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Salt Crystallization in Substitution Renders for Historical Constructions

Ana Fragata¹, Maria do Rosário Veiga¹ and Ana Luísa Velosa²

¹ Buildings Department, Laboratório Nacional de Engenharia Civil (LNEC), Portugal, afragata@lnec.pt, rveiga@lnec.pt
² Department of civil Engineering, Universidade de Aveiro, GeoBic, Portugal, avelosa@ua.pt

Abstract Salt damage is one of the major causes of render decay, not only near the sea but also in continental areas. These salts can appear in the walls from different sources: from the ground due to rising damp, carried by the wind as salt spray, flooding or originally present in materials, like unwashed beach sand or due to the salt transport behaviour of the substrate/render and the surrounding ambience severity (temperature and relative humidity) producing salt crystallization. In this paper an experimental laboratory campaign was developed where perforated red bricks rendered on both sides with four different render compositions and different permeability, were submitted to capillary absorption in a sodium chloride solution. Particular attention was given to the influence of different render solutions when contaminated with NaCl and attention was given to the several dissolution-crystallisation cycles: (a) in the location of sodium chloride crystallization in the specimens; (b) crystallization quantification of different specimens. The final goal is to understand the relation between the more or less permeable renders and the damage mechanisms of NaCl dissolution-crystallization cycles, in order to propose possible solutions to stop or slow down the salt decay process in walls contaminated subjected to changes in ambient temperature and relative humidity and contaminated with salt.

1 Introduction

In Portugal, rehabilitation and conservation interventions are assumed of increasing relevance. Renders are used as decorative and protective coats, acting as sacrificial layers that are particularly exposed to climatic actions and mechanical and environmental impact, becoming the most vulnerable constituents of historical buildings. In such buildings conservation renders that are
incompatible with the background and the pre-existing materials, and are inappropriate for the existing conditions, are often adopted, producing new pathologies [1-3].

Rising damp, amongst the sources of moisture present in old masonry, is the most dangerous. Systems based on physical cuts or on the injection of chemical products to prevent moisture in a structure, are often ineffective due to the heterogeneity of the masonry [4]. The high moisture content introduced in the masonry combined with its salt content, can promote the crystallization of such salts [5].

Salt crystallization, is considered one of the major causes of render decay. The extension of this phenomenon is dependent on the salt transport behaviour of the substrate/render as well as on the surrounding temperature and relative humidity. Unfavourable surrounding conditions may cause repeated cycles of dissolution/crystallization, leading to the rapid damage of building materials [6].

Salt damage may occur at the surface or within the render layer. In the first case salt accumulates on the surface as a result of salt moisture transport from inside the wall (rising damp, etc.) or from outside (salt-spray, etc.) and consequent dissolution/crystallization cycles may lead to superficial damage. Salt accumulation inside the render (crypto-florescence) usually causes more serious damage, and may be due to a drying front within the render, changes in porosity due to the co-existence of different materials and the use of water repellents, etc. [7].

In materials contaminated with hygroscopic salts, changes in temperature and relative humidity (RH) may produce dissolution/crystallization cycles of the salt which enhance the damage. In the specific case of sodium chloride (NaCl), cycles of temperature are not harmful, since the solubility of this salt does not significantly vary with temperature; however, a change in RH may lead to dissolution/crystallization cycles which can therefore cause increased damage. Salt damage is rarely a result of a single crystallization event, but rather the consequence of repeated crystallization cycles creating gradients in the salt and in the stress distribution which gradually weaken the material [5].

Recently crystallization damage mechanisms in mortars and plasters have been studied by several authors [4, 7, 8], however a deeper knowledge concerning the influence of the whole system (brick masonry + render) is often lacking.

In this study the entire system (brick + render) is taken into consideration and tested in the laboratory. For this experimental research has been developed to study the location and type of sodium chloride crystallization in rendered brick masonry when submitted to dissolution/crystallization cycles.
Experimental Work

Experiments were conducted in the laboratory. The samples, specially designed for the purpose of the work were composed of red perforated bricks (300×195×40mm) with a 1.5cm render on either both sides or one side (in the case of L and CRes specimens), to simulate internal plaster and external render on brick masonry. The samples were submitted to the same conditioning (temperature and relative humidity) and to a similar salt concentration solution.

2.1 Sample preparation

Four different renders were used: L and LMet - permeable lime based mortars; C and CRes - very hydraulic almost non-permeable mortars. The renders’ compositions are described in Table 1. All mortars were prepared according to standard procedures – EN1015-2.

Table 1 Mortars formulation

<table>
<thead>
<tr>
<th>Render</th>
<th>Formulation</th>
<th>Volumetric formulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>Slaked lime putty and Tagus River sand</td>
<td>1:3</td>
</tr>
<tr>
<td>LMet</td>
<td>Slaked lime putty, metakaolin and Tagus river sand</td>
<td>1:0.2:3.5</td>
</tr>
<tr>
<td>C</td>
<td>Cement and Tagus river sand</td>
<td>1:4</td>
</tr>
<tr>
<td>CRes</td>
<td>Ready-to-use cement mortar with acrylic addition</td>
<td>Ready-to-use</td>
</tr>
</tbody>
</table>

The samples were carefully executed to reduce workmanship problems (fig.1). They were cured in a conditioned environment at 20°C and 65% relative humidity (RH) and were wetted twice a day during the first 7 days, with the exception of specimens of pure lime putty, which were cured in dry conditions (23°C and 50% RH). Table 2 describes the sample compositions and curing conditions.

After curing, the samples were partially immersed in NaCl solution (fig. 2).
Table 2 Sample preparation and curing

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Side A</th>
<th>Curing conditions</th>
<th>Side B</th>
<th>Curing conditions</th>
<th>Curing time</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>L</td>
<td>23ºC/ 50% RH</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>L-L</td>
<td>L</td>
<td>-</td>
<td>L</td>
<td>23ºC/ 50% RH</td>
<td>4 months</td>
</tr>
<tr>
<td>L-LMet</td>
<td>L</td>
<td>20ºC/ 65% RH</td>
<td>L-Met</td>
<td>20ºC/ 65% RH</td>
<td>+</td>
</tr>
<tr>
<td>L-C</td>
<td>L</td>
<td>-</td>
<td>C</td>
<td>Wetted with water twice a day during the first 7 days</td>
<td></td>
</tr>
<tr>
<td>L-CRes</td>
<td>L</td>
<td>-</td>
<td>CRes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LMet-LMet</td>
<td>LMet</td>
<td>20ºC/ 65% RH</td>
<td>LMet</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LMet-C</td>
<td>LMet</td>
<td>-</td>
<td>C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LMet-CRes</td>
<td>LMet</td>
<td>Pulverized with water twice a day during the first 7 days</td>
<td>CRes</td>
<td>-</td>
<td>1 month</td>
</tr>
<tr>
<td>C-CRes</td>
<td>C</td>
<td>-</td>
<td>CRes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CRes-CRes</td>
<td>CRes</td>
<td>-</td>
<td>CRes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CRes</td>
<td>CRes</td>
<td>-</td>
<td>CRes</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

2.2 Dissolution/Crystallization Cycles

After curing, four dissolution/crystallization cycles were carried out over a total period of 4 months. The samples were partially immersed in NaCl solution (27g/L – similar to sea content) to allow capillary rise through them, reproducing in the laboratory the conditions seen in rising damp. After each wetting cycle the samples were dried at 40ºC in a ventilated oven. The samples were not brushed between cycles.

The salt crystallization was evaluated by visual monitoring and by weighing the specimens daily. The wetting and drying phases in each cycle were prolonged until a constant mass was reached.
3 Results and Discussion

3.1 Salt Crystallization – visual observation of efflorescence

Visual observations of sodium chloride crystallization were made at the end of the 4th dissolution/crystallization cycle (Table 3). These observations allowed the determination of crystallization patterns due to the different render compositions, which simulated internal plaster and external render in the same testing conditions. At this point almost no material loss was found.

Some differences were observed in the crystallization between the different samples at the end of the 4th dissolution/crystallization cycle:

- On C, L, L-C, L-Met, L-Met-C, LMet-C, Cres-CRes and CRes, where at least one render coat was based on cement, the salts formed a dense crust on the top of the brick, although variations between the samples did occur. On CRes render’s surface almost no salt crystallization can be seen, while on C, L and LMet render’s surface there was some salt accumulation. On samples with CRes render on one or both sides higher crystallization on the top of the brick and/or on the surface of the more permeable renders of the same specimen (C, L and LMet) was observed, probably because the transport through the CRes render is reduced.

- On L, L-L, L-Met, L-C, L-Met-LMet and LMet-C, salts appear as “hair crystals” on the top of the brick, but some differences can be observed. On the surface of the renders, salt crystallization appears as generalized “hair crystals” although for L, L-L, L-Met-LMet these crystals were less generalized. On the surface of L-LMet, L-C and LMet-C samples, the salts appear as generalized “hair crystals” on the upper part of the render, appearing higher than those with the same render formulation on both sides, as L, L-L or LMet-LMet.

Table 3 presents a synthesis of the observations of salt crystallization. Table 3 shows that the renders with a high and/or medium permeability, L-L, L-Met-LMet, L-C and LMet-C, are subject to concentrated crystallization, preventing damage to the brick. These renders should therefore be more favourable in protecting old masonry from salt damage where rising damp is prevalent.

3.2 Salt Crystallization – quantification during the 4 cycles

The quantification of crystallization (%) in each specimen is presented in Figure 3. This quantification is obtained by calculating the weight difference of each specimen by subtracting the weight before the beginning of the crystallization/dissolution test cycles from that at the end of each cycle. The crystallization at the end of each cycle is the crystallization in the referred cycle.
added to the crystallization of the previous cycles. Until the end of 4th cycle almost no material loss was found.

**Table 3** Visual evaluation of surface crystallization (4th cycle)

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Specimen crystallization</th>
<th>Crystallization evaluation</th>
<th>Mortar</th>
<th>Brick</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td></td>
<td>++(L)</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>L-L</td>
<td></td>
<td>++++(L)</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>L-LMet</td>
<td></td>
<td>++++(L)</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>L-C</td>
<td></td>
<td>++++(L)</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>L-CRes</td>
<td></td>
<td>++++(L)</td>
<td>+++</td>
<td></td>
</tr>
<tr>
<td>LMet-LMet</td>
<td></td>
<td>++++(LMet)</td>
<td>++</td>
<td></td>
</tr>
<tr>
<td>LMet-C</td>
<td></td>
<td>++++(LMet)</td>
<td>++</td>
<td></td>
</tr>
</tbody>
</table>
Some differences were observed in the crystallization % between the different specimens:

- An increase in crystallization amount after each cycle was found for all samples. This increase is higher for cement based renders in all cycles. The highest difference in crystallization is found from the 2nd to 3rd cycles in all samples.
- Samples with lime based renders on both sides (L-L, LMet-LMet) showed less crystallization in each cycle, than samples with cement based renders on both sides (C-C, CRes-CRes).
L-L and LMet-LMet showed a small difference between them at the end of 4th cycle; for the cement based samples C-C and CRes-CRes, a higher difference between them was found.

At the end of 4th cycle, sample L had the lowest crystallization amount. The highest crystallization amount corresponds to CRes-CRes and C-CRes.

Among samples with at least one render based on lime, the highest crystallizations at the end of 4th cycle were found on L-CRes and LMet-CRes.

LMet-LMet and LMet-C showed a lower weight gain (even a small weight loss), which is being interpreted as lower crystallization in 4th cycle compared when compared to the 3rd cycle. However, this weight loss may be due to some material loss.

![Crystallization (g/kg) of samples](image)

**Fig. 3** Crystallization (g/kg) of samples

### 4 Conclusions

The present experimental work demonstrates that accelerated dissolution/crystallization cycles with sodium chloride, favour the accumulation of NaCl salt efflorescence on the render and/or on the top of the brick with different samples showing different crystallization accumulation patterns.

The study of crystallization and damage localization and evolution is crucial for their understanding in brick masonry.

The main conclusions that can be drawn from this experimental work are:

- The samples specially designed for this experimental work were able to simulate brick masonry with internal plaster and external render.
With the adopted testing methodology, the main differences in crystallization, considering a whole system (brick masonry + render more or less permeable), could be understood.

The visual evaluation of specimens’ surface crystallization (Table 3) and the quantification of crystallization gave consistent results.

Relevant differences can be found in final salt distributions between samples with cement based render (less permeable) and only with lime based (permeable) render. For the latter, there is a similar distribution of salts on the surface of renders and on top of the brick; for less permeable specimens there is a higher salt concentration on the top of the brick when compared to render’s surface.

The samples with a high heterogeneity between the internal plaster and external render show the highest damage, namely those rendered on one single side, and those with a lime render (L or LMet) on one side and CRes on the other.

The low permeability render CRes showed the highest crystallization on the brick, especially on CRes-CRes samples. Apparently CRes render acts as a barrier, restricting the evaporation of the water through the render, allowing a higher crystallization on the top of the brick, where the evaporation occurs. This behaviour indicates a tendency of cement renders of low permeability to favour crystallization in the masonry, increasing damage inside the wall.

The samples with high and/or medium permeability renders L-L, LMet-LMet, L-C and LMet-C, concentrate crystallization on the render, preventing high damage in the brick. These results point to the conclusion that these referred types of systems are to be preferred in the conservation of old walls, considering that the objective is to increase the durability of the masonry, to the detriment of the render if necessary.

Based on these main conclusions, investigations must be carried out using scanning electron microscopy (SEM) to better understand the deposition of the salts in greater detail and the influence of render formulations on salt crystallization and possible decay.

It is also important to study the porous structure of the bricks and of the mortars applied, and to compare them, in order to establish a link to the degree and localization of salt damage.

5 Acknowledgements

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6 References


