International Building Lime Symposium 2005
Orlando, Florida, March 9 -11, 2005

LIME-POZZOLAN MASONRY MORTAR*

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Abstract

For centuries, lime and sand have been used in masonry mortar throughout Mexico. However, some masons are changing to quick-setting, very high compressive strength portland cement-admixture mortars (*mortero*). These masons are changing because: a) mortero comes pre-bagged, needing only the addition of the correct amount of jobsite sand and water; and b), bagged mortars help to insure consistent quality mortar. The main problem with mortars that achieve excessive compressive strength is incompatibility with relatively soft masonry units. To honor Mexican masonry traditions and, at the same time, satisfy the workability requirements of masons, a ready-to-use hydraulic lime (lime-pozzolan) mortar has been developed. The lime-pozzolan mortar has superior working properties, good yield, and moderate compressive strength. This paper provides comparative test data for lime-pozzolan and mortero mortars including, but not limited to, compressive strength, sand carrying capacity, board life (setting time), and unit masonry yield.

Keywords

Lime-Pozzolan Masonry Mortar, Boardlife, Compressive Strength, Mortar Yield, Air Content

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1 Introduction

The benefits of lime are well-understood among Mexican builders and have been taught from generation to generation. During the last 25 years, however, there has been a change to mortars with very high cement content (mortero) in some regions of Mexico. According to a market survey, masons were changing for several reasons: a) mortero comes pre-bagged, needing only the addition of the correct amount of jobsite sand and water; b), bagged mortars help to insure consistent quality mortar; and c), a perceived need for quicker setting times and higher compressive strength values at early ages.

The mortero available in the Mexican market satisfies the above-mentioned needs. However, it does not have some of the benefits of mortars with higher lime contents. To address these shortcomings, Grupo Calider developed a ready-to-use high lime-pozzolan masonry mortar. The product uses lime in combination with a pozzolanic source that would otherwise be wasted during a mining operation. This source is volcanic overburden material from a limestone quarry used to produce lime. The pozzolan is reactive in the presence of lime and marries Mexico's tradition of lime-based mortar with modern technology to create a less energy-intensive and more environmentally-sustainable material. This paper compares the physical properties of this high lime-pozzolan (HL-P) mortar to those of a commercially-available high cement content (HCC) mortar. Testing includes both field and laboratory investigations.

2 Field Testing

2.1 General

Field testing of masonry mortar was conducted at the Grupo Calider Cal Perla lime plant near Cd. Guzman, Jalisco, Mexico over two days in September, 2004. The testing site was flat, unshaded, and located in a low-traffic area especially set aside for creating masonry test panels. Sand was stockpiled in the testing area in uncovered piles. Bagged cementitious materials (high lime-pozzolan and high cement content) were stored dry under protective cover. Soft, indigenous, unfired clay brick was stored onsite in an uncovered condition. Water used in mixing was clear and potable. Sample clay brick wallettes were constructed as unreinforced freestanding panels on top of a low concrete stub wall. Simple scaffolding afforded the masons a comfortable working height (Figure 1).

On the first day, weather conditions were mostly sunny, with little or no wind (0 to 6.44 km/hr), relative humidity between 21.8 and 29.9%, and air temperature between 27.0 and 29.0°C. On the second day, weather conditions began with overcast skies progressing to partly cloudy, with clearing later to mostly sunny conditions. On day two, there was little or no wind (0-3.22 km/hr), relative humidity was between 79.4 and 84.9%, and air temperature was between 22.7 and 29.0°C.

Field mortars (combinations of the two cementitious materials with two different sands) were tested for apparent boardlife, modified Vicat cone penetrometer consistency, pressure pail method air content, mortar temperature rise, sand bulking, and mortar yield. Mortars were hand-mixed with flat-nosed shovels and mortar hoes in non-pervious metal mortar pans, which is the local custom. Mortar for boardlife and other testing was transferred to a similar metal mortar pan and was not used in the masonry yield calculations or bricklaying operation. Mortar was transferred to the panel location using square, non-pervious, metal mortar pans. Mortar mixing and wall building were supervised and conducted by a senior mason with 25 years of experience. He was assisted by up to three helpers.

Figure 1 Master Mason Rodolfo Cardenas on the wall and Helper Juan Mata mixing mortar at the Grupo Calider Cal Perla testing location.

Equal weights (25 kg) of cementitious materials were tested in each batch of mortar. Bulked sand and water in each batch were measured by filling to the top of a 18.9 L plastic pail and levelling. Materials were mixed by first adding sand; then cementitious material; and lastly, water. Prior to adding water, the sand and cementitious materials were completely mixed using the shovel and hoe. Consistency of the mortar was determined at the discretion of the mason. Mortar joints were struck flush to the face of the brick without any additional tooling.

Boardlife and consistency by cone penetration testing was conducted using disturbed samples following the requirements of Annexes A1 and A3 in ASTM C 780, Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry (ASTM C 780-00). Air content testing was conducted using a 0.75 L air pail modelled after the procedure outlined in ASTM C 780, Annex A6. Sand bulking was determined using a 250 mL volumetric cylinder modelled after a method described in CSA Specification A179 as reported by Grimm (1994) and demonstrated by Davison (1977).   Weather and mortar conditions were determined using a calibrated digital thermometer, relative humidity meter, and hand-held wind meter. Mortar yield was calculated based on the difference between the average volume measurements of brick and mortar in the wallette. Calculated mortar yield did not account for waste droppings that may have occurred during building (waste was minimal and estimated to be less than 1 to 2% of overall yield for each individual batch). Testing was supervised and conducted by a testing engineer with 5 years of mortar-specific laboratory and field testing experience. Testing assistance was provided by a senior chemical engineer with over 10 years of experience.

2.1.1 Field Testing Results

Field testing data results are summarized in Tables 1 and 2 and Figure 2 below:

Table 1 Field Testing Results Summary: Plastic Properties

Mortar ID (Cementitious-Sand)	# Bricks Laid	Mortar Yield (cm^3)	Apparent Boardlife (min.)	Vicat Start (mm)	Vicat Finish (mm)	Mortar Temp. Start ('C)	Mortar Temp. Finish ('C)	Air Content (%)
HL-P-Huescalapa	61.5	48705.8	56.0	76	42	28.2	28.7	3.6
HCC-Huescalapa	54	47719.6	15.0	85	45	27.0	30.2	3.5
HL-P-Michoacan	49	50357.8	205.0	77	39	20.6	29.3	5.2
HCC-Michoacan	42	35431.9	36.0	65	55	24.0	25.7	6.2

Table 2 Field Testing Results Summary: Sand Bulking

Mortar ID (Cementitious-Sand)	Sand Bulking (%)	Bulked Sand Carrying Capacity (cm^3)	Dry Sand Carrying Capacity (cm^3)
HL-P-Huescalapa	120.0	75708.2	60566.6
HCC-Huescalapa	120.0	66244.7	52995.8
HL-P-Michoacan	125.0	66244.7	49683.5
HCC-Michoacan	125.0	56781.2	42585.9

3 Laboratory Testing

3.1 General

Laboratory analyses of the two mortar sands and physical properties of both types of cementitious materials in mortar combinations with those sands were conducted by the mortar analysis laboratory of Chemical Lime Company, Henderson, Nevada, USA. All laboratory testing was conducted by a certified technician meeting the written and performance standards of the National Concrete Masonry Association. Standard physical mortar properties were evaluated in accordance with protocols in ASTM C 270, Standard Specification for Mortar for Unit Masonry (ASTM C270-03) and using calibrated mortar testing equipment. Evaluated properties included cement-aggregate ratio, water retention, air content and compressive strength. Lime-pozzolan mortars were cured in 75% relative humidity, while portland cement-lime mortars were cured in 100% relative humidity.

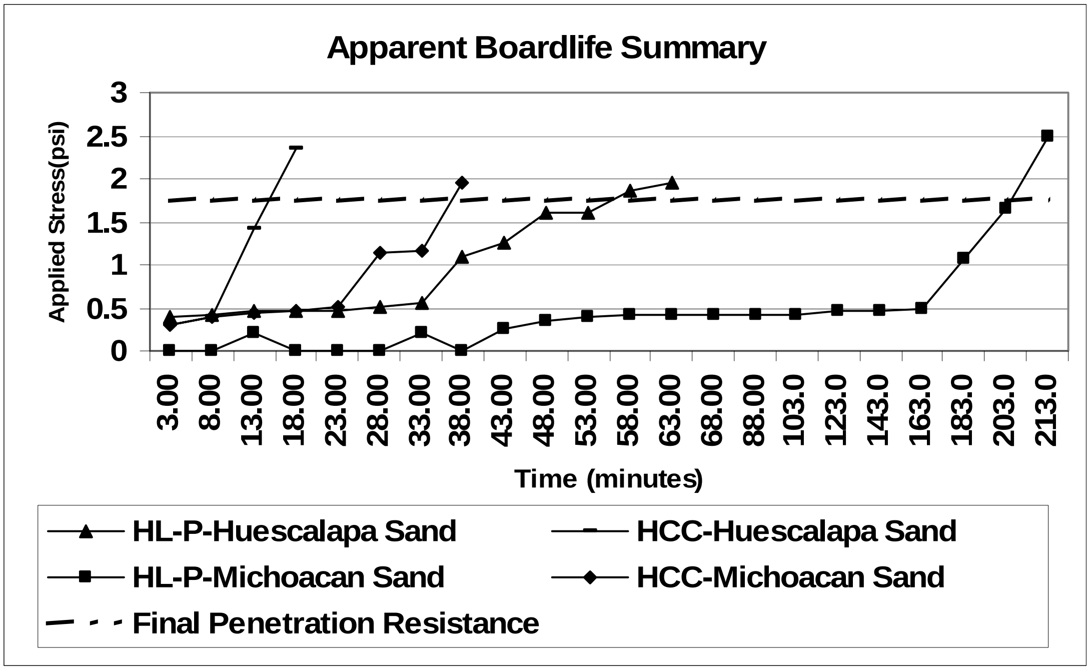

Figure 2 Apparent Boardlife Summary

3.2 Sand Analysis

Samples of the two sands were oven-dried and analysed in the laboratory using a Tyler Rotap Model RX-29 sieve shaker following the protocol outlined in ASTM C 136, Test Method for Sieve Analysis of Fine and Coarse Aggregates (ASTM C136-00) and the sieve size gradation requirements of ASTM C 144, Standard Specification for Aggregate for Masonry Mortar (ASTM C144-03). Results of the visual characterization and sand sieve analysis showing particle size distribution for the Huescalapa Regional River and Michoacan Crushed Volcanic Sand are shown in Figures 3 and 4 below:

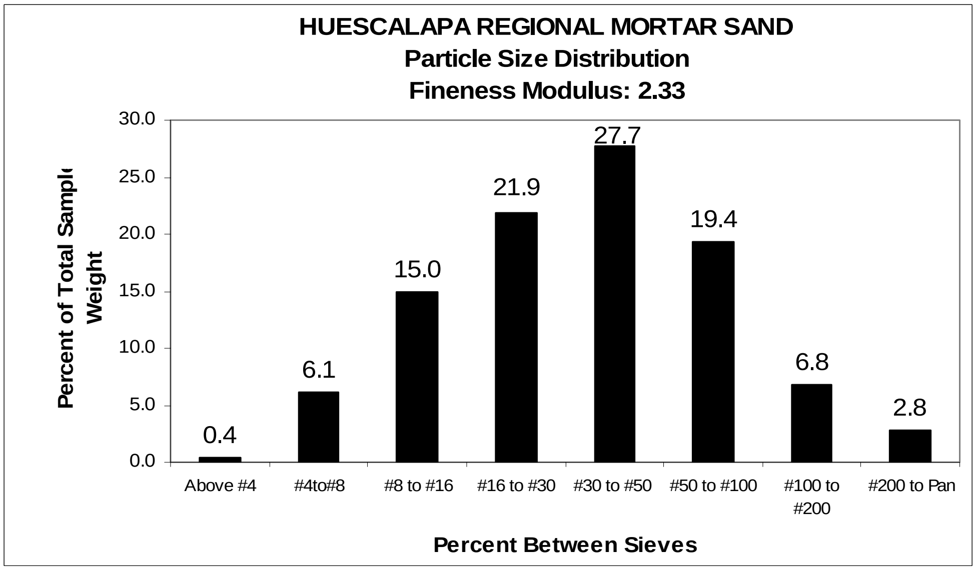

Figure 3 Huescalapa Regional Mortar Sand Particle Size Distribution.

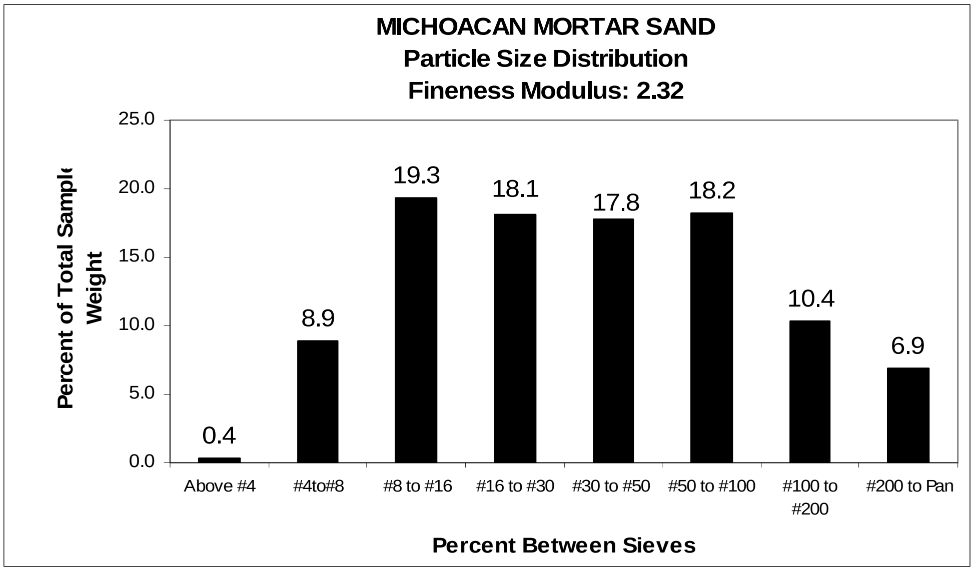

Figure 4 Michoacan Mortar Sand Particle Size Distribution.

The Huescalapa Regional River Sand is blonde-grey in color, with stream-rounded mixed grains of volcanic scoria, volcanic tuff, quartzose sandstone, and fine-grained shale. It contains a small amount (less than 0.1%) of hair-thin plant rootlets, and is geologically poorly-sorted (showing a good distribution of various particle sizes). Fineness modulus was measured to be 2.33.

The Michoacan Mortar Sand is dominantly black-colored vesicular volcanic scoria, angular, with a few grains of tan pumice. It contains a small amount (less than 0.1%) of hair-thin plant rootlets. The sand is manufactured by mechanical crushing and sieved by masons on-site using a ¼" sieve frame to remove larger particles. It is poorly-graded (showing a similar quantity of most particle sizes). Fineness modulus was measured to be 2.32.

3.3 Mortar Physical Properties

Each cementitious material was combined with each sand in ratios varying by quarter-steps from 1:2.25 (cement-sand) to 1:2.75. The plastic properties for these twelve mortars (cement-aggregate ratio, water retention, and air content) are presented in Table 3.

Each of the 12 mortars was molded into three 50mm cubes for replicate compressive strength testing at a curing date of 50 days. Mortar consistency varied from 105 to 115% flow, measured using a drop table. The lime-pozzolan mortars were cured in 75% relative humidity, and Mortero portland cement-lime mortars were cured in 100% relative humidity. Test results for these 50-day cubes are shown below in Table 4.

Table 3 Laboratory Plastic Property Results Summary

Mortar I.D.	Cement-Aggregate Ratio	Water Retention (%)	Air Content (%)
HL-P-Huescalapa	1 : 2.25	81.2	3.2
	1 : 2.50	79.6	3.1
	1 : 2.75	76.4	3.4
HL-P-Michoacan	1 : 2.25	79.7	4.3
	1 : 2.50	77.4	4.4
	1 : 2.75	69.2	4.3
HCC-Huescalapa	1 : 2.25	77.1	4.5
	1 : 2.50	74.6	4.7
	1 : 2.75	72.8	4.5
HCC- Michoacan	1 : 2.25	73.2	5.6
	1 : 2.50	70.8	5.7
	1 : 2.75	66.4	5.9

Table 4 Laboratory Mortar Compressive Strength Results Summary

Mortar I.D.	Compressive Strength - Kg/cm^2 (psi)
HL-P-Huescalapa 1 : 2.25	19.51 (277.5)
HL-P-Huescalapa 1 : 2.50	19.99 (284.3)
HL-P-Huescalapa 1 : 2.75	21.00 (298.7)
HL-P-Michoacan 1 : 2.25	17.32 (246.3)
HL-P-Michoacan 1 : 2.50	17.68 (251.5)
HL-P-Michoacan 1 : 2.75	19.52 (277.7)
HCC-Huescalapa 1 : 2.25	132.16 (1879.7)
HCC-Huescalapa 1 : 2.50	129.74 (1845.3)
HCC-Huescalapa 1 : 2.75	125.89 (1790.6)
HCC-Michoacan 1 : 2.25	144.36 (2053.3)
HCC-Michoacan 1 : 2.50	130.29 (1853.1)
HCC-Michoacan 1 : 2.75	118.13 (1680.2)

4 Discussion

The high lime-pozzolan content mortar (HL-P) laid more bricks, had higher yield, significantly longer boardlife, and significantly lower early compressive-strength than the high cement content mortar (HCC) (Figures 5,6,7, and 8). Water retention and sand carrying capacity for the high lime-pozzolan mortar were higher and the air contents were lower (see Tables 2, 3, and 4).

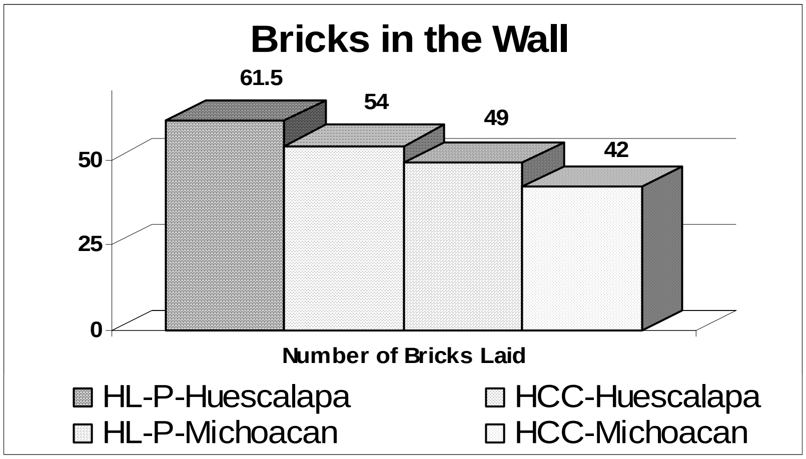

Figure 5 Number of Bricks Laid With Each Mortar.

Every mason would agree that the ability to use a highly-workable mortar that can lay more bricks is an advantage. With the Huescalapa sand in the lime-pozzolan mortar, the mason was able to lay 14% more bricks than with the high-cement mortar--see Figure 5. Additionally, the Huescalapa sand/lime-pozzolan mortar yielded 2% more mortar for the same weight of cementitious material. With the Michoacan sand in the lime-pozzolan mortar, the mason laid 17% more brick and 42% more mortar was yielded--see Figure 6. (This significant difference in mortar yield based on the sand is explained by the mason’s ability and choice to vary the joint thickness in the test panels to accommodate the additional mortar yielded by the lime-pozzolan mixtures.)

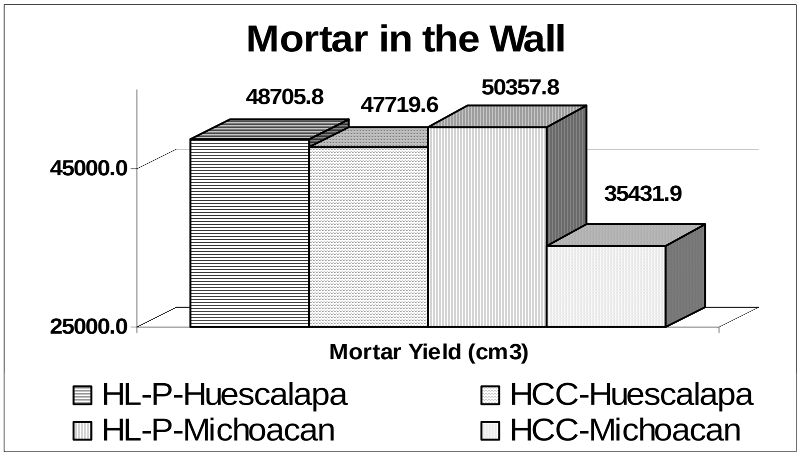

Figure 6 Mortar Yield.

Masons would also agree that mortars with longer boardlife are advantageous for at least three significant reasons: 1) the longer the time before a mortar needs retempering (boardlife), the less time the mason has to spend working on the mortar and the more time he can lay brick; 2) mortars with longer boardlife are typically more workable and they allow longer bed joints to be laid prior to placing

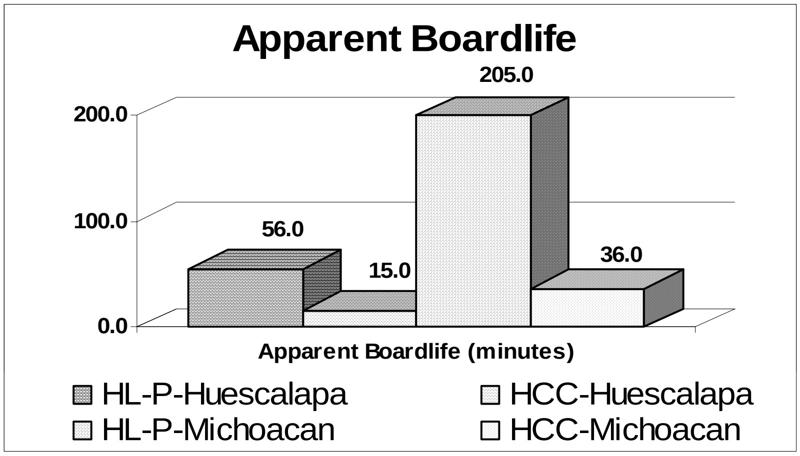

Figure 7 Apparent Boardlife

the brick; and 3) mortars with longer boardlife allow the batch the be used before retempering is necessary, thus allowing a pigmented mortar to be more easily controlled for color consistency (retempering, or adding water to a mortar after the initial mix, changes the color of a pigmented mortar). Compared to mortero, the high lime-pozzolan mortar had 73% more boardlife with the Huescalapa sand and over 500% longer boardlife with the Michoacan sand--see Figure 7.

Early age compressive strength of the high-cement mortar is significantly higher than that of the high lime-pozzolan material--see Figure 8. Mortar properties should be matched to the properties of the masonry units (Sneck, 1972). The assumption that higher compressive strength mortars make better walls is erroneous. In an important study summarized by Grimm (1994), "*Hoath, Lee and Renton (1971) found that mortar compressive strength is not a reliable means for predicting the strength of brickwork. Mortars containing lime may not always have the greatest compressive strength in a laboratory mortar cube but, when tested in the form of brickwork, produce a higher ratio of brickwork strength to mortar compressive strength. This is due to the higher bond strength of mortar containing lime*." The lime-pozzolan mortar gains strength more slowly over time. The authors cite an earlier paper showing the importance of curing regime on compressive strength gain for mortar made with this same high lime-pozzolanic material. In that study, this lime-pozzolanic mortar had compressive strength of 112 kg-f/cm^2 [1595.4 psi] , when cured in 50% relative humidity conditions for 791 days (Thomson and Godbey, 2004). Compressive strengths in this range are generally acceptable for unfired clay brick. However, the superior bond is probably a more important factor in terms of the overall wall system.

Water retentivity is a laboratory measurement of drop table flow after vacuum suction to remove water from a mortar. Several studies--since early in the last century--have shown that water retentivity (and workability) increases with increasing lime content (Voss, 1933; Tytherleigh and Youl, 1961; and Kampf, 1962). Water retentivity is one of the most important physical masonry mortar properties that affect bond (Goodwin and West, 1982). Mortars with higher water retentivity show improved bond over mortars with lower water retentivity, especially for soft, absorptive clay units like those used in Mexico. The high lime-pozzolan mortar showed improved water retention over the high cement

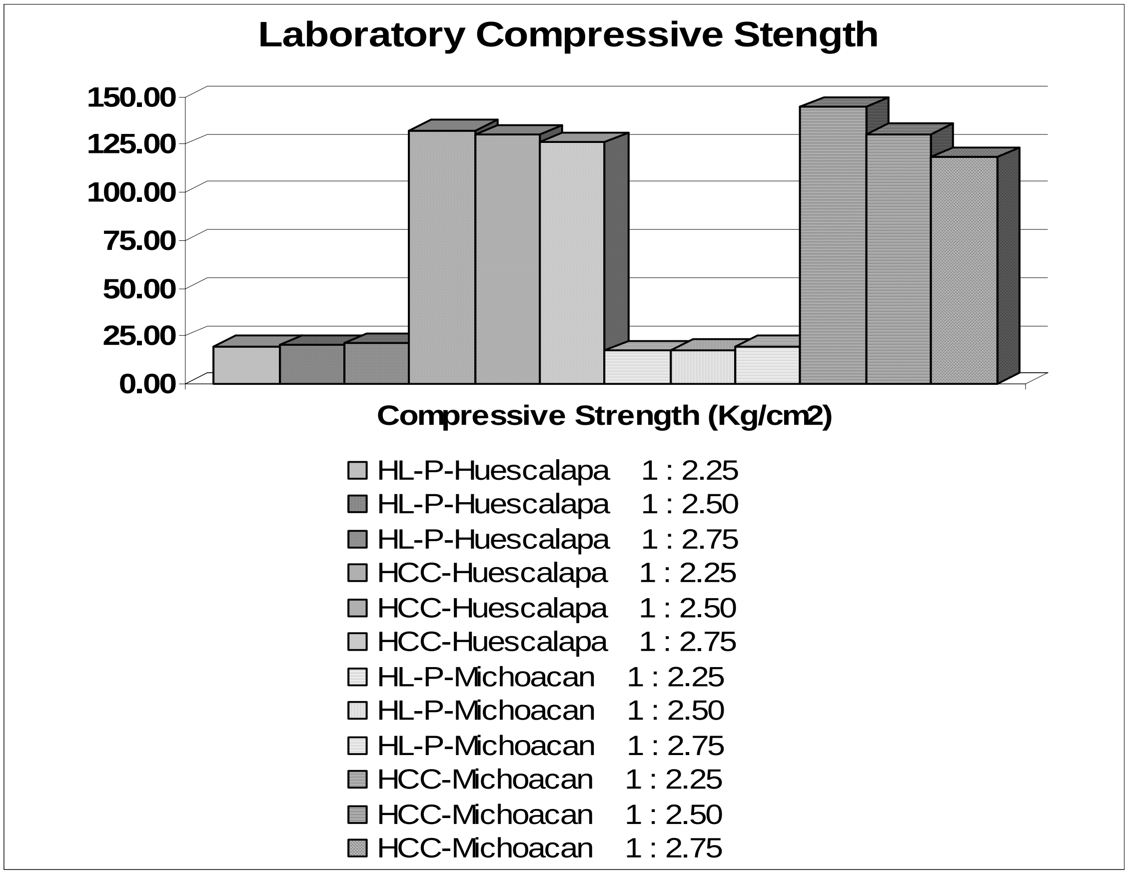

Figure 8 Laboratory Compressive Strength

mortar with each sand in each laboratory proportion (Table 3). However, the fact that higher lime content improves water retentivity does not necessarily mean that higher lime content alone improves bond. Air content (air-entrainment additives) can also increase water retentivity. However, increased air contents have been shown to reduce bond (Bloem, 1963; Fishburn, 1961). With both sands, the high-cement mortar showed higher air contents, suggesting that the bond is reduced with these high-cement mortars.

5 Conclusion

The field and laboratory studies shown here acknowledge the masonry tradition of Mexico. This tradition recognizes the superior workability, higher yield, longer boardlife, higher water retention, and moderate compressive strength values of lime-based mortars. In every instance, both in the field and the laboratory, the high lime-pozzolan masonry mortar had superior working and other physical properties. Compressive strength values are lower, but highly compatible with unfired clay brick.

The lime-pozzolan mortar has the important added benefit of using what would otherwise be wasted material from a mining operation and creating a less energy-intensive and therefore, more sustainable and earth-friendly product. The information provided in this paper may be used to help educate Mexican builders and masons that compressive strength alone is not the most important issue in the use and application of a masonry mortar.

Acknowledgements

The authors wish to acknowledge the help and cooperation of the crew of masons who built the test panels and made this study possible: Rodolfo Cardenas, Juan Mata, Martin Cervantes, and Fernando Franco. The authors also wish to thank Margaret Thomson, Chemical Lime Company (USA), Grupo Calider (Mexico), and Lhoist (Belgium) for their support during this project. Without these individuals and companies, our work with traditional and sustainable mortars would not be possible. Additionally, the authors would like to thank the peer reviewers for their thoughts and comments to make this a better paper.

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