Functional Behaviour of Traditional Lime Mortar
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Refurbishment Case Study 25, Maav of Shetland, HES

RIBA Advanced Conservation Course, Lancaster, June 2018
I hate you so much.

I hope you collapse.

Arch Enemies

Jason Berghsieker
Functional Behaviour of Lime Mortar
Presentation Overview

I. Historic lime mortars and masonry preservation

II. Modern mortars and sick buildings

III. Replicating the historic lime example of function
I. Historic lime mortars and masonry preservation
Historic lime mortars and masonry preservation

Masonry Decay: Drivers

- Mobilised by water
- Frost attack
- Keep masonry dry, avoid attack rather than resist
- Salt attack
- Salt harmless in solution, damaging when it precipitates
- Control where salt precipitates, control where decay occurs.

Lime has achieved frost and salt resilience for centuries! How?
Historic lime mortars and masonry preservation

WDR Index: As Onerous As It Gets

• And yet, predominantly non or feebly-hydraulic lime in UK masonry buildings

• Centuries-proven track record confirming a durable response to attack

• How has the masonry responded?

• After centuries with lime, why does cement damage so quickly??
“Interstitial condensation is a form of structural damping that occurs when warm, moist air penetrates inside a wall, roof or floor structure, reaches the dew point and condenses into liquid water” (Wikipedia definition)
Salt Resilience

- SPAB observation on moisture movement in 1979. How?
- Masonry needs to ‘breathe’
- Breathing: vapour and liquid egress
- Liquid egress intimately tied to durability of masonry fabric
- Liquid egress dictates where salt precipitates
Historic lime mortars and masonry preservation
Mind-boggling notion: rate of evaporation of porous materials is controlled by the capillarity of the material...

- Capillarity is speed of “conveyor belt”
- For a given external drying condition, rate of drying entirely controlled by speed of conveyor belt!
- Faster the stock leaves the factory door, the faster the conveyor belt goes
Historic lime mortars and masonry preservation

Sacrificial Weathering... How?

- Masonry unit coarse-pored
- Lime mortar fine-pored
- Add water, you have a poulticing interaction
- Moving water washes out the salts
- Repeat over time, very pronounced results
Liquid phase moisture is drawn out of the coarse-pored stone, by the capillary drying regime of the fine-pored lime.

Soluble salts advected, evaporation front forced away from the surface of the stone.
Historic lime mortars and masonry preservation

- Lime harling prime culmination of masonry preservation
Historic lime mortars and masonry preservation

- Lime harling prime culmination of masonry preservation

Capillary drying regime of porous masonry with traditional lime mortar joints & pointing

Capillary drying regime of masonry harled in traditional lime mortar
Historic lime mortars and masonry preservation

Masonry in plane of the wall needs to be able to accommodate minor (!?) movement without splitting the stones/bricks

Arches need to articulate. Voussoirs need to be able to rock relative to one another to accommodate thrust-line rattling around

Crosswall restraints need to maintain bond in spite of differential settlement

CEMENT MORTARS DO NOT DEFORM.
Historic lime mortars and masonry preservation

Various degrees of contact intimacy between porous materials

Real buildings shift, creak, groan and the mortar needs to maintain a good bond intimacy with the stone if it is to effectively draw the water (and salts) out of the fabric.
Historic lime mortars and masonry preservation

- Active drying-out capability of lime ties frost and salt resilience together. Lime manages the engine of decay.
II. Modern mortars and sick buildings
Modern mortars and sick buildings

Salts through mortar 😊
Modern mortars and sick buildings

Salts through stone 😞
Modern mortars and sick buildings

What’s wrong with cement?

• Because it looks wrong?
• Because it’s not authentic?
  – These don’t lead to accelerated decay.

Function.
Modern mortars and sick buildings

- Cement pores small & poorly interconnected
- Plugging effect forcing evaporation in the arrises

(Pores < 200nm ineffective)

(suction)

(plugged)
Modern mortars and sick buildings

- Badly managed water = ramifications for salt and frost
Modern mortars and sick buildings

NHL 3.5 Porosity = 28%

C.50% porosity ineffective

CEM-II Porosity = 20.0%

C.60% porosity ineffective

NHL and G.P. CEM-II... Spot the difference?
Modern mortars and sick buildings

Historic lime and NHL... Spot the difference!
How breathable is “breathable”???

- Capillarity of air lime is several times greater than NHL
- Vapour permeability of air lime >50% greater than NHL
- Breathability is a function of capillarity and vapour permeability so we need to consider both
- …Who said NHLs are breathable??

Measure it against the historic example.
Modern mortars and sick buildings

THE NEED FOR OLD BUILDINGS TO "BREATHE"

Philip Hughes

Warning
The term "breathing" is now being applied to many products which are only slightly vapour permeable. In general, no synthetic modern materials should be applied to the masonry or plaster surfaces of historic buildings. If in any doubt contact SPAB.

SPAB News, Spring 1986
Revised December 1987
Modern mortars and sick buildings

Proprietary mortars often full of additives!

Is the historic example? No.

- Porous materials with high VP and low capillarity…!??
- Widespread use of premixed NHLs with plasticisers, water retainers, air entrainers, water repellents and other rubbish
- Leads to hydrophobic surface chemistry and pore connectivity issues which together prohibit liquid-phase moisture egress

- Capillarity is absolutely fundamental to poultice function
Modern mortars and sick buildings

Effect of a vapour-permeable surface coating which has poor capillarity ("vapour-open / capillary-closed" material)

• Remembering the rate of drying depends of speed of conveyor belt
• If you hold up the queue at the factory door, the conveyor belt slows down

• CAPILLARY ACTIVITY IS VITAL TO EFFICIENT DRYING OF MASONRY STRUCTURES
Modern mortars and sick buildings

MECHANICAL COMPATIBILITY
- Air Lime (CL90): Very deformable!
- NHL3.5: ½ as deformable compared to CL90
- Cement: <¼ as deformable (>4x – 10x brittle!)
- Deformability is governed by binder type not mix proportions.
- **Strength isn’t the problem!! Brittleness.**

Ball et al. (2007), Construction Materials 160 Issue CM2

Air Lime, NHL and CEM-II... Spot the difference!

Water Management

Migration and evaporation of water through the lime mortar joint, effective drying out

Concentration of soluble salt precipitation, manifesting in the sacrificial protection of lime mortar

When exhausted, the mortar becomes friable and is then raked out and replaced, refreshing the projection for the next service life

Typical coarse-pored sedimentary dimension stone, notably sandstone and limestone. Historic bricks similar.

Lime water management makes masonry resilient to engine of decay!
III. Replicating the historic lime example of function
In porous materials, MICROSTRUCTURE IMPARTS FUNCTION when water is added.

(Just like sea monkeys)
Replicating the historic lime example of function

Evaluation of New Mortars: The Measuring Rod

Historic lime mortar characteristics (coral-like microstructure):

- High porosity (binder porous)
- Pore network well interconnected
- Predominant pore size ~ 1 micron
- 1-micron pore size widely attributable to calcite!
• Historic example is both the start and the end point
• Where does the imperative to replicate the historic example come from?
• Only talking about breathability because we got it wrong with the notorious cements
• Problem is, we’re still getting it wrong with strongly hydraulic mortars
• And worse still, we think we’re clever by chemically modifying stuff without understanding the big picture

AKA we’re not quite reaching the standard set down by history
Replicating the historic lime example of function

<table>
<thead>
<tr>
<th>Lime Mortar</th>
<th>Free Lime (Ca(OH)(_2)) Content According to Manufacturer (St Astier 2006) (%)</th>
<th>Free Lime (Ca(OH)(_2)) Content of St Astier Lime as Evaluated by (Hughes, D. &amp; Swann, S. 1998) (%)</th>
<th>Minimum Conformity Criteria for Free Lime (Ca(OH)(_2)) Content to BS EN 459-1:2010 (BSI 2010a) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL 90</td>
<td>-</td>
<td>-</td>
<td>≥ 80</td>
</tr>
<tr>
<td>NHL 2</td>
<td>≥ 50</td>
<td>43</td>
<td>≥ 35</td>
</tr>
<tr>
<td>NHL 3.5</td>
<td>24-26</td>
<td>36</td>
<td>≥ 25</td>
</tr>
<tr>
<td>NHL 5</td>
<td>15-20</td>
<td>23</td>
<td>≥ 15</td>
</tr>
</tbody>
</table>

Lime mortars for building & pointing work:

NHL 3.5 (1:2.5?) – “standard”… not ideal

• NHL 2 – NHL 5 (1:1.5)? – too strong, still low lime

...Need to target lime-rich CL90 binder in binder-rich mix proportions...!

Mix proportions...? See:
• Frew, C., Lime Harling, BLF Vol 22 (2015)
• Lynch, G., The Myth in the Mix (buildingconservation.com)
• Copsey, N. HES Technical Paper (2017)
Replicating the historic lime example of function

- How to physically get an air-lime binder in such binder-rich proportions to work? **Hot mix it.**

- Air lime CL90 quicklime @ 1:3 quicklime:aggregate mix (achieves 1:1.5 bdr:agg)
- CL90 quicklime gauged with NHL to achieve tempered hydraulicity with high free lime
- CL90 quicklime gauged with pozzolan to achieve the required hydraulicity whilst maintaining high free lime content (most authentic)

The goal is to make the mortar “just hydraulic enough” to cope with the practical setting environment, and have enough free lime left over to carbonate (or “seeded” pre-carbonated uncombined lime built in as aggregate) to achieve the open, capillary-active breathable microstructure observed in historic lime mortars.
Replicating the historic lime example of function

What does a pozzolan do to the microstructure?
- Pozzolans gobble up a proportion of free lime to create hydraulic compounds
- Lime consumption varies according to the reactivity of the pozzolan (Chapelle Index)
- With a typical traditional addition of 10% the weight of the lime, the pore size distribution barely notices.

And microporous calcitic aggregates?
- The pore size distribution of crushed (pure) limestone (CaCO3) is essentially identical to carbonated free lime
- Using a CL90 grade lime binder with crushed limestone aggregate gives a PSD essentially identical to that of the CL90 binder paste only
- Microporous calcitic aggregates can be used to recompensate (or enhance) the lime richness of mortars (cf: functional behaviour!!)
Replicating the historic lime example of function

Hot mixed limes specified at historic proportions are the best replication of the historic lime microstructure

Why?
• They’re used in the historic proportions…!!
• High carbonation set creates high capillary porosity
• Only viable way of getting the right ingredients in at the right proportions
• Granny’s cake
• Microstructure infers function

Efficient drying out and enhanced poulticing interaction

How did granny make it??

Good old granny!
I. Historic lime mortars and masonry preservation

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- Lime rich
- Binder rich
- Hot mix
Questions

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Further reading:

• Traditional lime mortars and masonry preservation, Journal of the Building Limes Forum (2017: Vol 24)
• Lime mortar and sacrificial protection of heritage stonework, Engineering History and Heritage, (2015: Vol 168 Issue EH4)