and render materials of different types and functions: bedding mortar jointing tuff blocks or bricks, plastering mortar covering hydraulic structures (cisterns) or residential facing work. On the basis of information on restoration interventions previously carried out at this site (4, 6), fragments of bedding and plastering mortars from restored areas were also collected in order to evaluate their compatibility with the original materials. Figure 3 shows the sampling points in the archaeological area.

Figure 3: Plans of the Residential Quarter (a) and Harbour Quarter (b) sites showing the layout of the rooms and sampling points.
Table 1 provides a complete list of the samples, reporting the collection site, the sample number and a brief macroscopic description of each sample.

<table>
<thead>
<tr>
<th>Site</th>
<th>Sample</th>
<th>Description</th>
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<tbody>
<tr>
<td>Le Stanze</td>
<td>G1</td>
<td>Bedding mortar between tuff blocks of <em>opus reticolatum</em>.</td>
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<tr>
<td></td>
<td>G1a</td>
<td>Bedding mortar between bricks of a testaceum belt.</td>
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<td>G2</td>
<td>Tuff block of <em>opus reticolatum</em>.</td>
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<td>G3</td>
<td>Mortar used in 2000 restoration work.</td>
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<td>G4, G4a</td>
<td>Interior plaster from the vaulted structure.</td>
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<td>Darsena</td>
<td>G13</td>
<td>Bedding mortar between tuff blocks of <em>opus reticolatum</em>.</td>
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<tr>
<td>Harbour Quarter</td>
<td>G5, G5b</td>
<td>Finishing layer.</td>
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<td></td>
<td>G5a</td>
<td>Plaster applied directly on rock.</td>
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<td></td>
<td>G6</td>
<td>Sample including both plaster and finishing layer.</td>
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<td>Cistern</td>
<td>G7</td>
<td>Bedding mortar used in 1990 restoration work.</td>
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<td>G8</td>
<td>Bedding mortar between tuff blocks, from a north-facing external wall.</td>
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<td>G9</td>
<td>Same bedding mortar as in G8, from a south-facing external wall.</td>
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<td>Residential Quarter</td>
<td>G11</td>
<td>Plastering mortar applied over <em>opus reticolatum</em> facing, characterised by the presence of a fine finishing layer.</td>
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<td>Villa Domitia</td>
<td>G10-G12</td>
<td>Bedding mortar.</td>
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3.2. Analytical Methodology

Analysis of the historic mortars is an obligatory step for performing conservation and repair related investigations. In fact, the mortar type identification is a necessary prerequisite for decisions concerning the selection of replacement materials (original and new material must be compatible) and/or in determining the cause of evident problems in the deterioration of the historic masonry (2, 7, 8).

As a first step, the samples collected were characterized to identify the typology of mortar employing a specifically developed procedure (9). The presence of damage on the different mortar types was also investigated following the procedure described by Van Balen et al. (10).

For the mineralogical and petrographical characterization of the material and damage products, thin cross sections were prepared and submitted to optical microscopy observations (OM) in transmitted light, using an Olympus BX 51 microscope, equipped with scanner and MICROMAX software “Primoplus 32” vers.8.11.02 for image acquisition and elaboration. The petrographical features previously identified by OM observation were integrated by x-ray diffraction analyses (XRD), for the purpose of
identifying the aggregate and the binder crystalline phases. The instrument used is a Philips PW 1730 diffractometer equipped with a copper anticathode and nickel filter. Scanning electron microscope observations were performed to study the morphological features and qualitative elemental chemical composition of samples. The instrument used is a scanning electron microscope SEM, Philips XL 20, equipped with an energy-dispersive analyser (EDX). In addition, ion chromatography (IC) analyses, with a Dionex 4500i, were carried out to measure the soluble ion concentrations in the samples.

4. Results and discussion

4.1. Material characterization

The analyses performed allowed the identification of the following types of bedding and plastering mortars:

- Original bedding mortars. This type of mortar was recognized in the Harbour Quarter and Residential Quarter masonry. The main distinctive feature is the co-presence of volcanic rock fragments and crushed brick fragments (*cocciopesto*) as aggregate components. The volcanic rock fragments consist of brownish tuff with both an amorphous and crystalline fraction (Fig. 4a), and pumice clasts. Quartz and crystals of clear volcanic origin, e.g. clinopyroxene (augite, diopside), leucite (Fig. 4b), feldspar, biotite, and rare olivine, were also encountered. In particular, leucite and clinopyroxene constitute typical pozzolan tracers (10), and their presence is highlighted by X-ray diffraction peaks (Table 2). In addition, the carbonate fraction in the mortar was identified thanks to the peaks attributed to calcite (Table 2), whose presence is due to the carbonation of the lime employed as binder in the mortar preparation.

Figure 4: Thin sections of original bedding mortars showing lithic fragments and single crystals of the aggregate. a) tuff fragment (*tuff*), clinopyroxene (*cpx*) and biotite (*bt*) phenocrystals (cross-polarized light); b) *cocciopesto* (*cpst*) and leucite (*let*) (plane-polarized light).
- **Original plastering mortars.** Macroscopic observations revealed the presence of two types of plaster, encountered in the Harbour Quarter and Residential Quarter, respectively. The former plaster type is probably the wall covering of the ancient cistern and consists of only one layer of pozzolanic mortar characterized by a coarse texture, with millimetric red grains of *cocciopesto* and dark volcanic rock fragments. Optical microscopy observations and x-ray diffraction peaks confirm the pozzolanic nature of the aggregate (Table 2). Moreover, the presence of calcite peaks indicates that lime was used as binder in the mortar preparation. The plastering mortar collected from the masonry of the Residential Quarter is composed of two layers of mortar (Fig. 5).

![Figure 5: Optical microscope image showing the two different layers in the plastering mortar of the Villa Domizia masonry and the overlying thin damage layer. (1) coarse layer; (2) finishing layer; (3) damage layer (cross-polarized light)](image)

The layer applied directly onto the original stone or brick masonry work is characterized by a coarse texture and has the same mineralogical composition as the plastering mortar previously described. The only difference between the two types of mortar is the smaller size and amount of *cocciopesto*. The finishing layer of this mortar type exhibits completely different textural and compositional features from those of the underlying layer. In fact, OM observations and x-ray diffraction clearly reveal the presence of calcite, as the only mineralogical phase constituting the aggregate and the binder, and the total absence of pozzolan tracers. Furthermore an inhomogeneous and thin damage layer, with cryptocrystalline texture, is evidenced by OM (Fig. 5).

- **Restoration mortar of 1990.** This kind of mortar is found only in the masonry of the Residential Quarter. The difference between this mortar and the original one is clearly visible by macroscopic view, under OM observation, and in the XRD results. The mineralogical features of the aggregate are completely different from those of the previous mortar type, consisting exclusively of carbonate metamorphic rock fragments and monocrystalline and polycrystalline quartz.

Such observations are in line with available information concerning the materials used during this restoration phase, which indicates the use of mixed mortars, composed of different kinds of binder (hydraulic lime and cement), washed river sand and natural soils.

- **Restoration mortar of 2000.** Macroscopic observation already reveals that this kind of mortar is more similar to the original ones than the restoration mortar used during the 1990 intervention, as far as the aggregate is concerned. Optical microscopy observations confirm that the aggregate is similar in mineralogical composition, being composed of volcanic rock fragments, *cocciopesto* and isolated crystals of clinopyroxene, feldspar and
leucite. The only difference is in the greater abundance of quartz and the presence of calcite crystals. The matrix also presents a similar colour and texture. The x-ray diffraction peaks confirm the presence of typical pozzolan tracers, while the calcite peaks indicate that the binder used in the mortar preparation contains a percentage of lime. The technical documentation relating to the 2000 restoration works reports that the consolidation of *opus reticolatum* masonry was performed using a bedding and rendering mortar composed of hydraulic lime, cement without salts, and an aggregate consisting of tuff and brick fragments.

Table 2 reports the results obtained by XRD analyses.

Table 2: X-ray diffraction results for original bedding mortar (OB), original plaster (OP) and repair mortar (R). (Cal) calcite, (Qtz) quartz, (Pl) plagioclase, (Kfs) K-feldspar, (Let) leucite, (Anl) analcite, (Cpx) pyroxene, (M) micas, (Ox) Fe-oxides, (HI) halite.

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++++  60-80%  I/I  0  |abundant -  absent I/I  0  absent
++  20-40%  I/I  0  tr  <10%  I/I  0  traces

4.2. Damage evaluation

The analytical results reveal that most of the samples are strongly decohesionated in the part directly exposed to the atmosphere. Microscope observation identified several pores and fractures running through the matrix, generally filled by microcrystals of secondary origin. The x-ray diffraction results highlight the presence of halite peaks in most of the samples of original mortars, both bedding and plastering, and in the 1990 repair mortars (Table 2). Scanning electron microscopy observations carried out on the original bedding mortar from the north-facing external wall of the Residential Quarter (sample G8)
confirm the presence of prismatic crystals (Fig. 6a), with chlorine as the main constituent element, as highlighted by the intense peaks of the EDX analysis (Fig. 6b).

![Figure 6: (a) Scanning electron micrograph showing prismatic crystals; (b) EDX relative analysis.](image)

Ion chromatography results (Fig. 7) also reveal a high concentration of chloride (Cl\(^{-}\)) and sodium (Na\(^{+}\)) in several samples, confirming the certain presence of sodium chloride (NaCl) as salt originating mainly from sea spray deposition and crystallization on the surface of the materials. In particular, at the Residential Quarter, a higher Cl\(^{-}\) concentration was measured on the north-exposed surfaces (16320 µg/g in sample G8) compared to the south-exposed ones (541 µg/g in sample G9). A considerable amount of nitrates (NO\(_3^{-}\)), probably produced by micro-organisms from organic refuse (11), was also detected, while the sulphates (SO\(_4^{2-}\)) measured are of two orders of magnitude lower than that measured in damage layers in monuments located in urban sites (12).

![Figure 7: Graph of the soluble anion concentrations from IC analyses.](image)
5. Conclusions

The original plastering and bedding mortars investigated in the masonry of the Villa Domizia archaeological site were clearly prepared using a lime based binder, adding pozzolan and cocciopesto to confer hydraulic properties. Pure lime mortar was found only as a finishing layer in the Residential Quarter facing. Concerning the two restoration works carried out in recent years, hydraulic lime and cement were used as binder in both cases. The analyses identified volcanic rock fragments and cocciopesto as the main components of the mortar aggregate in the 2000 restoration work, while quartz and calcite composed the aggregate in the mortars employed during the 1990 restoration. It is possible to conclude that in 2000 the restoration mortars were more similar to the original ones in terms of size and mineralogical composition of the aggregate. They can therefore be considered more compatible as far as this parameter is concerned.

The combination of both direct on-site observations and analytical results suggests that the state of conservation of the masonry presents several problems at the studied site, with frequent repercussions on structural stability. In general, the south-exposed wall faces reveal a higher degree of deterioration with respect to the north-exposed faces. Furthermore, the presence of halite, as a damage component in samples collected from both north and south wall faces, indicates that salt crystallisation is one of the causes of degradation, even if it does not always correspond to a high degree of deterioration. Thus, considering that the south-exposed wall faces are the most deteriorated, in spite of lower halite concentration, other environmental factors certainly participate in the damage processes affecting the masonry. Such factors are without doubt: temperature variations due to different sun exposure rates according to time of day and season, relative humidity, rainfall exposure, the presence of water (rising damp) and wind action (mainly from south-westerly winds).

Future research is required, including field tests involving the application of different types of restoration mortars at the Residential area of Villa Domizia in Giannutri, with the purpose of defining the relevance of the different physico-chemical and environmental parameters in the compatibility assessment of repair mortars.

6. Acknowledgements

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7. References


