South Carolina Brick Masonry - Green Forever

Insights in Preservation and Restoration

South Carolina Preservation Month Workshop, May 14, 2010

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Institute for Innovation in Building Materials

And The National Brick Research Center

Clemson University
Today’s Five Part Presentation

1. Something Old – Something New in “Sustainability”.


4. Mortar.

5. Case Studies.
Environmental Movement: From the Environment is a “Sink” To Conservation → Protection → Sustainability

Sustainability

“All humans should be able to enjoy a decent level of well being taking from nature sustenance without interfering with the continuity of nature and without harm to other life forms on the planet.”

Founder in 2001 of Johnston Design Group, Scott Johnston leads an architectural firm that is dedicated to environmentally sustainable design. The firm has been recognized nationally with numerous awards and publications for excellence in sustainable design. The practice offers sustainable design consulting and the authoring of green design guides, conservation development planning, historic preservation and adaptive reuse consulting, and architectural services for a variety of education, mixed use, affordable housing, and custom residential projects.

Scott Johnston AIA, Greenville, SC
U.S. Green Building Council

- National nonprofit organization based in Washington, DC
- Diverse membership of organizations
- Consensus-driven
- Committee-based product development
- Developer and administrator of the LEED™ Green Building Rating System
ASTM Sustainability Standards:


E 2129-05, “Standard Practice for Data Collection for Sustainability Assessment of Building Products”.


Do these standards accurately reflect the longevity of masonry materials?
Example of an Industry Association Publication

Brickwork is durable and . . .
Brick building can be and are reused. . .

However, Tech Note 15 seems to discourage use of salvaged bricks.

People in 1886 took bricks from the ruins for construction of their buildings.
All About Clay Bricks

Prof. James Campbell’s Book
Has Been Available for About Five Years
The world’s oldest mud bricks were discovered in Jericho near the Dead Sea (about 8300 to 7600 BC) with dimensions of 260 X 100 X 100 mm. Later bricks from the same site were longer and flatter (400 X 150 X 100 mm). The picture above shows an image from the Tomb of Rekh-mi-Re (1450 BC). The Egyptian bricks contained straw to strengthen the bricks and to reduce drying shrinkage from the alluvial clays.

*These were possibly the world’s FIRST composite materials.*
First Fired Bricks – Mesopotamia

The earliest fired bricks were found in Mesopotamia (Iran) made about 5000 BC and used to form a drain. Pottery was developed about 7000 – 6000 BC.

Thus, water resistance (“durability”) was a first reason to make fired bricks, as the area had frequent floods.

Nevertheless, records from 2003 BC indicate fired bricks were 30 times more expensive than mud bricks.

According to Campbell, “It took a civilization of much greater sophistication to ... afford fired bricks”.

Brickmaking was greatly improved by the Babylonians, who developed glazed bricks. Fired bricks in Babylon remained expensive at about five times the cost of mud bricks.
The Romans

Roman Tomb, 150 AD (Inset – Roman Brick Shapes), Notice the color of the bricks as “salmon”. This led to the tradition of coating bricks with stucco in Southern Europe.
Britain!

Is this a brick masonry building?

THIS IS UNLIKELY!
A large ship could carry about 6000 bricks. While bricks were imported into New York, particularly from Holland (yellow and black bricks), most claims of imported bricks seem to be claims of a status symbol coveted in the 1700’s. See Houses of Bricks Imported from England (1904).
Fire Resistance Becomes a Great Motivator: London (1666), Charleston (1861), Chicago (1871), Clemson (1894), San Francisco (1906), etc.
Beginnings in Charleston

Loading Levy at Lexington Plantation
Something Old/Something New

• To understand “Greenness” of brick masonry, you first consider the proven durability of fired bricks. Buildings 2000-3000 years old are still standing.

• Early motivation to use fired clay bricks included durability – water resistance and fire resistance.

• The Romans perfected brickmaking – establishing methods to make durable brick for Northern Europe by firing them “harder”.

• A thriving brick industry developed in South Carolina in the 1700’s along the coast.
Questions on Part I?
USC Grad Students Make Bricks on Lexington Plantation

One goal of this project was to illustrate methods to make restoration bricks for Fort Sumter National Monument. Students - Sarah Swinney and Lee Durbetaki.
Sarah and Lee were doing a special project for Dr. Bob Weyeneth, Professor of History, Director – Public History Program, University of South Carolina.
Skove Kiln, Photo in the Charleston Museum

Skove Kiln, Colonial Williamsburg

Sarah and Lee’s Bricks in a Kiln at Clemson
USC Student’s Bricks

Wall at Fort Sumter
Questions on Part 2?
### Part 3
### Some Key Properties of Bricks

<table>
<thead>
<tr>
<th>Property</th>
<th>Originates From</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>Partial vitrification in firing.</td>
<td>Load bearing capacity. Indicated by “ring” or “thud”.</td>
</tr>
<tr>
<td>Absorption</td>
<td>Porosity in the fired brick.</td>
<td>Assists in mortar adhesion, but excessive absorption leads to durability concerns.</td>
</tr>
<tr>
<td>Color</td>
<td>Mineral constitution of the brick (chemical analysis).</td>
<td>Red bricks contain hematite ($\text{Fe}_2\text{O}_3$), black bricks contain magnetite ($\text{Fe}_3\text{O}_4$), and yellow bricks (lime). White bricks contain little iron oxide.</td>
</tr>
<tr>
<td>Soluble salts</td>
<td>Soluble constituents in the fired brick (or mortar).</td>
<td>Discoloration called efflorescence.</td>
</tr>
<tr>
<td>Durability</td>
<td>Too many “fine pores” in the brick (Those generally less than about 5 microns).</td>
<td>Freezing of water or salt saturated brick causes “spalling” in the wall.</td>
</tr>
<tr>
<td>Property</td>
<td>Bricks Made Before ~1900</td>
<td>Modern Molded Bricks</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>--------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Compressive Strength (CS), psi</td>
<td>Commons: 2000-4000</td>
<td>5293 Average (σ=1822 psi)</td>
</tr>
<tr>
<td></td>
<td>Facing Bricks: 4500-6800</td>
<td></td>
</tr>
<tr>
<td>Cold Water Absorption (CWA), %</td>
<td>Commons: 7 – 16</td>
<td>&lt; 14 (implied); Have different specs for SW and MW bricks.</td>
</tr>
<tr>
<td></td>
<td>Facing: 7 - 15</td>
<td></td>
</tr>
<tr>
<td>Boiling Water Absorption (BWA), %</td>
<td>Commons: 9-23</td>
<td>&lt; 17 (average) and &lt; 20 (for any individual unit)</td>
</tr>
<tr>
<td></td>
<td>Facing: 11-19</td>
<td></td>
</tr>
<tr>
<td>CWA/BWA (C/B or S)</td>
<td>Commons: 0.67-0.93</td>
<td>&lt; 0.78 Average</td>
</tr>
<tr>
<td></td>
<td>Facing 0.66-0.91</td>
<td>&lt; 0.80 (for any individual unit)</td>
</tr>
</tbody>
</table>

Durability concerns for old brick usually involve high absorptions and high CWA/BWA.
Brick are fired to develop a glass phase that serves to bond particles together permanently. This phase is primarily responsible for the durability of bricks.

Bricks are *first characterized* by their absorption properties (cold water absorption or CWA and boiling water absorption or BWA).

The ratio CWA/BWA or C/B reflects the pore structure of the brick and is related to freezing and thawing durability.

Most people are very concerned with compressive strength. It requires further consideration.
Compressive Strength is measured by loading the brick to failure (left).

The compressive strength is the load at failure divided by the area of the loaded face.

In the process, the brick tends to slightly become “pancake shaped” resulting in tensile cracking.

Most old hand-made bricks have a compressive strength of 2000 – 3000 psi (lb/in²). The reason for the range in properties is the uneven heat distribution in skove kilns. It was the usual practice to sort bricks by color and/or “ring” with light colored bricks called “commons” – for use in interior locations. The bricks that had experienced higher temperatures were classified as facing bricks and always used on the exterior. The average load on individual bricks in a wall is less than 25 psi (1.25% of strength).

There is no exact relationship between durability and compressive strength! Usually the durability is best estimated using the water absorption characteristics.
Other Brick Considerations in Restoration:

*Modulus of Elasticity* – the ratio of stress to strain or an index of “stiffness”; Restoration bricks should *not be* stiffer than the majority of bricks on the structure. The method of forming and the degree of firing affect stiffness.

*Water Vapor Permeability* – the rate of vapor transmission is usually high in old bricks due to their high porosity. Very dense bricks, called “clinkers”, or paving bricks usually have low water vapor permeance. This property is estimated by some people using an index called “capillarity”.

*Color* – it is obvious that restoration units must match the color of bricks in the host structure. Color differences are easily noticed.

*Surface Texture* – hand molded bricks have a surface texture unlike any machine made bricks.

*Dimensions/Out of Square* – an obvious match is required.

*Thermal Expansion* – the bricks on Ft. Sumter have twice the thermal expansion of normal clay bricks due to their very high sand content.
Most Clays Darken As Temperature Is Increased
The reason is the chemical change transforming red iron oxide progressively into black iron oxide.

Brick produced before ~1900 exhibited a wide range in color due to the non-uniformity of temperature in updraft kilns, i.e. clamps or field kilns. Color is thought to reflect quality of bricks – as in English “Engineer bricks” that are typically “blue-black” in color.

\[
\text{Fe}_2\text{O}_3 \xrightarrow{\text{heat}} \text{Fe}_2\text{O}_3 + \text{Fe}_3\text{O}_4
\]

Color darkening can be accomplished with temperature AND flashing.

*hematite*

*magnetite*
Questions on Part 3?
What is a Mortar? A mortar is a mineral mixture with water forming a cohesive mass, which when applied to masonry units develops strength or hardens through chemical and physical processes.

Functions of a Mortar:
• Assuring a uniform stress distributed over “rough” brick surfaces.
• Leveling
• Adhesion
• Filling Gaps between Masonry Units
• A sacrificial component of brick masonry from a restoration perspective

Is Mortar Required in Masonry Construction? Most cathedrals in Europe were constructed without mortar before 800 AD – the stones used were so perfect in dimension that they were simply set one on top of another. Later, mortar became important for leveling of courses in masonry units of imperfect dimensions. It is reported that mortar was used in construction of the Great Pyramids to minimize the chances that Egyptian workers would break their toes.
## Filler + Plasticizer + Binder + $H_2O = Mortar$

<table>
<thead>
<tr>
<th>Filler</th>
<th>Plasticizer</th>
<th>Binder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provides “body”, compressive strength, and limits shrinkage.</td>
<td>Provides “flow” or “spread ability” (using a trowel).</td>
<td>Provides permanent strength or “hardens”.</td>
</tr>
<tr>
<td><strong>Materials:</strong></td>
<td><strong>Materials:</strong></td>
<td><strong>Materials:</strong></td>
</tr>
<tr>
<td>Sand</td>
<td>Clay</td>
<td>Natron, Pozzolan, Gypsum/Anhydrite, Ash, Feces, Resin/tar, Lime, Portland cement</td>
</tr>
<tr>
<td>Shells</td>
<td>Lime</td>
<td></td>
</tr>
<tr>
<td>Rock dust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brick fragments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sawdust</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Proportions by volume:**

3-7 Parts  +  $\frac{1}{4}$-2 Parts  +  0.1-1.0 Parts

**Filler**  **Plasticizer**  **Binder**
Mortar Properties

- Compressive Strength
- Density/Porosity/Pore Size Distribution
- Modulus of Elasticity
- Water Vapor Transmission/Permeability
- Chemical Composition
- Mineralogical Composition
- Color
- Chemical Resistance/Salt Resistance
- Thermal Expansion
**Mortar – Historical Overview**

Ancients made “*terras mortars*” using *natron* (sodium carbonate), silt, and stone dust. This mixture “set” or hardened when mixed with water. It is known that natron was scooped from dry lake beds in Egypt. Gypsum mortars were also known in antiquity.

Romans used *pozzolanic mortar*, i.e. mortar made from calcerous clays that had been exposed to heat – either naturally (volcanic activity) or by man. They also developed lime based mortar for use when pozzolanic clay was unavailable. *Tabby mortars* were used in the coastal area until burnt lime became available.

Lime based mortars were used, especially after the industrial revolution, until Portland cement was developed in the 1800’s. Portland cement was not widely available in the United States until after the 1970’s.

Limestone or sea shells (CaCO$_3$) are “burned” in a pit or a kiln, the latter sometimes called a “shaft kiln”, to a temperature of at least 800°C (1475°F) to produce lime (CaO). The lime is mixed with sand and water to constitute the mortar. It “sets” on reaction with CO$_2$ in the atmosphere. 

*A good example of a colonial lime kiln can be seen at the Santee Canal Park.*
**Tabby Mortar**

Tabby mortar was used at the Dorchester Historic Site at the navigable headwaters of the Ashley River (town founded 1697). Records show transport of burnt shells (lime) and shells (as aggregate) upriver.

*Tabby foundation with bricks and tabby mortar under door opening; Ruins of the Sams Plantation House (1786), Dataw Island, SC.*
Lime putty – hydrated lime or Ca(OH)$_2$ formed by mixing burnt lime or CaO with water. The colonial practice was to store lime putty for a substantial period prior to use to ensure good hydration. The Romans stored it for five years prior to use.

Lime achieves a set condition by reacting with atmospheric carbon dioxide or CO$_2$ forming a binder phase in mortar (binding sand particles and creating adhesion to masonry units) via:

$$\text{Ca(OH)}_2 + \text{CO}_2 = \text{CaCO}_3 + \text{H}_2\text{O}$$

This “recarbonation” is a slow process slowing down the pace of construction. Lime putty is available from the Virginia Lime Works in the USA.
Natural Hydraulic Lime – a product of burning argillaceous or siliceous limestone followed by slaking with or without grinding as may be necessary. They set by forming pozzolanic compounds as well as calcium carbonate.

The grades “2”, “3.5”, and “5” indicate the compressive strength developed in 28 days in Newtons/mm² (MPa). For reference, 2MPa, 3.5 MPa, and 5MPa correspond to 290 psi, 508 psi, and 725 psi respectively. This is much faster strength development than for lime putty mortars; yet it is “slow” by modern construction standards.
Natural Cement – Rosendale (Pre Civil War)

- 1817, natural cement rock discovered during the Erie Canal construction.
- 1824, Joseph Aspdin “invents” portland cement in the UK.
- 1825, natural cement rock discovered at Rosendale, NY. Rosendale becomes the dominant natural cement, although it was produced elsewhere.
- 1871, portland cement produced at scale in Coplay, PA.
- **1970, last or original Rosendale quarries closed.**
- 2004, Rosendale reintroduced by Edison Coatings.

Natural cement was based on the existing experience with HHL in Europe. The rock had a chemistry providing for pozzolanic reactions and hydration of belite ($C_2S$) – like NHL. The natural cement in the USA also contained a significant iron oxide content making it more resistant to salt attack than lime putty or NHL. It had a much higher hydration rate than lime putty or NHL (especially 3.0) allowing for faster construction.
<table>
<thead>
<tr>
<th>Species</th>
<th>Natural MD</th>
<th>Natural NY*</th>
<th>Range for NY in References**</th>
<th>Contemporary Rosendale</th>
<th>OH PC</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>36.50</td>
<td>27.8</td>
<td>33-60</td>
<td>28.19</td>
<td>63.09</td>
</tr>
<tr>
<td>MgO</td>
<td>11.93</td>
<td></td>
<td>12-21</td>
<td>0.36</td>
<td>1.16</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>11.23</td>
<td>5.50</td>
<td>5.5-10</td>
<td>4.84</td>
<td>5.91</td>
</tr>
<tr>
<td>SiO₂</td>
<td>29.92</td>
<td>27.8</td>
<td>27-33</td>
<td>51.24</td>
<td>21.86</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>4.78</td>
<td>4.3</td>
<td></td>
<td>0.28</td>
<td>2.45</td>
</tr>
<tr>
<td>TiO₂</td>
<td>--</td>
<td>--</td>
<td></td>
<td>0.14</td>
<td>--</td>
</tr>
<tr>
<td>K₂O</td>
<td>--</td>
<td>--</td>
<td></td>
<td>0.26</td>
<td>--</td>
</tr>
<tr>
<td>Total</td>
<td>94.36</td>
<td>94.32</td>
<td>85.31</td>
<td>94.47</td>
<td></td>
</tr>
<tr>
<td>CaO/SiO₂</td>
<td>1.22</td>
<td>1.28</td>
<td>&gt;1.0</td>
<td>0.55</td>
<td>2.89</td>
</tr>
</tbody>
</table>

Charles Wallace Howard, born in 1811, was a nineteenth century renaissance man: scholar, clergyman, writer, agronomist and geologist. He was a graduate of Franklin College and the Theological Seminary at Princeton, New Jersey.

In 1850, Reverend Howard founded the Howard Hydraulic Cement Company near Kingston. The quality of his natural cement had a national reputation and was used to build the East River Bridge in New York City, the Union Depot in Chattanooga, and buildings at Shorter College, to name only a few.

After the Civil War, Rev. Howard devoted his life to researching topics relevant to the economic growth of this area, writing many influential articles on minerals, coal, agriculture and livestock. Reverend Howard died in 1876 at his second home on Lookout Mountain. He is buried in the family cemetery at Spring Bank.
<table>
<thead>
<tr>
<th>Species</th>
<th>Natural MD</th>
<th>Natural Rosendale</th>
<th>Range for NY in References</th>
<th>Howard Georgia</th>
<th>OH PC</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>36.50</td>
<td>27.8</td>
<td>33-60</td>
<td>48.18</td>
<td>63.09</td>
</tr>
<tr>
<td>MgO</td>
<td>11.93</td>
<td></td>
<td>12-21</td>
<td>15.00</td>
<td>1.16</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>11.23</td>
<td>5.50</td>
<td>5.5-10</td>
<td>3.35</td>
<td>5.91</td>
</tr>
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<td>27-33</td>
<td>22.58</td>
<td>21.86</td>
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<tr>
<td>Fe₂O₃</td>
<td>4.78</td>
<td>4.3</td>
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<td>7.23</td>
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<tr>
<td>TiO₂</td>
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<td>--</td>
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<td>--</td>
</tr>
<tr>
<td>K₂O</td>
<td>--</td>
<td>--</td>
<td></td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Total</td>
<td>94.36</td>
<td>94.32</td>
<td></td>
<td>96.34</td>
<td>94.47</td>
</tr>
<tr>
<td>CaO/SiO₂</td>
<td>1.22</td>
<td>1.28</td>
<td>&gt;1.0</td>
<td>2.13</td>
<td>2.89</td>
</tr>
</tbody>
</table>
Example: Ft. Sumter Material
Summary: Mortar, Sample 5
Left flank exterior sample C bedding mortar

### Mortar Chemistry

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃</td>
<td>0.98</td>
</tr>
<tr>
<td>SiO₂</td>
<td>66.85</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.49</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.01</td>
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<tr>
<td>MgO</td>
<td>7.44</td>
</tr>
<tr>
<td>CaO</td>
<td>0.59</td>
</tr>
<tr>
<td>Na₂O</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.57</td>
</tr>
<tr>
<td>Sum of Major Constituents</td>
<td>88.11</td>
</tr>
<tr>
<td>LOI</td>
<td>11.55</td>
</tr>
</tbody>
</table>

### Sand Chemistry

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>SiO₂</td>
<td>97.27</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.71</td>
</tr>
<tr>
<td>TiO₂</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>MgO</td>
<td>0.60</td>
</tr>
<tr>
<td>CaO</td>
<td>0.69</td>
</tr>
<tr>
<td>Na₂O</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.11</td>
</tr>
<tr>
<td>Other MnO</td>
<td>0.01</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.24</td>
</tr>
<tr>
<td>S</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

### Mortar Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Density, g/cm³</td>
<td>1.32</td>
</tr>
<tr>
<td>Apparent Porosity, %</td>
<td>44.1</td>
</tr>
<tr>
<td>Percentage ≤1μ Pores</td>
<td>29.4</td>
</tr>
</tbody>
</table>
Portland cement (often referred to as OPC, from Ordinary Portland Cement) is the most common type of cement in general use around the world because it is a basic ingredient of concrete, mortar, stucco and most non-specialty grout. It is a fine powder produced by grinding Portland cement clinker (more than 90%), a limited amount of calcium sulfate (which controls the set time) and up to 5% minor constituents (as allowed by various standards). As defined by the European Standard EN197.1:

Portland cement clinker is a hydraulic material which shall consist of at least two-thirds by mass of calcium silicates alite and belite ($3\text{CaO}.\text{SiO}_2$ and $2\text{CaO}.\text{SiO}_2$ respectively), the remainder consisting of aluminum- and iron-containing clinker phases and other compounds. The ratio of CaO to SiO$_2$ shall not be less than 2.0. The magnesium content (MgO) shall not exceed 5.0% by mass. (The last two requirements were already set out in the German Standard, issued in 1909).

Portland cement clinker is made by heating, in a kiln, a homogeneous mixture of raw materials to a sintering temperature, which is about 1450 °C for modern cements. The aluminum oxide and iron oxide are present as a flux and contribute little to the strength. For special cements, such as Low Heat (LH) and Sulfate Resistant (SR) types, it is necessary to limit the amount of tricalcium aluminate (3CaO.Al$_2$O$_3$) formed. The major raw material for the clinker-making is usually limestone ($\text{CaCO}_3$) mixed with a second material containing clay as source of alumino-silicate.

Normally, an impure limestone which contains clay or SiO$_2$ is used. The CaCO$_3$ content of these limestones can be as low as 80%. Second raw materials (materials in the raw mix other than limestone) depend on the purity of the limestone. Some of the second raw materials used are: clay, shale, sand, iron ore, bauxite, fly ash and slag. When a cement kiln is fired by coal, the ash of the coal acts as a secondary raw material.

Two factors have facilitated use of modern Portland Cement in construction: (1) The widespread availability of limestone for its production and (2) the rapid setting of the material to speed construction.

In 28 days, Portland cement based mortars reach at least 60% of their ultimate strength.
OPC Mortars are Mixtures of Cement, Sand, and Lime

Quick Generalities about OPC mortars
• Strength increases as the cement content increases.
• The Modulus of Elasticity (rigidity) increases as the cement content increases.
• The workability of the mortar increases as the lime content increases.
• The mason is a “technique sensitive” human being – *only dentists are more extreme*.

<table>
<thead>
<tr>
<th>Type</th>
<th>Parts Cement</th>
<th>Parts Lime</th>
<th>Parts Sand</th>
<th>28-day Strength, psi (N/mm(^2))</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>1</td>
<td>¼</td>
<td>3</td>
<td>4800-5400 (33-37)</td>
<td>General use; foundations, sidewalks, in contact with ground.</td>
</tr>
<tr>
<td>S</td>
<td>1</td>
<td>½</td>
<td>4.5</td>
<td>2100-2800 (14-19)</td>
<td>Resistance to lateral shear.</td>
</tr>
<tr>
<td>N</td>
<td>1</td>
<td>1</td>
<td>6</td>
<td>800-1200 (5.5-8)</td>
<td>General use severe exposure above grade.</td>
</tr>
<tr>
<td>O</td>
<td>1</td>
<td>2</td>
<td>9</td>
<td>&lt;1000 (&lt;7)</td>
<td>Low strength load bearing walls.</td>
</tr>
</tbody>
</table>

For comparison, 28-day strength of NHL mortars is about 0.3 N/mm\(^2\) (3.0), 1.0 N/mm\(^2\) (3.5), and 3.0 N/mm\(^2\) (5.0).
Jahn Facts:
• Developed in the Netherlands.
• Favored on continental Europe (but NOT in the UK).
• An outgrowth of “Dutch “Glue Mortar” (a finer particle size pumpable mortar product).
• Contains portland cement and substances to encourage pozzolanic reactions, i.e. possibly fly ash/fumed silica.
• 28 day strength of 3000-3800 psi (21-26 N/mm²).
• Porosity can be varied in the range 4% - 16% to deal with vapor permeability.
“Masonry cement - a hydraulic cement, primarily used in masonry and plastering construction, consisting of a mixture of portland or blended hydraulic cement and plasticizing materials (such as limestone, hydrated, or hydraulic lime) together with other materials introduced to enhance one or more properties such as setting time, workability, water retention, and durability.” ASTM C91-05.

GLOSSARY

Hydraulic cement – substances that chemically react with water to form a solid mass. The reaction is influenced by temperature and pH of the water.

Portland cement – forms compounds of lime, silica, and water on setting.

Blended cement – “other” hydraulically setting phases with portland cement. These “other” phases might be by-products of portland cement production.

Plasticizers – limestone, lime, and other minerals – some partially soluble.

Other materials – primarily substances that provide air entrainment.
About Efflorescence

- Efflorescence is a discoloration due to the deposition of soluble salts on the surface of a masonry wall during a “drying period”.
- Wetting is essential for efflorescence to develop – more water is usually linked to more efflorescence.
USE CARE! I do not recommend use of masonry cements or mortar cements in ANY historic preservation and restoration effort without careful laboratory evaluation of its efflorescence potential.
**Properties of Field Produced and Cured Historic Mortar**

<table>
<thead>
<tr>
<th>Mortar</th>
<th>Bulk Density g/cm³</th>
<th>Apparent Porosity, %</th>
<th>% Pores &lt;1µ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rosendale 1:3:3 (#9)</td>
<td>1.72</td>
<td>30.0</td>
<td>80.4</td>
</tr>
<tr>
<td>OPC 2:1:6 (#5)</td>
<td>1.95</td>
<td>19.8</td>
<td>84.0</td>
</tr>
<tr>
<td>Jahn (#10)</td>
<td>1.59</td>
<td>34.5</td>
<td>94.0</td>
</tr>
</tbody>
</table>

**Modern Mortar (cement/lime/sand)**

- Type M: 1:¼ :3
- Type S: 1:½:4.5
- Type N: 1:1:6
- Type O: 1:2:9

---

**Implied Vapor Permeance**

Mosquera, et. al., report vapor permeance of mortars of similar porosity and similar fraction of pores <1µ to be in the range of 3-5.4 (X10⁻⁶ m²/s). The fraction of pores less than one micron influenced vapor permeability in a more significant amount than quantity of porosity. Mosquera found lime putty to be 5-6 times more permeable than cementitious mortar or NHL. (See “Addition of cement to lime based mortars: effect of pore structure on water transport”, Cement and Concrete Research 36 (2006) 1635-1642.

The results imply similar vapor permeabilities when comparing modern Rosendale mortars with OPC based mortars. Since hand molded bricks have much larger pores than the mortars, the high attention to vapor permeance may not be *always* justified.
## Comparison of Mortar Strength and Rigidity

<table>
<thead>
<tr>
<th>Material</th>
<th>Compressive Strength, psi</th>
<th>MOE, ksi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ft. Sumter Bricks</td>
<td>1235-1440</td>
<td>508-1160</td>
</tr>
<tr>
<td>OPC mortars*</td>
<td>1865 @ 7 days 1:1 cement/sand</td>
<td>1923-3571</td>
</tr>
<tr>
<td>Natural cement mortars*</td>
<td>85-210 @ 7 days</td>
<td>1667-2500</td>
</tr>
<tr>
<td>Rosendale mortars**</td>
<td>1020 @ 28 days 1:1 cement/sand</td>
<td>535-640</td>
</tr>
<tr>
<td>Jahn mortars (M110)</td>
<td>370 and higher (Type O)</td>
<td>105-155</td>
</tr>
</tbody>
</table>

*Cement and Concrete by L.C. Saban (1907); Ft. Sumter brick data by Brosnan; Other data from manufacturer.

Any mortar containing lime is likely to be weaker and less rigid than the existing Charleston Grey bricks on Ft. Sumter. Pointing mortar, HOWEVER, based on OPC and sand can be stronger and more rigid than the bricks.
Reasons Not to Love PORTLAND

• It’s not historically original! (But is today’s Rosendale authentic?)
• It is too rigid - high Modulus of Elasticity! (But the same may be true for historic Rosendale).
• It is not permeable to water vapor! (But all mortars are permeable to water vapor).
• Rosendale is a natural cement – like Roman cement! (But portland cement is based on a similar chemistry idea – cement hydrates in the lime-alumina-silica chemical “system” provide strength.)
Masonry Assemblies

Wood Frame Structure with Brick Veneer. Technically: Drainage Wall Construction

Load Bearing Wall Sheldon Church Technically: Barrier Wall Construction
Tests For Brick Assemblies

Flexural Strength, E 518 and C 1072

Water Penetration, E 514

Freezing and Thawing Resistance
(British Panel Test)

Fire Resistance

Shear Strength, E 518 (In-Plane)

Strength and Deformation (Out-of-plane)

Modulus of Elasticity

Heat Storage and Transmission

Pull Out/Penetration/Impact Tests (Fixtures)

Creep

Questions on Part 4?
Case Studies

POMPION HILL CHAPEL

One quarter mile north, the first Church of England edifice outside of Charleston, was erected of Cypress in 1703, largely through the efforts of Gov. Sir Nathaniel Johnson. The present brick structure was erected in 1763. The parish of St. Thomas, of which this was a chapel of ease, was established by Act of Assembly, Nov. 30, 1706.
The solubility of calcium carbonate in water is 0.0014 grams in 100 cubic centimeters. This is sufficient for the long-term destruction of the carbonate phase in lime based mortars. Salts from ground water or sea water exacerbate the solution of the lime. This is frequently seen when there is pooling of water in a foundation.
Calcium carbonate decomposes before 1775°F. Modern engineers think this destroys the mortar joint. What they don’t know is that the mortar will “re-carbonate” given enough time. It was common practice prior to WWII to re-use the load bearing shell of a building after a fire.
Wind

Over 150 years of exposure to airborne sand particles created a “sandblasted” look to the face of Ft. Sumter. Hard “chert nodules” (black) stand out from the softer vitrified continuum in the bricks. Paving brick standards reference a “sandblasting” test for bricks (C 418), but there is no data for bricks in the technical literature.
Salt laden water has removed the carbonate phase (now seen as “black holes”).
The key observation is that the CALCIUM in masonry comes from the mortar. Therefore, mortar more resistant to salt attack preserves both the mortar and the brick.
Cryptoflorescence

Failure - Bricks

This type of failure illustrates the role of pointing mortar in failures. The dissolved calcium has precipitated in cracks on the edge of the brick formed by cryptoflorescence and mechanical processes. The face of the brick bows outward and pops off. It is also called “scaling”.

The presence of ettringite suggests subsurface expansion that can damage the bricks.

Cubic salts in center (Ca Present)

Ettringite near edge in brick. (calcium sulfoaluminate)
Movements; Imposed Stress

It is fairly common to see cracks in the mortar joint where foundation subsidence provides a “familiar” stepwise crack up the masonry (below).

On a corner, forces where walls meet may cause fractures through bricks suggesting movements were caused, in part, by thermal expansion of the walls.
Dissimilar Materials (Different Modulus of Elasticity)

The Cannery, San Francisco (1907)
Replacement Bricks at High Elevation
The 1907 brick was hand molded, and contains some mineral phases only attributable to the San Francisco area.

The 1967 replacement bricks were hand molded and did not meet ASTM C 216 SW property values suggesting they were of Mexican origin.

Did the restoration architect choose authenticity over engineering common sense?
Pointing – periodic replacement of surface mortar is required to maintain effective barriers to the elements. Pointing mortars are lightly “sanded” to form a smooth surface.

An “original” pointing mortar at Ft. Sumter national Monument contained Rosendale cement, lime, and sand in volumetric proportions:

1 (cement) : 1 (lime) : 0.5 (sand)

P = pore;  L = lime agglomerate;  C = cement agglomerate,  Py = pyrite.
Coating Historic Bricks

Searls Hall, Bowdoin College, ME  Built (1844-55)
What Caused the Salt Staining on Searls Hall?

The investigation found:
• The building was painted in the 1950’s because of its light color.
• Limestone and ash relics in the brick composition contributing to soluble calcium within the bricks.
• 13.8% CaO on the brick surface (<3% in the bricks).
• 8861 ppm of soluble sulfate (SO₄) in the Searls Hall mortar.
• The salt deposit is comprised primarily of calcite or CaCO₃.

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Specimen B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al₂O₃</td>
<td>25.61</td>
</tr>
<tr>
<td>SiO₂</td>
<td>55.75</td>
</tr>
<tr>
<td>Na₂O</td>
<td>3.00</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.20</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>5.85</td>
</tr>
<tr>
<td>MgO</td>
<td>3.65</td>
</tr>
<tr>
<td>CaO</td>
<td>2.85</td>
</tr>
</tbody>
</table>
Can you Insulate Load Bearing Walls in a Building from the 1800’s?
Will Face Cracks Cause My Building to Fall Down?
Authenticity Versus Engineering

Beaverdam Baptist Church
Mountville, SC
(Built before the Civil War up to eves; Finished after the Civil War). Did the kiln fireman survive the war?
Mortar Performance Tests: Immersion Cycles with Expansion and Soluble Salt Measurements - 2009

- Specimens field fabricated, cured 7 days @ 70F at 100% RH, also cured 7 days at 70F in 100% CO₂.

- Best performers in sea water immersions for Ca removal: Rosendale mixes and Jahn

- Low expansion: Rosendale and Jahn equivalent.

- Performance in Sodium Sulfate: Rosendale and OPC similar. Jahn best!

- Lime putty intermediate in Ca leaching but high expansion.

- Worst Performer in Sea Water: NHL
Questions on Part 5?
A Little Review on “Greenness” and South Carolina Brick Masonry

• Brick masonry is GREEN because of its proven longevity. Fired bricks date back to 5000 BC. Brick masonry from the colonial period in America survives!

• Bricks were made by societies because of their durability and fire resistance.

• Brick masonry needs periodic maintenance, and “best practices” need to be logically developed for historic buildings.

• A new generation of architects is focused on sustainability. This is driving us to build “green” institutional structures. Our society needs to find ways to make green residential buildings affordable.
A Little South Carolina Mystery
Why three different bricks in the firebox?