NPA NATURAL POZZOLAN ASSOCIATION

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Established - March 2017

Website: Pozzolan.org

What is old, is new again!

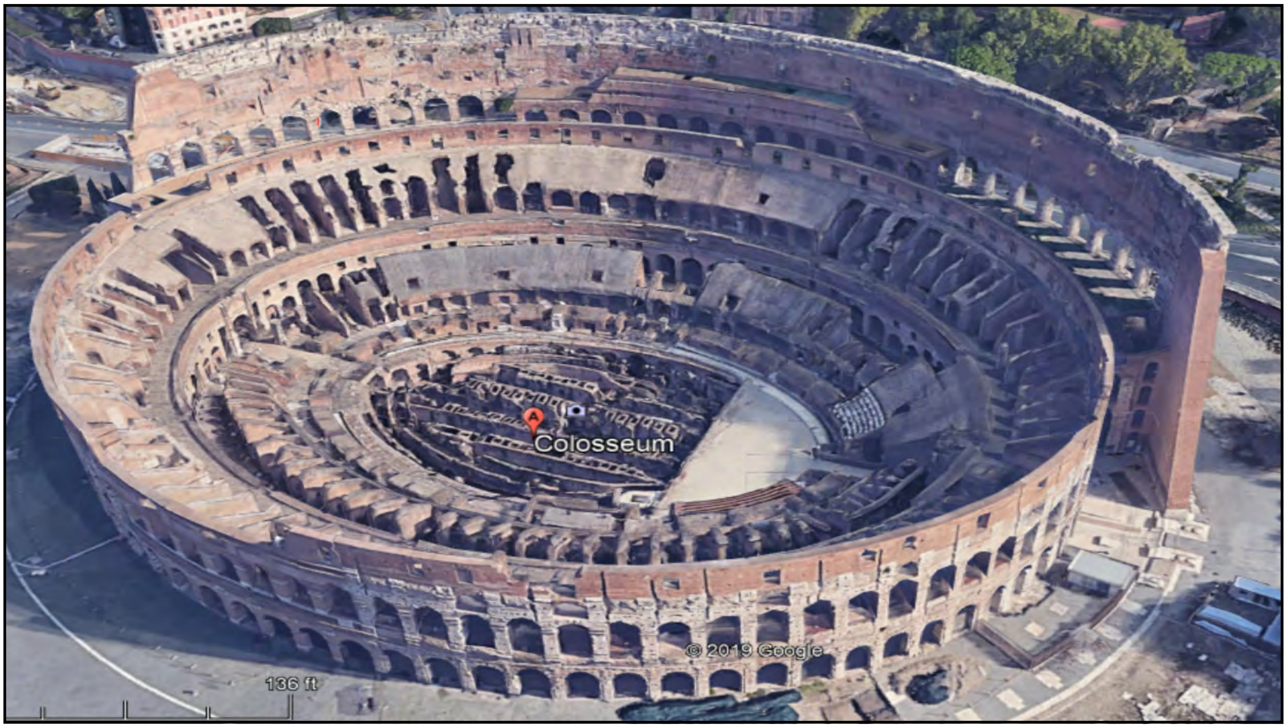
A brief

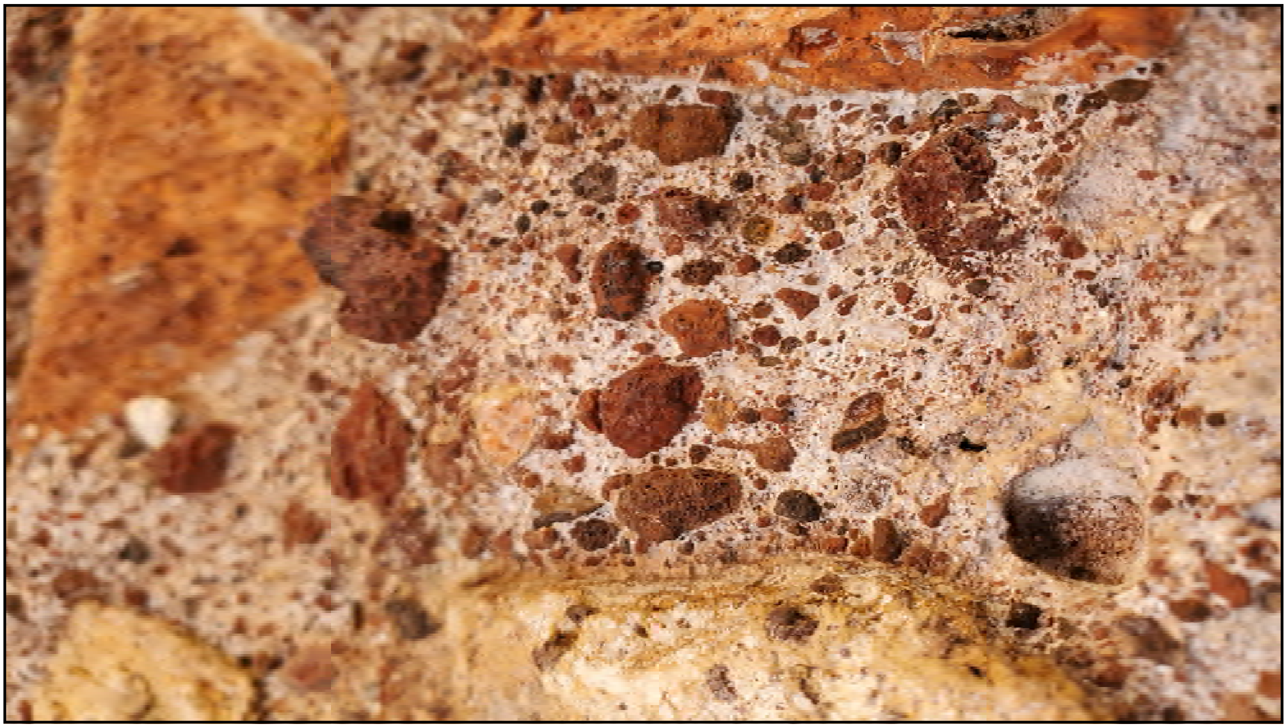
History

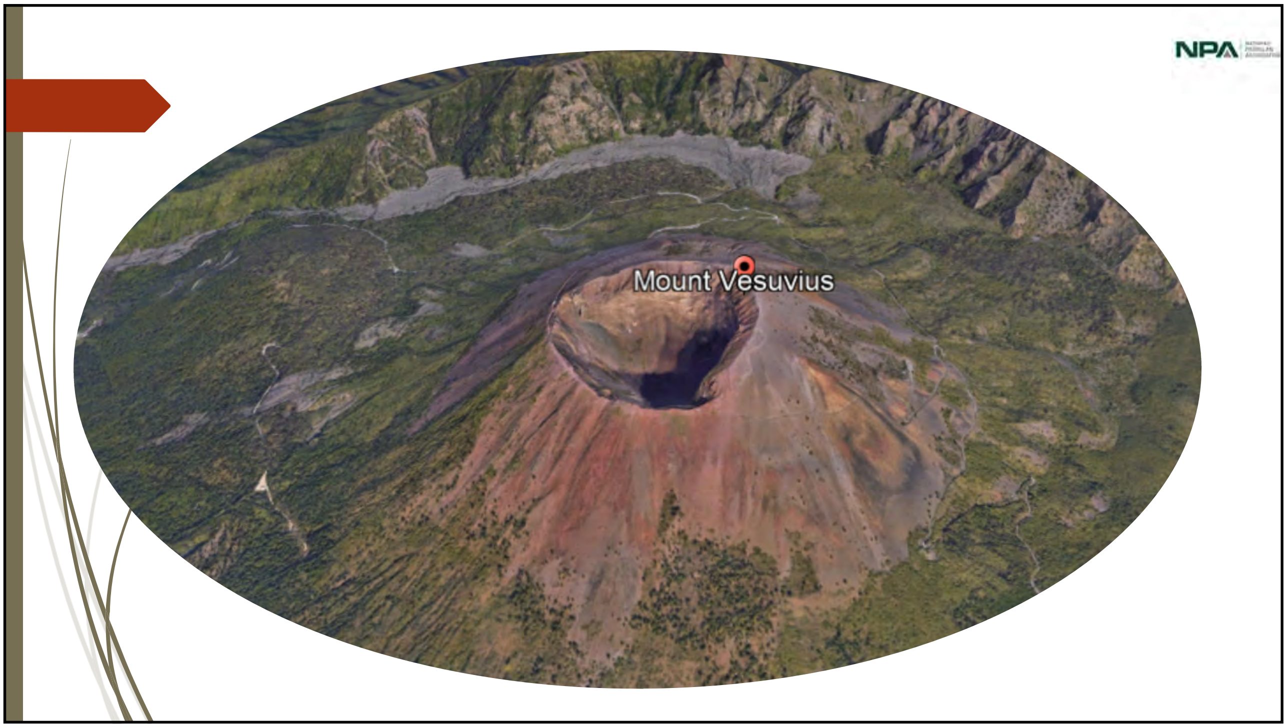
of

Natural Pozzolans


Pantheon


Colosseum
© 2019 Google
136 ft




Mount Vesuvius

Vitruvius – Roman Engineer

General recipe for Roman Concrete:

1 part - Lime
3 parts - Pozzolana
Sand/Aggregates (aggregates were generally lightweight materials such as pumice, scoria, & terracotta)

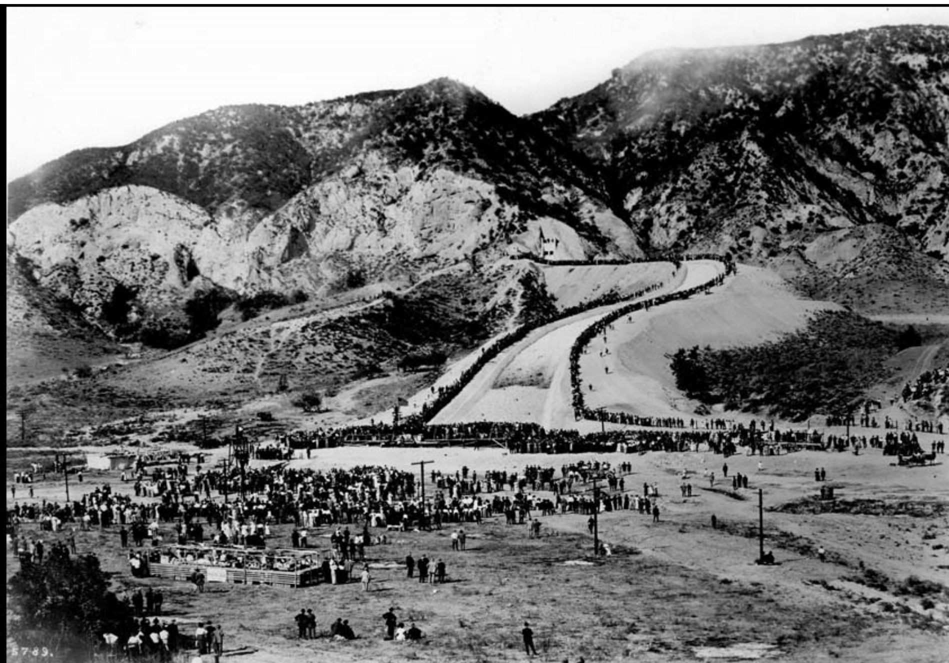
Roman Concrete: "It's the most durable building material in human history, and I say that as an engineer not prone to hyperbole," Roman Concrete expert Phillip Brune told the Washington Post. July 4, 2017, Washington Post

There are 2 types of Natural Pozzolans (NP):

1. **Raw NP** (Volcanic ejecta-based materials – pumice, pumicite, volcanic ash, etc. Pre-calcined by Mother Nature)

2. **Calcined NP** (such as MetaKaolin)

First renaissance of Natural Pozzolan: 1900~1970



Los Angeles Times File Photo

Hoover Dam, and hundreds of other infrastructure, projects used natural pozzolan. Picture/USBR

Glen Canyon dam used several hundred thousand tons of natural pozzolan in its construction.

File photo: Construction of Glen Canyon Dam, Page, Arizona, circa 1960

USBR & USACE have lists of projects (100s) on their websites, mostly dams and large infrastructure projects dating from the early 1900s through to the 1960s, incorporating NPs.

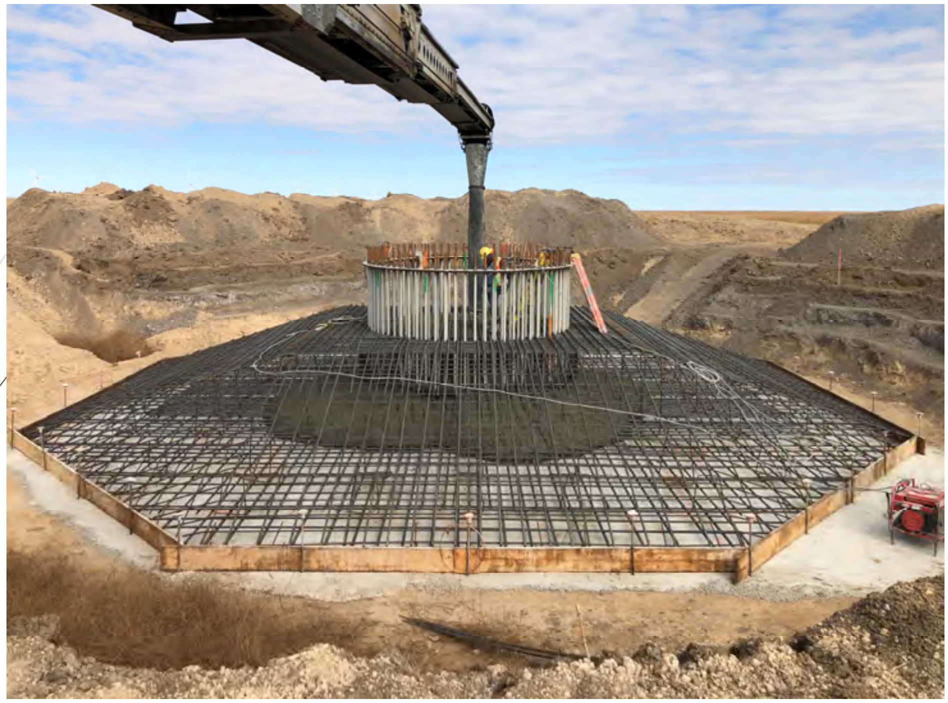
In the case of the previous two slides, Hoover dam and the LA Aqueduct, there was abundant NPs nearby. They were used mostly to reduce heat of hydration and to reduce costs. Other benefits, such as mitigating chemical attack, were not clearly understood at the time…..

NP production tapered off to essentially zero in the 70s (Except for Metakaolin)with the advent of pollution control equipment in coal fired power plants' capturing the effluent – known as fly ash – which was discovered to have similar properties to NP and was, at the time, free for the taking, or very inexpensive.

NP in concrete infrastructure: Diminishing-Fly Ash Era

2nd Renaissance

Credit: FHWA



Wind Turbine - Kansas

So, how does Natural Pozzolan enhance and protect concrete? Let's count the ways…….

Listed Benefits of Natural Pozzolan:

1. Consistency: LOI represents bound water, not carbon content!

2. Reduced Carbon Footprint: Raw NPs were calcined by Mother Nature (Magma), and calcined NPs are heated to less than 50% of the heat required to produce clinker. Calcined NPs do not emit carbon upon heating like limestone does when used to produce clinker. Almost a lb for lb (approx. 90~93%) reduction of carbon with raw NP and 65~70%+ reduction for Calcined NP.

Reduction of Carbon Footprint is significant:

Typical GWP of cement: .922~.95 mt/1 ton of Cement produced*
GWP for raw NP: < .05~.08 mt/1 ton of Raw NP produced**

There is a massive reduction in carbon footprint when cement is replaced with NP. Currently some customers are replacing up to 40% of their cement with NP and still hitting their strength requirements, reducing embodied carbon, permeability, and heat of hydration while also mitigating ASR and Sulfate attack. It is a win-win-win proposition. It typically costs less than cement as well (except calcined NP) – another win.

* *PCA EPD OPC 2021*
** *Each process is slightly different*

Benefits of Natural Pozzolan (Cont'd):

3. Permeability Reduction: When used at 25% replacement levels, C1202 data shows coulomb transmissivity rates reduced to less than 1000 (versus over 3000 for a straight cement mix). Resistivity Testing reveals similar permeability reduction. **More on that later**.

4. Control Efflorescence: When used at a 20~25% replacement rate, NPs significantly reduce or eliminate efflorescence completely.

Benefits of Natural pozzolan (Cont'd):

5. ASR: ASR in aggregates shown to expand to nearly .7% in 16 days (C1260) were mitigated down to .03% expansion in 16 days, essentially flatlining the Alkali-Silica reaction (C1567). **Long-term testing shows that ASR mitigation rates are steady (correlate) whether using the rapid C1567 test (2-week test) or the C1293 (2-year test).**

6. Sulfate Attack: Using the C1012 18-month test method, expansion from sulfate attack is reduced to less than .05% versus above .1% for straight TI/II cement in 18 mo. test.

Mitigates ASR to 0 expansion in the Std 14d test, and .01% at 28d (For FAA job in KS)

SUMMARY TABLE

Figure ID	Mix Constituents				14-Day Expansion	28-Day Expansion	ASTM C 1567 Classification (14-Days)
	Aggregates		Cementitious Materials				
	Coarse	Fine	Cement	NP			
Control Sand	0%	100%	100%	0%	0.29%	0.42%	Potentially Deleterious
A-1	0%	100%	75%	25%	-0.01%	0.01%	Acceptable

The ASTM C 1567 test method defines the potential of an aggregate for deleterious expansion as follows, based on the 14-Day expansion:

Test Expansion (14-Days)	Classification	Potential for Deleterious ASR
< 0.1%	Acceptable	Low
> 0.1%	Potentially Deleterious	High

Based on our test results and ASTM standards for performance, the use of 25% a NP mitigates the reactive rock to a "Low" potential for deleterious ASR. The 28-day performance can be compared to other project specific requirements, if applicable.

Benefits of Natural pozzolan (Cont'd):

7. Reduce Heat of Hydration: The heat of hydration can be reduced up to 40% by incorporating NPs into your mix design. This is especially helpful in mass pours and/or placing concrete in hot weather.

8. LOI: Loss on ignition testing on an NP provides data on the amount of bound water in the material. NPs do not have carbon content to burn off like fly ash, therefore, regardless of the LOI figure, NP does not interfere with Air Entrainment (AE) in concrete. Some DOTs are placing enhanced LOI limits on both Fly Ash and NP as a preventative measure to ensure their DOT projects have no AE problems. Such restrictions on NP are based on a lack of knowledge/understanding and needlessly prevents use of NPs.

9. Natural Pozzolans are essentially light weight aggregates, or micro-aggregates, that hold extra water in the concrete matrix for gradual release to allow for internal curing properties. This extra water is essential for an enhanced, long-term pozzolanic reaction in the concrete. **Water is both essential to the reaction as well as an essential component of the binder in concrete: C-S-H (and C-A-S-H)**

Sample Date: 8/9 - 8/11/15 **MTRF ID:**

Sample ID:

Chemical Analysis			**ASTM / AASHTO Limits** Class F	Class C	**ASTM Test Method**
Silicon Dioxide (SiO_2)	59.73	%			
Aluminum Oxide (Al_2O_3)	23.01	%			
Iron Oxide (Fe_2O_3)	4.47	%			
Sum of Constituents	87.21	%	70.0% min	50.0% min	D4326
Sulfur Trioxide (SO_3)	0.37	%	5.0% max	5.0% max	D4326
Calcium Oxide (CaO)	4.84	%			D4326
Moisture	0.05	%	3.0% max	3.0% max	C311
Loss on Ignition	0.85	%	6.0% max 5.0% max	6.0% max 5.0% max	C311 AASHTO M295
Available Alkalies, as Na_2Oe **When required by purchaser**	1.36	%	not required 1.5% max	 1.5% max	C311 AASHTO M295
Physical Analysis					
Fineness, % retained on #325	17.13	%	34% max	34% max	C311, C430
Strength Activity Index - 7 or 28 day requirement					C311, C109
7 day, % of control	84	%	75% min	75% min	
28 day, % of control	84	%	75% min	75% min	
Water Requirement, % control	95	%	105% max	105% max	
Autoclave Soundness	0.00	%	0.8% max	0.8% max	C311, C151
Density	2.25				C604

Typical Class F – Fly Ash

Report Date: *05/04/2017*	Docket: *Natural Pozzalon* -Raw	Date Received: *02/27/2017*

Chemical Composition (%)
(by Wyoming Analytical Laboratories, Inc.)

			ASTM C618-15 Class N
Total Silica, Aluminum, Iron:	86.6		70.0 Min
Silicon Dioxide:		72.5	
Aluminum Oxide:		13.2	
Iron Oxide:		0.9	
Sulfur Trioxide:	0.1		4.0 Max
Calcium Oxide:	1.3		
Moisture Content:	1.5		3.0 Max
Loss on Ignition:	4.1		10.0 Max
			AASHTO M295-11 Specifications
Available Alkalies (as Na_2O):	1.5		1.5 Max
Sodium Oxide:		0.76	
Potassium Oxide:		1.12	

Physical Test Results

Class-N Pozzolan

		ASTM C618-15 Class N
Fineness, Retained on #325 Sieve (%):	5.7	34 Max
Strength Activity Index (%)		
Ratio to Control @ 7 Days:	89.6	
Ratio to Control @ 28 Days:	95.4	75 Min
Water Requirement, % of Control:	99.2	115 Max
Soundness, Autoclave Expansion (%):	-0.03	0.8 Max
Drying Shrinkage, Increase @ 28 Days (%):	0.02	0.03 Max
Density Mg/m^3:	2.40	

Comments: *Meets ASTM C618-15/ AASHTO M295-11 Type N. Retested SAI.*

CTL | Thompson Materials Engineers, Inc.

COLORADO REGISTERED PROFESSIONAL ENGINEER 14540 5/4/2017

ASTM C618-19 - Chemical and Physical Analyses - Fly Ash/Pozzolans

CTL Ticket: 21130	Plant of Origin: NP	Sample Date Range: 07/09/2021
CTL Project: CT16959	Sample ID: #1	to:
Report Date: 08/24/2021	Supplier:	Date Received: 07/12/2021

NPA

Chemical Composition (%)
(by Wyoming Analytical Laboratories, Inc.)

			ASTM C618-19 Class N	Class F	Class C
Silicon Dioxide:		72.4			
Aluminum Oxide:		13.2			
Iron Oxide:		0.7			
Total Silica, Aluminum, Iron:	86.2		≥70.0%	≥50.0%	≥50.0
Sulfur Trioxide:	0.0		≤4.0%	≤5.0%	≤5.0%
Calcium Oxide:	0.6		N/A	≤18.0%	>18.0%

Product Class: Class N — Conforms to Class: Yes

Volatile Composition (Mass%)

		Class N	Class F	Class C
Moisture Content:	0.7	≤3.0%	≤3.0%	≤3.0%
Loss on Ignition:	4.8	≤10.0%	≤6.0%	≤6.0%

Physical Test Results

Class-N Pozzolan

		Class N	Class F	Class C
Fineness, Retained on #325 Sieve (%):	1.7	≤34%	≤34%	≤34%
Strength Activity Index (%) *		* No 7-day limit if 28-day meets		
Percent of Control @ 7 Days:	82	≥75%	≥75%	≥75%
Percent of Control @ 28 Days:	95	≥75%	≥75%	≥75%
Water Requirement, % of Control:	105	≤115%	≤105%	≤105%
Soundness, Autoclave Expansion (%):	0.01	≤0.8%	≤0.8%	≤0.8%
Density (g/cm3) :	2.34	N/A	N/A	N/A

Uniformity Established from 10 previous tests

			Class N	Class F	Class C
Average Fineness:	3.5	Difference 1.9(%)	±5(%)	±5(%)	±5(%)
Average Density:	2.35	Difference 0%	±5%	±5%	±5%

Supplementary Requirements

Available Alkalis, as Na_2O	1.08%		
Sodium Oxide:	0.7%	Drying Shrinkage %: 0.02	Max 0.03%
Potassium Oxide:	0.58%		

CTL Ticket: *19081*	Source: *Metakaolin*	Sample Date Range:
CTL Project: *16638*	Sample ID:	to:
Report Date: *08/23/2019*	Docket:	Date Received: *06/03/2019*

Chemical Composition (%) (by Wyoming Analytical Laboratories, Inc.)			ASTM C618-15 Class N
Total Silica, Aluminum, Iron:	*96.0*		70.0 Min
Silicon Dioxide:		*53.4*	
Aluminum Oxide:		*42.0*	
Iron Oxide:		*0.6*	
Sulfur Trioxide:	*0.1*		4.0 Max
Calcium Oxide:	*0.1*		
Moisture Content:	*0.2*		3.0 Max
Loss on Ignition:	*0.5*		10.0 Max
			AASHTO M295-11 Specifications
Available Alkalies (as Na_2O):	*0.0*		1.5 Max
Sodium Oxide:		*0.03*	
Potassium Oxide:		*0.00*	

Physical Test Results		ASTM C618-15 Class N
Fineness, Retained on #325 Sieve (%):	*2.5*	34 Max
Strength Activity Index (%)		
Ratio to Control @ 7 Days:	*109.8*	
Ratio to Control @ 28 Days:	*122.0*	75 Min
Water Requirement, % of Control:	*111.6*	115 Max
Soundness, Autoclave Expansion (%):	*-0.07*	0.8 Max
Drying Shrinkage, Increase @ 28 Days (%):	*0.00*	0.03 Max
Density Mg/m^3:	*2.52*	

Class-N Pozzolan

Comments: *Meets ASTM C618-17 Class N and AASHTO M295-11 Spec.*

CTL | Thompson Materials Engineers, Inc.

COLORADO REGISTERED PROFESSIONAL ENGINEER 14540 *8/23/2019*

Does higher water demand for NP mean more permeability, less density, or diminished durability?

NO!

The extra water required for natural pozzolans to achieve similar slump to a fly-ash mix is used for both internal curing as well as a necessary ingredient in the pozzolanic reaction itself. Limiting water to similar w/c ratios as employed with fly ash is also limiting the long-term potential of the pozzolan to react and form additional binder, density and strength in the concrete. **(More on this later)**

USA Unified Forces Guide Spec. UFGS 03-31-30 **Marine Exposure** Requirements (Feb. 2019)

Doug Hooten/Univ. of Toronto

Table 1 - Concrete Design Requirements

Prescriptive requirements	Minimum	Maximum
ASTM C666/C666M Method A Durability Factor at 300 cycles	90	--
Concrete ASTM C157/C157M Drying Shrinkage percent, at 28 days except for high volume fly ash (HVFA) at 56 days.	--	0.05 percent
Initial acid-soluble chloride content in cast-in-place concrete per ASTM C1152/C1152M, percent/cement	--	0.10
Prescriptive requirements	**Minimum**	**Maximum**
Initial acid-soluble chloride content in prestressed concrete determined following ASTM C1152/C1152M, percent/cement	--	0.08
Average spacing factor for three specimen following ASTM C457/C457M inch	--	0.008 with no value greater than 0.010
Chloride ion penetrability ASTM C1202 at 56 days, Coulombs ASTM C1202 limit	--	1000
Alternatively to ASTM C1202, the concrete surface resistivity AASHTO T 358 at 56 days can be measured, kohm-cm Alternate resistivity limit	20	--

5 exposure categories

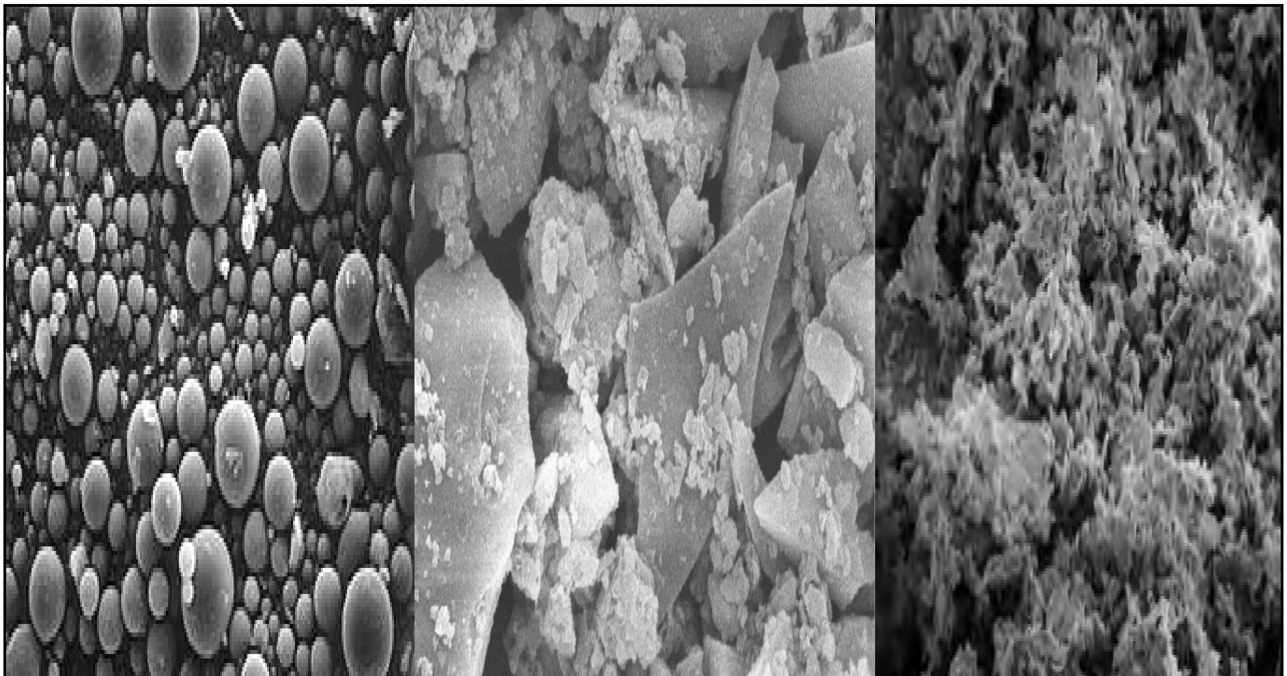
Table 2 - Concrete Quality Requirements

Zone	Exposure Condition	Maximum W/CM
Submerged zone, Tidal Splash Zone	(a) Directly exposed to salt water	0.40
	(b) Subject to severe abrasion	0.40
Atmospheric Zone	(a) Directly exposed to marine atmosphere	0.40
	(b) Protected from direct exposure to marine atmosphere	0.45
Buried Zone	(a) Permanently buried in soil	0.40

Table 3 - Supplementary Cementing Material Requirements

SCM	Minimum Content
Class N Pozzolan or Class F Fly Ash SiO_2 plus Al_2O_3 plus Fe_2O_3 > 65 percent or where exposed to sulphates as defined in ACI 318 Table 4.2.1	30 percent
Class N Pozzolan or Class F Fly Ash SiO_2 plus Al_2O_3 plus Fe_2O_3 greater than 70 percent	25 percent
Class N Pozzolan or Class F Fly Ash SiO_2 plus Al_2O_3 plus Fe_2O_3 greater than 80 percent	20 percent
Class N Pozzolan or Class F Fly Ash SiO_2 plus Al_2O_3 plus Fe_2O_3 greater than 90 percent	15 percent
Ultra fine fly ash/Pozzolan	7 percent
Ground granulated blast-furnace slag	40 percent

Minimum SCM reqts.



ASTM C618-19 - Chemical and Physical Analyses - Fly Ash/Pozzolans

CTL Ticket: 21102	Plant of Origin:) NP	Sample Date Range: 06/08/2021
CTL Project: CT16959	Sample ID: ie Comp #1	to:
Report Date: 07/29/2021	Supplier:	Date Received: 06/10/2021

NPA

Chemical Composition (%)
(by Wyoming Analytical Laboratories, Inc.)

ASTM C618-19

			Class N	Class F	Class C
Silicon Dioxide:		73.4			
Aluminum Oxide:		12.4			
Iron Oxide:		1.3			
Total Silica, Aluminum, Iron:	87.1		≥70.0%	≥50.0%	≥50.0%
Sulfur Trioxide:	0.0		≤4.0%	≤5.0%	≤5.0%
Calcium Oxide:	0.9		N/A	≤18.0%	>18.0%

Product Class: Class N   Conforms to Class: Yes

Volatile Composition (Mass%)

		Class N	Class F	Class C
Moisture Content:	0.9	≤3.0%	≤3.0%	≤3.0%
Loss on Ignition:	3.8	≤10.0%	≤6.0%	≤6.0%

Physical Test Results

		Class N	Class F	Class C
Fineness, Retained on #325 Sieve (%):	3.2	≤34%	≤34%	≤34%
Strength Activity Index (%) *		* No 7-day limit if 28-day meets		
Percent of Control @ 7 Days:	85	≥75%	≥75%	≥75%
Percent of Control @ 28 Days:	100	≥75%	≥75%	≥75%
Water Requirement, % of Control:	103	≤115%	≤105%	≤105%
Soundness, Autoclave Expansion (%):	-0.01	≤0.8%	≤0.8%	≤0.8%
Density (g/cm3) :	2.33	N/A	N/A	N/A

Meets AASHTO M321 HR Pozz

Uniformity
Established from 10 previous tests

			Class N	Class F	Class C
Average Fineness:	3.4	Difference 0.3(%)	±5(%)	±5(%)	±5(%)
Average Density:	2.35	Difference -0.85%	±5%	±5%	±5%

Supplementary Requirements

Available Alkalis, as Na_2O 1.29%

Modern portland cements, other than a few Type-IP cements, produce unreacted excess free lime. Standard TI/II cements can release up to 25% calcium hydroxide (a by-product of the hydraulic reaction) into the pore solution - unbound, & free to go about its deleterious work - **Ca(OH)2** is:

1. A key ingredient in ASR
2. A key ingredient in Sulfate Attack
3. A key ingredient in Efflorescence
4. A key ingredient in Chlorides induced expansion
5. A key contributor to porosity in concrete - (allowing ingress of chlorides, sulfates, etc)

Natural Pozzolan consumes the excess $Ca(OH)_2$ and converts it into additional C-S-H (and C-A-S-H), the binder in concrete, thereby densifying the concrete, which in turn increases the impermeability of the concrete and thus its resistance to ingress of damaging chemicals.

By converting the free-lime into additional C-S-H, a concrete using NP at a 20~25% replacement of cement will have greater ultimate compressive strength than a 100% cement mix design - up to 140% SAI of the straight cement mixes at 1 year.

Pumice Producing Facilities

Metakaolin Processing Plant

Some cement companies are producing a NP and/or a Type IP cement

First US-based NP production facility dedicated solely to producing natural pozzolan (2018). There are several more to follow.

Pit run at the KMC pozzolan mine in AZ - 2022

New 500K+ TPY NP plant in AZ.

There are approximately 10 NP production facilities in North America, and about 10 more in various phases of development (that we know of....).

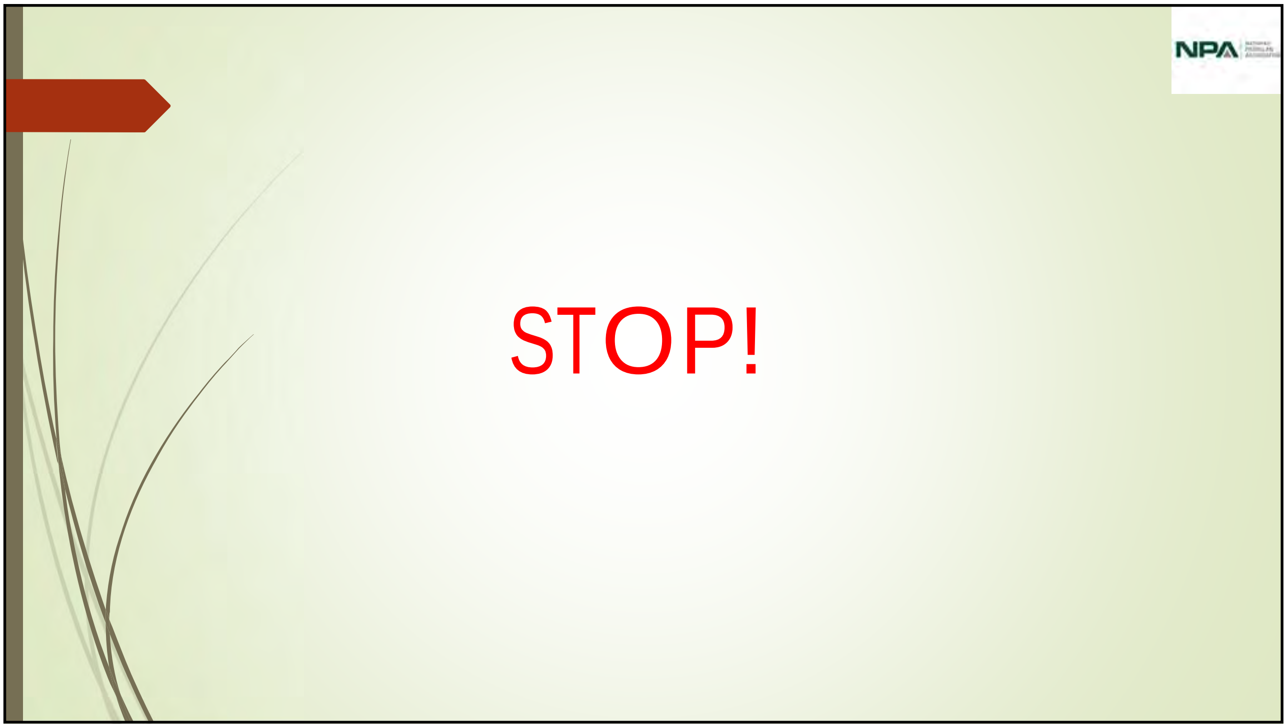
Currently there is a total production capacity of an estimated 1.5m tons - and much more to follow.

- Operational or Permitted
- Proposed

Natural Pozzolan Symposium –
16-18 May 2023, Wickenburg, AZ

Learn more at:

Pozzolan.org


NPA
STOP!