Desalination using clay and lime sacrificial plasters with additives on field stone wall and fired clay bricks

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Abstract. Salt deteriorations can ruin the appearance as well as the structure of buildings. Salt deteriorations can be mitigated by passive and active methods. Common active methods include sprinkling water on the structure, scraping off the concentrated salts from the surface and the use of sacrificial plasters. Sacrificial plasters are traditionally used for desalination. Two tests at different sites were performed in order to determine the effectiveness of desalination of different sacrificial plasters. The first test site was a two hundred years old stable wall in Mooste county, Estonia. Salt percentage by mass in the test wall was determined in 2017 and again in 2019. In December 2019 different plasters of local natural clay and lime with additives such as hemp flax, charcoal and turf were tested on the wall. The second test was performed on burnt clay bricks that were placed into salt solution until efflorescence appeared. For desalination process again, different clay and lime based sacrificial plasters were used. After removing the sacrificial plaster, samples from the mortar and bricks were taken to measure the salt content by using Ion chromatography. Clay and hemp flax based sacrificial plasters were the most suitable for desalination and removal.

Keywords: local natural materials, sacrificial plaster, desalination

1. Introduction

Fired clay bricks have been used as construction material in many historical buildings. It dates back 5000 years to Babylonia where there was a shortage of timber and stone but there was enough clay available in the riverbed. In the Middle Ages the use of field stone as building material gained popularity in Europe. Fired clay bricks manufacturing was introduced in Estonia by crusaders in 13th century [1]. Fired clay bricks masonry is prone to decay that is caused by excessive moisture combined with salts and temperature fluctuations [2]. In field stone walls dissolved salts affect mortar. High temperature causes biological degradation and mould [2]. When exposed to freezing temperatures fully saturated materials are sensitive to freeze-thaw cycles [3]. Moisture can access masonry and walls through capillary intake, condensation, soil water or rainfall [3]. With moisture movement dissolved salts may be transported [3], [4].

Masonry and walls can absorb salts from clay, contaminated air and soil. Main salt compounds damaging masonry are sulphates (SO₄²⁻), nitrates (NO₃⁻), nitrites (NO₂⁻), carbonites (CO₃²⁻) and chlorides (Cl⁻) [5], [6]. Main deterioration to structures comes from sulphates - up to 80% of the cases [7]. Chlorides are typical to coastal areas and can be found in road salts [7]. Nitrates can be mainly found...
in agricultural buildings due to animal excrements. In urban areas bird excrements often cause similar damage [2].

Salt content values are categorised in three levels in Austrian Ö NORM B 3355-1 “Trockenlegung von Feuchtem Mauerwerk — Bauwerksdiagnostik und Planungsgrundlagen “ (Dehumidification of masonry — Building diagnostics and planning principles). For nitrates salt content above 0.15% and for chlorides salt content above 0.1% needs active salt removal [8]. Masonry with salt content above 4% can bind 22% more water in relative humidity of 90% [9]. Efflorescence affects aesthetical appearance of buildings and salts inside the material can cause dimensional instability [10].

Desalination process becomes difficult when rising damp is not suspended as salts move along with moisture. The most effective solution is to eliminate damp rise and efflorescence simultaneously. To increase the efficiency of desalination surrounding soil containing salts should be removed. Most frequently used desalination methods are: dry-mechanical methods, diffusive methods, using poultices and convective methods [2]. In Estonia using sacrificial plaster is most common desalination method. Improper repairing methods of masonry can do significant collateral damage (using improper refinement with high vapour resistivity value) [11].

2. Materials and methods

Tests were performed on test sites “Mooste” and “Office”. All test samples were sent to laboratory to measure salt percentage with Ion chromatography.

2.1. Site description

Test site “Office” where fired clay bricks were used as test object was located in a warehouse in Tartu. During the entire test period the indoor air temperature at test location remained above 15 °C and RH above 40%. During the period of 21.01-29.01.2020, the measured average indoor relative humidity (RH) was 63.0% and measured average temperature was 16.7 °C, recorded by Rotronic CL-11 datalogger.

Test site “Mooste” was in Mooste Manor stable located in Mooste, Põlva county, Estonia. It is a 200-year-old building that is registered as a National Cultural Monument and is under cultural heritage protection. Test object was a field stone wall with clay brick patches without any damp rise layer between foundation and wall. The building was used as a stable for a long period of time, therefore there are a lot of different salts in the masonry and surrounding soil. The NW oriented stable wall was chosen for tests as it had the highest salt content measured in 2017. The wall contained 3.02% nitrates, 0.36% sulphates and 0.44% chlorides [12]. In “Mooste” stable exact temperature and RH were not measured during the test period, but temperature remained above 15 °C and RH above 40%. The exact salt content in surrounding soil and applied sacrificial plaster was not measured.

2.2. Samples and sacrificial plasters

In test site “Mooste” four samples were taken from test wall mortar between field stones. Salt percentage of the samples was measured (Figure 1).
View of the test wall with five different sacrificial plasters (LC1, LC2, CC1, CC2, TC1). Numbers represent the samples taken from the mortar.

Fragment of the stable plan where the salt samples were taken and sacrificial plaster applied.

**Figure 1.** Test wall in Mooste stable [4].

For sacrificial plastering five different plasters were used (Table 1).

| Plaster’s marker | Compounds of the sacrificial plaster | Mass percentage of compounds |
|------------------|-------------------------------------|-----------------------------|
| LC1              | Lime from the island Saaremaa, charcoal | 80% lime plaster, 13% crushed charcoal (Keminet International Ltd), 7% water |
| LC2              | Lime from the island Saaremaa, hemp flax | 65% lime plaster, 32% hemp flax, 3% water |
| CC1              | Clay (South-Estonia), charcoal | 56% lime plaster, 6% crushed charcoal, 28% water |
| CC2              | Clay (South-Estonia), hemp flax | 56% clay plaster, 28% hemp flax, 16% water |
| TC1              | Plaster from peat and oil shale ash | 38% sifted peat, 28% oil shale ash, 3% crushed charcoal, 31% water |

*a* All the materials are Estonian origin and the small amount of water binded with lime is not taken into account.

Sacrificial plasters were applied to the test wall on 13th December 2019 mainly on the porous mortar plaster materials between field stones (Figure 1). Plasters for the desalination process were applied by hand. On 29th May 2020 sacrificial plasters were removed and test samples were sent to laboratory for measuring salt percentage.

In test site “Office” 24 burnt clay bricks (Aseri PTT) were used. On 24th October 2019 burnt clay brick masonry imitating a wall with height 1.2 m was placed into salt solution (S1 - 10 l water, 20 g...
NH₄NO₃, 14.5 g NaCl, 35.5 g Na₂SO₄) (Figure 2). The idea to build a wall originated from the study of Franoni and Bandini [13]. Initially, salt solution was added so that the bottom of the bricks was covered with solution by 3 cm. On 25th October, 19th November and 27th November the salt solution S1 was added to ensure 3 cm coverage. Due to slow capillary intake the salination process was too stagnant, so new salt solution (S2 – 10 l water, 42 g NH₄NO₃; 30 g NaCl, 69 g Na₂SO₄) was made, the wall (with height of 1.2 m) was demolished and each brick was placed into the salt solution S2 (Figure 3). Salt solution S2 was added on 21st, 23rd and 29th January 2020, 03rd, 08th, 23rd February 2020 to ensure 3 cm coverage.

Impregnation was carried out until efflorescence occurred. Samples from salinated clay bricks were taken to the laboratory to measure the percentage of salts. Nine different sacrificial plasters (Table 2) were applied to the clay bricks on 21st March 2020. In order to have even thickness of plastering formwork was used. The thickness of the plaster was 12.5 mm.

### Table 2. Plasters by volume weight used in the test site “Office” [4].

| Plaster’s marker | Brick’s no in the test | Compounds of the sacrificial plaster | Mass percentage of compounds |
|------------------|------------------------|--------------------------------------|-------------------------------|
| LC1              | 21                     | Lime from the island Saaremaa, charcoal | 80% lime plaster, 13% crushed charcoal (Kemimet International Ltd, active carbon), 7% water |
|                  | 13                     |                                      |                               |
|                  | 1                      |                                      |                               |
| LC2              | 11                     | Lime from the island Saaremaa, hemp flax | 65% lime plaster, 32% hemp flax, 3% water |
|                  | 9                      |                                      |                               |
|                  | 7                      |                                      |                               |
| CC1              | 23                     | Clay (South-Estonia), charcoal        | 56% lime plaster, 6% crushed charcoal, 28% water |
|                  | 15                     |                                      |                               |
|                  | 3                      |                                      |                               |
| CC2              | 20                     | Clay (South-Estonia), hemp flax      | 56% clay plaster, 28% hemp flax, 16% water |
|                  | 12                     |                                      |                               |
|                  | 8                      |                                      |                               |
Plaster from silica smoke, peat and oil shale ash: 38% sifted peat, 28% oil shale ash, 3% crushed charcoal, 31% water.

Lime from the island Saaremaa: 90% lime plaster, 10% water.

Clay from South-Estonia: 80% clay, 20% water.

Lime from the island Saaremaa: 74% lime plaster, 24% smectite, 2% water.

Clay from South-Estonia: 63% clay plaster, 21% smectite, 17% water.

All the materials are Estonian origin and the small amount of water binded in lime is not taken into account.

On 1st April 2020 1.75 litres of pure water was added to accelerate the desalination process. On 2nd April 2020 one litre of pure water was added again. Samples from the clay bricks were taken on 29th February and sent to laboratory to measure salt percentage.

Salt percentage was measured with Ion chromatography (Metrohm 930 Compact IC Flex – Metrosep A Supp 5 – 100/4.0). Test samples were weighted by Digital Jewelry scale KL20-Series, accuracy 100 g/0.00 g. Each test sample mass was one gram. For one gram test sample 30 ml of pure water (MilliQ) was added. Then samples were covered with foil and left on hold for 24 hours before filtration through injection filter with pore measure of 0.45 µm. Then samples were diluted with 10 ml MilliQ water and analysed with Ion chromatography.

2.3. Plaster removal assessment

Sacrificial plasters are removed after desalination process and there are risks inherent in the removal process of different mixtures. Table 3 describes how difficult it is to extract the sacrificial plaster and the risk of damage to the surface. Risk is assessed on the scale from 0 to 10, mixtures ranging from 2 to 6 are reasonable to use as a sacrificial plaster. Statistic t-test was applied in the comparison of averages of the results. Risk levels of plasters were calculated as an average of all the bricks covered with relevant plaster (Table 2).

| Risk level | Description |
|------------|-------------|
| 0 – 2      | Minimal adhesion to the surface, easy removal in one or some big pieces and the risk of damage to the surface is minimal. Great risk that sacrificial plaster will not stick to the surface. |
| 2 – 4      | Required adhesion accomplished, easy removal in medium sized pieces. The risk of damage to the surface is minimal, though some plaster might stick to the surface. |
| 4 – 8      | Good adhesion to the surface, difficult removal in small pieces, significant risk to damage the surface. |

3. Results and discussion

Salt content from the mortar taken from the wall before applying sacrificial plaster and after the desalination are described in the Table 4. As the salt content under sacrificial plaster LC1 was not measured initially the salt content before and after cannot be directly compared (Table 4). In the test site “Mooste” the best outcome was achieved in reduction of NaCl. The reduction of Na$_2$SO$_4$ was the least remarkable. The rise of Na$_2$SO$_4$ took place in two areas. Damp rise is not eliminated in the stable wall.
in “Mooste” so capillary intake from soil moisture and sulphates from the soil can consistently influence salt content inside the wall. As the content of salts of the sacrificial plaster was not measured before applying it to the wall it can also affect the salt content in the wall.

| Table 4. Salt content of samples taken before and after sacrificial plastering [4]. |
|-------------------|-------------------|-------------------|-------------------|
| Plaster’s marker | Content of salts before plastering (mg/l) | Content of salts after plastering (mg/l) | Changes in content of salts (mg/l) |
|                  | chloride | nitrate | sulphate | chloride | nitrate | sulphate | chloride | nitrate | sulphate |
| LC1              | -        | -       | -       | 4.27     | 534.5   | 6.76     | -3.46    | -205    | 4.27     |
| LC2              | 7.72     | 739.5   | 2.49    | 3.20     | 362.1   | 1.61     | -41.88   | -33.2   | 0.49     |
| CC1              | 7.41     | 681.6   | 2.85    | 0.32     | 232.1   | 1.89     | -7.09    | -449.5  | -0.96    |
| CC2              | 57.07    | 69.3    | 1.20    | 15.20    | 36.2    | 1.61     | -41.88   | -33.2   | 0.49     |
| TC1              | 3.12     | 328.5   | 1.48    | 2.09     | 225.4   | 1.29     | -1.03    | -103    | -0.19    |

Clay plaster with charcoal (CC1) represented the best results (Table 5). Reasonable risk level for sacrificial plaster is 2-6 therefore only CC2 clay plaster with hemp flax (5 points) is appropriate to use.

| Table 5. Salt content change and risk level after removal of sacrificial plaster [4]. |
|------------------------|-------------------|-------------------|-------------------|
| Place                  | Risk level        | Plaster           | Change in content by percentage (%) |
|                        |                   |                   | Chloride | Nitrate | Sulphate |
| -                      | -                 | LC1               | -        | -       | -        |
| 1                      | 7.0               | LC2               | -44.74   | -27.71  | 171.72   |
| 4                      | 7.0               | CC1               | -95.68   | -65.94  | -33.52   |
| 2                      | 5.0               | CC2               | -73.37   | -47.85  | 43.57    |
| 3                      | 8.0               | TC1               | -33.07   | -31.39  | -12.73   |

The summary of content of salts before and after plastering in test site „Office” is presented in Table 6. The main purpose of sacrificial plasters is the removal of salts. In general, the amount of salt ions was greatly reduced using all studied sacrificial plasters during the experiments (within two months). Sacrificial plaster CC2 removed salts from the bricks most efficiently and TC1 performed the weakest (Table 6). The least amount of salt was eliminated in brick 18 using plaster TC1. From four bricks nitrates were 100% removed whereas the main component of three sacrificial plasters used was clay.

| Table 6. Salt content of samples taken before and after sacrificial plastering [4]. |
|------------------------|-------------------|-------------------|-------------------|
| Brick no | Plaster | Salts content before plastering mg/l | Salts content after plastering mg/l | Decrease of salts content in plaster mg/l |
|          |         | chloride | Nitrate | sulphate | chloride | nitrate | sulphate | chloride | nitrate | sulphate |
| 1        | LC1     | 6.33     | 10.31   | 81.14    | 0.67     | 0.57    | 71.26    | -5.66    | -9.74    | -9.89    |
| 7        | LC2     | 2.31     | 2.80    | 31.87    | 1.74     | 2.02    | 18.52    | -0.57    | -0.78    | -13.35   |
| 8        | CC2     | 12.42    | 19.91   | 132.93   | 0.27     | 19.91   | 39.50    | -12.15   | -19.9    | -93.4    |
| 4        | C7      | 2.62     | 3.57    | 47.05    | 0.26     | 3.57    | 24.16    | -2.36    | -3.57    | -22.9    |
| 3        | CC1     | 7.41     | 13.27   | 158.44   | 0.32     | 13.27   | 58.40    | -7.09    | -13.2    | -100.0   |
| 18       | TC1     | 10.32    | 16.38   | 85.78    | 8.94     | 14.57   | 92.57    | -1.38    | -1.62    | 6.79     |
| 2        | C6      | 3.54     | 5.22    | 71.10    | 0.36     | 5.22    | 36.18    | -3.19    | -5.22    | -35.51   |
Table 7. Salt content change and risk level after removal of sacrificial plaster [4].

| Brick no | Risk level | Plaster  | Change of content by percentage (%) |
|----------|------------|----------|-------------------------------------|
|          |            | Chloride | Nitrate            | Sulphate       |
| 1        | 7.3        | LC1      | -89.5              | -94.5          | -12.2          |
| 7        | 7.0        | LC2      | -24.7              | -27.7          | -41.9          |
| 8        | 5.3        | CC2      | -97.9              | -100.0         | -70.3          |
| 4        | 4.7        | C7       | -90.3              | -100.0         | -48.7          |
| 3        | 5.3        | CC1      | -95.7              | -100.0         | -63.1          |
| 18       | 7.5        | TC1      | -13.4              | -10.0          | 7.9            |
| 2        | 6.7        | C6       | -89.9              | -100.0         | -49.5          |

Clay plaster with charcoal (CC2) was found to be the most efficient (Table 8) in the removal of salts. Sacrificial plasters CC1 (clay), C6 (lime) and C7 (clay) were found to remove salts also quite efficiently. The efficiency of removal of salts of sacrificial plasters without additives C6 (lime) and C7 (clay, Table 2) was statistically insignificant (t-test, p-value > 0.05) when compared to sacrificial plasters with additives. The removal of salts of sacrificial plaster (TC1) was the least effective, which might have been caused by the fact that no water was added to this particular sacrificial plaster.

The test specimens, which were not additionally water soaked, were subjected to the movement of salt ions into the plaster or to the surface of the test specimen mainly by pure water infiltrating the plaster base, which dissolved the salts to form a higher concentration solution in the brick. Therefore, salt ions were diffused from bricks to plaster. The process lasted as long as there was water in the test piece. Only salts dissolved in water move in the capillaries. Therefore, additional water enabled the diffusion to balance the content of salts between bricks and plaster.

The efficiency of removal of chlorides, sulphates and nitrates were also separately assessed. Four sacrificial plasters (CC2, C7, CC1, C6) successfully removed all the nitrate content. Sacrificial plaster CC2 removed most efficiently sulphates and again TC1 performed the weakest as it even increased the content of sulphates. The increase of sulphate content (in Table 7) could be caused by the content of TC1 (silica smoke, peat and oil shale ash), which could contain sulphate salts.

In addition, the easiness of removal of sacrificial plasters is also an important property when assessing sacrificial plasters. Sacrificial clay plasters C7, CC1 and CC2 were the easiest to remove from the clay bricks assessed in terms of risk level of removal. Lime plasters, regardless of their additives, were more difficult to remove (t-test, p-value < 0.05; Table 7) in terms of their risk levels. Risk levels of plasters were calculated as an average of all the bricks covered with relevant plaster (Table 2).

4. Conclusions
In general, all the studied sacrificial plasters were found to be effective in the removal of salts. Sacrificial plasters with clay demonstrated better efficiency in desalination process than lime plasters. The existence of additives of clay or lime sacrificial plasters was insignificantly affecting the efficiency of removal of salts. Adding or not adding pure water has been found a substantial reason in enhancing/mitigating desalination process in current study. The sacrificial clay plasters were also easier to remove from the brick surface in comparison with the lime plasters. In order to have more accurate salt content results salt percentage of the plaster should be measured and damp rising layer should be mandatory if there are salts in the soil. The porosity of salinated material has great impact on salt movements as using advection for desalination the process gets less time-consuming.
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