# Properties of Lime Mortar

## Understanding the Nature of Lime-Sand Mortars

By Margaret Thomson

Stand in the street of just about any major urban center of a North American city, and look around at the buildings. It is very likely that one of those massive stone or brick buildings was built using a mortar consisting of lime and sand – no cement. This realization might bring a structural engineer to contemplate if they could do the same thing today. As with every good engineering question, the answer is a firm maybe.

Modern masonry mortars are composed primarily of portland cement, hydrated lime and sand as aggregate. However, prior to the development of portland cement in 1864 and its introduction and commercial production in the United States in the 1880s, lime-sand mortars were the standard for building construction. In a modern context, lime-sand mortars are still appropriate. Let's explore the nature of a lime-sand mortar in terms of materials, properties and current standard specifications and codes.

### What is Lime?

Lime is a generic term referring to the calcium oxide component of a material. When the term lime is used, it should always be followed by another term. For instance, lime in terms of a rock type is limestone and lime in the context of mortar is quicklime, lime putty and hydrated lime. When a farmer wants to lime his field he will use crushed limestone, and when he wants to white wash or lime wash his dairy, he may use crushed limestone in the form of chalk or may use hydrated lime in a wet slurry. To only say lime is not often enough information. Always think about which lime is being discussed.

To manufacture hydrated lime, one must first calcine (heat) limestone to quicklime, then add water to hydrate the quicklime to get hydrated lime (see *Figure 1*). The phrase quicklime refers to very rapid exothermic reaction that occurs on the addition of water to the calcium oxide (CaO). Once the reaction starts, it is quick and hot.

The added complexity is that not only limestone, which is pure or high in calcium, is calcined to be used for a varied number of applications. The following is a summary of the terms commonly used by United States lime industry for quicklime. The terms are derived from the different rock types.

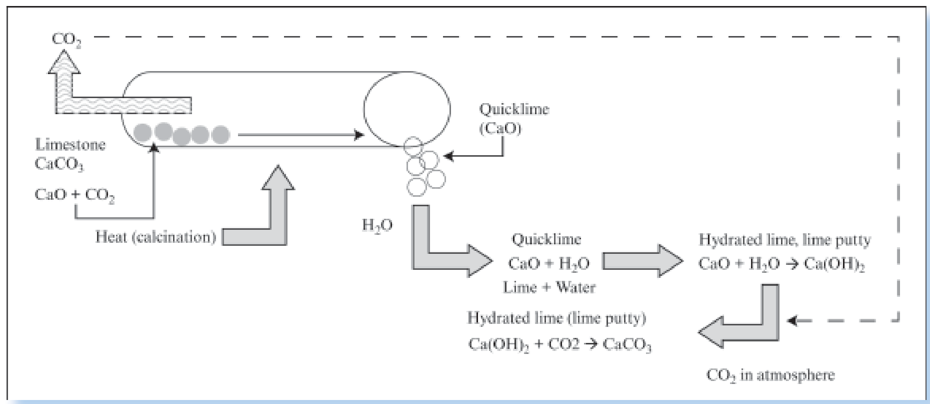


*Figure 1: Simplified diagram of the lime cycle in the context of manufacturing building lime*

- *High calcium quicklime* – derived from limestone containing the mineral calcite and 0 to 5 percent magnesium in the calcite structure ($CaCO_3 \Rightarrow CaO$).
- *Magnesian quicklime* – derived from limestone containing 5 to 20 percent magnesium in the calcite structure ($(Ca(Mg)\ CO_3 \Rightarrow CaO$ + minor $MgO$)
- *Dolomitic quicklime* – derived from the rock dolomite, made up of the mineral dolomite containing the ratio of 40 to 44% calcium and 54 to 58% magnesium ($(CaMg(CO_3)_2 \Rightarrow CaO + MgO$)

Today in the United States, hydrated lime for masonry, stucco and plasters is dominantly from dolomitic quicklime. Lime putty when formed directly from quicklime is dominantly from high calcium quicklime.

### What are the Differences between Hydrated Lime and Lime Putty?

*Hydrated lime* is a dry powder manufactured by water to quicklime only in a sufficient amount to satisfy the chemical reaction of converting the oxides to hydroxides. Depending on the type of quicklime used and the hydrating conditions employed, the amount of water in chemical combination varies, as follows:

- *High calcium hydrated lime (normal)* – atmospheric hydrating conditions produces a powder of calcium hydroxide ($Ca(OH)_2$ ) containing generally 23 to 24 percent chemically combined water.
- *Dolomitic hydrated lime (normal)* – atmospheric hydrating conditions produces a powder of calcium hydroxide ($Ca(OH)_2$) with some magnesium hydroxide ($Mg(OH)_2$), but also some magnesium oxide ($MgO$) component, generally containing 15 to 17 percent chemically combined water.
- *Dolomitic hydrated lime (special)* – pressure (100-150 psi) hydrating conditions produces calcium hydroxide ($Ca(OH)_2$) and magnesium hydroxide ($Mg(OH)_2$) with no magnesium oxide ($MgO$), generally containing 25 to 27 percent chemically combined water.

*Lime putty* is manufactured by adding an excess amount of water to the quicklime. It is a slurry that ranges in consistency from yogurt to a farmer's cheese and may vary in solid content (hydroxide minerals) from 40 to 80%. The source of the quicklime does not differ from that of hydrated lime.

Limestone and dolomite are rocks. While lime producers pride themselves in having very pure carbonate deposits, there are always impurities. These might include iron, clays, which contribute to color variations and other minerals which might produce grittiness. Calcination produces variability within the resulting quicklime, although the objective is to calcine each rock to the same degree. The final processing may involve modification of the upper size fraction by screening, grinding or air separation. All of this leads to variations, which the manufacturer should aim to keep at a minimum.

Converting quicklime to hydroxide is often termed *slaking*. A slaked lime implies that the oxide phases have been converted to hydroxide phases. It does not imply how this was done. There is often considerable confusion about whether or not hydrated lime is slaked. It is! One can also make a lime putty out of hydrated lime powder, and call it a slaked lime putty. There is implication that the very process of slaking quicklime produces a product which is superior to a hydrated lime. Each process can produce high quality building lime.

## What are the Characteristics of Building Lime as Defined by ASTM?

The current ASTM standard specifications for building limes are listed later. Defining, and quantifying properties was completed by the National Bureau of Standards between 1906 and about 1956, and adopted by ASTM in the specifications.

There is a requirement for chemical purity, completeness of hydration, limited coarse fraction, but also key physical properties of water retentivity and plasticity. *Table 1* is a generalized summary of the specifications for Type N (normal) and Type S (special). For specific details please refer to the standard specifications.

The chemical specifications for all are the same. They require that the product contain no less then 95% combined values of calcium or magnesium and not more than 5% carbon dioxide. These dictate that the source rock must be pure and that the calcination must be virtually complete.

For mortar: The coarse fraction for hydrates is limited to not more then 0.5 weight percent held on a 30 mesh screen (600µm). By testing, a small amount of coarse fraction can be tolerated only if it is essentially inert, that is, no pits or pops.

For finishing applications: No more than 0.5% of a 30 mesh screen and no more than 15% on a 200 mesh screen (75µm) and no pits or pops are allowed. It requires that there be < 15% hydrated lime coarser than 200 mesh or 75µm and that there is no component that can cause pits or pops.

Plasticity values over 200 are required within 30 minutes after mixing for Type S hydrated lime and lime putty used for mortar and finishing plaster. Type N hydrated lime must achieve plasticity values of 200 after 16 hours, but less than 24 hours of soaking for the finishing lime and has no requirement for mortar applications.

| Requirement | Type S<br>ASTM C5, C206, C207, C1489 |
|---|---|
| | **Chemical Properties** |
| Calcium and magnesium oxides (non-volatile basis), min. % | 95 |
| Carbon dioxide, min. % | 5 |
| Unhydrated oxides, max. % | 8 |
| | **Physical Properties** |
| No. 30 mesh (600 µm), max. % | .05<br>or if greater<br>no pits or pops |
| No. 200 mesh (75 µm), max. % | no value assigned |
| Pits or pops | Not applicable unless No. 30 mesh > 0.5%, then none |
| Plasticity, min. Emley value | 200 within 30 min. |
| Water retention, min. % | 85 within 30 min. |

*Table 1: Specification Requirements for Type N and Type S Hydrated Lime*

Water retention values are only required for the mortar application. For Type N hydrated lime, a value of 75% must be met after 16, but less than 24 hours of soaking; whereas, the Type S hydrated lime a value of 85% must be met within 30 minutes after mixing. There is no water retention requirement for finishing lime. If the plasticity value is over 200 Emley units, then the water retention value will be greater than 85%.

A Special hydrated lime for finishing purposes can be designated a Type N in either specification, but not vice versa. What makes a Type S hydrated lime different from a Type N is limiting the amount of unhydrated oxides, obtaining a plasticity value of 200 within 30 minutes of mixing and requiring a water retention value of 85%. There is no distinction made based on whether the source is limestone (high calcium), magnesium-limestone or dolomite.

ASTM C1489 *Specification for Lime Putty for Structural Purposes* became a specification in 2000, and is meant to reflect the spirit of ASTM C5 Specification for Quicklime for Structural Purposes. If quicklime is purchased under ASTM C5 qualifications it needs to meet the requirements of C 1489 when slaked to a lime putty.

## Properties of Lime Mortars

Hydrated lime or lime putty will not set under water. It is not hydraulic as is portland cement. For a lime-sand mortar to harden, it must first lose its excess water by suction to the backing material and evaporation to the atmosphere, which makes it stiff, and then carbonate, which makes it harden.

$Ca(OH)_2$ (calcium hydroxide) + $CO_2$ (gas from atmosphere) ⇒ $CaCO_3$ (calcite)

This process has advantages and disadvantages are summarized in *Table 2*.

Lime-sand mortar produces a highly plastic and workable mortar that is prized by masons. With a water retentivity requirement of 85% wet lime will hold on to water, which promotes an even moisture loss due to suction or evaporation.

Over time, lime-sand mortar develops a surface coating of calcium carbonate. This is formed initially, but also tends to build up, as calcium hydroxide saturated water is moved to the surface and carbonates. This surface, often referred as the patina and is almost marble like, provides excellent resistance to water penetration, but allows for vapor penetration (see *Figure 2*). Similarly fine cracks that might developed are filled with a calcium hydroxide

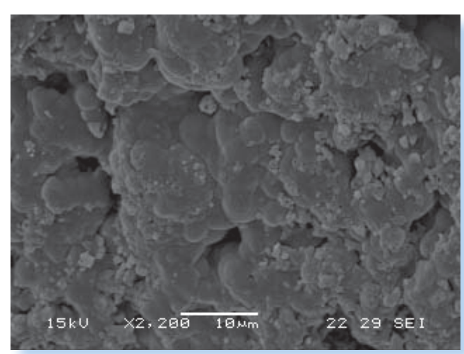


*Figure 2: Scanning Electron Photomicrograph of the calcium carbonate patina on lime-sand mortar. This surface is developed initially but is added to over repetitions of wetting and drying*

| Benefit | Drawback |
|---|---|
| Highly plastic and workable mortar (mason efficiency) | Slow to harden (must carbonate) |
| High water retentivity (brick compatibility) | Low near term compressive strength compared to lime-cement mortars |
| High ductility to joint and massive masonry | Lime bloom |
| High open porosity | |
| Dissolution/reprecipitation (autogenous healing) | |
| No salts to effloresce | |

*Table 2: Lime-Sand Mortar*

saturated solution, and carbonate, autogenous *self-healing* the crack.

The most obvious use of lime-sand mortars is in masonry restoration, particularly for re-pointing, of historic structures which used lime-sand. Older clay bricks which are relatively soft and porous benefit from lime-sand mortars that bear the moisture/vapor transport load, which includes salts, so that the masonry units remain undamaged. Where the masonry unit is very dense stone, lime-sand mortar provides the optimum route for moisture/vapor transport, providing for drainage. For the same reason, lime-sand mortars should always be considered first when exterior stucco is considered for historic masonry.

## Specifying Lime for Masonry

When specifying lime for masonry mortar, under ASTM C270 *Specification for Mortar for Unit Masonry*, use Type S Hydrated Lime or lime putty (ASTM C5, C207, C1489). Type N hydrated lime is permitted if shown by test or performance record to not be detrimental to the soundness of the mortar.

Air entrained hydrated lime, Type SA or Type NA hydrated lime or lime putty, may also be specified. The air content produced by air entraining agents of the hydrated lime or lime putty will be greater than 7% and less than 14%. However, C270 indicates that cement-lime mortars when used with steel reinforcement may not have air contents in excess of 12%. Air content of the cement-lime mortars produced by air entraining agents with the lime will vary with the type of sand and cement used, and typically will be reduce from  measured for the e building lime only.

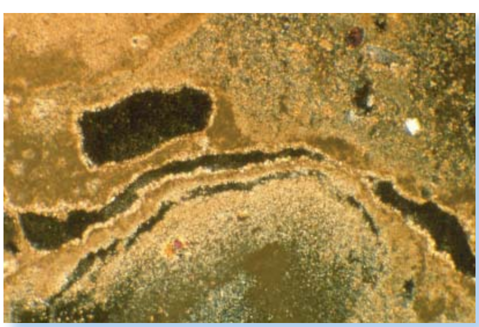

*Figure 3: Transmitting Light Photomicrograph of crack in line-sand mortar healed with later calcium carbonate or calcite. (Width of photomicrograph 3.94 mm. Photography courtesy of Dr. B. Middendorf, Kassel University, Germany)*

If specifying hydrated lime or lime putty outside of ASTM specifications, the user should understand the potential consequences of not knowing the chemical and physical properties of the hydrated lime or putty being used. It is recommended that some basic information on the product should include chemistry (Ca+Mg, $CO_2$ content) and plus 30 mesh values.

ASTM C 270 for mortar was first published as a temporary standard in 1954. The binder materials were a combination of Type S-special hydrated with Portland cement or masonry cement. The designations M(1:0:3), S(1:½:4½), N(1:1:6), O (1:2:9) K(1:3:12) were adopted. The ratios represent the cement:lime:sand volume ratios. Decreasing cement content results in a) an increase in lime content to maintain a 3 to 1 sand to binder ratio, and b) a reduced compressive strength. K-type mortar was dropped in the 1980's.

Lime-sand mortars were never included in ASTM C270. In response to this absence, there is a task group charged with developing a specification for mortars for historic masonry (ASTM C12.03.03). The most critical aspect is to develop appropriate test methods to assess the properties of mortars such as lime-sand in the context of when they have reached at least 75% of their final properties. The specification is probably at least two years in the offing.

The following is taken from Hook & Johnson (1929, p. 978):

*The Building Code Committee of the U.S. Department of Commerce in March 1926, prepared a compilation of data on compressive tests on brick masonry. The strengths of straight lime mortar, show results 95% of which vary from a maximum of 2000 psi to a minimum of approximately 500 psi. Taking the average minimum strength of 500 psi and applying a factor of safety of 4, a safe working load of 125 psi is obtained for straight lime mortar. This is entirely logical code strength and is developed along legitimate engineering lines.*

*It is well-known fact that, in general, designers do not figure the stresses on brickwork, and for this reason little consideration has been given to its economical features. In order to form a more careful consideration of masonry, the Department of Commerce Building Code Committee, as the result of various tests, saw fit to include a clause in its code which permits a load of 135 psi on straight lime mortar when stresses are calculated.*

Current guidance for specification of lime-sand mortars comes from the National Park Service Preservation Briefs (1998). The document is an excellent guide on the use of lime-sand mortars but does not provide engineering guidance or testing methods.▪

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*Lime stone quarry. Note the truck on the lower bench for scale (Apex, Nevada, Chemical Lime Company)*

## Archaic Materials

The following is taken from the California Historical Building Code (2001), describing allowable conditions for specific archaic materials. It does not give a clear path for the use of lime-sand mortars, nor does it preclude it's use. Rather it indicates that the masonry be assessed for its conditions and loads required.

### SECTION 8-804 – Allowable Conditions for Specific Materials

Archaic materials which exist and are to remain in historic structures shall be evaluated for their conditions and for loads required by this code. The structural survey required in Section 8-703 of this code shall document existing conditions, reinforcement, anchorage, deterioration and other factors pertinent to establishing allowable stresses and adequacy of the archaic materials. The remaining portion of this chapter provides additional specific requirements for commonly encountered archaic materials.

8-805.1 Existing Solid Masonry. Existing solid masonry walls of any type, except adobe, may be allowed, without testing, a maximum value of 3 pounds per square inch (20.7 kPa) in shear where there is a qualifying statement by the architect or engineer that an inspection has been made, that mortar joints are filled and that both brick and mortar are reasonably good. The allowable shear stress above applies to unreinforced masonry, except adobe, where the maximum ration of unsupported height or length to thickness does not exceed 12, and where the minimum quality mortar is used or exists. Wall height or length is measured to supporting or resisting elements that are at least twice as stiff as the tributary wall. Stiffness is based on the gross section. Allowable shear stress may be increased by the addition of 10 percent of the axial direct stress due to the weight of the wall directly above. Higher-quality mortar may provide a greater shear value and shall be tested in accordance with UBC Standard 21-6.▪

## The Building Lime Group

The 2005 International Building Lime Symposium was held March 9-11 in Orlando. Sponsored by the National Lime Association (NLA) Building Lime Group, the symposium addressed contemporary and historic uses of lime in mortars, plasters, and stucco. The NLA is a trade association of American and Canadian manufacturer's of high calcium and dolomitic lime products. The Building Lime Group promotes high standards for materials and construction techniques through symposiums, research, technical publications, and codes and standards.

The symposium included 39 papers and four workshops. Some topics of interest to structural engineers included:

- Restoration with Lime Mortars
- Lime Renders
- Stuccos and Plasters
- Sustainable Design
- Lime Mortars: Case Studies
- Lime in Building Construction

The peer-reviewed proceedings are available from the National Lime Association by calling 703-243-5463, x222. Abstracts are available on-line at **www.lime.org/BLG/Abstracts.pdf**▪

## References


American Society for Testing and Materials, West Conshohocken, PA, U.S.A.

ASTM C 1489. Standard Specification for Lime Putty for Structural Purposes

ASTM, C 206. Standard Specification for Finishing Hydrated Lime.

ASTM, C 207. Standard Specification for Hydrated Lime for Masonry Purposes

ASTM, C 5. Standard Specification for Quicklime for Structural Purposes.

ASTM C270. Standard Specification for Mortars for Unit Masonry.

California Historical Building Code, 2001. California Code of Regualtions, Title 24, Part 8. Alternative Regulations for qualified historical buildings. International Conference of Building Officiails, Whittier, Ca. **http://www.bsc.ca.gov/title_24/documents/Part8/2001_part8.pdf.**

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