

Evaluation of Set Accelerating Admixture for Portland Cement and Lime Masonry Mortar

for

**Grace Construction Products
7221 Parkland Court West
Milwaukee, WI 53223**

Conducted by:



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11/19/2010

Nicholas R. Lang, Manager, Research & Development Laboratory

Date



11/19/2010

Jason J. Thompson, Director of Engineering

Date

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Statement of Revision

November 19, 2010 – Corrected inch-pound to SI unit conversion in Table 1.

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Evaluation of Set Accelerating Admixture for Portland Cement and Lime Masonry Mortar

1.0—INTRODUCTION

Admixtures may be used in masonry mortars to alter one or more of the mortar's properties, one of which is to decrease the setting time of masonry mortar through the use of a set accelerating admixture. This project evaluated a set accelerating chemical admixture for use in masonry mortar for compliance with ASTM C1384-06a, *Standard Specification for Admixtures for Masonry Mortars* (Ref. 1).

2.0—MATERIALS

2.1 Cementitious Materials

The mortar prepared in this project was Type S portland cement and lime mortar. The portland cement used was a Type I/II portland cement. The lime used as a Type SA hydrated lime. While the packaging of these materials stated compliance with their respective ASTM standards, compliance was not verified by the Laboratory because compliance with the property specification of ASTM C270-08a, *Standard Specification for Mortar for Unit Masonry* (Ref. 2), was performed as part of this project and is required for mortars evaluated in accordance with ASTM C1384-06a.

2.2 Masonry Sand

The sand used for this project was masonry sand from a local quarry that met the gradation requirements of ASTM C144-08, *Standard Specification for Aggregate for Masonry Mortar* (Ref. 3).

2.2 Masonry Mortar Admixtures

The masonry mortar admixture evaluated here was a set accelerating admixture with the trade name "MORSET® Non-Chloride/Non-Corrosive Set Accelerator". This admixture was provided to the Laboratory by the client in a 1 gal (3.8 L) bottle.

3.0—TESTING PROCEDURES

3.1 Air Content, Water Retention, and Compressive Strength Testing

Two batches of mortar were evaluated for compliance with ASTM C270-08a, a control batch without admixture and a test batch containing the admixture. Testing was performed for air content as per ASTM C185-08, *Standard Test Method for Air Content of Hydraulic Cement Mortar* (Ref. 4), water retention as per ASTM C1506-08, *Standard Test Method for Water Retention of Hydraulic Cement-Based Mortars and Plasters* (Ref. 5), and compressive strength as per ASTM C109/C109M-08, *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2 in. or [50-mm] Cube Specimens)* (Ref. 6), as modified by ASTM C270-08a.

3.2 Consistency Retention Testing

Consistency retention testing was performed in accordance with ASTM C780-09, *Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry* (Ref. 7). The procedure used is found in Annex A2, *Consistency Retention of Mortars for Unit Masonry*, specifically the 'disturbed sample' procedures. As with the testing described previously, consistency retention testing was performed on two batches, a control and a test batch. The batches were mixed

according to ASTM C780-09 to an initial cone penetration of 60 ± 5 mm (2.36 ± 0.20 in.). Subsequent cone penetration readings were taken at 15 minute intervals until the penetration was less than 70% of the initial reading. Using this data, a linear interpolation was used to determine the exact time that the penetration was at 70% of the initial penetration. This interpolated time is reported as the board life.

3.3 Time of Set Testing

Time of set was evaluated using the procedures in ASTM C403/C403M-08, *Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance* (Ref. 8). For each test, three individual samples were taken from the same test batch. Reported values are the average results from the samples taken from the same batch. This test was performed on two batches; a control batch containing no admixture and a test batch containing the admixture. Accelerating admixtures are typically used in masonry construction during cold weather. Given the typical use of accelerating admixtures ASTM C1384-06a requires that both control and modified mortars be evaluated for time of set at an ambient temperature of $41 \pm 3.6^\circ\text{F}$ ($5 \pm 2^\circ\text{C}$) to determine the admixture's effect on set time.

3.4 Number of Tests Performed

Section 7.1 of ASTM C1384-06a states in part that "Unless more specimens are required by a specific test method, a minimum of three specimens shall be tested and the results averaged". For this project, three specimens were taken from each batch for ASTM C403/C403M-06 testing. A single determination of air content and water retention was taken from each batch for ASTM C270-08a and three cubes were tested at each of 7 days and 28 days of age. For ASTM C780-09 testing, a single determination was made from each batch.

4.0 MORTAR VARIABLES AND BATCHING PROCEDURES

As discussed in Section 2.1, the masonry mortar evaluated was Type S portland cement and lime mortar. The proportions of constituent materials used to batch each mortar evaluated in this investigation complied with ASTM C270-08a. These proportions are shown in Table 1. For the set accelerating admixture, the manufacturer's recommended dosage rate varied based on the ambient testing temperature. Therefore, the dosage rate for the admixture for ASTM C403/C403M-06 testing was 32 oz per 94 lb cement (946 mL per 42.6 kg cement), while for ASTM C270-08a and ASTM C780-09 testing the dosage rate was 16 oz per 94 lb cement (473 mL per 42.6 kg cement).

Material	Volume Proportions	Weight of Material for C270-08a, g (lb)	Weight of Material for C403/C403M-06, lb (kg)	Weight of Material for C780-09, lb (kg)
Portland Cement	1	376 (0.828)	13.06 (5.92)	13.06 (5.92)
Lime	0.5	80 (0.176)	2.78 (1.26)	2.78 (1.26)
Sand	4.5	1440 (3.175)	50.0 (22.7)	50.0 (22.7)
MORSET ¹	See above	5.4 (0.012)	0.38 (0.172)	0.19 (0.086)

¹ Admixture not used in control batches.

5.0—RESULTS

5.1 Requirements and Results

Table 2 shows the requirements for mortar modified with a set accelerating admixture as per ASTM C1384-06a as well as the test results. Requirements are based on deviation from the values obtained from the control sets. Additionally, all modified mortars are required to meet the property specification of ASTM C270-08a.

The air content and water retention results for the test batches are shown in Table 2. All results meet the property requirements for air content and water retention for a Type S portland cement and lime masonry mortar in accordance with ASTM C270-08a. Detailed results can be found in Appendix A.

Table 2 also shows the compressive strength results. Both sets meet the ASTM C270-08a property requirements for compressive strength for a Type S portland cement and lime masonry mortar. Additionally, the mortar with admixture complies with the requirements in ASTM C1384-06a at both 7 and 28 days of age that the strength of the modified mortar be 80% or more of the control batch. Detailed results can be found in Appendix A.

ASTM C1384-06a has no specific requirements for the performance of the mortar with a set accelerating admixture for consistency retention (board life), although it is required to report the results for each batch. A summary of the C780-09 results are shown in Table 2, with detailed results in Appendix B.

Results for time of set by penetration resistance are shown in Table 2. The modified mortar complies with the requirements of ASTM C1384-06a at both the initial set, where the mortar with admixture shall reach initial set at least 1 hour, but not more than 3.5 hours earlier than the control, and at final set, where the modified mortar shall reach initial set at least 1 hour earlier than the control. Detailed results can be found in Appendix C.

Table 2: ASTM C1384-06a Requirements and Summary of Test Results						
Physical Property	ASTM C270-08a Property Requirements	Set Accelerator Admixture Requirements	Control Mortar	MORSET® Set Accelerator	% of Control	Pass/Fail /Report
7 day compressive strength, psi (MPa)	---	80% minimum of control	2800 (19.3)	2620 (18.1)	94	Pass
28 day compressive strength, psi (MPa)	1800 (12.4)	80% minimum of control	3190 (22.0)	3300 (22.8)	103	Pass
Water Retention, %	75	Report only*	86.9	82.9	-	Report*
Air Content, %	12	Report only*	5.4	7.2	-	Report*
Board Life, %	---	Report only*	66.6	98.5	-	Report*
Initial Time of Set At least Not more than	---	1:00 hr earlier than control 3:30 hr earlier than control	10:27	8:14	Within Permitted Range (6:57 to 9:27)	Pass
Final Time of Set At least Not more than	---	1:00 hr earlier than control ---	18:24	15:43	Within Permitted Range (17:24 or earlier)	Pass

*ASTM C1384-06a does not require or specify a maximum or minimum value for this mortar property, only that the measured difference relative to the control batch be reported.

6.0—SUMMARY OF OBSERVATIONS

A chemical admixture was evaluated for suitability for use in masonry mortars. Pursuant to the requirements of ASTM C1384-06a, testing was performed on a control mortar and a mortar with MORSET set accelerating admixture for compressive strength, air content, water retention, consistency retention, and time of set. The mortars were both a Type S portland cement and lime masonry mortar, and complied with the property specification of ASTM C270-08a. The admixture was provided to the Laboratory by the client.

Based on the results provided above, the set accelerating masonry mortar admixture with the trade name “MORSET” meets all the requirements of ASTM C1384-08a at the dosage rates as reported in this report when used with a Type S portland cement and lime mortar.

7.0—REFERENCES

1. ASTM Standard C1384, 2006a, “Standard Specification for Admixtures for Masonry Mortars”, ASTM International, West Conshohocken, PA, www.astm.org.
2. ASTM Standard C270, 2008a, “Standard Specification for Mortar for Unit Masonry”, ASTM International, West Conshohocken, PA, www.astm.org.
3. ASTM C144, 2004, “Standard Specification for Aggregate for Masonry Mortar”, ASTM International, West Conshohocken, PA, www.astm.org.
4. ASTM Standard C185, 2008, “Standard Test Method for Air Content of Hydraulic Cement Mortar”, ASTM International, West Conshohocken, PA, www.astm.org.
5. ASTM Standard C1506, 2008, “Standard Test Method for Water Retention of Hydraulic Cement-Based Mortars and Plasters”, ASTM International, West Conshohocken, PA, www.astm.org.
6. ASTM Standard C109/C109M, 2008, “Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)”, ASTM International, West Conshohocken, PA, www.astm.org.
7. ASTM Standard C780, 2009, “Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry”, ASTM International, West Conshohocken, PA, www.astm.org.
8. ASTM Standard C403/C403M, 2008, “Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance”, ASTM International, West Conshohocken, PA, www.astm.org.

APPENDIX

In the appendix, the values presented are in inch-pound units. The following conversions to SI units can be used:

$$1 \text{ in} = 25.4 \text{ mm}$$

$$1 \text{ lb/ft}^3 = 16.0 \text{ kg/m}^3$$

$$1 \text{ lb (mass)} = 0.4536 \text{ kg}$$

$$1 \text{ lb (force)} = 4.45 \text{ N}$$

$$1 \text{ psi} = 6.895 \text{ kPa}$$

Appendix A – ASTM C270-08a Results

Control Batch

ASTM C 270-08a Test Report Mortar for Unit Masonry

Job No.: 09-110-1A
Report Date: 12/30/2009

Client: Grace Construction Products
Address: 7221 Parkland Court West
Milwaukee, WI 53223

Testing Agency: National Concrete Masonry Association
Address: Research and Development Laboratory
13750 Sunrise Valley Drive
Herndon, VA 20171-4662

Mortar Description:
Portlant Cement and Lime Masonry Mortar
Type S
Control - No Admixture

Sampling Party: Grace Construction Products
Date Samples Received: 2/24/2009

Batch Information (C270)		Volume	Weight	Density	Volume
Material	Type/Brand/Source	Proportions	(g)	(g/cc)	(cc) or (mL)
Portland Cement	Type I/II	1	376.0	3.15	119.4
Lime	Type SA	0.5	80.0	2.34	34.2
Masonry Sand (OD)	C144	4.5	1440.0	2.65	543.4
Water Added to Mix	---	---	310.0	1.00	310.0
Admixture	None	---	---	---	---
Date Mixed: 6/2/2009		Total Wt. = 2206.0		Total Vol. = 1006.9	
Air Calculation (C91)		2-inch Cube Compressive Strength (C109/C109M)			
400 mL Brass Cup, full	1569.8 g	Date Tested: 6/9/2009		Cube	
Tare Weight of brass cup	740.6 g	Cube Age: 7 Days		Strength	
400 mL of mortar, W_{dm}	829.2 g	Cube #	Cube Wt (g)	Load (lbs)	Strength (psi)
Density of mortar, D =	2.19 g/mL	1	278.0	12100	3030
Air = $100 - W_{dm}/4D =$	5.38 %	2	273.0	11150	2790
Density w/ Air, $W_{dm}/400 =$	2.07 g/mL	3	274.9	10350	2590
Unit Wt. = $(D \text{ w/ Air}) \times 62.4 =$	129.36 pcf	Average	275.3	11200	2800
Water Retention (C1506)		2-inch Cube Compressive Strength (C109-C109M)			
Initial Flow (%)	107.0	Date Tested: 6/30/2009		Cube	
Flow After Suction (%)	93.0	Cube Age: 28 Days		Strength	
Water Retention (%)	86.9	Cube #	Cube Wt (g)	Load (lbs)	Strength (psi)
		1	276.4	13240	3310
		2	276.6	12130	3030
		3	275.5	12880	3220
		Average	276.2	12750	3190

Tested Property	Specified Values	Tested Values
Compressive Strength, 7 Day		2800 psi
Compressive Strength, 28 Day	1800 psi min	3190 psi
Air Content	12% max	5.4 %
Water Retention	75 % min	86.9 %

NOTE: The tested materials meet the requirements of ASTM C270-08a for Type S portland cement and lime masonry mortar.

Test Batch with MORSET Set Accelerator

**ASTM C 270-08a Test Report
Mortar for Unit Masonry**

Job No.: 09-110-5A
Report Date: 12/30/2009

Client: Grace Construction Products
Address: 7221 Parkland Court West
Milwaukee, WI 53223

Testing Agency: National Concrete Masonry Association
Address: Research and Development Laboratory
13750 Sunrise Valley Drive
Herndon, VA 20171-4662

Mortar Description:
Portland Cement and Lime Masonry Mortar
Type S
Test - with Set Accelerating Admixture

Sampling Party: Grace Construction Products
Date Samples Received: 2/24/2009

Batch Information (C270)		Volume	Weight	Density	Volume
Material	Type/Brand/Source	Proportions	(g)	(g/cc)	(cc) or (mL)
Portland Cement	Type I/II	1	376.0	3.15	119.4
Lime	Type SA	0.5	80.0	2.34	34.2
Masonry Cement	C144	4.5	1440.0	2.75	523.6
Water Added to Mix	---	---	310.0	1.00	310.0
Admixture	MORSET	---	5.4	1.00	5.4
Date Mixed: 8/3/2009		Total Wt. = 2211.4		Total Vol. = 992.6	
Air Calculation (C91)		2-inch Cube Compressive Strength (C109/C109M)			
400 mL Brass Cup, full	1568.1 g	Date Tested: 8/10/2009		Cube Strength	
Tare Weight of brass cup	740.7 g	Cube Age: 7 Days			
400 mL of mortar, W_{dm}	827.4 g	Cube #	Cube Wt (g)	Load (lbs)	
Density of mortar, $D =$	2.23 g/mL	1	277.2	10520	2630
Air = $100 - W_{dm}/4D =$	7.16 %	2	275.8	10520	2630
Density w/ Air, $W_{dm}/400 =$	2.07 g/mL	3	277.1	10370	2590
Unit Wt. = $(D w/ Air) \times 62.4 =$	129.07 pcf	Average	276.7	10470	2620
Water Retention (C1506)		2-inch Cube Compressive Strength (C109/C109M)			
Initial Flow (%)	111.0	Date Tested: 8/31/2009		Cube Strength	
Flow After Suction (%)	92.0	Cube Age: 28 Days			
Water Retention (%)	82.9	Cube #	Cube Wt (g)	Load (lbs)	
		1	276.8	13340	3340
		2	273.8	13150	3290
		3	273.2	13080	3270
		Average	274.6	13190	3300

Tested Property	Specified Values	Tested Values
Compressive Strength, 7 Day		2620 psi
Compressive Strength, 28 Day	1800 psi min	3300 psi
Air Content	18% max	7.2 %
Water Retention	75 % min	82.9 %

NOTE: The tested materials meet the requirements of ASTM C270-08s for Type S portland cement and lime masonry mortar.

Appendix B – ASTM C780-09 Results – Consistency Retention

Control Batch

NCMA Research and Development Laboratory

NCMA Job Number: 09-110-1B
Report Date: 12/30/2009

**ASTM C780-09 Standard Test Methods Preconstruction and Construction
Evaluation of Mortars for Plain and Reinforced Unit Masonry
Annex A2: Consistency Retention of Mortars for Unit Masonry**

Client: Grace Construction Products
Address: 7221 Parkland Court West
Milwaukee, WI 53223

Testing Agency: National Concrete Masonry Association
Research and Development Laboratory
Address: 13750 Sunrise Valley Drive
Herndon, VA 20171

Project Identification: Portland Cement and Lime Masonry Mortar Type S

Sample Identification: Control - No Admixture

Batch Information: Mortar Type: S

Material	Description	Batch Weight (lb)
Portland Cement:	Type I/II	13.1
Lime:	Type SA	2.8
Masonry Sand:	C144	50.0
Admixture:	None	---
Water:	---	11.5

NOTE: Mixing water added to achieve an initial cone penetration of 60 ± 5 mm as per ASTM C1384.

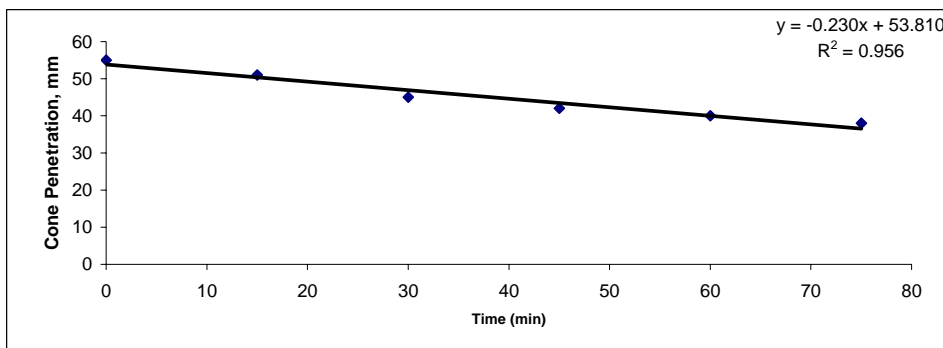
Test Results:

Mixing Time: 5 min

Reading Number	Time (min)	Cone Penetration
		mm
T ₀	0	55
2	15	51
3	30	45
4	45	42
5	60	40
6	75	38

70% of T₀, mm = 38.5
Board Life, min = 66.6

NOTE: As per ASTM C1384, board life is defined as the interpolated time that the cone penetration is at 70% of the initial penetration, T₀.



Trendline: y = -0.230 * x + 53.810

Test Batch with MORSET Set Accelerator

NCMA Research and Development Laboratory

NCMA Job Number: 09-110-5B
Report Date: 12/30/2009

**ASTM C780-09 Standard Test Methods Preconstruction and Construction
Evaluation of Mortars for Plain and Reinforced Unit Masonry
Annex A2: Consistency Retention of Mortars for Unit Masonry**

Client: Grace Construction Products
Address: 7221 Parkland Court West
Milwaukee, WI 53223

Testing Agency: National Concrete Masonry Association
Research and Development Laboratory
Address: 13750 Sunrise Valley Drive
Herndon, VA 20171

Project Identification: Portland Cement and Lime Masonry Mortar Type S

Sample Identification: Test - with Set Accelerating Admixture

Batch Information: Mortar Type: S

Material	Description	Batch Weight	
Portland Cement:	Type I/II	13.1	lb
Lime:	Type SA	2.8	lb
Masonry Sand:	C144	50.0	lb
Admixture:	MORSET	85.4	g
Water:	---	10.7	lb

NOTE: Mixing water added to achieve an initial cone penetration of 60 ± 5 mm as per ASTM C1384.

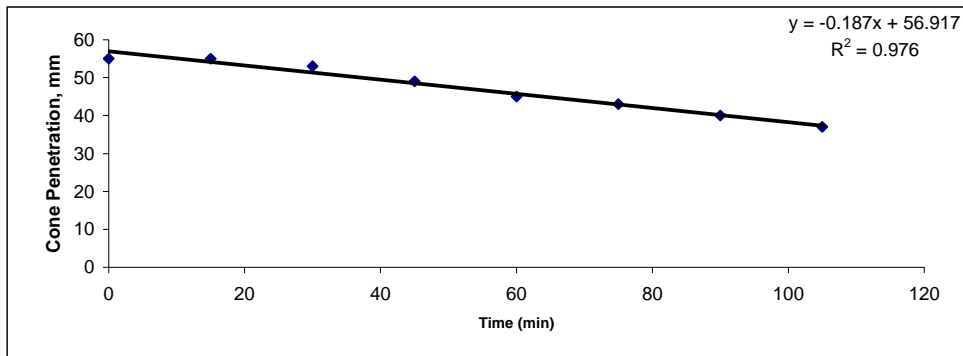
Test Results:

Mixing Time: 5 min

Reading Number	Time (min)	Cone Penetration.
		mm
T ₀	0	55
2	15	55
3	30	53
4	45	49
5	60	45
6	75	43
7	90	40
8	105	37

70% of T₀, mm = 38.5
Board Life, min = 98.5

NOTE: As per ASTM C1384, board life is defined as the interpolated time that the cone penetration is at 70% of the initial penetration, T₀.



Trendline: y = -0.187 * x + 56.917

Appendix C – ASTM C403/C403M-06 Results – Time of Set

Control Batch

NCMA Research and Development Laboratory
ASTM C403/C403M-08 Standard Test Method for Time of Setting
of Concrete Mixtures by Penetration Resistance

NCMA Job Number: 09-110-1E
Date Tested: 10/8/2009
Report Date: 12/30/2009

Client: Grace Construction Products
Address: 7221 Parkland Court West
Milwaukee, WI 53223

Testing Agency: National Concrete Masonry Association
Research and Development Laboratory
Address: 13750 Sunrise Valley Drive
Herndon, VA 20171

Sample Identification: Portland Cement and Lime Type S Masonry Mortar Control - No Admixture at 41 °F

Summary of Test: A masonry mortar mix was batched and prepared using the procedures defined in ASTM C780. The amount of water added was such to produce a flow of $110 \pm 5\%$ when tested in accordance with ASTM C1437. Three test specimens were molded, each with a diameter of 6 inches and a height of approximately 6 inches. These specimens were cured at ambient laboratory temperatures and sealed in a water-tight container to minimize water evaporation. During the course of testing, the samples were uncovered, any bleed water that had accumulated was removed using a syringe, and the specimens were penetrated with needles of varying surface area. The penetrations were taken periodically until the force required to penetrate one inch into the mortar exceeded 4000 psi. At that point, the testing was stopped. The data is plotted on a graph of time vs. penetration resistance. A power function trendline is fitted to the data and the resulting equation is used to determine the time of setting. Initial setting is defined as the time when the penetration resistance equals 500 psi and final setting is the time when the penetration resistance equals 4000 psi. The data is presented below for each of the three samples, and also as an average for the set.

Batch Information:	Material	Description	Batch Weight (lb)
	Portland Cement:	Lafarge Type I/II	13.05
	Lime:	Type SA	2.78
	Aggregate 1:	C144	50.00
	Admixture 1:	None	---
	Water:	---	9.89

Water to Cementitious Materials Ratio: 0.62 Curing Temperature of Mortar: 41°F
Cementitious Materials to Aggregate Ratio: 0.32

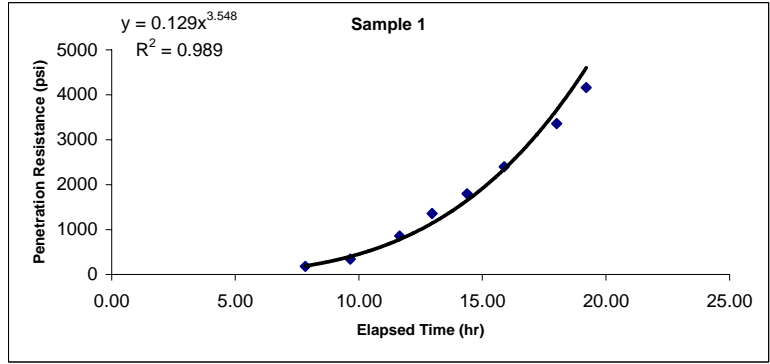
Summary of Time of Set Results:

	Initial Set (hr)	Final Set (hr)
Sample 1	10.27	18.45
Sample 2	10.74	18.59
Sample 3	9.79	17.69
Average	10.27	18.24

Experimental Data and Plots

Sample 1

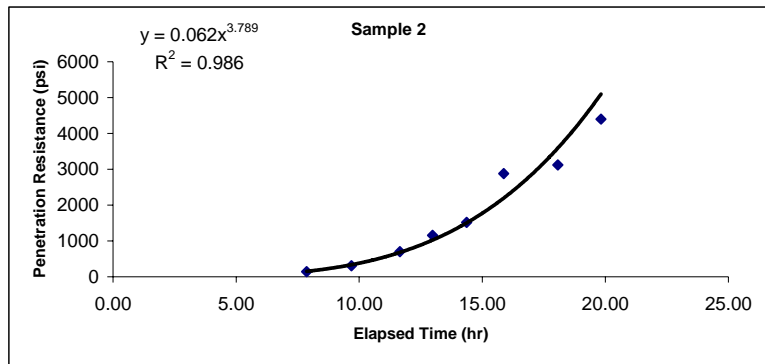
Elapsed Time (hr)	Penetration Resistance (lb)	Needle Area (in ²)	Penetration Resistance (psi)
7.83	92	0.5	184
9.65	86	0.25	344
11.65	86	0.1	860
12.97	68	0.05	1360
14.38	90	0.05	1800
15.88	60	0.025	2400
18.00	84	0.025	3360
19.20	104	0.025	4160



Penetration Resistance= 0.129 *time^{3.548}

Sample 2

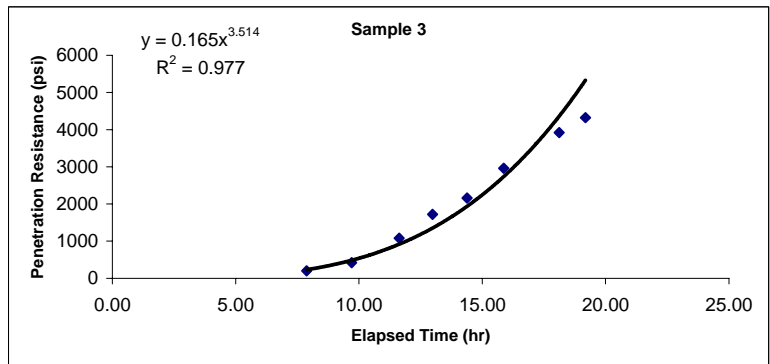
Elapsed Time (hr)	Penetration Resistance (lb)	Needle Area (in ²)	Penetration Resistance (psi)
7.87	72	0.5	144
9.68	78	0.25	312
11.65	70	0.1	700
12.98	58	0.05	1160
14.37	76	0.05	1520
15.87	72	0.025	2880
18.07	78	0.025	3120
19.82	110	0.025	4400



Penetration Resistance= 0.062 *time^{3.789}

Sample 3

Elapsed Time (hr)	Penetration Resistance (lb)	Needle Area (in ²)	Penetration Resistance (psi)
7.88	102	0.5	204
9.70	106	0.25	424
11.63	108	0.1	1080
12.98	86	0.05	1720
14.38	108	0.05	2160
15.87	74	0.025	2960
18.12	98	0.025	3920
19.18	108	0.025	4320



Penetration Resistance= 0.165 *time^{3.514}

Test Batch with MORSET Set Accelerator

NCMA Research and Development Laboratory
ASTM C403/C403M-08 Standard Test Method for Time of Setting
of Concrete Mixtures by Penetration Resistance

NCMA Job Number: 09-110-5C
Date Tested: 10/29/2009
Report Date: 12/30/2009

Client: Grace Construction Products
Address: 7221 Parkland Court West
Milwaukee, WI 53223

Testing Agency: National Concrete Masonry Association
Research and Development Laboratory
Address: 13750 Sunrise Valley Drive
Herndon, VA 20171

Sample Identification: Portland Cement and Lime Type S Masonry Mortar Test - with Set Accelerator

Summary of Test: A masonry mortar mix was batched and prepared using the procedures defined in ASTM C780. The amount of water added was such to produce a flow of $110 \pm 5\%$ when tested in accordance with ASTM C1437. Three test specimens were molded, each with a diameter of 6 inches and a height of approximately 6 inches. These specimens were cured at ambient laboratory temperatures and sealed in a water-tight container to minimize water evaporation. During the course of testing, the samples were uncovered, any bleed water that had accumulated was removed using a syringe, and the specimens were penetrated with needles of varying surface area. The penetrations were taken periodically until the force required to penetrate one inch into the mortar exceeded 4000 psi. At that point, the testing was stopped. The data is plotted on a graph of time vs. penetration resistance. A power function trendline is fitted to the data and the resulting equation is used to determine the time of setting. Initial setting is defined as the time when the penetration resistance equals 500 psi and final setting is the time when the penetration resistance equals 4000 psi. The data is presented below for each of the three samples, and also as an average for the set.

Batch Information:	Material	Description	Batch Weight	
	Portland Cement:	Type I/II	13.05	lb
	Lime:	Type SA	2.78	lb
	Aggregate 1:	C144	50.00	lb
	Admixture 1:	MORSET	170.80	g
	Water:	---	7.77	lb

Water to Cementitious Materials Ratio: 0.49 Curing Temperature of Mortar: 41°F
Cementitious Materials to Aggregate Ratio: 0.32

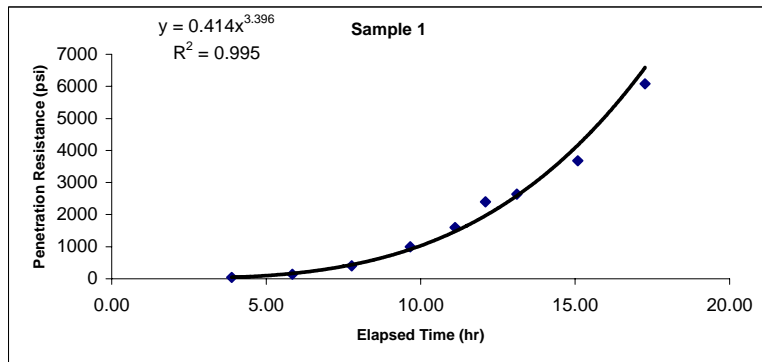
Summary of Time of Set Results:

	Initial Set (hr)	Final Set (hr)
Sample 1	8.08	14.91
Sample 2	8.32	15.70
Sample 3	8.03	15.67
Average	8.14	15.43

Experimental Data and Plots

Sample 1

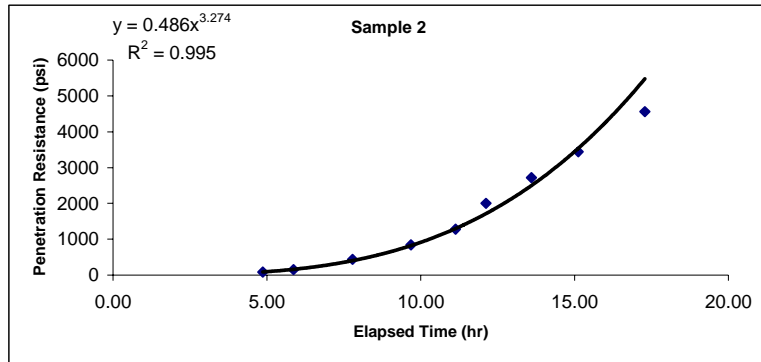
Elapsed Time (hr)	Penetration Resistance (lb)	Needle Area (in ²)	Penetration Resistance (psi)
3.88	22	0.5	44
5.85	36	0.25	144
7.77	40	0.1	400
9.67	100	0.1	1000
11.12	80	0.05	1600
12.10	60	0.025	2400
13.12	66	0.025	2640
15.08	92	0.025	3680
17.27	152	0.025	6080



Penetration Resistance= 0.414 *time^{3.396}

Sample 2

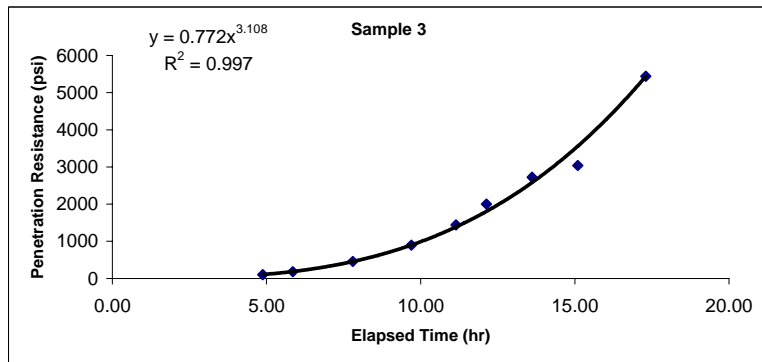
Elapsed Time (hr)	Penetration Resistance (lb)	Needle Area (in ²)	Penetration Resistance (psi)
4.87	40	0.5	80
5.87	38	0.25	152
7.78	44	0.1	440
9.68	84	0.1	840
11.13	64	0.05	1280
12.12	50	0.025	2000
13.60	68	0.025	2720
15.12	86	0.025	3440
17.28	114	0.025	4560



Penetration Resistance= 0.486 *time^{3.274}

Sample 3

Elapsed Time (hr)	Penetration Resistance (lb)	Needle Area (in ²)	Penetration Resistance (psi)
4.88	52	0.5	104
5.85	46	0.25	184
7.80	46	0.1	460
9.70	90	0.1	900
11.15	72	0.05	1440
12.13	50	0.025	2000
13.62	68	0.025	2720
15.10	76	0.025	3040
17.30	136	0.025	5440



Penetration Resistance= 0.772 *time^{3.108}