Salt extractions of brickwork: a standard procedure?

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Abstract

Crystallization of salts is recognized as a major factor in the degradation of porous materials in built heritage. Salt damage occurs in the presence of salts and moisture, in liquid or vapour form. This implies that, in case one of both can be excluded, salt damage can be mitigated. A salt extraction aims to reduce a maximum amount of salts present. In practice salt extractions are often executed without scientific background or control of its effect or durability.This paper deals with the results of salt extractions using a poultice consisting of a mixture of kaolin, sand and cellulose fibers applied on salt contaminated brickwork of two cases, the abandoned coal mine site named C-mine in Winterslag and two chapels of the Cathedral of Our Lady in Antwerp. Results have shown that several factors influence the salt extraction effect: the amount and distribution of salts, the pre-wetting properties, the physical properties of the building materials as well as the environmental conditions of the salt extraction execution. From the experimentally determined salt contamination and distribution as well as the properties of the poultice and the building materials of the masonry, the salt extraction execution parameters and its effect were first approached theoretically through modelling. The predicted effect was compared to the one experimentally determined. Concerning the last, powder drill samples were lifted from brick and mortar, before and after each salt extraction from which the ion content was determined quantitatively. From the results it was concluded that the optimum conditions for the execution of a salt extraction cannot be considered as a standard copy-paste application suitable for all types of salt contaminated brickwork. A critical note is to be tackled with respect to the term “salt extraction” as the reality shows that an important part of the salts migrate deeper into the brickwork.

Keywords: brickwork, salt extraction, poultice

1 Introduction

The crystallization of salts is a major cause of damage on historic built heritage and stone sculptures. Compared to new buildings, historic ones suffer more severely from salt damage due to their higher salt contamination accumulated over time. Mitigating of salt damage contributes to a sustainable preservation of our precious historical and architectural heritage. The occurrence of salt damage implies the presence of salts and moisture, in liquid or vapor form. Moisture can be regarded as the main catalyst for salt damage; without moisture transport processes and dissolution-crystallization cycles of the salts there would be no salt damage of porous material [1].

While the removal of salts from movable stone objects by means of the water bath method is quite well known [2], salt extraction of masonry by means of salt extraction poultices is often applied ‘ad hoc’, in most cases without control of the effect deeper in the masonry [3, 4] or a long term monitoring.

In the framework of a European project “Desalination” (FP6, project number SSPI 22714) a so-called modular system for poultices was developed [5, 6], by which the pore structure of the poultice was tailored towards that of the support to be extracted. Promising results were obtained with salt extraction products based on a mixture of kaolin, sand (0.5 – 1 mm grain size) and cellulose fibers (200 µm) in a weight ratio of 2-1-1 and a water weight content of 0.8 related to the total solid material.

This paper goes deeper into the salt extraction technique using such a poultice and focuses on the influence of some of the experimental parameters on the salt extraction effect on brickwork of two test cases, the abandoned coal mine complex in Winterslag, named C-mine, and two chapels of the Cathedral of Our Lady in Antwerp.

2 Methodology

For both cases drilled samples are lifted on numerous locations from the mortar and the brick at different heights and at least two different depths (0-2 and 2-5 cm). From each lifted powder sample the ambient moisture content is determined by comparing the initial weight to the weight reached after drying at 60°C. The hygroscopic moisture content is determined by conditioning the dried sample at 95% RH until constant weight. The hygroscopic moisture content is calculated from the increase in weight.

Demineralized water is added to the samples. The solution is left to mix for 4 hours to dissolve all ions present followed by a filtration. From the extract, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) cations and chlorine (Cl^-), nitrate (NO_3^-) and sulphate (SO_4^{2-}) anions are quantitatively determined with Ion Chromatography (IC, Metrohm). The quantitative ion data, expressed as mole-fractions, are entered into the ECOS/RUNSALT thermodynamic model (Environmental Control Of Salts) that determines the crystallization behaviour of the salt mixture at changing climatic conditions [7, 8]. After evaluation of the salt content in the walls, a zone characterized by a high salt content is selected for the extraction test. Experimental conditions of salt extractions were designed by simulations using the porous media transport model DELPHIN 5.5 [9].

3 Results and discussion

The *Kempen*, the eastern part of Belgium, was during the 20th century known for its coal mine activities. One of the seven coal mines was located at Winterslag (Figure 1), active from 1917 till 1988. After a period of neglect, the entire mine site became the subject of stepwise rehabilitation projects. The C-mines, where the “C” stands for “creativity”, comprise a unique industrial heritage and a witness of historical industrial activities typical for the region.

Figure 1: Coal mine site in Winterslag (wikipedia)

A section of the old C-mine buildings was transformed into workshops and exhibition rooms for a local artist designing ceramics. Salt analyses on mortar and brick samples revealed a high salt content, principally composed of sodium chloride at contents up to 7.5 w% in the mortar while at least 1 w% in the brick, crystallizing around 75% RH (ECOS/RUNSALT output, not shown here) and causing damage to the finishing layers as shown in Figure 2.

Climate control of the rooms in the large complex was for financial reasons not considered, nor technically possible due to the activities of the artists’ team working with mortars for the preparation of ceramics;

therefore, it was advised to carry out salt extractions to decrease the salt content in the walls. The paint layer was carefully removed followed by a pre-humidification (2 l/m^{-2}) prior to the application of a poultice for the salt extraction. The poultice, with a composition as described earlier, was applied on 1m² four times, such that a new application immediately followed the previous one, again after pre-humidification (2l.m^{-2}). The poultice was easily mixed and applied to the wall; it dried equally starting at the borders curling off the substrate. No shrinkage cracks were noticed. During all four application it took approximately ten days before it partly sagged down. Because it still adhered to the wall it was then removed mechanically. After each application, drill powder samples were lifted from the brick and the mortar at a depth of 0-2 and 2-5 cm from which the salt content was quantitatively determined [10]. The results of the total ion content before and after 4 salt extractions are shown in Figure 3.

Initially, the brick contains a lower salt content compared to the mortar. The results show that after one poultice application the salt content in the brick is reduced to an acceptable value and even more so after two applications. This is not the case for the mortar for which at least three applications seem necessary. An inconsistency was noticed within the depth of the mortar as the salt content increased after the fourth application at a depth between 2-5 cm. This could indicate that the dissolved ions are being pushed deeper into the wall rather than being extracted. In the following case study the sample depth was increased to understand this phenomenon.

Figure 2: interior wall with salt damage due to the presence of up to 7.5 w% sodium chloride in the mortar and at least 1 w% in the brick

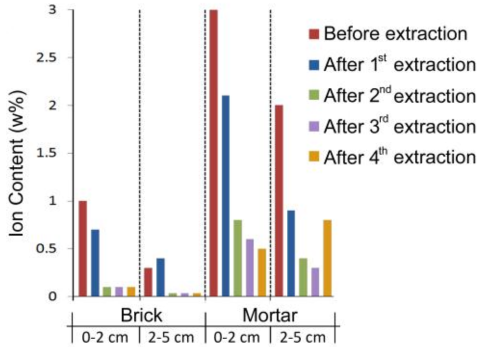

Figure 3: results of the total ion content before and after 4 salt extractions of brick and mortar samples, 0-2 and 2-5 cm.

The 19th century mural paintings of the St.-Vincentius- and St.-Jozeph Chapel of the Antwerp Our Lady Cathedral showed salt efflorescence and severe damage. Figure 4 illustrates an example of the typical damage. The restoration vision includes the preservation and restoration of the mural paintings and underlying plaster layer, if advised from a material-technical point of view. To scientifically approach this vision, the salt contamination of the plaster and underlying brick masonry was mapped out according to the damage patterns (discoloration, staining and/or loss of the paint layer and lack of adhesion and powdering of the plaster). Similar to the previous case study, samples were lifted from the plaster and underlying brickwork to a depth of 5 cm from which the salt content was determined.

As an example Figure 5 illustrates the results of the salt content in plaster, brick and mortar at several heights and depths. Excluding gypsum the salt contamination consisted of mainly sodium chloride and nitrates.

Figure 4: typical damage pattern of a 19th century mural painting in the St-Vincentius Chapel.

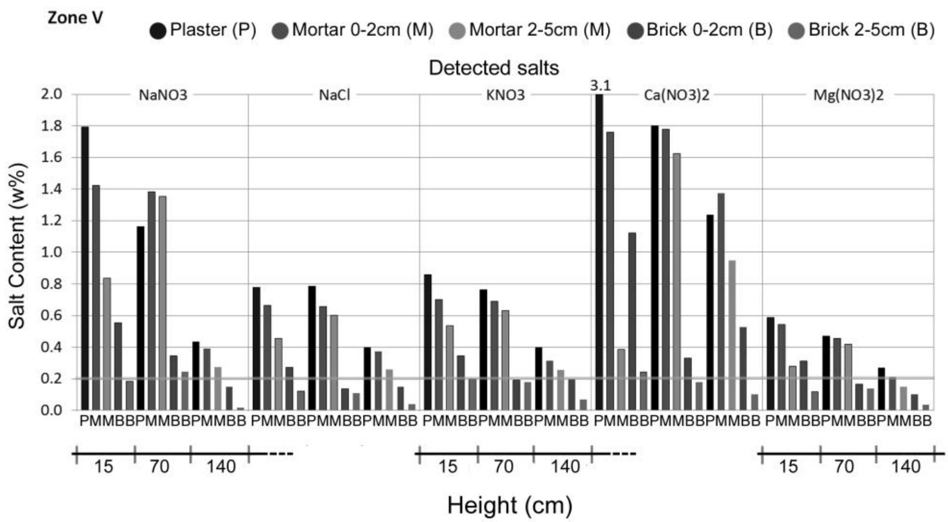

Figure 5: zone V, content of sodium chloride and nitrates of plaster and underlying brick and mortar at two depths and several heights.

As the salt content decreases with depth, the testing of the effect of a salt extraction by means of a poultice was considered. At selected test locations additional samples were lifted to a depth of 10 cm and the finishing layers were removed. For the salt extraction, the same type of poultice as used on the test zone at C-mine was applied.

Prior to the experimental poultice application, the execution parameters were approached theoretically through modelling (Delphin 5.5). To do so the material parameters of brick, mortar and poultice were determined, as described in [11]. From the salt extraction simulation results, it was predicted that:

1. Pre-wetting (2 l/m^{-2}) has a positive effect on the salt extraction in terms of time and efficiency;
2. A salt extraction is more effective on brick (46% extracted) compared to mortar (1 to 8%);
3. A humid environment (95% instead of 50% RH) drastically slows down the extraction process (application times of 20 days instead of 6) mainly due to a reduced drying rate of the poultice.

Following the results of the simulated extraction process, a poultice was applied three times on two different zones of about 2 m height and 1 m length of a brick wall. The effect of the salt extraction was controlled by moisture and salt content measurements. Figures 6 and 7 illustrate the results expressed as total average salt content for respectively brick and mortar before and after the third application.

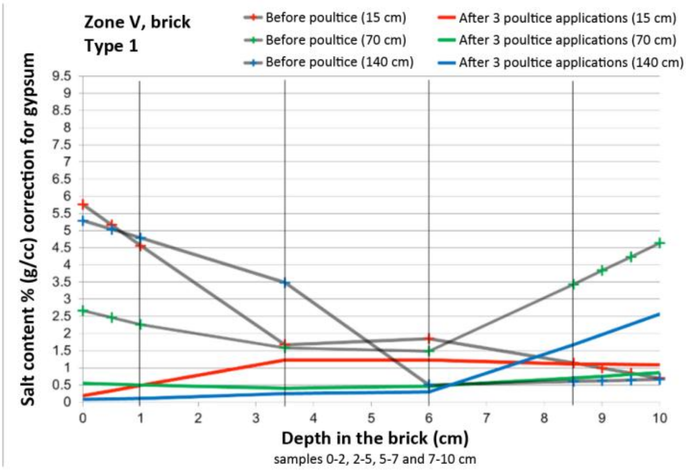

Figure 6: average salt content (%, g/cc) before and after the third salt extraction of brick samples lifted at different heights and to a depth of 10 cm.

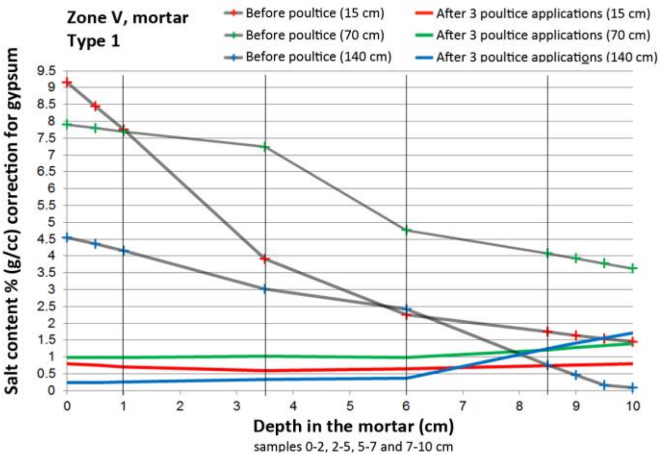

Figure 7: average salt content (%, g/cc) before and after the third salt extraction of mortar samples lifted at different heights and to a depth of 10 cm.

The experimental results were compared to the ones theoretically determined by modelling (Dephin 5.5) (Figure 8) from which a good agreement was concluded.

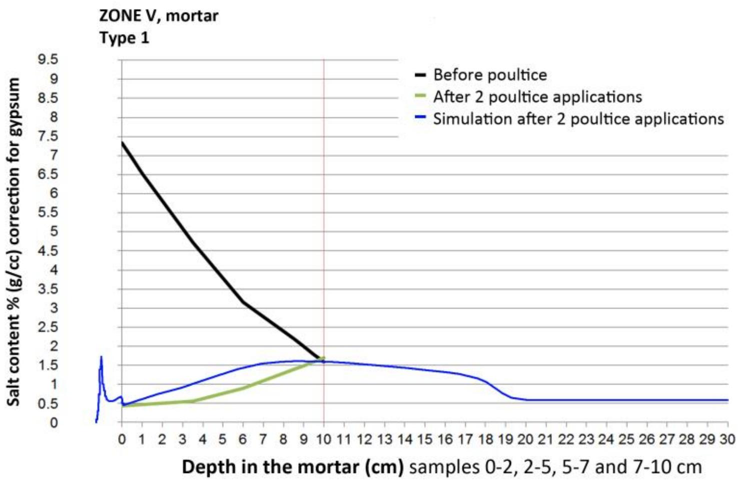

Figure 8: experimental average salt content (%, g/cc), before and after the second salt extraction of the mortar and related to the theoretical one.

Both experimental and simulated results show that the salt content was significantly reduced, especially in the first 5 cm. However, especially at a height of 140 cm, an increase of the salt content was noticed starting at a depth of about 6 cm, indicative for a salt migration deeper into the masonry. In terms of durability of the restoration strategy, the extent of their migration back to the surface is a crucial point.

Hence, in order to address the influence of the application of a 1 cm thick lime plaster layer on the long-term salt distribution of brickwork, and hence the risk assessment of salt damage to the future plaster and paint layer, further simulations were carried out. For example, Figure 9 illustrates the simulated total salt content for mortar of brickwork, without a plaster layer, after 1 year, while in Figure 10 that for brickwork including a plaster layer over a longer time span (3 years).

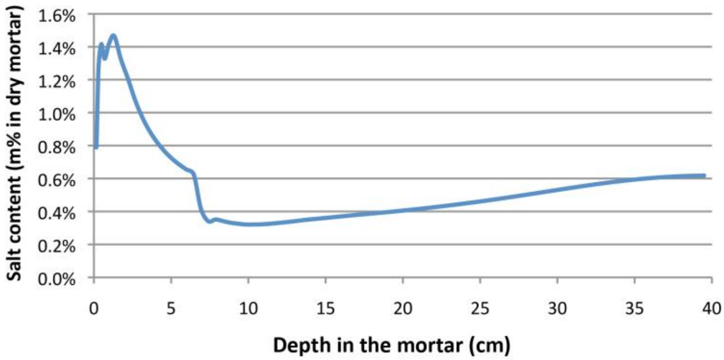

Figure 9: simulated total dissolved salt content (m%) in the mortar for a brick masonry after 1 year.

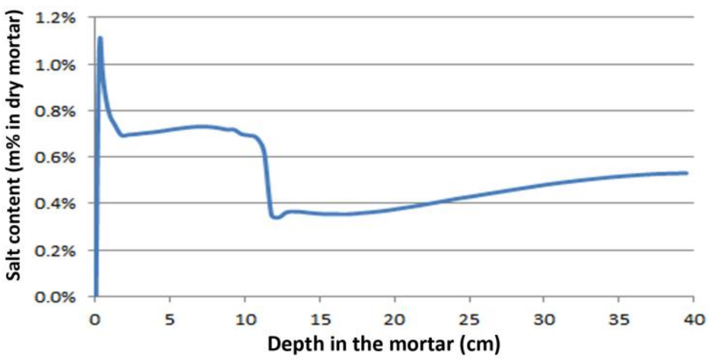

Figure 10: simulated total dissolved salt content (m%) in the mortar for a brick masonry containing a 1 cm thick plaster layer after 3 years.

The simulated results revealed that, without plaster, the water introduced during the pre-wetting of the three salt extractions, dries out very slowly; after one year the outer 5 cm of the mortar is quite dry, while the underlying part is still quite wet (not shown here). In this surface layer, the salt content increases to 1.1 w% on average. Applying a plaster of 1 cm thickness results in a further decrease of the drying, and hence of the amount of salts migrating back to the surface; in this case the outmost 5 cm contains on average 0.8 w% of salts after 3 years. Taken into account that initially, before salt extraction, the average salt content of this surface layer was maximum 4.9 w%, this corresponds to a long-term decrease of at least 80 %. Moreover, it is supposed that the paint layer as such will further reduce the drying process and hence the migration of salts to the surface.

4 Conclusions

From the experimental results of test salt extractions it can be concluded that after three applications of aforementioned poultice materials, the salt content in the first centimetres of the wall is reduced to an acceptable amount of 0.5 w% on average, while the content increases in the depth. These experimental results were also identified by means of computer simulations. As a major part of the salts is pushed inwards, the application of the term “salt extraction” by means of this technique is questioned.

The phenomenon of migration of salts deeper in walls seems to be inevitable. According to the simulations, salts migrate back to the near surface of an non-plastered wall till a content of 1.1 w% after 1 year, while on a plastered wall this may take several years. This amount corresponds to about 20 % of the initial total salt content. As such, the risk of salt damage to the future murals was considered rather low.

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