AN INVESTIGATION INTO THE FIELD PRACTICE OF PREFERRING AIR-ENTRAINED HYDRATED LIME IN THE HEAT OF THE SUMMER

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ABSTRACT

During the summer months mixing and working with mortar in air temperatures in excess of 38°C and relative humidity often far less than 30% is common practice in many of the southern United States. This can also occur for weeks at a time in some parts of the northern states and in southern Canada. In northern Texas, there has been a practice of switching to Type SA hydrated lime, (air entrained) for cement-lime mortars to aide in extending board life, particularly when using white cement. Some proprietary products made of bentonite clay with air entrainment are reportedly used for the same reason.

This study investigates hot weather board life of mortars made with Type S and SA (air entrained) hydrated lime and a bentonite clay-air entrainment admixture combined with white and gray cement. Test procedure is outlined in ASTM C 780 Annex 3. Twenty-two mortar mixes were completed in southern Nevada in September with site air temperatures greater than 38°C (45°C max.) and relative humidity less than 25% (10% min.) Local mortar sand was used.

In summary, the results indicate the following:

- Cement-SA lime mortars showed the longest board life, cement-S lime mortars intermediate, and cement-bentonite clay with air entrainment showed the shortest board life.
- White cements have a shorter board life when compared to common gray cement.
- Water/cement ratios for the cement-bentonite clay and air entrainment mortars are higher than the cement-lime mortars to achieve similar consistency, but these higher water/cement ratios did not improve board life.

Key words: hot weather masonry, board life, cement-lime mortar, air entraining agent

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INTRODUCTION

Summer construction projects in many locations throughout Canada and the United States can have ambient air temperatures in excess of 38 °C and relative humidity less than 30%. High temperatures, low relative humidity and wind can combine to considerably shorten the board life of masonry mortar. To extend hot weather board life, especially when working with white cement masons in Texas and Florida have a practice of switching from cement-Type S hydrated lime mortar to cement-Type SA (air entrained) hydrated lime mortar. It is also reported that for the same reason some Texas and Florida masons may switch to cement with proprietary air entrained products.
This study investigates and compares the board life of common gray Portland cement and two white Portland cements formulated with Type S hydrated lime, Type SA hydrated lime and a proprietary air entrained bentonite clay mortar admixture and local sand. The hot weather conditions were achieved by testing in the Mojave Desert, at Henderson, Nevada. Ambient air temperatures were greater than 38°C (45°C Max) and relative humidity less than 25% (~10% min.).

MATERIALS AND MIX DESIGN

All Portland cements used in this study were Type I and certified by their manufacturers to meet ASTM C 150. The two white Portland cements in this study were produced by different Texas manufacturers and are designated as WP1 and WP2. All white Portland cements were purchased off-the-shelf from a retail supplier in San Antonio, Texas. The common gray Portland cement (GP) used in this study was manufactured in California and purchased off-the-shelf from a retail supplier in Henderson, Nevada. The Type S (S) and Type SA (SA) hydrated limes were produced by Chemical Lime Company's New Braunfels, Texas plant and conforms to ASTM C 207. The proprietary air-entrained bentonite clay admixture (AEB) was acquired directly from masonry contractors in paper bags that were sealed and labeled by the manufacturer (There is no current or accepted ASTM standard for mortar materials such as air-entrained bentonite clay). After delivery to Chemical Lime Company's Henderson, Nevada laboratory, all products were removed from their distribution bags and stored in air-tight 18.9 L (5 gallon) plastic pails until weighing for use.

Sand was purchased in bulk from a producer. It was loaded into air-tight 18.9 L (5 gallon) pails at the aggregate producer's yard and transported to the laboratory. The sand was tested for size gradation to determine conformance with ASTM C 144. The sand was considered to be dry. To bulk the sand to saturated surface dry, water was added to the pre-weighed sand proportion in the amount of 6% by weight of the sand. Figure 1 indicates that the sand conforms to the gradation requirements of the C 144.

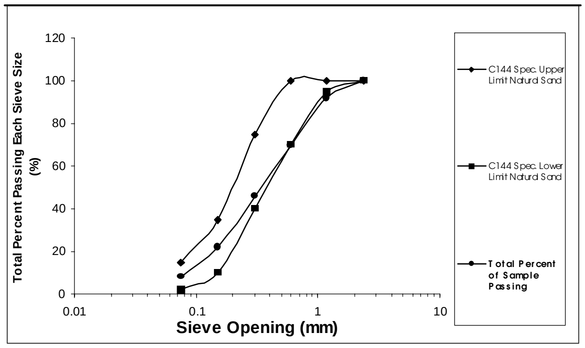

Figure. 1. Particle size distribution of mortar sand.

All mixing water was potable, taken from a garden hose left outside. Water was measured initially by weight, with additions by volume. No temperature factor was applied to back calculate volume to weight, as it was not considered significant to the study.

All cement-lime mortars were proportioned as Type S following ASTM C 270-2000 Table 1. Cement-air entrained bentonite clay (AEB) mortars were proportioned following printed instructions on the manufacture's distribution bag. Two differing dosages were used for the cement-AEB mortars because bags obtained at different locations indicated different proportions for a "Type S" mortar. The bulk densities of the mortar constituents were determined, and volume proportions were converted to mass values. Weights for the mortar mix materials are presented in Table 1.

Table 1. Weight of Mortar Materials.

Mortar	Cement (g)	Lime (g)	AEB (g)	Sand (g)	Total Water
GPSA	10659.4	2268.0	NA	40823.3	8420.9
WP1SA	10659.4	2268.0	NA	40823.3	9486.9
WP2SA	10659.4	2268.0	NA	40823.3	9060.9
GPS	10659.4	2268.0	NA	40823.3	8527.5
WP1S	10659.4	2268.0	NA	40823.3	9700.0
WP2S	10659.4	2268.0	NA	40823.3	8420.9
GPAEB1	10659.4	NA	396.9	40823.3	8420.9
GPAEB2	10659.4	NA	793.8	40823.3	10126.4
WP1AEB1	10659.4	NA	396.9	40823.3	9380.3
WP1AEB2	10659.4	NA	793.8	40823.3	10126.4

MIXING PROCEDURE

A commercial grade 0.04 m^3 (1½ bag), electric, horizontal paddle mixer was used. It was located in full sun, on the south facing side of the laboratory building. Potable water was taken from a garden hose left in the sun. The water was initially weighed, with additions for workability made by volume. Calculation from volume to mass did not include considerations of air temperature, as it was not considered significant to this study. All the materials were stored in a warehouse prior to use

The mixing practice for the cement-lime mortars was as follows:

- turn on mixer; within 45 seconds the mixer was charged as follows.
- add ½ mixing water
- add all the sand
- add pre-blended cementitious materials

Any additional mixing water needed to adjust plastic mortar consistency was added during the first four minutes of mixing. Total mixing time, after charging was five minutes.

The mixing practice for the cement-AEB mortars followed the manufacturer's instructions

- turn on mixer; within 45 seconds the mixer was charged as follows.
- add ⅔ mixing water
- add AEB and mix for 90 seconds
- add ¼ sand and cement, mix for 120 seconds
- add remaining sand and water

Additional mixing water needed to adjust plastic mortar consistency was added during the first five minutes of mixing. Total mixing time after charging was 8 minutes.

BOARD LIFE TEST PROCEDURE

This investigation measured board life of masonry mortars for heavier masonry units using equipment and procedures outlined in ASTM C 780 Annex 3. Annex 3.1.1 specifies the use of a concrete penetrometer modified with steel disk that is 2.54 cm (1") thick and 6.86 cm (2.70") in diameter. The penetrometer scale readings must converted to force/unit area (MPa, psi) which is unique to each instrument. Fig. 2 illustrates the determined calibration curve for this study.

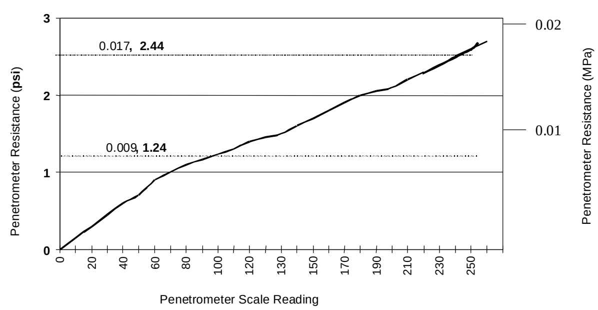

Figure 2.   Modified Concrete Penetrometer Calibration Curve. Dashed line indicates board life range for heavier masonry units.

Other apparatus used in this testing included: a mason's trowel, square nosed shovel, 40.64 cm (16") inside diameter by 7.62 cm (3") high steel mortar molding ring with exterior opposing handles, 60.96 cm by 91.44 cm by 1.91 cm (2'x3'x3/4") exterior grade plywood mortar testing board, 60.96 cm (24") long aluminum straightedge, 1000 ml plastic graduated cylinder, digital weigh scale, digital timer, calibrated digital temperature/humidity meter and a NIST traceable digital probe type mortar thermometer.

The air content was determined using a pressure similar in design and principle to the concrete air pail described in ASTM C231 (Type B pail). It uses only 0.75 liters of material, which is more appropriate for mortar testing.

Immediately after mixer discharge, a digital timer was started and test mortar was transferred by shovel to the steel ring centered on the dampened mortar test board. The mortar was placed to overfilling in the molding ring, spaded with the shovel to eliminate voids and screeded flush to the top surface of the ring with the straightedge. At precisely 3 minutes after mixer discharge, the molding ring was removed. Three individual penetrometer resistance measurements were made by applying steady pressure within 3 seconds at locations on the top surface of the mortar at a depth of 2.54 cm (1") and least 1 disk diameter from the edge and from previous test areas. After initial resistance measurements were made and recorded, and within 2 minutes, the test mortar was thoroughly remixed with the trowel from top to bottom and side-to-side. After remixing, the molding ring was replaced in the center of the mortar test board over the bulk of the remixed mortar and any remixed material remaining outside of the molding ring was transferred into the ring with the trowel so that the material once again overfilled the ring. After refilling, the remixed mortar was spaded with the trowel to eliminate voids and screeded flush. After screeding, the molding ring was removed and set aside. The mortar remained in this condition until it was time for the next penetration resistance measurement. This sequence of measurement and remixing was repeated for each time interval until the penetration resistance measurements exceeded the upper limit for mortar of heavier masonry units (0.017 MPa, 2.44 psi).

ASTM C 780 Annex 3 requires penetration resistance readings on mortar that has remained undisturbed for a period of 15 minutes. Preliminary tests at 15-minute intervals on similar mortars studied in this investigation indicated that harsh site conditions did not allow accurate data resolution for interpolation to the test end point. Note A3.2 allows measurements other than 15 minutes for the purpose of research or other testing needs. The investigators chose a time interval of 5 minutes between measurements and remixing for the purpose of increasing data resolution and to more closely imitate the action of a mason who is more frequently disturbing the mortar prior to placement in the construction.

Ambient air temperature/humidity measurements and mortar temperature measurements were made and recorded at each penetration resistance measurement time interval. Estimated wind speed was recorded at the beginning of the mixing sequence. Cone penetrometer measurements utilizing a Vicat apparatus conforming to the requirements specified in ASTM C 187 were recorded at the start and end of the test.

RESULTS

Table 2 summarizes the board life test results and ambient conditions. Board life in minutes and subsequent rates of stiffening presented in Table 2 was interpolated form penetrometer data using Mathsoft, Mathcad 5.0 software.

Table 2. Board Life Data Summary

Mortar Reference ID n=number	BL [min] (±1σ)	R of S [MPa*10^{-3}/ min] (±1σ)	W/C ___ *% air*	Initial Vicat [mm]	Final Vicat [mm]	Site Temp [°C]	RH [%]	Wind Speed [kph]
GPSA	35.25	0.207	0.79					
n=1			*4.9*	49	33	42.4	9.6	6-9
WP1SA	31.67	0.276	0.89					
n=3	(7.14)	(0.07)	*5.6*	60	47	39.2	15.0	3-9
WP2SA	27.49	0.276	0.85					
n=3	(6.53)	(0.07)	*5.0*	57	34	43.9	15.0	3-9
GPS	28.02	0.276	0.80					
n=1			*3.2*	60	35	42.4	9.6	6-9
WP1S	18.28	0.414	0.91					
n=3	(2.34)	(0.07)	*4.5*	56	35	43.5	20.2	0-6
WP2S	21.67	0.483	0.79					
n=3	(1.88)	(0.07)	*3.1*	52	35	41.3	9.3	0-9
GPAEB1	18.01	0.483	0.79					
n=1			*4.5*	59	25	42.4	8.4	9-15
GPAEB2	25.17	0.345	0.95					
n=1			5.0	58	32	42.3	8.0	9-15
WP2AEB1	21.89	0.0552	0.88					
n=3	(5.09)	(0.14)	*6.8*	50	35	40.9	21.7	0-6
WP2AEB2	15.16	0.552	0.95			43.67		
n=3	(0.81)	(0.00)	*7.2*	53	30	43.7	17.1	0-9

BL – board life in minutes; R of S – rate of stiffening in MPa*10^{-3}/minute; W/C – water to cement ratio; RH – relative humidity.

Fig. 2 indicates the individual plots of resistance to penetration over time of the different mix designs. The difference in time between the values at the lower and upper resistance penetration is the board life. The slope of the curve between these limits corresponds to the rate of stiffening. Fig. 3 indicates the average board life data.

Fig. 4 indicates the ambient air temperature in the sun, mixing water temperature and the temperature of the mortar over time during board life testing.

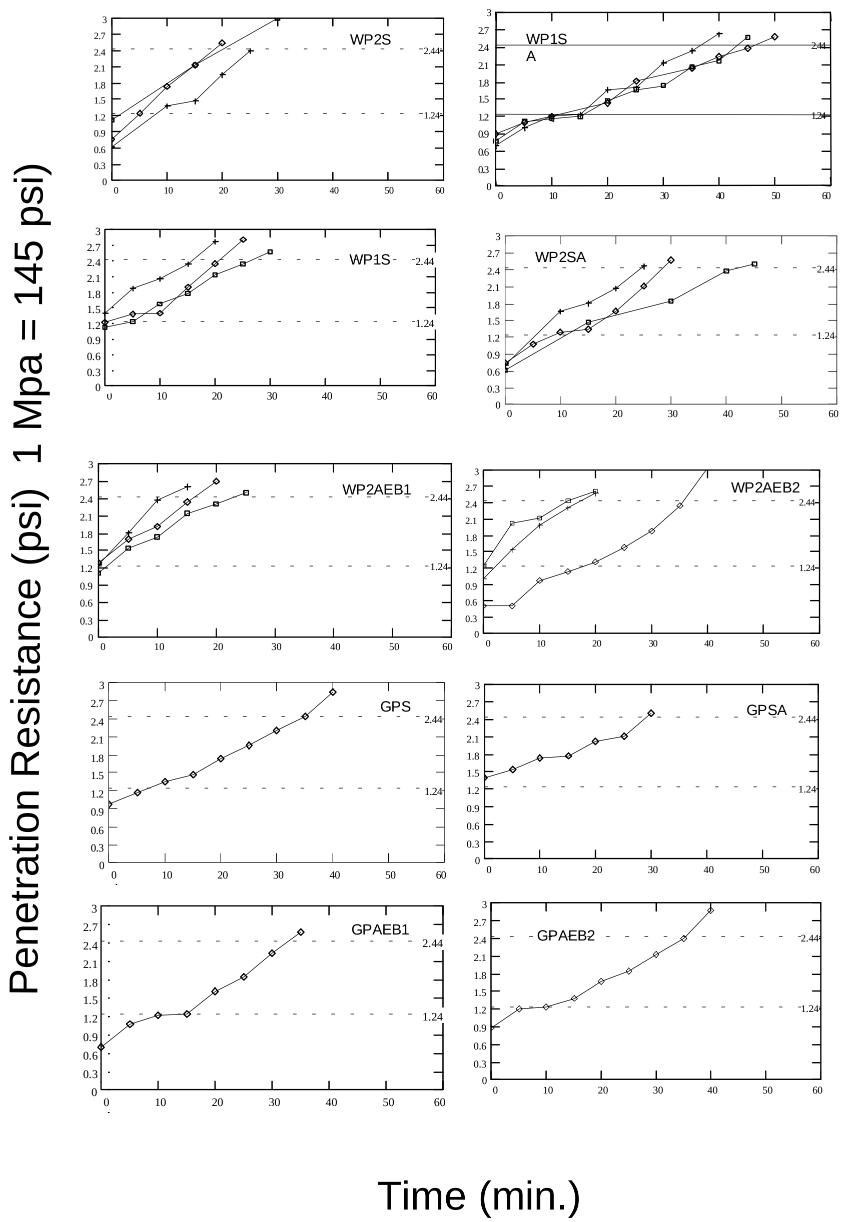

Figure 2. Penetration resistance versus time of the mixes tested. Mix 1 is open diamond, Mix 2 is open square and Mix 3 is cross.

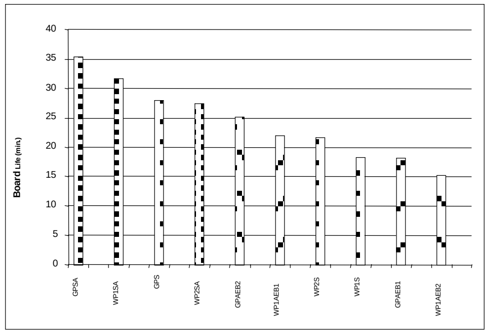

Figure 3. Histogram of board life values for different mix types.

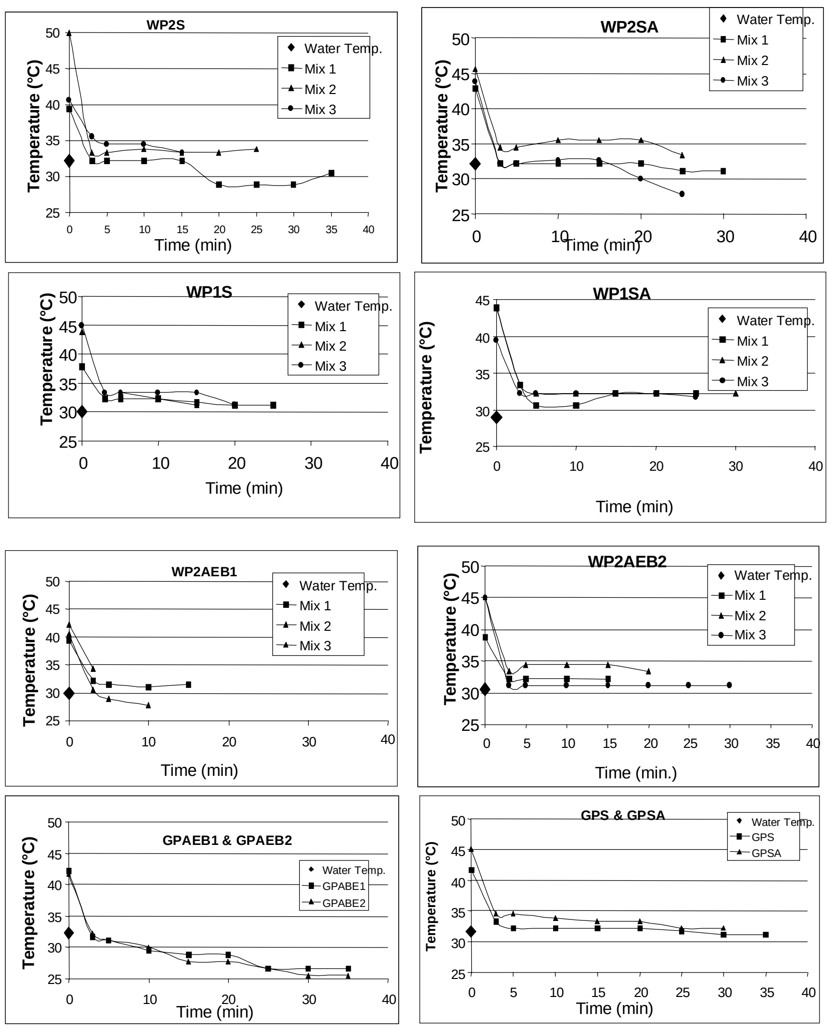

Figure 4. Temperature of mortar during board life testing. Temperature at time zero represents the temperature in the sun.

DISCUSSION

ASTM C 780 ANNEX 3.

Previous work (van der Hoeven *et al*., 1999) suggests that the test method outlined in ASTM C 780 Annex 3 has limitations in both the procedure and the interpretation of the results. This study supports this position. Initial penetration resistance with the modified concrete penetrometer does not provide the required resolution of Annex 3 (±0.345 $*10^{-3}$ MPa (±0.05 psi)). The scale readings on the penetrometer have markings from 0 to 700 that are 20 units apart. The markings cannot be easily read off the penetrometer scale at the required resolution. The mortars in this study were mixed to an initial penetrometer resistance scale reading below the initial penetration resistance of 0.09 MPa (1.24 psi) and allowed to stiffen to the final penetration resistance of 0.017 MPa (2.44 psi).

Achieving absolute values of board life from this type of testing is well beyond the reliability of the test method. However, comparison of data for a group of mortars mixed in the same way, under the same or similar environmental conditions provides a reasonable comparison.

It is important for the tester to discriminate between the apparent board life during the test to that which is calculated. The apparent board life of a mortar is the time from discharge from mixer to the final resistance penetration value. In the field this would be the point at which the mason would retemper. Calculated board life is the difference in time between the initial penetration value and the final penetration value measured by the penetrometer. For instance for mix WP2AEB2 Mix 1 the test ended at 40 minutes, but the actual board life was only calculated at 15 minutes.

HOT WEATHER PERFORMANCE OF THE MORTARS

Type SA hydrated lime showed the longest board life with all cement types tested. Type S hydrated lime showed better performance with gray Portland cement, and intermediate performance with the white Portland cements.

Doubling the dosage of the air entrained bentonite clay to the gray cement appears to have improved the board life, but with white cement there was a decrease in board life.

The white Portland cements do appear to have a decreased board life compared to gray cement under these test conditions. The difference between the two white cements with type SA lime is less significant than without air entrainment, indicating some influence of air entrainment.

It is interesting to note that the air volume values (Table 1) indicate no more than 7% air content for the cement-air entrained bentonite clay mortars, but most values at about 5%. Air entrained cement-lime mortars when tested in the laboratory range in air content from 8% to 12%, and cement-air entrained bentonite clay mortars have air values from

14% to 22%. The generally improved board life with air entrainment would suggest a chemical influence on the hydration of the cement (retardation?), but not in the development of well formed, abundant air voids.

The influence of Type S and Type SA hydrated lime on mortar board life is directly related to the fine particle size of the lime. Lime particles are much less than 1μm in diameter. The air entrainment of the Type SA lime is so much more effective than that of the air entrained bentonite clay because of dispersion. Not only is the volume of lime greater in a mortar mix, but the ability of the small particle size to disperse the air entraining agent is much more effective. .

GUIDE TO HOT WEATHER CONSTRUCTION

Hot weather construction guides (for instance IBC 2000) imply that when ambient temperature exceed 38 °C, there is a need to keep the mortar below a temperature of 40°C. Not considered, however, is that where the relative humidity is low, evaporative cooling will occur and the mortar will not heat up until all the water is evaporated out. The mortar should be thrown out at this point, but it could occur so rapidly that the mason would just retemper. Guidance for hot weather construction, would be better served by indicating the frequency of needed retempering of the mortar, perhaps based on the resistance to penetration. Determining the influence of the retempering would is also an important consideration.

CONCLUSIONS

- Type SA hydrated lime allows for a longer workable mortar under hot weather conditions
- White Portland cement has a shorter board life than gray Portland cement.
- The air entrainment of the cement-air entrained bentonite clay is inconsistent in improving board life
- In hot, dry conditions mortar will cool due to evaporation, making the current guides to hot weather construction problematic

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