IV.29
Mortars for Conservation-Restoration of Wall Painting Support in Rupestral Churches

Ileana Mohanu1, Ioana Gomoiu2, Dan Mohanu2 and Daniela Nastac1

1 S.C. CEPROCIM S.A., Romania, ileana.mohanu@ceprocim.ro, daniela.nastac@ceprocim.ro
2 National Arts University, Romania, gomoiu@hotmail.com, dan_ileana_m@yahoo.com

Abstract The paper presents the laboratory research of lime base mortars for conservation-restoration of mural painting support situated in severe microclimate conditions. The repair mortars were analyzed from the point of view of chemically (soluble salts content), physically (water absorption, coefficient of saturation in water, adherence at support), mechanically (compressive strength) and resistance to the freeze-thaw phenomenon. The mortar test panels were then applied in situ inside of the Corbii de Piatra rupestral church (14th century), Arges County, Romania. Their behavior has been studied over a period of 6 months. The hardening of the mortars was observed by X-ray diffraction and loss on ignition. The adherence of the mortars to the mural painting support and their behavior in relation to the degradation factors (excessive humidity, the migration of soluble salts, biological attack) was also observed.

1 Introduction

Preliminary researches [1] of mural painting support from rupestral church Corbii de Piatră, Arges county - Romania have showed that original mortar (14th century), from the walls and nave arch and altar, is a mortar rich in lime reinforced with straw. The mortar has a porosity of about 19%, possible due to degradation of vegetal aggregate under influence of temperature, humidity and salts from walls. The mortar from iconostasis (19th century) is a mortar based on lime of which composition is of about 97% lime and about 3% fine siliceous aggregate.

In order to find a solution for monument conservation series of mortars based on lime were tested in laboratory. These were then applied in situ and their behavior was followed on the period of next 6 months.
2 Experimental

2.1 Materials

Hydrated lime (CL 80) was used as binder and different types of aggregates: finely ground limestone (content of CaCO$_3$ of 97.20%), river sand (grain size 0-1 mm), sandstone – similar with that of church walls (grinded up to a grain size of 0-1 mm) were used. Taking into account the conditions of microclimate specific to rupestral church, in some compositions pozzolanic additions were used as follows: silica fume (content of about 92% SiO$_2$), volcanic tuff (content of about 62% SiO$_2$ reactive).

Raw materials have a low content of soluble salts, expressed as SO$_3$, Cl’, Na$_2$O, respectively K$_2$O (table 1). Soluble salts were determined on chemical way, from the solution resulted as consequence of maintaining 18 hours in distilled water of 2 g of grinded mortar.

<table>
<thead>
<tr>
<th>Raw materials</th>
<th>K$_2$O</th>
<th>Na$_2$O</th>
<th>SO$_3$</th>
<th>Cl’</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrated lime</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.000</td>
</tr>
<tr>
<td>Limestone</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.017</td>
</tr>
<tr>
<td>Volcanic tuff</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.017</td>
</tr>
<tr>
<td>River sand</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.034</td>
</tr>
<tr>
<td>Sandstone</td>
<td>0.00</td>
<td>0.01</td>
<td>0.09</td>
<td>0.025</td>
</tr>
</tbody>
</table>

Mortars carried out from these raw materials were noted from C1 to C6 and are within compositional systems: C1 lime-limestone (1:1.86); C2: lime-limestone (1:2.70); C3: lime-sandstone (1:2.70); C4: lime-silica fume-sandstone (1:0.05:2.85); C5: lime-silica fume-river sand (1:0.05:2.85); C6: lime-limestone-volcanic tuff-river sand (1:0.86:0.62:2.92). The ratios are expressed as weight parts.

2.2 Experimental conditions and methods of testing in laboratory

In laboratory, evaluation of mortars characteristics was performed on prismatic specimens (40x40x160mm) prepared and kept in accordance with EN 1015-11 [2]. The water content for preparation of specimens was established according to a consistency of 140±10 mm, determined on flow table (EN 1015-3 [3]).
The mortars were characterized from point of view: physically (apparent density, water absorption; coefficient of saturation in water, adherence at support), chemically (content of soluble salts), mechanically (compression strength) and sustainability (freeze-thaw resistance).

Values of the apparent density were obtained by ratio of the weight and volume of the dry mortar samples. Water absorption was performed in accordance with the method of immersion in water from STAS 2414/91 [4]. Saturation coefficient was determined making the ratio between absorbed water at room temperature and that absorbed at boiling [5, 6]. For the adherence at support the mortar was applied on full burnt brick, in a layer with thickness of about 6 mm. Testing was performed with DYNA Z16 apparatus, at the age of 56 days. Content of soluble salts was determined as in case of raw materials. Mechanical resistance (compressive strength) was tested in accordance with SR EN 1015-11 [2] at age of 28 and 56 days. Resistance at freezing-thawing consisted of keeping the mortar prisms immersed 8 hours in distilled water, then 8 hours in air at -15 to -17°C. Determination was considered complete when specimens was recorded a weight loss of over 5% or were destroyed by cracking.

2.3 Experimental conditions and methods of testing of mortars applied in situ

The mortars were applied in situ in two areas of the monument, such as:

- on iconostasis, to north, the brick wall, area without mural painting. The mortars being noted: C1-C, C2-C, C3-C, C4-C, C5-C and C6-C;
- in altar, on northern wall, lower register, direct on sandstone wall, without mural painting. The mortars being noted: C3-Z, C4-Z, C5-Z.

Conditions of microclimate inside church, in the moment of mortars application (at the end of March), were temperature about 5°C and relative humidity of the air 70%.

Behavior of the mortars in situ was remarked from the application moment and on a period of 6 months from application. Temperature and relative humidity of the air in this period were registered minimum values of 5.8°C and 42% of RH and maximum of 21.7°C and 95%.

To evaluate the behavior of the mortars the following characteristics were taken into consideration: workability, capacity of modeling – expressing the possibility to confer to material the desired relief; mural aspect – representing chromatic tonality of mortars in relation to the original, adherence of mortar at support, phenomena of contraction – which may be manifested through detachments of support and appearance of some cracks in puttying field; reversibility – expressing material quality to be removed without difficulties and without entrain support damaging; resistance at environment factors – modifications as consequence of
humidity, temperature; resistance at bio-degradation factors – counting units forming of colonies from mortar samples; appearance of saline efflorescences.

The hardening process was evaluated soon after application and after 6 months of curing by determination of loss on ignition at different temperatures (450°C, 1000°C) and through X-ray diffraction.

3 Results and discussions

3.1 Results obtained in laboratory

Results of physical-mechanical determinations are presented in the table 2. It is noted that mortars have low apparent density which was considered as an advantage for the works of restoration because they do not add supplementary weight at original materials. The mortars C1 and C2, which have a very fine granulation and contain limestone as aggregate, present values of water absorption higher than the other mortars that have as component river sand or sandstone as aggregate. From the last ones, the mortar C6 has a higher water absorption (17.7%) in comparison with C3, C4 and C5 (15.3-15.9%) because of presence in its composition of the tuff and a lower proportion of aggregate (river sand). The mortars present a good adherence at support and the detachment takes place through breaking in mortar mass. Of all the mortars, those containing river sand and sandstone (C3…C6) have higher values of adherence. The explanation may be the larger grain size and aggregates nature, which make the composition of the mortar closer to that of the altar's wall and iconostasis.

Table 2 Physical-mechanical characteristics of mortars

<table>
<thead>
<tr>
<th>Mortar code</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent density (g/cm³)</td>
<td>1.49</td>
<td>1.53</td>
<td>1.64</td>
<td>1.70</td>
<td>1.73</td>
<td>1.70</td>
</tr>
<tr>
<td>Water absorption (wt. - %)</td>
<td>24.9</td>
<td>23.5</td>
<td>15.6</td>
<td>15.9</td>
<td>15.3</td>
<td>17.6</td>
</tr>
<tr>
<td>Water absorption by boiling (wt. - %)</td>
<td>25.5</td>
<td>24.04</td>
<td>16.92</td>
<td>16.78</td>
<td>17.33</td>
<td>18.17</td>
</tr>
<tr>
<td>Coefficient of saturation with water</td>
<td>0.97</td>
<td>0.98</td>
<td>0.92</td>
<td>0.95</td>
<td>0.88</td>
<td>0.97</td>
</tr>
<tr>
<td>Adherence at support (N/mm²)</td>
<td>0.06</td>
<td>0.06</td>
<td>0.09</td>
<td>0.07</td>
<td>0.13</td>
<td>0.11</td>
</tr>
<tr>
<td>Compression strength (MPa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28 days</td>
<td>0.7</td>
<td>1.2</td>
<td>0.9</td>
<td>2.0</td>
<td>2.2</td>
<td>2.7</td>
</tr>
<tr>
<td>56 days</td>
<td>0.5</td>
<td>1.1</td>
<td>0.9</td>
<td>2.7</td>
<td>2.6</td>
<td>3.1</td>
</tr>
<tr>
<td>Freeze-thaw resistance (nr. cycles)</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>7</td>
<td>9</td>
<td>15</td>
</tr>
</tbody>
</table>

Obtained values of mechanical strength demonstrate that all tested mortars have a low compressive strength (0.5-1.0 MPa) and moderated (max. 3.1 MPa), that make them compatible with conservation state of mural painting support of
the monument. The values of coefficient of saturation with water are between 0.88 and 0.97. In literature [5, 6] is mentioned that as much coefficient of saturation with water is closer of 1 as lower is freezing resistance of the samples. Consequently, in accordance with the data from table, all tested mortars are susceptible to not have frost resistance. Nevertheless, because of different mechanical strength at compression, mortars behavior at frost is different. Thus, for same coefficient of saturation (0.97) in case of the mortars C1 and C6, the most resistant at frost is the mortar C6 (min. 15 cycles) because has a higher mechanical strength (3.1 MPa in comparison with 0.5 MPa in case of the mortar C1). Also, from the mortars with comparable mechanical strengths (1.1 MPa for mortar C2 and 0.9 MPa for mortar C3), more resistant to freeze-thaw process is the mortar C3, because its lower coefficient of saturation (0.92 in comparison with 0.97 for mortar C2). The mortars C4 and C5 have the same behavior with mortars C2 and C3.

From chemical point of view, it may be considered that the mortars not contain soluble salts.

3.2 Results obtained in situ

From the evaluation of the mortars in fresh state it can be said that they have presented a good behavior, assuring a sufficient working time for application. Also, they have presented a good modeling capacity, and also a good adherence at support. From point of view of the mural aspect, the mortars which contain sandstone as aggregate (C3, C4) are closer as chromatic tonality of the iconostasis or altar’s wall. The mortars with limestone (C1 and C2) are closer as chromatic tonality of the lime mortar of mural painting support. Below (Fig. 1 a, b) presents the areas with applied mortars.

![Fig. 1 Mortars applied on iconostasis (a) and on sandstone wall (b)](image)

At the end of observation period, the adherence of mortars was tested through mechanical removal with scalpel, of a part from these. It was observed that there was no separation of mortars to the interface with the support, which means a
good adherence of these to substrate. Mortars are reversible, because their mechanical removal occurred easily without producing deterioration in the area on which these have been applied.

The mortars C1 and C2 which contain fine calcareous aggregate, present on their surface micro-cracks of contraction (Fig. 2a). In case of the mortars C3 to C6 which contain aggregate with 0 -1 mm granulation not presented cracks of contraction (Fig. 2b).

![Image](image_url)

**Fig. 2** Images where micro-cracks of contraction on mortar surface C1 are remarked (a) and their lack on the mortar C4 (b) applied on iconostasis

From chromatic point of view the mortars which contain sandstone as aggregate (C3 and C4) or river sand (C5 and C6) have tonalities compatible with the support. All mortars proved a good resistance at environment factors (temperature, humidity) during the observation period (summer and autumn). On mortars surface, saline efflorescences were not remarked and X-ray diffraction not put into evidence the presence of salts and degradation products, in detectable limits. Also, at the end of observation period, the lime was not completely carbonated: the XRD patterns revealed small quantities of portlandite (see cap. 3.3).

Microbiological analysis of samples taken from the surface of mortars did not put in evidence any contamination with bacteria or fungi. It could be due to inorganic material content of the mortars and presence of portlandite which makes an alkali pH which inhibits the growth of micro-biodeteriogens. We did not find photoautotrophic microorganisms or any organic deposits which could act as nutrients for heterotrophic microorganisms (bacteria and fungi).

### 3.3 Evaluation of hardening process

Hardening process of performed mortars takes place either as carbonation reaction only (mortars C1, C2, C3), or as carbonation and pozzolanic reaction between lime and pozzolanic additives –silica fume or volcanic tuff (mortars C4, C5, C6).

Following the determinations for all terms and in case of all mortars it was found diminishing loss on ignition at 450°C, simultaneously with an increasing
values of loss on ignition at 1000°C in comparison with the initial one, which means transformations of calcium hydroxide in calcium carbonate as consequence of carbonation process of the lime (Fig. 3).

![Graph showing loss on ignition at 450°C and 1000°C](image)

**Fig. 3** Loss on ignition at 450°C and 1000°C of the mortars applied on iconostasis (C1-C – C6-C) and on sandstone wall (C3-Z – C5-Z)

Through diffraction analyze same evolution of hardening process was stated, being more pronounced at the term of 6 months. In the figure 4 the diminishing of the peaks specific to portlandite and increasing of those specific to calcite at the term of 6 months in comparison with the initial term is remarked.

![X-ray diffraction patterns](image)

**Fig. 4** X-ray diffraction patterns of mortar C1-C at different terms

The X-ray diffraction analysis of the mortars with pozzolana (C4 to C6) were not put into evidence the presence of pozzolana reaction compounds in detectable limits.
4 Conclusions

Obtained mortars, tested in laboratory, have characteristics which sustain their use in the activity of conservation and restoration of historical monuments: low apparent density, low mechanical strength at compression (0.5 MPa) up to moderate (max. 3.1 MPa at 56 days), good adherence at brick support, resistance at freeze-thaw phenomena (especially mortars C4, C5, C6).

After 6 months of monitoring of behavior and esthetic aspect, under mentioned conditions of temperature and humidity, it was stated that all mortars have maintained an appropriate adherence at support, efflorescences have not appeared on mortars surfaces, are reversible and may be removed without danger to damage the area where these have been applied.

Mortars with aggregate of river sand or sandstone (C3…C6) have not presented cracks of contraction at hardening. From point of view of composition and chromatic tonality these mortars are more compatible with the masonry of the iconostasis and with the sandstone wall.

Mortars with limestone (C1 and C2) have a composition and a tonality more compatible with lime mortar of the mural painting support.

Modifications because of temperature and humidity variations have not stated. Chemical composition of mortars does not sustain biological growth respectively biodegradation.

Evaluation of the compatibility for the mortars applied with original support will be finished after a period of minimum 2 years.

5 References

2. EN 1015-11:2002 Methods of test for mortar for masonry. Determination of flexural and compressive strength of hardened mortar
3. EN 1015-3:2002 Methods of test for mortar for masonry. Determination of consistence of fresh mortar (by flow table)
4. STAS 2414:1991 Concrete. Determination of density, compactness, water absorption and porosity of hardened