DEVELOPMENTS ON REPOINTING OF SALT-LADEN HISTORIC MASONRY IN THE NETHERLANDS

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ABSTRACT
Interpreting the results of laboratory research program and analyzing practical experience from the execution of restoration projects an overview is given of the development of compatible repointing for salt-laden massive historic masonry over the past years in the Netherlands.

In the paper, firstly, frequently occurring damage in repointing is analyzed. From these analyses requirements are derived with respect to the composition and the application technique of repointing mortars.

Subsequently, requirements have as much as possible been quantified comparing laboratory testing results and the interpretation of field experiences.

Finally, requirements regarding the composition and application technique of repointing mortars applied in salt-laden massive historic relatively weak masonry are formulated.

1. INTRODUCTION
Over the past decades repair of repointing in historic masonry was often performed using ‘too hard and too dense’ mortars (mostly cement based). These mortars applied in ‘soft’ masonry, relatively weak fired clay bricks and lime-based bedding mortars, caused unexpected effects on the moisture movements in the masonry, leading to several types of damage.

However, restoration practice learned as well that repair with ‘soft’ repointing mortars, applying as binder only air-lime was not successful if the masonry contained significant amounts of salts (e.g. in towers close to the sea).

The application of a limited amount of hydraulic binder in the repair repointing mortar seems to be a promising approach in the sense that the durability (decrease of salt damage) may significantly improve, while the mechanical and hygric characteristics remain compatible to the existent historic masonry.
2. DAMAGE OF REPOINTING

The most prominent causes of damage regarding repointing in the Netherlands were studied, with a view to obtain more insight into the requirements applicable to repointing. Not only materials characteristics, as well and to a considerable degree, the application technique turns out to be a decisive parameter to the durability of the repointing.

2.1. Frost damage

2.1.1 Causes
In practice the following types of frost damage are observed, if are applied (i) ‘hard’, dense cement repointing or (ii) repointing mortars containing water repellents:

- Push-out of repointing (see figure 1a): this may occur if a period of intensive rain is directly followed by a frost period. The cause of this phenomenon may be the presence of a cavity between the bedding mortar and the repointing, as a result of an incomplete filling up by the mason. This cavity may be filled with water (surrounded by saturated material) during the raining period; subsequently, the expansion caused by the freezing of the water will result into the push-out of the repointing. In case of cement repointing the bond between mortar and adjacent brick may be so high that with the push-out a part of the brick breaks as well.

- Frost damage in the bedding mortar behind the repointing (see figure 1b). These bedding mortars (mostly pure air-lime mortars) often survived centuries without any damage, as a result of good drying characteristics of the masonry. A restoration intervention, the application of a dense or water repellent containing repointing, delayed the drying of the bedding mortar to such a degree, that it became frost-prone.

![Figure 1: Examples of frost damage](image)

2.1.2 Requirements
Composition repointing:
Should be such that drying of the bedding mortar is not delayed and the direction of the drying (the capillary moisture transport) should be from brick to mortar (a ‘breathing’ mortar); and as durable as possible, to withstand salt deterioration. The bottom line is that, the repointing should be sacrificial and every damage to the bricks of the exiting historic masonry should be avoided.
Application technique
The application technique of the repair repointing plays an important role in the durability. The whole process, from raking out of the old joint (how to do, joint form, depth etc see figure 2) through prewetting substrate, applying of the new mortar and the curing asks for knowledge and understanding of a skillful mason/pointer [2],[5].

![Image](image1.png)

Figure 2: Skillful removal of a hard repointing: without damaging the adjacent bricks, with adequate depth (2 to 2.5 x the width of the joint), with adequate form: rectangular.

2.2 Salt damage

2.2.1 Causes
Historic masonries frequently contain soluble salts. The source of these salts may be the applied materials themselves (e.g. sulfates in fired clay bricks, sea water used preparing the mortar etc.) or the salts may be migrated from the surrounding soil (through ground water); other reasons may be a previous inappropriate use of the building (salt storage, stable), floods of seawater, aerosol of sea salts, de-icing salts [10].

In various ways salts may be the cause of damage:
- through chemical interaction between the salt and the binder, resulting into expansive compounds (e.g. thaumasite formation) or dissolution of compounds (e.g. CaCl₂)
- through salt crystallization cycles, where damage is caused by expansion. The crystallization cycles may occur at different locations in the masonry, depending on where drying takes place (the position of the drying front). If salt concentration and crystallization cycles take place at the surface of the masonry the damage mostly is rather restricted. However, if the salt concentration and crystallization cycles occur in the material, under the surface, the damage may be substantial (crypto-florescence leading to spalling.)

Crypto-florescence in repointing may occur if
(i) the masonry is treated with a water repellent (concentration of salts under the repellent layer)
(ii) the repointing mortar is not in good contact with the bedding mortars (salt crystallization cycles may occur then in the void between repointing and bedding mortar)

2.2.2 Requirements

Binder choice
An adequate choice of the binder and moisture-salt transport characteristics of the mortar resulting into crystallization of the salts at an outer face of the masonry are basic requirements under possible salt attack conditions.
With regard to the binder choice, close to the sea, rather good experiences have been obtained with mortars based on natural hydraulic lime (type NHL3.5 St. Astier, France). These mortars are, depending on the environmental conditions, applied with or without an addition of blast furnace cement (for instance ¼ BF cement of the total binder volume; mortar composition for instance (total) binder: sand ratio ~ 1 : 2½). In the interior of the Netherlands mostly a pure NHL as binder is adequate to the environmental conditions.

A serious point of attention is the relatively slow strength development of the NHL mortars. The work should preferably be done early in the season, so that the strength of the mortar is sufficiently high to survive the first winter without damage.

Remarque
Observing severe salt attack conditions there is always the temptation to choose a strong mortar. However, it should not be forgotten that the future soundness of the historic masonry should prevail over the durability of the repointing: the repointing should always be the sacrificial element in the masonry.

2.3 Damage caused by thermal stresses

2.3.1 Causes
Thermal deformation may cause damage in masonry. This may be the case if the deformations are restrained. This phenomenon appears to be underestimated in practice. The stresses are the result of thermal expansion of materials. The elasticity (E-modulus) of the material plays a role as well.

For a material with a linear thermal expansion coefficient $\alpha$ [1/K], a (dynamic) E-modulus $E$ [N/mm$^2$] and a temperature increase of $\Delta\theta$ [°K], under restrained deformation conditions a stress may develop according to [4]:

$$\sigma_{\text{compr}} = \alpha \cdot E \cdot \Delta\theta \text{ [N/mm}^2]$$

$\alpha \cdot E$ [N/(mm$^2$ °K)] is a materials dependent parameter, specific for each different pointing mortar, indicating the proneness of the material to build up stresses under temperature increase.
2.3.2 Requirements
From the previous section it can be concluded that a low thermal expansion coefficient and a high deformation capacity (low E-modulus) of the repointing mortar will result into low thermal stresses in the historic masonry (for a further elaboration of the thermal behavior of the various repointing mortars see chapter 3.6).

3. LABORATORY TESTING PROGRAM

3.1 Introduction
The aim of the research program was, where possible, to determine quantified limit ranges with regard to the requirements as formulated in chapter 2.

The research program contained 8 site-mixed and 4 prefab repointing mortars (see figure 5). Starting point was that the repointing mortars should be moderately salt-resistant: as this is under many circumstances a requisite in historic masonry. However, at the same time the mortars should show a moderate compressive strength, a moderate E-module and a high porosity (to be compatible with the low strength/high porous historic bedding mortar and the usually high porous adjacent (fired clay) bricks.

In order to resist salt damage the following binders were chosen: natural hydraulic lime from St. Astier (as this company could provide reliable research results on the salt resistance of their products) and blast furnace cement (to mitigate sea salt damage).

The 8 site-mixed mortars were basically lime-based (air lime or natural hydraulic lime) with an addition of a hydraulic binder.

The mortar compositions of the 4 prefab mortar are not known, but they usually contain Portland cement as a binder.
Figure 5: Composition of the 8 site-mixed repointing mortars and 4 prefab repointing mortars with an unknown composition. The applied binders for the first types of mortars are: natural hydraulic lime (NHL2 and NHL3,5 from St Astier). Air limes: ‘Lime (Harl)’ (CL70) and Supercalco, Carmeuse (CL90); further on, Trass (‘Rheinische Tras’), BFC: blast furnace cement (HC CEM III/B). PC: Portland cement
Applied sand: standard repointing (rounded river)sand (Sand 1) with Fineness Modulus of 1,8 and very fine sand (Sand 2) with a FM of 1,0

### 3.2 Workability
The repointing mortars were evaluated by a master mason/pointer with regard to their workability. The evaluation was focused on the plasticity, sand grading, water retention, sticking, staining, and production capacity. Apart from these partial judgments an overall judgment was given.

It was concluded that the site mixed compositions performed better than the prefab mixes (see figure 6,left). Poor workability often leads to incomplete filling of the joint, impairing the durability of the repointing.

It is advised to seriously take into account the judgment of the mason before applying a mortar with a defined composition.

### Workability evaluation

<table>
<thead>
<tr>
<th>Site-mixed mortars</th>
<th>prefab mortars</th>
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<tbody>
<tr>
<td>VB02</td>
<td>NHL3,5</td>
</tr>
<tr>
<td>VB03</td>
<td>NHL2</td>
</tr>
<tr>
<td>VB04</td>
<td>NHL3,5</td>
</tr>
<tr>
<td>VB05</td>
<td>Lime (Harl)</td>
</tr>
<tr>
<td>VP01</td>
<td>A</td>
</tr>
<tr>
<td>VP04</td>
<td>B</td>
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<tr>
<td>VP05</td>
<td>C</td>
</tr>
<tr>
<td>VP06</td>
<td>D</td>
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</tbody>
</table>

Figure 6: Left: workability evaluation of the repointing mortars. Right: Compressive strengths of repointing mortars after 28 days (acc to NEN)
3.3 Compressive strength

Traditional binders such as air limes, natural hydraulic limes, trass-lime combinations show a slow strength development; this means that the compressive strength, usually determined after 28 days acc to NEN, does not give end-values (sometime these end-values will be reached after some years). Addition with (blast furnace) cement accelerates the strength development, so that the mortar is less vulnerable to aggressive surrounding conditions (frost, salts).

From figure 6 (right) can be derived that VB04, the pure natural hydraulic lime mortar, shows a very slow strength development (test after 28 days); end values of 6-8 N/mm² are to be expected of this type of mortar, which are reached after ½ to 1 year under outdoor conditions. This means that this mortar should be applied early in the season to prevent frost damage during the winter period.

From the prefab mortars especially VP01 shows a very high compressive strength (this may point to a relatively strong cement content).

3.4 ‘Breathing’ of the repointing

Adequate moisture absorption and drying characteristics of the repointing mortar are essential to ensure a sacrificial behavior of the repointing mortar. Especially slow drying may cause, as was shown in chapter 2, serious frost and salt damage problems.

In the lab research program absorption as well as drying experiments were performed. An important conclusion was that quick absorption mostly goes hand in hand with quick drying: compare results figures 7a and 7b.

![Water absorption coeff (WAC) prisms](image1)

![Drying coefficients (first phase drying) of the different pointing mortars (prisms)](image2)

**Figure 7:** Moisture absorption by repointing mortars (prisms) expressed in the Water Absorption Coefficient (WAC) [the test results of VB08 and VB09 are questionable, good mixing with the fine sand (Sand 2) gave serious problems: uneven composition of the mixes]

Some observations:

- Striking is the high WAC of the still not completely hydrated pure hydraulic lime mortar (VB04); as the fineness of the porosity of VB04 will increase with a further completion of the hydration it is to be expected that WAC of VB04 will decrease with time.
- The WAC of VP01 is very low. The drying rate was very low as well. As the prism test underestimates the moisture absorption of masonry (with its numerous absorption cracks), slow drying means structurally higher water contents behind the repointing, explaining the increase in vulnerability to frost damage.
3.5 Freeze-thaw behavior

The tests have been performed in one of freeze-thaw test boxes of TNO-Delft NL. The test regime was similar to that used for the testing of repointing mortars in the European Pointing project [3]. The tests may show (i) surface damage (ii) impaired bond between the repointing with the adjacent material and (iii) frost damage in the bedding mortar behind the repointing.

![Test specimens in the freeze-thaw container](image)

Figure 8: Preparation of the test specimens for the freeze-thaw test at TNO

Test results

Deterioration and debonding of the repointing

Only test specimen VB09 (for composition see figure 5) showed damage; as a result of the freeze thaw cycles the joint started to loose material from the surface to the inside (sanding).

None of the test specimens showed problems regarding bond between repointing mortar and brick.

This result is better than in the EU-Pointing project, which was executed some years ago; as the other parameters were similar most probably the reason for the better results is that in the current research program a joint depth was applied of 2 times the joint width (2 times deeper than in the case of the EU-pointing project)

It was concluded that the depth of joint is crucial to the durability of the repointing.

Damage to the bedding mortar behind the repointing.

In the test specimens VB05, VP01, VP04 and VP06 a beginning of frost damage was observed in the bedding mortar behind the repointing. So the slowly drying mortars (three of the four mortars are prefab mortars!) show frost damage in the bedding mortar behind the repointing.
3.6 Thermal stresses

In a series of tests the thermal expansion coefficient (α) and the E-modulus (E) of the repointing mortars have been determined. In figure 9 are shown the thermal stress coefficients: the product of (α) and (E).

Figure 9 shows that the prefab repointing mortars, and then especially VP01, may cause under the influence of temperature increase, relatively high stresses.

With an comparative example the differences in possible stress development can been demonstrated. Assuming a temperature increase of 50 °C (south or west facade), and comparing VB06 with VP01 the following stresses may develop under restrained conditions:

\[
\sigma_{\text{compr}} = \alpha \cdot E \cdot \Delta \theta
\]

VP01 (a cement repointing mortar)
with \( \alpha \cdot E = 170 \cdot 10^{-3} \) [MPa/°K] (see figure 9) and \( \Delta \theta = 50 \) [°K]
\( \sigma_{\text{compr}} \approx 8.5 \) MPa [N/mm²]

VB06 (a NHL mortar with \( \frac{1}{4} \) (vol %) of the binder containing blast furnace cement)
with \( \alpha \cdot E = 34 \cdot 10^{-3} \) [MPa/°K] (see figure 9) and \( \Delta \theta = 50 \) [°K]
\( \sigma_{\text{compr}} \approx 1.7 \) MPa [N/mm²]

So it can be concluded that there may be a significant difference in possible stress development depending on the repointing mortar composition.
4. RECOMMENDED TECHNICAL REQUIREMENTS FOR REPOINTING IN ‘WEAK’, SALT-LADEN HISTORIC MASONRY

Application conditions:

- ‘weak’ historic masonry (with lime based bedding mortar and weak to moderate strength of the fired clay bricks)
- moderately salt-laden fired clay brick masonry

Evaluating the test results and interpreting them in the context of over the past decade obtained field experience the following requirements are recommended:

- Workability: evaluated as good by an experienced mason/pointer
- Depth of the joint 2 à 2,5 the width of the joint (for further technical execution requirements see [6])
- Compressive strength: 3 – 7 [N/mm²]
- Water absorption coefficient (WAC): 0,3 – 0,9 [kg/(m²·min⁰·⁵)]
- Thermal stress coefficient $\alpha$. $E < 80$-100 [(N/(mm²·K)). 10⁻³] (working hypothesis to be proven in practice)
  $\alpha$: linear expansion coefficient
  $E$: dynamic elasticity modulus
- Freeze-thaw test (according to EU-pointing project [3])
  no damage to the joint
  the joint should not be debonded
  no frost damage to the bedding mortar behind the repointing

5. REFERENCES


