THE MORTAR STORY

CHRONOLOGICALLY,

the OPC[1] Era, what might be called the Pseudolithic Age, is a mere blip on the long and honorable historic continuum of the use of lime mortar in masonry structures.

VOLUMETRICALLY,

however, it is a monstrous phenomenon that has pushed aside the traditional ways of building with stone and brick and come to dominate the masonry aspect of the contemporary construction industry. Cement based mortars, CMUs (concrete masonry units) and reinforced concrete are the norm. Stone, once a Primary building material has largely been reduced to a Tertiary role; not structural, but something applied to structures: cladding.

The current dominance of OPC extends not only beyond the horizon, into the foreseeable future, but it has infiltrated the past by its indiscriminate use on historic structures—to detrimental effect, and in many cases severe detrimental effect.

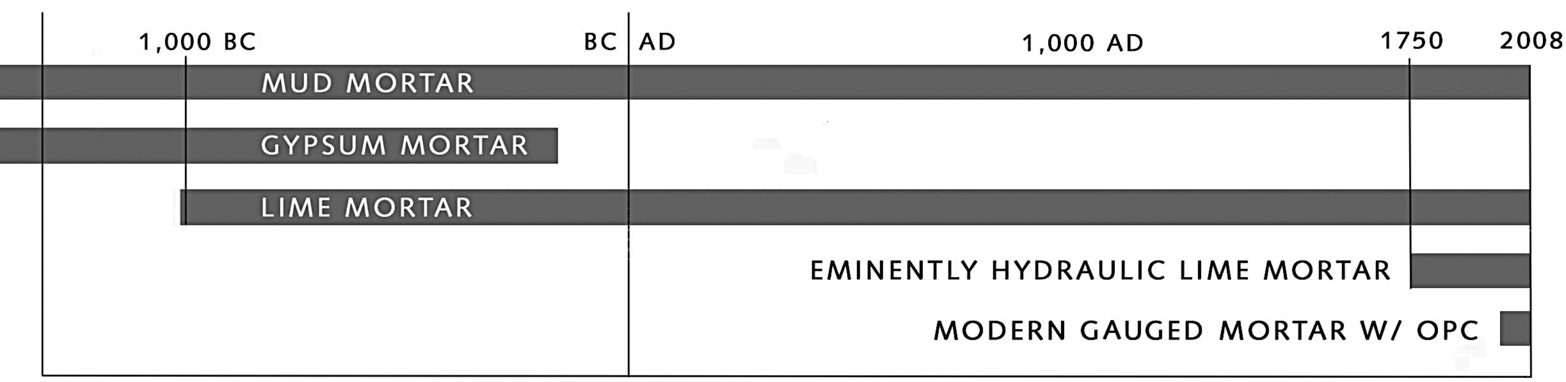
The OPC Monster has BAD breath. The manufacture of cement and lime accounts for 10% of the entire world's contemporary carbon emissions. It must be said, however, that making hydraulic lime and quicklime requires less heat and produces less carbon dioxide. And, to their credit, lime mortars readsorb carbon from the atmosphere as they set and harden, through the process called carbonation, thus ameliorating harm to the environment .

As the drawbacks of modern mortars have become evident, the values of traditional lime mortars are being rediscovered and they are once again being used, particularly in restoration work, and in new construction as well. As might be expected, this is happening to a greater extent in Europe than in America, but the New World is also realizing the value of Old Style mortars, realizing that they make sense: structural, ecological, even economical sense. What costs less—in labor and materials—is not, in all ways, best (nor, to be sure, is what costs most.)

At STONEWORK SYMPOSIUM 2006, the Stone Foundation's annual gathering that year in Hood River Oregon, Blair Bates, restoration contractor and loyal SF member, delivered a presentation on "The Mysteries of Mortar" that was interesting and intriguing and in less that an hour provided more information than one could possibly take in. An article in these pages was called for and Blair's response follows here, augmented by consultation with Patrick McAfee, Mark Liebman and others, as well as a distillation of the fruits of my own research.

First, a History Lesson:

MORTAR TIME LINE CHART



It can be said that masonry began when mud was used as mortar unifying blocks, bricks and stones to form a regular, composite mass.

Over the ages, other indigenous materials were combined to create mortar. The Babylonian and Sumerian masons mixed naturally occurring bitumen with clay, certain earths and plant fiber. Masons in Mycenean Greece had a bituminous clay at their disposal.

Cooking food must have been the first way by which early man altered the chemistry of substances for a practical purpose. Cooking rocks may have been the second. Egyptian masons early on learned to burn gypsum and use the resulting material to make mortar and plaster, but lacked the fuel supply to produce the higher heat necessary to render limestone into quicklime. Lime mortar was "born" not in Egypt[2] as is popularly believed, but in Minoan Crete about three thousand years ago. Besides combining slaked lime with aggregate to make mortar, Minoan masons added ground fired clay (bricks and tiles) and a more durable mortar evolved.

SO already, here, at a point of origin, the duality of lime mortar is in evidence. Mortars were created that achieved their set in two different ways: by hydration—a chemical reaction stimulated by the water used to mix them; and/or by carbonation—interacting with air, the atmosphere, absorbing carbon dioxide to form stable state calcium carbonate.

The Roman masons, building on what they learned from their Greek neighbors, made a science of the craft. They, who had also used ground fired brick and tile, further transformed the element of mortar by introducing volcanic sand or ground volcanic rock to the lime in precise proportions.[3] These materials are called pozzolans[4] after the volcanic sand from Pozzuoli (a former Greek colony) on the Gulf of Naples. Mortars made in this way did not need air to achieve their set and harden. They can do so under water, which is why we call them hydraulic mortars today. Early pozzolanic mortars were only slightly or moderately hydraulic but they set sooner, were harder and had greater compressive and tensile strength than the non-hydraulic (air) lime mortars.

Lime has continued to be burned for mortar in the western world and elsewhere from the Roman times until now, generally in local kilns still found today, in various stages of ruin, wherever limestone was prevelant.

Then, in the late 18th century British engineers achieved major technological developments that rival gunpowder and the infernal combustion engine in the beneficial yet devastating effects they have had on our world. The brilliant John Smeaton, who was commissioned to (re)build the famous Eddystone Lighthouse on the southwestern tip of England, in his attempt to find the ultimate 'water lime'—they were not called hydraulic limes until French civil engineer, bridge and road builder Louis Vicat applied the term 50 or so years later)—succeeded. He discovered that clay and limestone in certain proportions, those found in Blue Lias limestone, an argillaceous limestone prevalent in England, would, if heated to a certain temperature, produce what we know today as Eminently Hydraulic Lime. It was he, Smeaton, who first likened hydraulic lime to the prized Portland stone, for its solidity and durability and, as well, its color.

Smeaton broke ground for a number of entrepreneurial emulators, inventors who came up with, and took out patents for, marketable products such as "Roman Cement," "British Cement" and "Portland Cement" the latter being a term applied by a bricklayer named James Aspdin to what was simply another eminently hydraulic lime formulation. The discovery of true Portland Cement was due to providential accident on the part of a chemist in the employ of one of Aspdin's competitors. Isaac Charles Johnson (1811-1911) set out to discover Aspdin's carefully guarded secret and in the process accidentally over-fired some clay-bearing limestone past the point where it was transformed into clinker. The clinker was considered worthless and most of it was thrown away, but Johnson ground some and immersed it in water and was amazed to find the resulting material was actually harder than the Aspdin's hydraulic mortar.

And so it began.

T L

The Eddystone Light

[1] OPC = Ordinary Portland Cement.

[2] "The mortar employed in ancient Egypt before Graeco-Roman times was of two kinds depending on the nature of the construction, namely, clay for use with sun-dried bricks and gypsum for use with stone. The former is still used for sun-dried bricks at present day and is still the most suitable material for the purpose, but gypsum is not now employed as a mortar, haven given place to the more recent lime-sand mixture or to the still more modern cement.

No instance of the use of lime mortar in Egypt, or of lime in any form, is known to the author as occurring before the time of Ptolmey I (323 to 285 BC). From this period and from later periods it has however been found and, from the few specimens analysed, it appears to have been, as is only to be expected, of much the same composition as the lime mortar of today."A. Lucas and J. R. Harris.

[3] "If to river or sea sand, potsherds ground and passed through a sieve, in the proportion of one third part, be added, the mortar will be the better for use." Vitruvius, *De Architectura*, 1 BC.

[4] Burnt rice hulls are also a pozzolan.

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NEW VS. HISTORIC MORTARS

by Blair Bates

SO WHAT'S THE DIFFERENCE AND WHAT SHOULD I USE?

In today's modern-paced world there is a continual striving for mortars that are technologically superior to what is currently available. In the rush for improvements, however, we have forgotten many of the durability aspects that thousands of years of history have shown us mortar can provide.

This paper hopes to take the mystery out of mortar mixes and encourage a new appreciation for old style mortars.

WHAT IS OLD (HISTORIC) MORTAR?

It was discovered that when limestone was burnt and then combined with water, it produced a plastic material that would dry and then harden with age. The lime mortar used before the 20th century was simply an aggregate and a binder. The binder was lime, obtained by burning limestone or sea shells. The aggregate was sand or earth. As a binder in masonry construction, lime is generally considered inferior to Portland-cement based mortars, though limestone (calcium carbonate) is a raw material for both.

Lime may be weaker, take longer to set, set in a different way, and require a higher level of skill or understanding to use properly, but it has distinct long-term advantages. These include: greater compatibility with soft materials, good workability, increased initial adhesion, flexibility, greater porosity (breathability) and better weathering properties. The mortar lets moisture out as well as in. Cement mortars lock the moisture in so that the only way it can escape is through the brick or stone, deteriorating it in the process.

Lime mortar is self-healing. Movement in masonry structures may result in large individual cracks where hard cement mortars are used, but lime mortar will develop multiple fine cracks. The lime mortar possesses a unique capability known as *autogenuous healing*, the process whereby free lime in the mortar combines with water and CO_2 from the atmosphere and through carbonization is transformed into calcium carbonate which seals the minute fissures that occur as the mortar flexes.

Old time mortars were used in masonry construction not as glue, but as a gasket or separator between the individual masonry units. The purpose of this gasket (just like in an automobile engine) was to absorb small amounts of movement yet keep the pieces together. It is important to note that, while the lime mortar and masonry unit are not glued together, there is a bond between them and this bond has helped masonry walls to resist expansion and contraction, wind shear, and seismic as well as gravity loads.

Bricks and stones bonded with lime mortars, unlike those glued together with cement mortars, can be recycled.

WHAT IS OLD (HISTORIC) MASONRY CONSTRUCTION?

Until the 19th century, masonry buildings were just that—solid masonry structures. All loads placed on the building were transferred to and through the masonry. In proper stone masonry, the stone was laid to a dry stone standard and properly bonded as the first level of strength with the mortar being used in a subsidiary role—to hold the stones in place and transfer the loads more uniformly. Many historic structures were built with lime/rubble infill between walls of solid masonry. The result was more like a lime concrete, though often little effort was made to consolidate it or insure consistency of the materials.

WHAT IS NEW MORTAR?

New masonry mortars are commonly used in veneer construction for brick and stone buildings.

Initial attempts to use pure Portland cement and sand mortar mixes were quickly discounted due to workability issues. New mortars are designed to a specific performance or proportion criteria known as ASTM C-270. This allows the mortar manufacturer to either use an exact blend of lime and Portland cement or to blend any of a number of materials into the mortar to meet specific requirements. These additives are used to extend or shorten the set time, add waterproofing, increase workability for the mason and to achieve ultimate strength earlier.

Some new developments have resulted in mortars which count on other materials for their workability. There may be little or no lime at all in the mix.

WHAT IS NEW MASONRY CONSTRUCTION?

In modern (post-early 1900's) building, the masonry, once the primary material, is now used as cladding applied to the structural elements, such as steel, wood, cement blocks or concrete, which are hidden underneath it. With such a thin cladding masonry system, the requirements for the mortar are very different from historic masonry, even when the cladding is adhered to structural, load-bearing block construction.

WHAT ARE THE PROPERTIES OF MORTAR?

The properties of mortar that are most important in mix design considerations are:

(1) **The Coefficient of Expansion:** The amount a material moves as a result of temperature change. A 200 foot stone wall that sees an annual temperature low of -20°F and a maximum stone surface temperature of 160°F could expand/contract as much as an inch and a half. Something needs to accommodate this movement. If this movement is not accommodated by the mortar, the wall will crack.

(2) **Compressive Strength:** The ability of the mortar itself to hold a compressive load without failure. This is normally tested at a 28 day strength, which is a standard for Portland cement-based products, but has little relevance to lime based mortars that need time to carbonate, as much as a year per inch.

(3) **Ductility:** Basically, the mortar's ability to deform under stress without failure.

(4) **Porosity:** The mortar's ability to pass moisture through it. In new mortars porosity is minimal. The porosity of old mortars enables the masonry to dry out or "breathe."

(5) **Bond Strength:** The mortar's ability to adhere to the masonry unit, normally measured in psi (pounds per square inch).

(5) **Modulus of Elasticity:** A mortar's ability to allow for minor movements without cracking, an important factor in building without construction joints or expansion joints.

(6) **Tensile Strength:** The mortar's ability to take a tensile (pulling) force without failure.