Binder leaching from hydraulic lime mortars
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Binder leaching – the problem
Collapse of outer leaf of masonry  Stalactites in a vault
Source: Glasgow Herald

Background to lime mortar
- Burn limestone: CaCO$_3$ → CaO + CO$_2$
- Slake the quicklime: CaO + H$_2$O → Ca(OH)$_2$
- Mix with sand (either hot or cold, dry or as ‘putty’)
- Mortar sets by drying and reaction with air or water
- ‘Air lime’ (CL90) – also ‘dry hydrate’ is from pure limestone and hardens with CO$_2$: Ca(OH)$_2$ + CO$_2$ → CaCO$_3$
- ‘Hydraulic lime’ (NHL2, NHL3.5, NHL5) is from limestone with clay impurities which form C$_2$S in the kiln. It hardens with CO$_2$ and by hydraulic reaction: C$_2$S + H$_2$O → C-S-H
- Some components are sufficiently soluble for leaching in water to be a possibility. (Climate change = more rain!!)

Accelerated leaching
- Hardened cement: 8M ammonium nitrate (Nguyen et al 2007)
- Hardened lime:
  \[ \text{Ca(OH)}_2 + 2\text{NH}_4\text{NO}_3 \rightarrow \text{Ca(NO}_3)_2 + \text{NH}_3 + \text{NH}_4\text{OH} + \text{H}_2\text{O} \]
  \[ \text{CaCO}_3 + 2\text{NH}_4\text{NO}_3 \rightarrow \text{Ca(NO}_3)_2 + (\text{NH}_4)_2\text{CO}_3 \]
- Highly soluble
- 8M is too aggressive – 1M is sufficiently strong for lime
Objective of the work

To determine the rate of calcium leaching in a range of hardened hydraulic lime mortars, using ammonium nitrate as an accelerated leachant, and to assess the effect on physical and mechanical properties.

Procedure

- NHL2, NHL3.5, NHL5 limes
- 1:3 Lime:sand mortars (proportions by volume, batched by mass)
- 160 x 40 x 40 mm prisms
- Cured in the moulds for 7 days at 100%RH
- “Uncarbonated” or carbonated at 800-1000ppm CO₂
- Specimens immersed in 1M NH₄NO₃ for up to 169 days
- Tested for flexural strength, compressive strength, sorptivity, and by petrography on thin sections

Leaching depth – uncarbonated mortars

<table>
<thead>
<tr>
<th>Time of leaching</th>
<th>1</th>
<th>4</th>
<th>9</th>
<th>16</th>
<th>25</th>
<th>36 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>NHL2</td>
<td></td>
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<tr>
<td>NHL3.5</td>
<td></td>
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<tr>
<td>NHL5</td>
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</tbody>
</table>

Leaching depth – uncarbonated mortars

- NHL2
- NHL3.5
- NHL5
Strength reduction – all mortars

Sorptivity changes – all mortars

Thin sections – examples 1
NHL2 uncarbonated untreated
NHL2 uncarbonated leached for 36 days

Thin sections – examples 2
NHL5 carbonated untreated
NHL5 carbonated leached for 36 days
Thin sections – point counting assessment

Binder 100%

Porosity 100%

Aggregate 100%

Zone enlarged on next slide

Thin sections – point counting assessment

Binder %

□ carbonated

○ carbonated treated

× uncarbonated

◊ uncarbonated treated

Water exposure: predicted lifetimes (assuming acceleration factor = 20)

<table>
<thead>
<tr>
<th></th>
<th>uncarbonated</th>
<th>carbonated</th>
</tr>
</thead>
<tbody>
<tr>
<td>NHL2 Leached depth one year (mm)</td>
<td>3.5</td>
<td>2</td>
</tr>
<tr>
<td>NHL3.5 Leached depth 100 years (mm)</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>NHL5 Time to leach to 20mm (years)</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>NHL2 Time to leach to 50mm (years)</td>
<td>15</td>
<td>1.5</td>
</tr>
<tr>
<td>NHL3.5 Time to leach to 20mm (years)</td>
<td>70</td>
<td>24</td>
</tr>
<tr>
<td>NHL5 Time to leach to 50mm (years)</td>
<td>100</td>
<td>20</td>
</tr>
</tbody>
</table>

Conclusions

• 1M NH₄NO₃ works as an accelerated leachant for NHL mortar

• Leaching of calcium from the binder reduces strength, increases porosity and sorptivity: this has implications for durability

• Leaching resistance increases in the order NHL2<NHL3.5<NHL5

• Carbonated mortar is more resistant to leaching than uncarbonated mortar.
Thank you!

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