LIME-BASED MORTARS CREATE WATER TIGHT WALLS

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WATER TIGHT WALLS

Scientific Evidence Demonstrates that Type S Lime-Based Mortars Protect Masonry from Water Leakage

SUMMARY

Moisture penetration can be a problem with any type of wall construction. The ability of masonry walls to resist water penetration is a key indication of quality for both architects and contractors[i]. No specifier, contractor or owner of a masonry building wants the walls to leak.

In the mid-70s a relatively high incidence of leaky masonry walls occurred in Chicago, IL. Masonry contractors from Chicago sponsored pioneering research to determine why these walls leaked. The H.H. Holmes Testing Laboratories in Wheeling, IL conducted the study, which evaluated the effect of different mortar mixes on the water permeance of masonry panels. Forty-eight masonry panels were built with varying mortar types and subjected to artificially wind driven rain for 72 hours. The cement-lime mortars were made with Type S hydrated masonry lime.

In 1978, Dr. Russell Brown presented the study findings[ii]. His principal conclusion was that **walls constructed with cement-lime mortars were more resistant to water leakage than those constructed with masonry cement mortars!**

These controversial results prompted further research. Results of Brown's study were confirmed by a second independent study at the H.H. Holmes Testing Laboratories in 1977 sponsored by three National Lime Association members[iii]. Dr. John Matthys, of the University of Texas at Austin, also confirmed that far less water permeance was seen in brick assemblages that used cement-lime mortar[iv]. A recent study jointly funded by several prominent masonry groups showed again that assemblages built with cement-lime mortars are more resistant to water permeance when compared to masonry cements[v]. Cement-lime mortars containing Type S hydrated lime have also shown more resistance to water penetration than mortars containing "lime replacement" products[vi].

Cement-Lime Mortar

Cement-lime mortar combinations are defined in the ASTM standard for Mortar for Masonry (C 270)[vii]. Each of the studies referenced above used Type S hydrated lime to make cement-lime mortars meeting the specifications of ASTM C 270. Appendix I provides more detail on how cement-lime mortars and Type S hydrated lime are defined.

Water Permeance Test Method

The current test method for determining the resistance to water permeance is ASTM method E 514. This test examines the impact of near-hurricane wind and rainfall conditions on a masonry panel. Water is sprayed against the masonry at a rate representing a 5 inch-per-hour downpour in an environmental chamber attached to the masonry panel. Air pressure inside the environmental chamber is maintained to represent a 62.5 mile-per-hour wind.

Observations are made of the backside of the masonry after 24, 48, and 72 hours of exposure to the water sprays to determine the extent of water leakage through the panels. At the bottom of the panels, metal flashing troughs collect the water that has penetrated through the panel for measurement. In addition, time of first appearance of both dampness and visible water on the backs of the wall panels are noted.

This is a harsh test that represents the potential for water leakage during wind-driven rain. It is used to evaluate the effect of different materials of construction on the water leakage potential of a masonry system. A more detailed explanation of the test procedure can be found in Appendix II.

Research Project Design

Five independent studies have explored the differences between masonry assemblages constructed with cement-lime and non-lime based mortars. Though there were some differences in the methods used, each test complied with the E 514 test procedure. The test conditions for each study are outlined in Table 1.

Table 1
Summary of Testing Conditions

Variable	ASTM E 514 Procedure	Research Study				
		Chicago Contractors Holmes Laboratory	USG/ Rockwell/ Western Holmes Lab	NLA Matthys Brick	BIA/PCA/ NLA Nelson	Chemical Lime Atkinson, Nolan
Year (Reference)		1976-77[ii]	1977[iii]	1988[iv]	1998-99[v]	1999[vi]
Moist Chamber Size (ft^2)	12	12	12	12	12	12
Wall Panel Size	56" x 72"	49" x 52"	50" x 56"	40" x 53"	40" X 53"	40" x 53"
Panel Wythes (Type)	Single (Job[2])	Two[1] (4" Clay and 4" Cement)	Two[1] (3" Clay and 4" Cement)	Single (4" Clay)	Single (4" Clay)	Single (4" Cement)
Mortar Types (ASTM C 270 Proportion Specification)	Job[2]	M,S,N,O + 3 Masonry Cements[3]	S,N,O + 4 Masonry Cements[3]	S,N,O + 4 Masonry Cements[3]	N + 1 Masonry Cement[3]	S (4 lime products) + 4 Lime Replacements
Cure Time (days)	14	28[4]	28[4]	28[4]	28[4]	28[4]
Cure Conditions	Lab Plastic[6]	Lab NR[7]	Lab Plastic[6]	Outdoors[5] Plastic[6]	Lab Plastic[6]	Lab Plastic[6]
Pretest Drying (hr.)	4	24	24	NR[7]	NR[7]	NR[7]
PreTest (Optional)	28 days	None	6 months	NR[7]	NR[7]	NR[7]
Replications	3	3	3	3	3	3
Tooling	Job[2]	Concave	Concave	Concave	Concave	Concave
Test Time, minimum hours	4	72	72	4	72	4
Sand	Job[2]	Job[2]	Job[2]	Job[2]	Job[2]	Job[2]

1 Double brick wythes were used to simulate contemporary construction practice.
2 "Job" refers to materials representative of current construction practice.
3 Commercial one bag dry mortar mixes.
4 28 days is a standard curing time for many ASTM mortar test procedures.
5 Panels were built, cured, and tested under ambient conditions to duplicate conditions under which actual masonry walls are constructed.
6 Panels were wrapped in plastic to maintain high humidity and consistency during curing.
7 "NR" indicates no data given for this condition in published reports.

Test Results

1. Comparisons of Masonry Cement to Cement-Lime Mortars

The results for cement-lime mortars and masonry cement mortars appear in Table 2. Data for all mortar types (M,S,N and O) within each mortar system (cement-lime or masonry cement) is averaged. Significant differences exist between cement-lime and masonry cement mortars:

Table 2
Summary of Water Permeance Test Data

Tests Performed	Chicago Contractors Holmes Laboratory		USG/ Rockwell/ Western Lime Holmes Lab		NLA Matthys Brick		BIA/PCA/ NLA Nelson	
	CL	MC	CL	MC	CL	MC	CL	MC
First Dampness, hr.	2.9	2.0	2.7	2.0	2.3	1.0	0.25	0.1
First Visible Water, hr.	11.6	3.8	12.1	2.1	9.7	2.0	0.50	0.1
% Dampness, 4 hr.	16.8	28.4	13.0	18.7	15.1	18.7	90.0	95.0
Total Water, 72 hr.	1,744	103,471	3,529	70,650	2,550	6,000	1,170	18,000
Number of Panels	4	31	5	11	18	12	3	3
Leakage/Panel, ml	436	3,338	706	6,423	142	500	234	3,600

CL = cement-lime MC = masonry cement

- **Time To First Dampness** – Walls constructed with cement-lime mortars took 35% to 250% longer to show signs of dampness.
- **First Visible Water** - It took approximately 350% to 575% longer for cement-lime mortars to show signs of visible water.
- **Percent Dampness** – Cement-lime walls showed 5% to 40% less area of dampness than seen with masonry cement mortars.
- **Leakage Per Panel** – The total amount of water leakage collected per wall panel during the test for masonry cement assemblages was 3.5 to 15.3 times the amount collected for cement-lime mortars.

2. Comparison of Lime to "Lime Replacement" Products in Cement-Lime Mortar

The results of water leakage tests for lime and "lime replacement" materials appear in Table 3. Four Type S hydrated lime products from different production sites were used for this study (Series A-D). Mortar "E" includes a pozzolanic lime-replacement; mortar "F" is a proprietary mixture, and "G" uses proprietary resin compounds as the lime-replacement. Test results show that the assemblages containing "lime-replacement" materials have, on average, three times more wall leakage than assemblages made with the same mortar type containing Type S hydrated lime.

Table 3
"Lime Replacement" Mortar Study

Series	Type	Total Water Collected at Flashing (28 days) (liters)
A	CL	23.9
B	CL	11.0
C	CL	16.0
D	CL	11.3
E	LR	43.3
F	LR	34.0
G	LR	64.8

CL = cement-lime LR = lime replacement

CONCLUSIONS

Each of these studies demonstrates that Type S hydrated lime reduces the potential for water leakage through masonry walls. Though the ASTM E 514 test method is harsh, many of the cement-lime mortar panels showed no signs of water leakage. This cannot be said for the other types of mortars tested.

The test results lead to a clear conclusion:

Masonry walls constructed with mortars containing Type S lime are more resistant to water leakage than those constructed with mortars containing no lime.

The test results indicate that dampness and/or visible water leakage through masonry walls may be prevented or reduced considerably by using Type S lime in mortars. The percent wetness on the backside of the panels tested was almost 50% greater for panels constructed with masonry cement than panels built with cement-lime mortar. Total water leakage through the masonry cement panels was up to 15 times greater than the panels containing Type S hydrated lime.

Leakage in masonry can be caused by one or more of the following three factors:

1. Improper design details
2. Poor workmanship
3. Use of improper (often incompatible) materials which bond together poorly

Type S hydrated lime enhances the ability of masonry walls to resist water penetration by making the mortar more compatible with the masonry unit. Masonry units vary widely in their water absorption capacities. Improper water absorption by the masonry unit can reduce the bond strength between the mortar and masonry unit. Clayford Grimm, a prominent masonry authority, made the following statement about the importance of masonry bond strength: "Bond strength between mortar and masonry units is the most important physical property of masonry. Low bond strength causes every problem that can happen to masonry – cracks, leaks, stains, weathering, and structural failure."[viii]

Type S hydrated lime provides improved bonding because of the following qualities:

1. High water retention due to the high surface area and micro-fineness of Type S hydrated lime. This results in increased water holding capacity. Water is the lubricant of mortars. The more water a mortar can hold, and still be workable, the greater its plasticity, board life, and bond strength.
2. Type S hydrated lime increases the extent of bonding because of its micro-fineness (50% less than one micron in size). These small lime particles will penetrate deeply into brick pores.
3. Lime can reconstitute itself through recarbonation (referred to as autogenous healing)[ix]. Carbon dioxide from the atmosphere combines with lime to form new calcium carbonate. The minute crystals formed tend to plug the voids or any hairline cracks that may have been developed. Two studies have demonstrated that walls containing lime tend to resist moisture penetration better after six months of outdoor curing[iii,x].
4. Type S hydrated lime in mortar creates fewer air voids[xi]. This makes the mortar less permeable to wind driven rain.

For owners, architects, and contractors the results of these studies are clear: Walls containing Type S hydrated lime are more resistant to water leakage. Cement-lime mortars containing Type S hydrated lime are an important component of quality masonry construction.

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Appendix I

A Cement-Lime Mortar Primer

What is a cement-lime mortar?

Masonry mortar mixtures made of cement and lime are well defined in ASTM Standard C 270 (Mortars for Unit Masonry)*.

A cement-lime mortar has the following ingredients:

1. **Hydrated Lime** – Meets ASTM C 207 Type S or SA.

2a. **Portland Cement** – Meets ASTM C 150 Types I, IA, II, IIA, III, or IIIA.

or

2b. **Blended Hydraulic Cement** – Meets ASTM C 595 Types IS, IS-A, IP, IP-A, I(PM) or I(PM)-A.

3. Sand – Meets ASTM C 144.

Cement-lime mortars are specified in two steps. First the mortar type must be determined based on the strength required for the application. Secondly, a choice must be made between specifying proportions or properties listed in ASTM C 270.

What Is Lime?

The term "lime," in spite of being used broadly and loosely, includes only burned lime products - quicklime and hydrated lime. Lime is not pulverized limestone, which is used in many masonry and mortar cements. Limestone containing calcium and magnesium carbonates is a sedimentary rock, possessing completely different properties than lime, which is an oxide or a hydroxide of calcium or calcium-magnesium. Quicklime is a manufactured product made from limestone by calcination at high temperature (about 2400 ^{o}F) in kilns. Quicklime (unslaked lime), can be converted to hydrated lime by adding a controlled amount of water, enough to satisfy its chemical affinity. This hydration process disintegrates the lump, pebble, or granules of quicklime into an extremely fine, white powder. Hydrated lime is the form of lime used in mortars.

Limestone has no cementing value, whereas lime contributes some strength to mortar by recarbonation, i.e., absorbing carbon dioxide from the atmosphere and reverting to its original carbonate form.

Hydrated limes are divided into four types, as described in ASTM Standard Specification C 207 (Hydrated Lime for Masonry Purposes):

Type N – Normal Hydrated Lime
Type S – Special Hydrated Lime
Type NA – Normal air-entraining hydrated lime
Type SA – Special air-entraining hydrated lime

Types S and SA are differentiated from Types N and NA principally by their ability to develop high early plasticity, higher water retentivity, and by their limitation on unhydrated oxide content. The maximum air content of cement-lime mortar made with Types NA and SA is 14%; with Types N or S lime, 7%.

The ASTM Standard C 270 (Mortars for Unit Masonry) provides the basis for specifying cement-lime mortars. This specification provides the basis for five different mortar types (Type K is listed in section X3 of the appendix) depending on the strength of mortar needed for an application. The names for these mortar types were based on alternating letters of the phrase "**M**A**S**O**N** W**O**R**K**". ASTM Standard C 270 provides both a proportion specification and a property specification for each of these mortar types.

The **proportion specification** provides a recipe based on volume. It is assumed that mortars mixed by the proportion specification will meet the property specifications for the same mortar type. For cement-lime mortars the proportion specification indicates the volume of cement followed by the volume of hydrated lime and finally the volume of sand. For example a 1:½:4 ½ mix contains 1 cubic foot of portland cement, ½ of a cubic foot of hydrated lime, and 4 ½ cubic feet of sand. For the purposes of determining volumes, ASTM C 270 provides typical bulk densities for portland cement, hydrated lime, and sand. These densities appear in Table 1. Table 2 details the material proportions for each mortar type.

Table 1

Mortar Component	Bulk Density (lbs/ft3)
Cement	94
Hydrated Lime	40
Masons Sand, damp & loose	80 (dry)

* Standard Specification for Mortar for Unit Masonry (ASTM C 270), American Society for Testing Materials, Philadelphia, PA.

Table 2 – ASTM C 270 Proportion Specification

Mortar Type	Proportions by volume (cementitious materials)		Aggregate Ratio – Measured in damp, loose conditions
	Cement	Hydrated Lime	
M	1	¼	Not less than 2 ¼ and not more than 3 times the sum of the separate volumes of cementitious materials
S	1	Over ¼ to ½	
N	1	Over ½ to 1 ¼	
O	1	Over 1 ¼ to 2 ½	

The **property specification** requires that the mortar exhibit certain characteristics when tested under laboratory conditions. As seen in Table 3, compressive strength, water retention, and air content tests are to be performed on the mortar mixed in the laboratory. Since jobsite water additions may not be the same as those in the laboratory, however, the properties of field mixed mortar cannot be compared to the property requirements of ASTM C 270.

Table 3 – ASTM C 270 Property Specification[A]

Mortar Type	Average Compressive Strength at 28 Days (psi)	Water Retention (%)	Air Content max. %	Aggregate Ratio
M	2,800	75	12	Not less than 2 ¼ and not more than 3 times the sum of the separate volumes of cementitious materials
S	1,500	75	12	
N	750	75	14[B]	
O	350	75	14[B]	

A – Laboratory Prepared Mortar Only
B – When structural reinforcement is incorporated in cement-lime mortar, the maximum air content shall be 12%.

Portland cement/lime mortars should be specified by either the property or the proportion specification but not both. When neither the proportion or property specifications are specified, the proportion specifications govern.

ASTM C 270 includes **mortar recommendations** (and alternatives) for several applications:

Table 4 – ASTM C 270 Mortar Recommendations

Application	Recommended Mortar Type
Exterior, Above Grade, Load-Bearing Wall	N (or S or M)
Exterior, Above Grade, Non-Load-Bearing Wall	O (or N or S)
Exterior, Above Grade, Parapet Wall	N (or S)
Exterior, At- or Below-Grade	S (or M or N)
Interior, Load-Bearing Wall	N (or S or M)
Interior, Non-Bearing Partition	O (or N)

Availability

The ingredients for cement-lime mortars are readily available throughout the United States and Canada. Traditionally, separate bags of lime and cement have been mixed on the job-site. Other forms of cement-lime mortar materials are also available, including:

1. **Pre-blended cement-lime mortar mixes** – Cement and lime preblended in accordance with the proportion or property specification in 65 to 85 lb. bags.
2. **Silo systems** – These portable silos are delivered to the job-site. Mortar is made in a screw type mixer-blender fastened to the bottom of the silo. Two different types of silo systems have been used:
   - Blend of cement, lime and dry sand in a single compartment silo.
   - A two compartment silo with one compartment containing cement and lime and the other compartment containing sand.
3. **Supersacks** – Large, "supersacks" containing blends of cement, lime, and sand are lifted into a holding bin above a conventional mortar mixer.

For the sources of building lime products in your area see the list at www.lime.org/masons.pdf, or call the National Lime Association at 703-243-5463. Additional information and publications on lime can be found on the Internet at www.lime.org.

Appendix II

ASTM Test Method E 514
Water Penetration and Leakage Through Masonry

Scope

ASTM test method E 514 describes a procedure for determining the resistance to water penetration and leakage through masonry subjected to wind driven rain.

Apparatus

The test chamber must be similar to that shown in photo. Attached to the chamber is an air line to provide wind pressure, a water line for water spraying the masonry test sample, flashing to collect water penetrating through the masonry specimen, and a drain pipe for overflow water.

Test Specimens

Masonry and/or mortar being tested shall be representative of construction and materials under study. Specimen size shall be a minimum of 1.08 m^2 (12 ft^2). After construction, the specimens shall be cured for a minimum of 7 days wrapped in impervious plastic and an additional 7 days minimum in laboratory air. Curing of specimens is to be done in laboratory air temperature maintained at 24 $\pm$ 8 ^oC (75 $\pm$ 15 ^oF). The relative humidity shall be not less than 30% and not more than 80%. Each test shall consist of at least 3 specimens.

Test Chamber

The test chamber opening shall be a minimum of 1.08 m^2 (12 ft^2). The edges of the chamber shall be lined with a closed-cell type gasket material. An observation port shall be provided on the face of the chamber. A 19 mm. (¾ in.) diameter spray pipe with single 1.0 mm (0.04 in.) diameter holes spaced 25.0 mm (1 in.) apart provide the water spray. The water spray cannot impinge on the specimen more than 75.0 mm (3 in.) below the top of the test chamber. An air line with a manometer is attached to the test chamber.

Procedure

Clamp the pressure chamber firmly to the test specimen so that there is no water or pressure leak through the gasket. Apply a 3/8-in. layer of mortar parging to all exposed surfaces of the test specimen, except the backside of the wall and the area enclosed by the pressure chamber. The water flow rate should be 138 L/m^2 (3.4 gal/ft^2). Air pressure should be simultaneously adjusted to 500 Pa (10 lb/ft^2). The test conditions are maintained for not less than 4 hours.

Data Collection

During the testing period, observations are made at 30 minute intervals of the following:

1. Time of first dampness on back of specimen.
2. Time of first visible water on the back of the specimen.
3. Total water collected and the percentage of damp area.