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MEMORANDUM

To: Technology Development Program Manager, Dam Safety Office
Attn: 84-44000 (LKrosley)

From: Catherine Lucero, Civil Engineer
Concrete, Geotechnical, and Structural Laboratory (86-68530)

Digitally signed by CATHERINE LUCERO
Date: 2017.09.25 16:01:40 -06'00'

Subject: Dam Safety Technology Development Report DSO-2017-04 – Temperature Rise of Mass Concrete Containing Class N Pozzolan

A report on Temperature Rise of Mass Concrete Containing Class N Pozzolan, DSO-2017-04 from the Dam Safety Technology Development Program has been prepared by the Technical Service Center at the request of the Dam Safety Office. The report will be available in Adobe Acrobat Format on the Dam Safety website and will also be loaded into DSDAMS.

This report is one of two reports under the project "Evaluating the effectiveness of natural pozzolans for use in mitigating temperature rise in mass concrete". If you have any questions, please contact me at 303-445-2343 or at cllucero@usbr.gov.

cc (w/att):
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86-68530 (Bartojay)

RECLAMATION
Managing Water in the West

Temperature Rise of Mass Concrete Containing Class N Pozzolan

Concrete, Geotechnical, and Structural Laboratory, 86-68530, DSO-2017-04 (8530-2017-27)

Dam Safety Technology Development Program

U.S. Department of the Interior
Bureau of Reclamation

September 2017

Mission Statements

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Thermal effects from hydration and the environment can lead to thermal gradients within the concrete section and induce thermal cracking. Temperature effects are especially important in mass concrete, where the size of the placement can produce large amounts of heat and relatively little surface area to dissipate it. Even in smaller placements, concrete containing high cement contents or supplementary cementitious materials (SCMs) such as silica fume can produce high temperatures. Some Reclamation Regions are experiencing a shortage in Class F fly ash which is usually the SCM used to lower the heat of hydration. This study reports the adiabatic temperature rise and heat of hydration for concrete containing Class N pozzolan from a source near several Reclamation projects. The data from this report is compared to mixtures containing Class F fly ash.

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BUREAU OF RECLAMATION

Concrete, Geotechnical, and Structural Laboratory, 86-68530
DSO-2017-04 (8530-2017-27)

Temperature Rise of Mass Concrete Containing Class N Pozzolan

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Acronyms and Abbreviations

ACI	American Concrete Institute
CGSL	Concrete, Geotechnical, and Structural Laboratory
NMSA	nominal maximum size aggregate
OPC	ordinary portland cement
RSMC	Reinforced Structural Mass Concrete
SCM	supplementary cementitious materials
w/c	water to cementitious material ratio

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Abstract

Thermal effects from cement hydration and environmental factors can lead to thermal gradients within the concrete section and induce thermal cracking. Temperature effects are especially important in mass concrete, where the size of the placement can produce large amounts of heat with relatively little surface area to dissipate it. Even in smaller placements, concrete containing high cement contents or supplementary cementitious materials (SCMs) such as silica fume can produce high temperatures. Some Reclamation Regions are experiencing a shortage in Class F fly ash which is usually the SCM used to lower the heat of hydration. This study reports the adiabatic temperature rise and heat of hydration for concrete containing Class N pozzolan from a source near several Reclamation projects. The data from this report is compared to mixtures containing Class F fly ash.

Background

The thermal behavior of concrete has long been studied to reduce cracking, especially in massive members, where heat generation is great. Heat dissipation and restraint create volume changes that can induce stresses at an early age, when strength and modulus are low. Pozzolans or other supplementary cementitious materials can be used to reduce the temperature rise in large concrete placements. Reclamation has recently updated thermal property data sets for pure ordinary Portland cement (OPC), OPC + Class F fly ash, and OPC + slag [1]. However, there are other options that could be just as effective in mitigating temperature rise.

Natural pozzolans (Class N per ASTM C618 [2]) such as rice husk ash, calcined shale, or calcined clay, have not been thoroughly researched recently in terms of thermal behavior. It is well established that pozzolans reduce the temperature rise of concrete in two ways: by diluting the amount of cement in the paste and by inherently having a lower heat of hydration compared to cement [3]. Generally, the rule of thumb is that the heat of hydration is half of that of Type I/II cement. Since there is a wide range of natural pozzolans with varying chemical compositions and pozzolanic activity, it is unknown how accurate that rule is when estimating the temperature rise.

Quality Class F fly ash is becoming increasingly more difficult to obtain and many concrete suppliers are using Class N pozzolan as an alternative. In Reno, Nevada, two out of three producers are carrying Class N pozzolan. The need to specify Class N pozzolans rather than Class F fly ash is becoming more common as the supply of quality fly ash diminishes.

Currently the Concrete, Geotechnical, and Structural Laboratory (CGSL) is researching a number of natural pozzolans for use in concrete (Reference DSO-2017-07). Based on recent discussion with concrete suppliers in the California and Nevada areas, CGSL recommends that a source of rhyolitic glass from Nevada Cement Co. be tested for potential use at several sites including Boca Dam, Stampede Dam and the Battle Creek Project. The variability of natural pozzolans is higher than that of fly ash so testing of each source is required to ensure performance requirements are met.

Traditionally, Reclamation's large-scale infrastructure projects, including dam safety modifications to existing structures, often require massive concrete placements. An increase in cracking on newly constructed Reclamation concrete placements was noticed eight years ago at the Warren H. Brock Reservoir Inlet/Outlet Structure and since then, investigation have been made into the issues and aggressive thermal control has been specified. Designer's sometimes use outdated "rules of thumb" that the heat of hydration of pozzolans is half of that of cement, and updating these guidelines specifically for concrete with Class N pozzolans would make Reclamation's designs applicable to a wider variety of available materials.

Objective

The objective of this project is to test a source of Class N pozzolan for adiabatic temperature rise for use in mass concrete elements.

Methods

Mixture Proportioning and Fresh Properties

The Class N pozzolan used for this study is a raw-ground rhyolitic glass conforming to ASTM C618. The cement used was a Type I/II cement. Mill certificates for cementitious materials can be found in Appendix A.

Three mixtures were made to generally comply with Reclamation specifications for Reinforced Structural Mass Concrete (RSMC). The specified concrete proportions are given in Table 1 below. The fresh properties and the corresponding test methods used are summarized in Table 2.

Table 1. Typical mixture proportions for RSMC containing Class N pozzolan

Feature	f'c (lb/in^2)	Max w/c	NMSA	Class N Pozzolan (%)	Slump (in)	Air Content (%)
Reinforced Structural Mass Concrete	4500 at 56 days	0.45	No. 57	25±10	1 to 3	4 to 7

Table 2. Test methods used for concrete fresh properties

Fresh Property Tested	ASTM Standard
Slump	ASTM C143
Air Content	ASTM C231
Unit Weight	ASTM C138
Time of Setting	ASTM C403

Compressive Strength

The compressive strength of the specimens was determined using 4-inch by 8-inch cylinders in accordance with ASTM C39 [4]. Strength was tested at 7, 14, 28, and 56 days.

Adiabatic Temperature Rise

The adiabatic temperature rise of the concrete was measured in accordance with USBR 4911 [5]. The individual components were pre-cooled to 50 °F overnight prior to mixing. The temperature rise was recorded for at least 42 days (6 weeks) and up to 56 days (8 weeks).

In addition to adiabatic calorimetry, the heat of hydration was measured using isothermal calorimetry in accordance with ASTM 1702 [6].

Test Results

Fresh Properties

Three mixtures were tested to cover the range of pozzolan replacement allowed in Reclamation's specifications for RSMC. Replacements were made at 15, 25, and 35% by weight of cement. Mixture proportions were selected using USBR 4211 [7]. All mixtures contained an air entraining admixture as well as a mid-range water reducer.

Table 3. Concrete mixture proportions

Class N Pozzolan (%)	15%	25%	35%
Total Cementitious (lbs)	543	543	543
Cement (lbs)	461	407	353
Class N Pozzolan (lbs)	81	136	190
Water (lbs)	244	244	244
Sand (lbs)	1183	1178	1172
¾" Rock (lbs)	1917	1908	1898
AEA (oz/cwt)	0.4	0.7	0.5
WRA (oz/cwt)	3	4	5
w/c	0.45	0.45	0.45

As shown in Table 4, the fresh properties meet the specified requirements listed in Table 1. The initial and final set times were slightly retarded due to the addition of the Class N pozzolan shown in Figure 1. Initial set times were between 5-½ to 6 hours and final set times were between 7 and 7-¾ hours for all three mixtures containing the pozzolan.

Table 4. Fresh concrete properties

Fresh Property Tested	15%	25%	35%
Slump (in.)	2	2 ¾	2 ¾
Air Content (%)	5.3	7.2	6.5
Unit Weight (lb/ft^3)	144.5	142.2	142.6

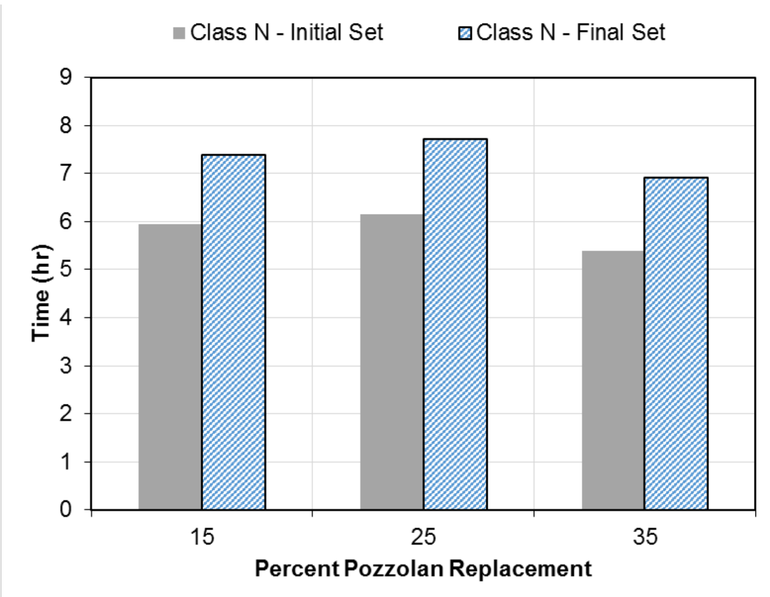


Figure 1. Initial and final setting time via penetrometer (ASTM C403).

Compressive Strength

The compressive strength was tested at 7, 14, 28, and 56 days. The mix design was not optimized for strength, as the focus of this study was temperature rise. The mix had a low total cementitious content (as recommended by USBR 4211 for mass concrete). To improve the strength, a higher cementitious content could be used. Additionally, an appropriate admixture (water reducer) formulated to use with natural pozzolans and a lower water to cementitious materials ratio (w/c) could result in higher compressive strengths.

Table 5. Compressive strength at 7, 14, 28, and 56 days

	Average Compressive Strength (psi)			
	7	14	28	56
15%	3500	3770	3900	4270
25%	3145	3410	3525	3830
35%	2845	3140	3565	4007

Adiabatic Temperature Rise

The temperature rise of the three concrete mixtures are shown in Figure 2. The difference between the 28-day temperatures of concrete with 15% and 35% Class N pozzolan is not large, only 6.5°F. The temperature of the mixture containing 15% pozzolan increased more rapidly within the first 7 days compared to the 25% and 35% mixtures.

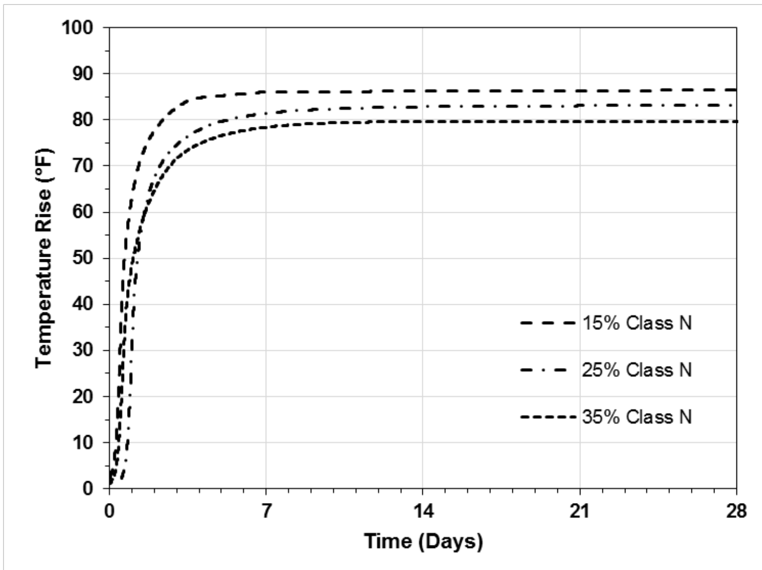


Figure 2. Adiabatic temperature rise of mass concrete mixtures using Class N pozzolans

Table 6. Temperature rise at 1, 3, and 7 days.

Temperature Rise (°F)	15%	25%	35%
1-day	63.0	30.0	48.0
7-day	86.0	81.5	78.5
28-day	86.5	83.0	80.0

Heat of Hydration

The heat of hydration was measured for 7 days in accordance with ASTM C1702. Figure 3 shows both cumulative heat release in the first 7 days as well as the heat flow within the first 24 hours. The Class N mixtures were compared to a neat cement paste with the same w/c of 0.45. As expected, the heat of hydration decreased as the amount of pozzolan increased. As a comparison, the heat of hydration at 7 days for a paste containing 25% Class F fly ash is 298.5 J/g, slightly higher than that of the paste with Class N [8].

Table 7. Heat of hydration at 1, 3 and 7 days.

Heat of Hydration (J/g)	0%	15%	25%	35%
1-day	251.9	217.2	203.3	187.7
3-day	337.8	288.9	270.2	249.0
7-day	369.8	305.2	285.5	264.5

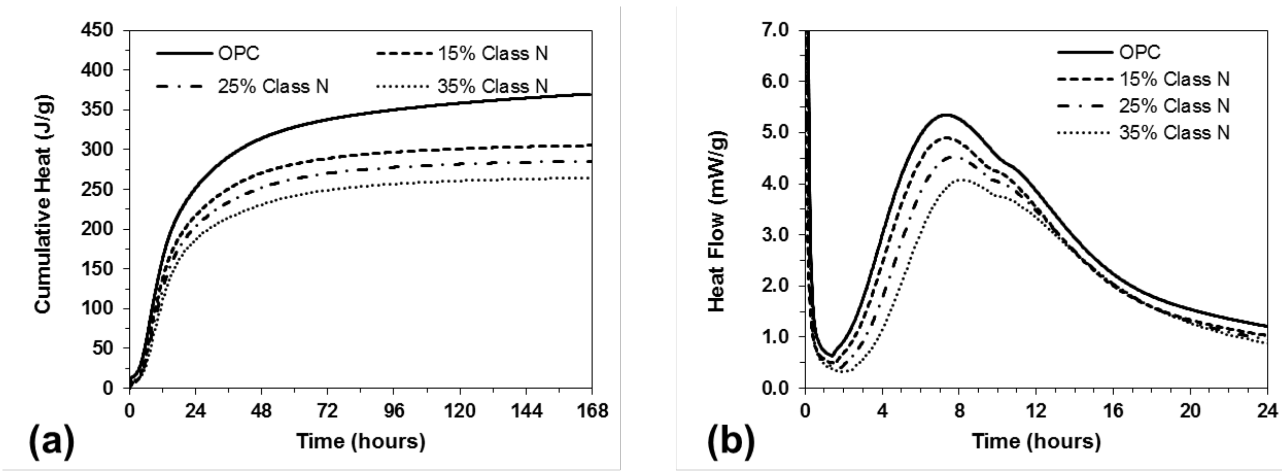


Figure 3. (a) Cumulative heat release and (b) heat flow of pastes containing 15 to 35% Class N pozzolan.

Conclusions

Class N pozzolans can be used to mitigate temperature rise in mass concrete. The heat of hydration of pastes with the Class N pozzolan used in this study and Class F fly ash were similar, indicating that the temperature rise would be similar in similar RSMC mixtures.

On future Reclamation projects, careful consideration of specifying natural pozzolans could be an economically viable option to use in mass concrete and not place undue burden on the contractor in areas where Class F fly ash is not available.

References

[1] K. Bartojay and C. Lucero, "Updating Thermal Data Sets to Better Evaluate Thermal Effects of Concrete." DSO-2015-02, Dam Safety Technology Development Program, Bureau of Reclamation, 2016.

[2] ASTM Standard C618-08, "Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete." ASTM International, West Conshohocken, PA, 2008.

[3] D. P. Bentz, C. J. Bognacki, K. a Riding, and V. H. Villareal, "Hotter Cements , Cooler Concretes," *Concr. Int.*, no. Bentz, pp. 41–48, 2011.

[4] ASTM Standard C39/c39M-14a, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens." ASTM International, West Conshohocken, PA, 2014.

[5] USBR 4911-92, "Temperature Rise of Concrete," in *Concrete Manual, Part 2*, 9th ed., Denver, CO: Bureau of Reclamation, 1992.

[6] ASTM Standard C1702-15a, "Standard Test Method for Measurement of Heat of Hydration of Hydraulic Cementitious Materials Using Isothermal Calorimetry." ASTM International, West Conshohocken, PA, 2015.

[7] USBR 4211-92, "Selecting Proportions for Concrete Mixtures," in *Concrete Manual, Part 2*, 9th ed., Denver, CO: Bureau of Reclamation, 1992.

[8] C. Lucero, "Comparison of Thermal Property Models of Concrete." DSO-2017-05, Dam Safety Technology Development Program, Bureau of Reclamation, 2017.

Appendix A – Materials Data Sheets

NEVADA CEMENT COMPANY

Post Office Box 840, Fernley, Nevada 89408 - 0840 (775) 575 - 2281

LABORATORY TEST REPORT
SAMPLE : Class "N" Pozzolan

Date: September 2016

Silo: 8

Customer:______________________ Bill of Lading: ______________________

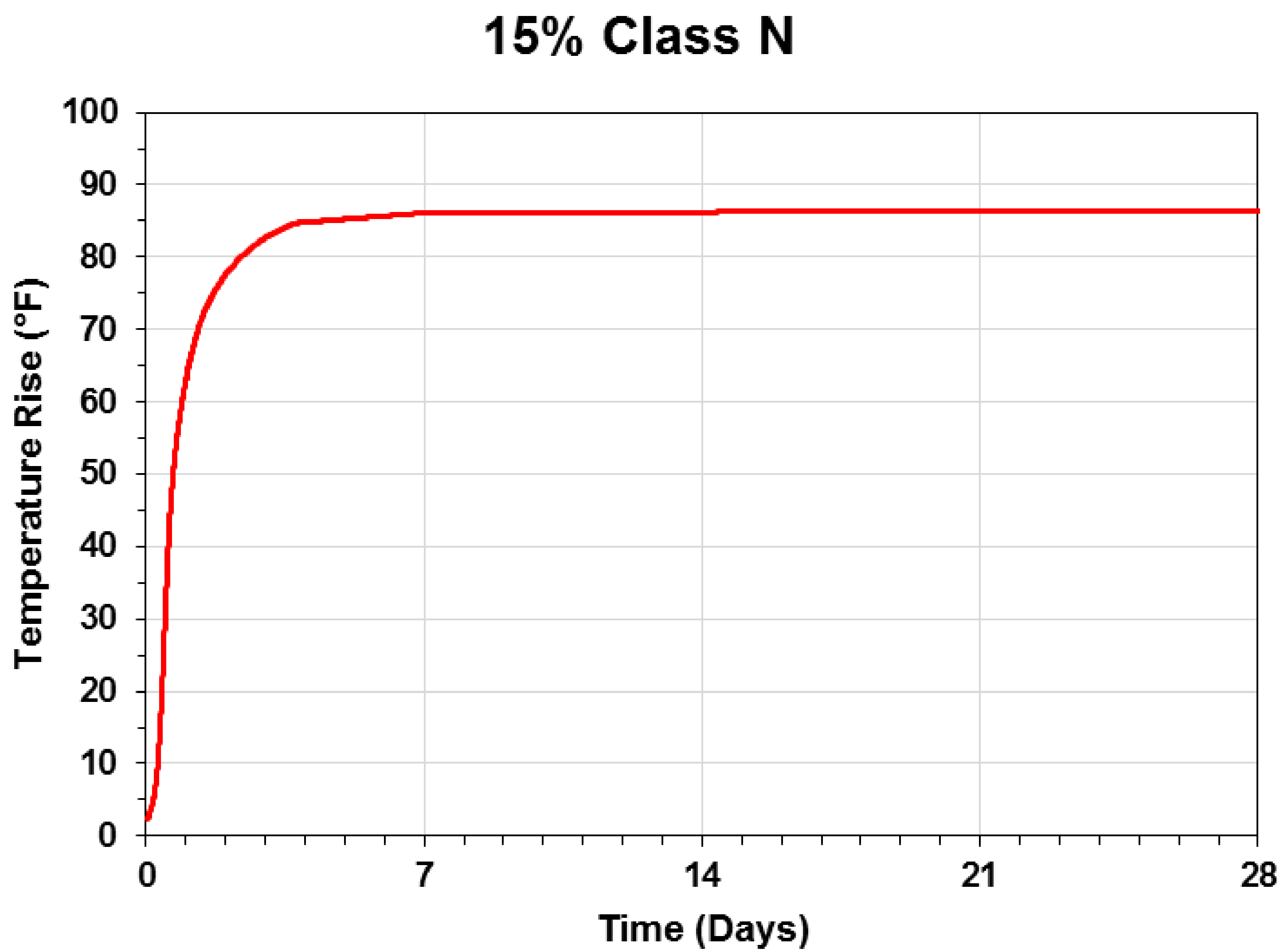
Chemical Composition (%)-ASTM C-311			**ASTM C 618 Specifications** Class N
Total Silica, Aluminum, Iron:	79.3		70.0 Min
Silicon Dioxide:	65.8		
Aluminum Oxide:	12.8		
Iron Oxide:	0.7		
Moisture content	1.2		3.0 max
Sulfur Trioxide:	0.0		4.0 Max
Calcium Oxide:	1.1		
Loss on Ignition:	2.8		10.0 Max
Available Alkali As Na2O	1.4		
Physical Testing Results			
Density:	2.36		
Blaine:	4820		
Retained on -325 Sieve:	8.4	%	34 Max
20% 7 Days	83		75 Min
20% 28 Days	85		75 Min
20% Water Requirement	100		115 Max
25% 7 Days	76		
25% 28 Days	81		
25% Water Requirement	100		
Autoclave Expansion @ 20%	-0.02		0.8 Max

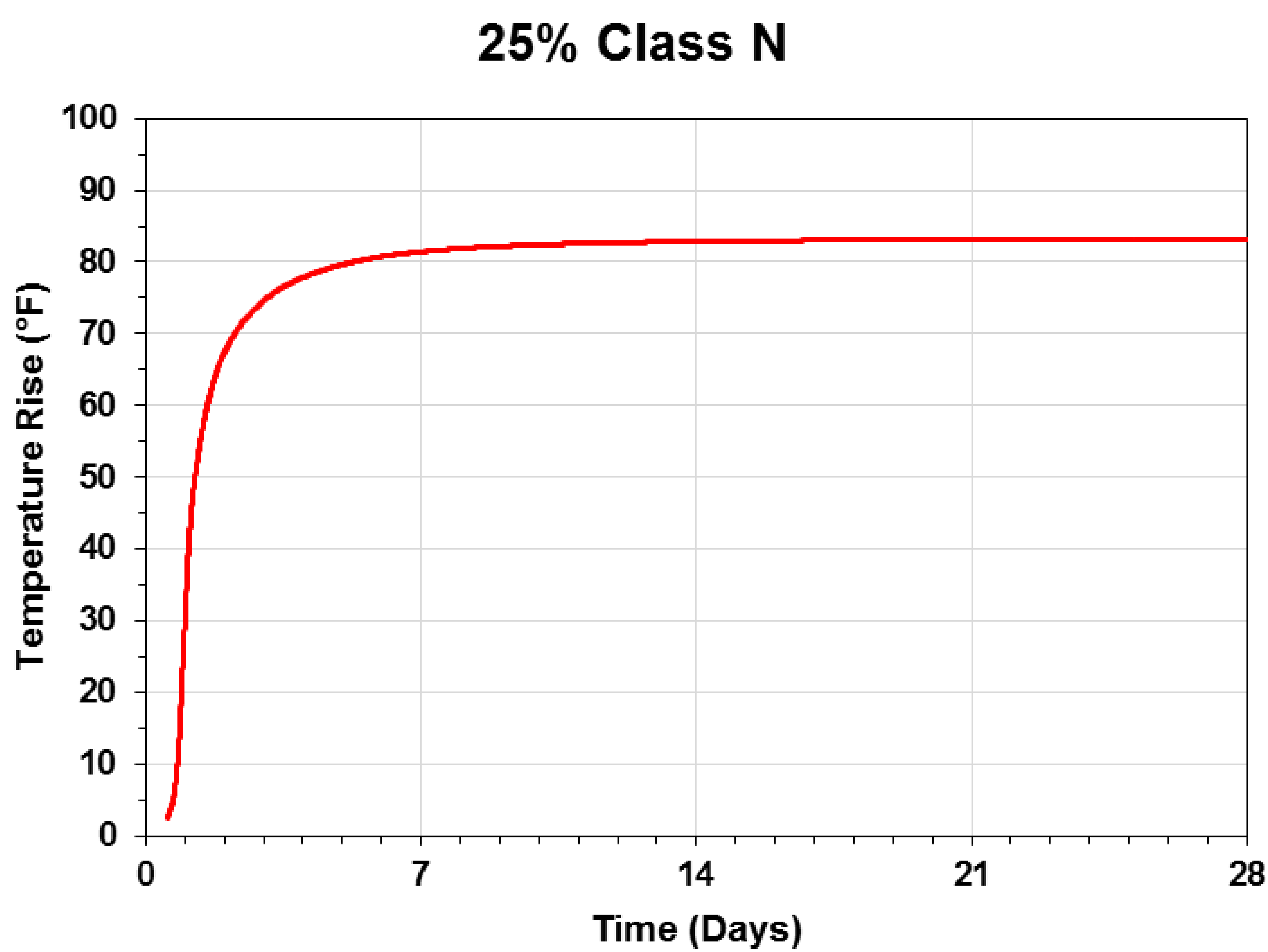
Nevada Cement Company complies with the requirements of the current ASTM C618 and AASHTO M 295 specifications for class "N" pozzolan. The material is tested following the current ASTM C311. The above data represents the average of the silo or bins ground during the month of August 2016 from which this material was shipped.
All test results are certifed to comply with the type specification designated.
We are not responsible for improper use or workmanship.

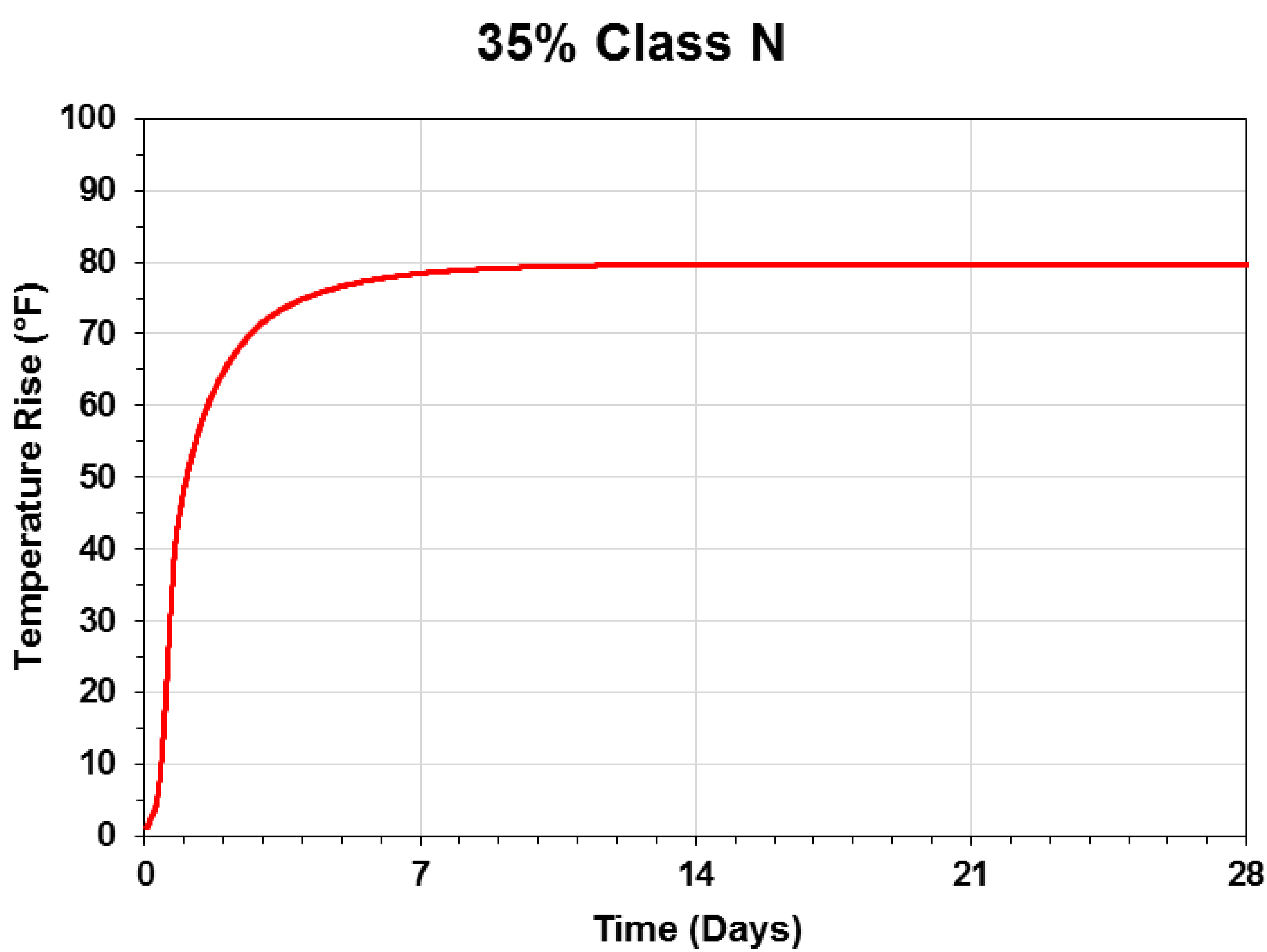
AASHTO Accredited since 1996

Eric Dutcher
Chief Chemist

Appendix B – Adiabatic Temperature Rise Curves


15% Class N
Temperature Rise (°F)
100
90
80
70
60
50
40
30
20
10
0
0
7
14
21
28
Time (Days)


25% Class N
Temperature Rise (°F)
100
90
80
70
60
50
40
30
20
10
0
0
7
14
21
28
Time (Days)


35% Class N
Temperature Rise (°F)
100
90
80
70
60
50
40
30
20
10
0
0
7
14
21
28
Time (Days)