Laboratory and on-site assessment of durability assessment of natural hydraulic lime plasters with encapsulated crystallization inhibitor

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1. Introduction

Plasters and renders in historic buildings are often damaged by salt crystallization, because of their relatively low mechanical strength and their location at the surface of the wall, where evaporation and salt accumulation take place. Current solutions to provide plasters and renders with a better resistance with respect to salt decay are mostly based on the use of stronger binders, such as cement, or of water repellent additives. Unfortunately, both these solutions show often a low compatibility with the materials used in historic buildings.

In the past decade, research has been carried to improve the durability of plasters against salt damage by the use of crystallization inhibitors (e.g.[1-2]) Crystallization inhibitors are ions or molecules able to delay crystal nucleation and growth of the crystal by preferentially adsorbing on specific crystal faces. Sodium ferrocyanide (NaFeC) is a well-known inhibitor of sodium chloride. Past research has shown that NaFeC, is able to provide hydrated lime-based mortars with an improved resistance to salt decay[3]. However, leaching of this water-soluble inhibitor may compromise its effect in time. Recently, encapsulation of NaFeC in chitosan-calcium alginate capsules was proven effective to control the release of the inhibitor in mortar[4]. In this paper, the durability of a natural hydraulic lime plaster with encapsulated NaFeC crystallization inhibitor is discussed based on the results of laboratory accelerated salt weathering test and monitoring of test panels applied on site.

2. Assessment of durability in laboratory

For the preparation of the plasters natural hydraulic lime (NHL) by St Astier) with quartz sand in 1:3 volume proportion were used in the preparation of the plasters. Plaster specimens with NaFeC inhibitor directly mixed in the mass (NHL-F) and with chitosan-calcium alginate capsules containing the NaFeC inhibitor (NHL-CsCA-F) were prepared; as reference, plasters without inhibitor (NHL-R) were also prepared. The inhibitor and the capsules containing the inhibitor were added during mortar preparation, in such a way to obtain 1 % NaFeC content (as % of the binder weight). For details on capsules production and inhibitor content, please see. The fresh and hardened properties of the plasters are summarized in Table 1 (see 4 for more details).

For the assessment of the durability of the plasters to salt crystallization, cylindrical specimens (5 cm diameter) were prepared; these were composed of a 3 cm thick stone substrate and a 2 cm plaster layer which was applied on top of the substrate. Maastricht limestone, with a porosity of 50% v/v and a mean pore size of 30 µm[5] was used as the substrate.

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1 Granneman et al. 2019.
2 Lubelli et al. 2010.
3 Granneman et al. 2019.
4 Kamat 2024.
5 Nunes et al. 2021.

Property	NHL-R	NHL-F	NHL-CsCA-F
Workability (mm)	165.67 ± 0.9	172.33 ± 3.1	164 ± 1.4
Compressive strength (MPa)	0.42 ± 0.08	0.39 ± 0.07	0.62 ± 0.8
Porosity (vol %)	21.83 ± 0.36	22.35 ± 0.27	22.37 ± 0.6
Bulk density (g ml^{-1})	2.03 ± 0.01	2 ± 0	1.99 ± 0.02
Water abs coefficient (g m^{-2} $s^{-0.5}$)	159	147	156

Table 1. Properties of plasters without inhibitor (NHL-R), with inhibitor mixed in the mass (NHL-F), and with encapsulated inhibitor (NHL-CsCA-F)

The procedure used for the assessment of the durability to salt decay is based on the RILEM 271-ASC recommendations[6], and was carried out in two subsequent stages: 1. Accumulation stage, in which 10 % NaCl solution was introduced in the specimens in an amount equal to the capillary moisture content of the stone substrate, followed by drying of the specimens at at 40°C/15% RH until 80% of the water had evaporated. 2. Damage propagation stage, during which specimens were subjected to repeated crystallization/dissolution cycles of the salt in the specimens, induced by temperature and RH changes. Damage was photographically assessed during the test; at the end of the propagation phase, the specimens were brushed and the damage quantified in terms of material and salt loss and efflorescence. The amount of NaFeC leached out was calculated based on the measurement of the concentration of Fe(II/III) ions assessed by Inductively coupled plasma-optical emission spectroscopy (ICP-OES) (see 4 for details). The results of the accelerated weathering test clearly show that the inhibitor, either directly mixed in or in the encapsulated form, clearly reduces the amount of material loss with respect to the refence mortar (Figure 1). Besides, the amount of inhibitor leaching out of the specimens is 30% lower for NHL-CsCA-F mortar than for NHL-F mortar. A slightly higher amount of salt efflorescence is observed in plasters containing the inhibitor (see for details).

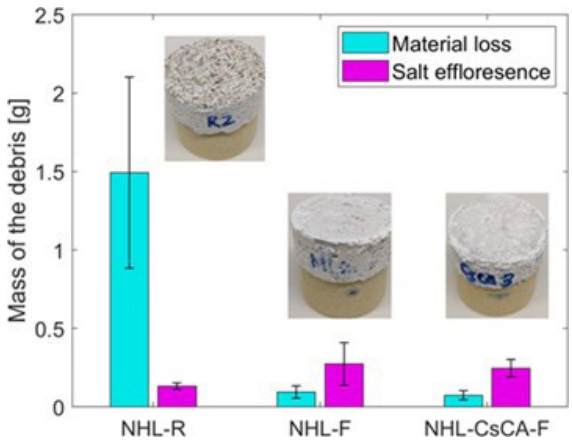

Figure 1. Material loss and salt efflorescence brushed from the surface of the specimens at the end of the propagation stage

3. Assessment of durability on test panels on site

The durability of the NHL plaster with encapsulated inhibitor (NHL-CsCA-F) was assessed on test panels applied on a building (St. Nicolaas church in Brouwershaven, NL) affected by high salt (NaCl) and moisture load from rising damp. In this case, because of the time consuming work needed for the preparation of the capsules, capsules were added only to the inner layer of the plaster (1 cm thick); in the outer layer (1 cm thick) no inhibitor was used. Another panel with NHL mortar without inhibitor (NHL-R) was used as reference.

The assessment of the damage was carried out visually and by assessing the moisture content in the plaster and the masonry after after about 1.5 years from the application. After 1.5 years no visible damage is visible to both the plasters, despite a high salt and moisture load; therefore, more time is needed to draw definitive conclusion on this onsite test. However, it is interesting to notice that no blue discoloration (due to formation of Prussian blue), an earlier observed problem in plasters with mixed-in NaFeC, is visible in the panel with encapsulated inhibitor. This suggests that encapsulation of the inhibitor can not

6 Lubelli et al. 2023.

only reduce leaching of NaFeC[7] while still providing an improved durability to salt decay, but possibly also reduce or avoid the negative side-effect of blue discoloration. Further research on a longer time span is on-going to further validate these conclusions.

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