Hyaloclastite based Natural Pozzolanic Material Performance

as a Substitution for Fly Ash, Slag, Silica Fume and Metakaolin in Normal and High Performance Concretes

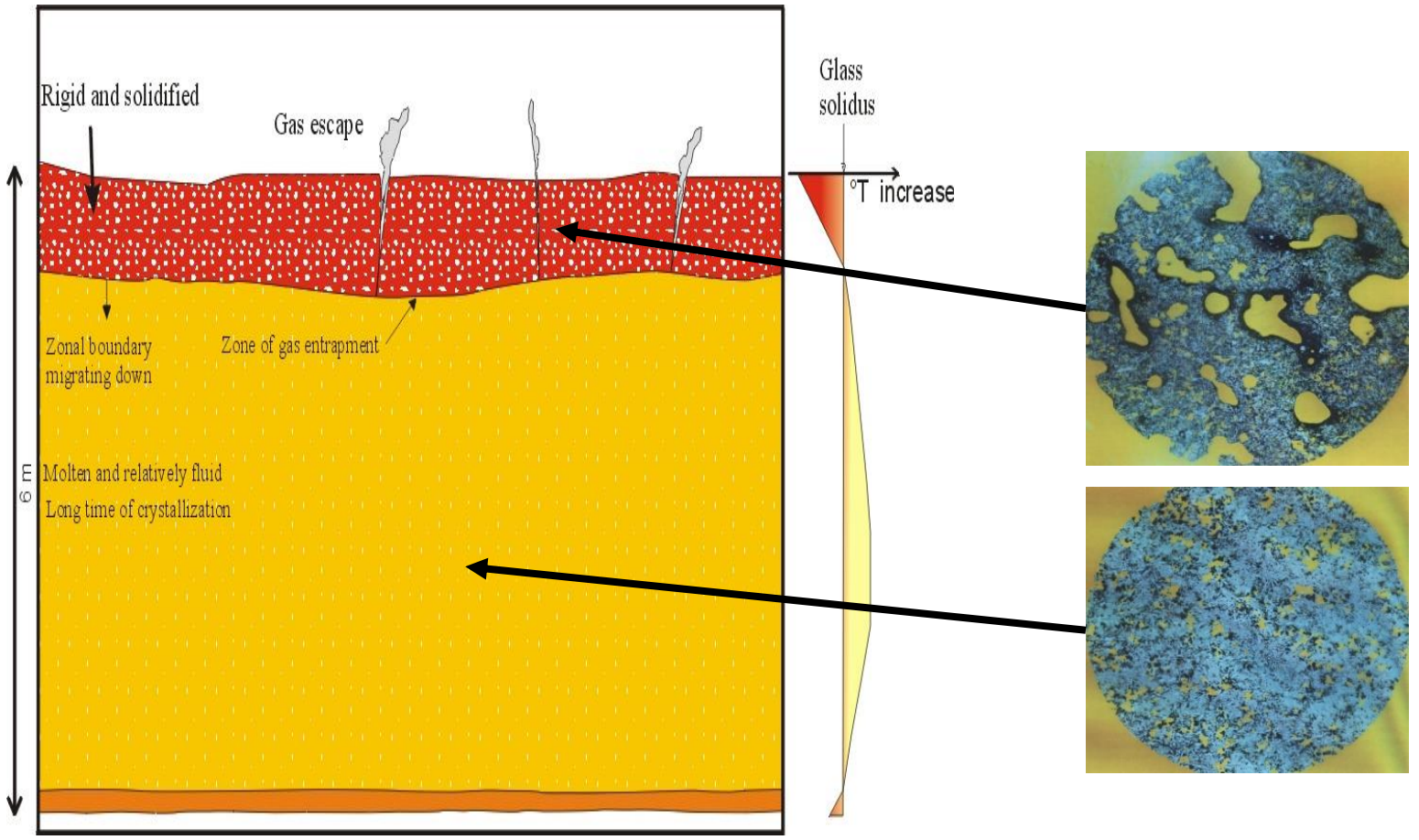
March 28, 2022

What is Hyaloclastite?

lava quenched by water

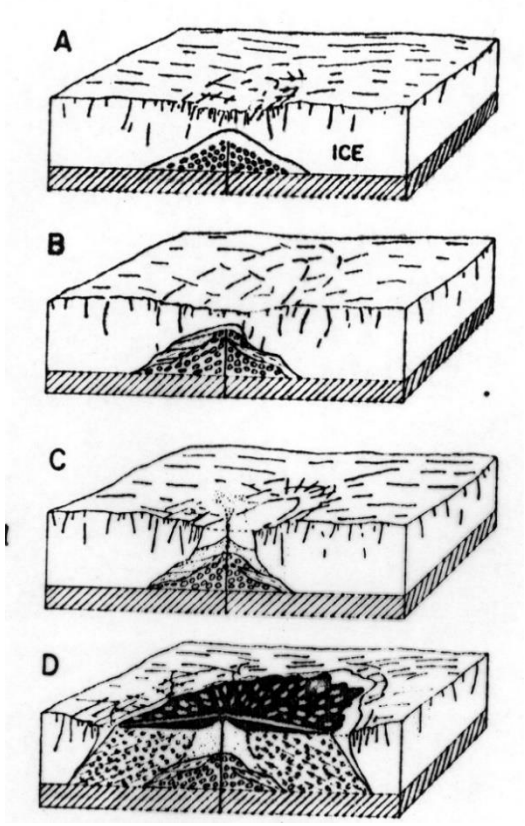
Subaerial lava eruption:

- Lava flow showing the relatively rapidly cooled scoraceous top and the more slowly cooled central part of the lava.
- right photos examples of the relatively finely crystallized matrix with more glassy rims around the vesicles, while the picture to the right shows the relatively large crystals due to the longer crystallization time of the magma.



Hyaloclastite: lava quenched by water prevents lava crystallization generally resulting in fractured lava with high amorphous content.

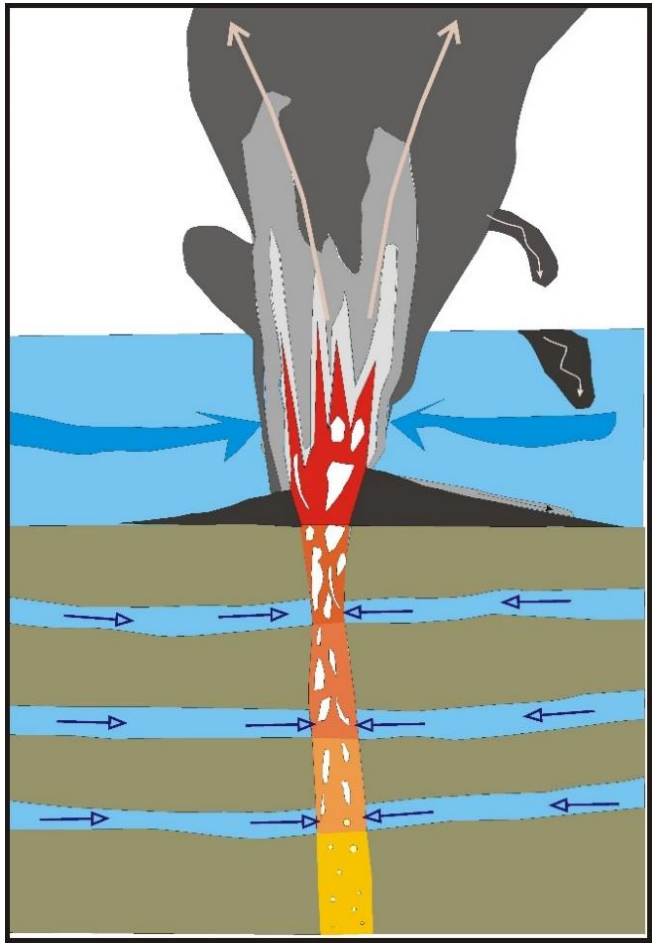
- Hyaloclastite formation is common at the bottom of the ocean where lava is extruded into the sea water, such as at the Mid Atlantic Ocean Ridge, but very rarely occurs on land.
- On land they are dominantly found as ancient volcanic eruptions into thick ice sheets of past glaciations.
- Such Hyaloclastite deposits are found in Iceland, Upper British Columbia and the Central Siberian Plateau



Growth of sub-glacial monogenetic volcano:
A. Pillow basalt forms in deep meltwater lake
B. Pillow breccia forms by slumping.
C. Hyaloclastite tuffs are erupted at shallow depth
D. Lava cap formed above water table

US Underwater Eruption Hyaloclastite deposit:

- Eruption approx. 16,000 years at bottom of Lake Bonneville
- Lake depth approx. 300 feet of glacial cold water
- Lava travels through several aquifers which injects water under pressure into the lava tube, pre-quences the lava
- Lava is intensely and homogeneously quenched to glass-like grains that are largely “pulverized”
- Hyaloclastite deposit is fine sand and some – ¼” gravel
- Single magma chamber, single chemistry
- Unconsolidated, un-altered mineral virtually the same as the time of eruption



US Based: High Performance Alternative Cementitious Material

- PVT is natural pozzolan that is 70% amorphous and meets the requirements of ASTM C618 Class N.
- PVT 70-4 and PVT 70-8 at particle sizes of 4 µm and 8 µm d50 were compared to Class F fly ash, silica fume and metakaolin for the following properties:
  - ASR Performance (TCG)
  - Mortar Cube Strength Versus Time (TEC)
  - Concrete Testing (TCG)
    - Plastic properties
    - Compressive strength versus time
    - Freezing and thawing resistance
    - Transport properties related to water and chloride ingress
  - Calorimetry (TCG)
- The results in the following slides show that it outperforms fly ash and is comparable to or better than silica fume or metakaolin.

Mortar Cube Results ASTM C618 using Mitsubishi Type II/V Cement

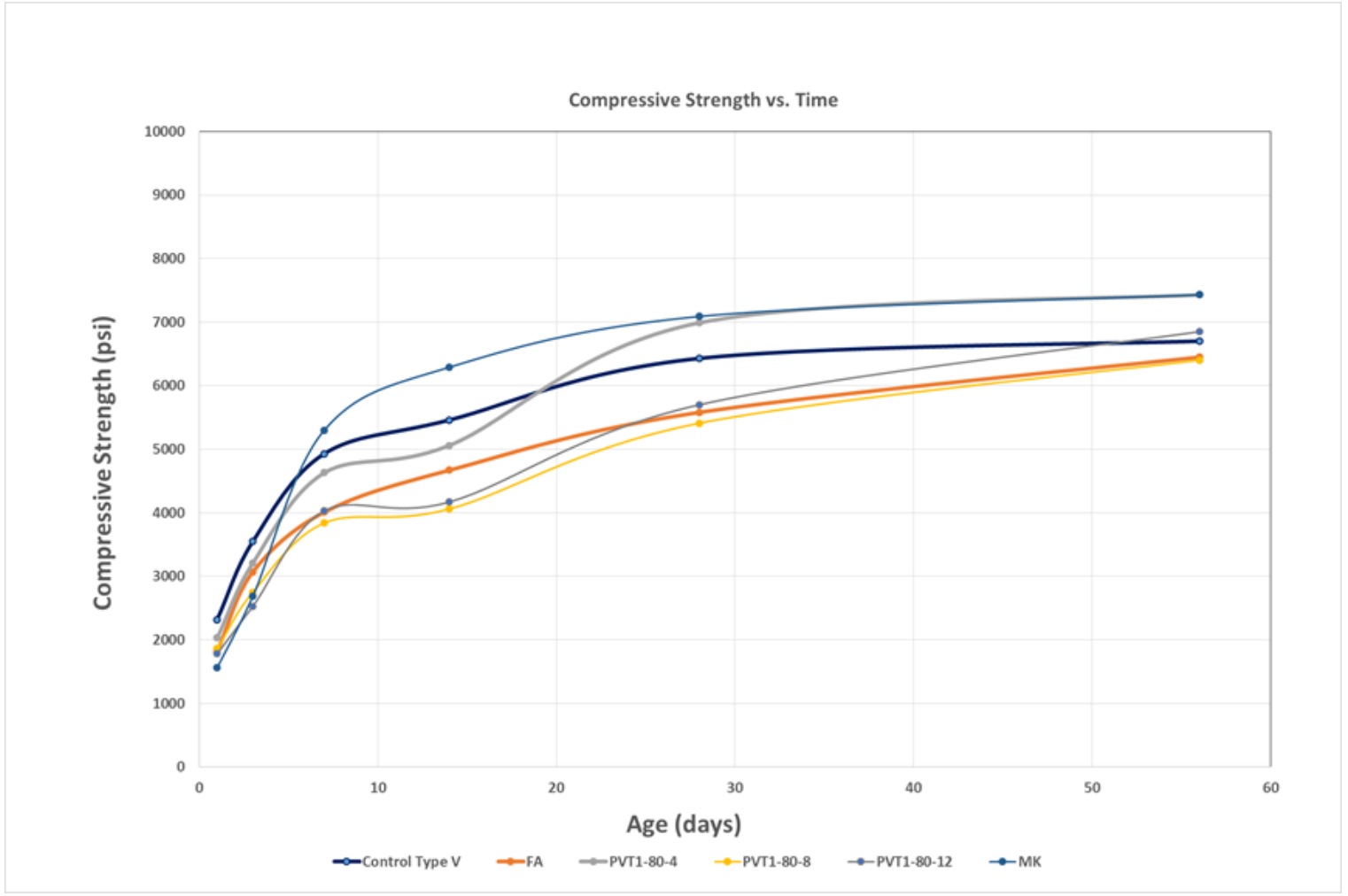
Strength (psi)

% Increase

		Control (Miths V)	FA (Chulla)	PVT1-70-4	PVT1-70-8	PVT1-70-12	MET (BASF)		Control (Miths V)	FA (Chulla)	PVT1-70-4	PVT1-70-8	PVT1-70-12	MET (BASF)
1 Day	1	2320	1820	2030	1860	1780	1560		100	78	88	80	77	67
3 Day	3	3550	3070	3210	2750	2530	2690		100	86	90	77	71	76
7 Day	7	4930	4010	4630	3840	4030	5300		100	81	94	78	82	108
14 Day	14	5460	4670	5060	4060	4170	6290		100	86	93	74	76	115
28 Day	28	6430	5580	6990	5410	5700	7090		100	87	109	84	89	110
56 Day	56	6700	6450	7430	6400	6850	7430		100	96	111	96	102	111

	Control (Miths V)	FA (Chulla)	PVT1-70-4	PVT1-70-8	PVT1-70-12	MET (BASF)
Specific Gravity	2.29	2.83	2.77	2.78	2.48	
Soundness	0.01	0.03	0.02	0.02	-0.12	
Wash #325	24.16	0.00	0.00	0.00	0.00	
Water Req %	98	101	103	104	125	

Mortar Cube Results ASTM C618



Meets

ASTM C 618 Class N

MITSUBISHI CEMENT CORPORATION
CUSHENBURY PLANT, 5808 STATE HIGHWAY 18, LUCERNE VALLEY, CA 92356-9691 TELEPHONE (760) 248-7373

October 26, 2020

The following data are the chemical and physical analyses of the Greencraft LLC pozzolan sample received in the MCC laboratory on September 3, 2020. The sample was assigned the lab # 20090301 (269-F). This sample was tested in accordance with ASTM C 618 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Concrete. The listed results are not a complete evaluation of the sample and is not a certification of the sample as a fly ash. The testing is only an evaluation of the potential for the sample to be used as a fly ash additive with MCC's Type II/V Portland cement.

SiO2	46.39 %
Al2O3	14.78 %
Fe2O3	9.88 %
Sum	71.05 %
CaO	14.23 %
MgO	5.86 %
SO3	0.05 %
Na2O	2.87 %
K2O	1.04 %
TiO2	1.43 %
P2O5	0.27 %
Chlorine	0.000 %
Loss on Ign	3.35 %
Moisture	0.48 %
325 Sieve	0.0 % Retained
Water Requirement	101 %
Strength Activity Index	
@ 7 days	82.4 %
@ 28 Days	97.5 %

C-618 Specification	N	F	C
Sum SiO2, Al2O3, Fe2O3	≥ 70 %	≥ 70 %	≥ 50 %
SO3	≤ 4.0 %	≤ 5.0 %	≤ 5.0 %
Moisture	≤ 3.0 %	≤ 3.0 %	≤ 3.0 %
Loss on Ignition (LOI)	≤ 10 %	≤ 6.0 %	≤ 6.0 %
325 Sieve (% Retained)	≤ 34 %	≤ 34 %	≤ 34 %
Water Requirement	< 115 %	< 105 %	< 105 %
Strength Activity Index at 7 & 28 Day for all types (N,F,C)			≥ 75%

This analysis indicates that the Greencraft pozzolan passes the listed ASTM C 618 specifications and has potential for used as a pozzolan additive in concrete made with MCC's Type II/V Portland cement.

Tom Gepford, Quality Control Manager
(760) 248-5173, tgepford@mitsubishicement.com

MITSUBISHI CEMENT CORPORATION
CERTIFICATE OF TEST

Portland Cement - Type I, II, II (MH) & V **Date: 09/08/2021**
Source: Cushenbury Plant, 5808 State Highway 18, Lucerne Valley, CA 92356

ASTM designation: C 150 - 16 for Type I, II, II (MH) & V low alkali Cement **Production Period**
CALTRANS Specification: Section 90 – 2.01 for Type II modified and V (2006) Specification: Section 90 – 1.02B(2) (2015) **From: 08/01/2021**
NDOT Specification: Section 701.03.01 for Type II and V **To: 08/31/2021**
AZDOTSpecifications Subsection 1006-2.01 for Type II and V

Chemical Composition:

	ASTM C-150 Limits Type I	Type II	Type V		Test Results
Silicon Dioxide (SiO_2), %	—	—	—	Min.	20.8
Aluminum Oxide (Al_2O_3), %	—	6.0	—	Max.	4.1
Ferric Oxide (Fe_2O_3), %	—	6.0	—	Max.	3.9
Calcium Oxide (CaO), %	—	—	—		62.8
Magnesium Oxide (MgO), %	6.0	6.0	6.0	Max.	2.7
Sulfur Trioxide (SO_3), %	3.0	3.0	2.3	Max.	2.1
Loss on Ignition (LOI), %	3.5	3.5	3.5	Max.	2.0
Insoluble Residue	1.5	1.5	1.5	Max.	0.52
Total Alkali (%Na_2O + 0.658 * %K_2O)	0.60	0.60	0.60	Max.	0.50
Tricalcium Silicate (C_3S), [b] %	—	—	—		56
Tricalcium Aluminate (C_3A), [b] %	—	8	5	Max.	4
$C_4AF + 2*C_3A$ [b]	—	—	25	Max.	20
$C_3S + 4.75*C_3A$ [b]	—	100	—	Max.	76
CO_2, %	—	—	—		1.1
Limestone, %	5.0	5.0	5.0	Max.	3.0
$CaCO_3$ Limestone Purity, %	70	70	70	Min.	84

PHYSICAL RESULTS:

Blaine Fineness (m^2/kg)	260 / —	260 / 430	260 / —	Min / Max 381
325 Mesh (% Passing)	—	—	—	98.6
Autoclave Expansion (%)	0.80	0.80	0.80	Max. 0.06
Time of Set Initial Vicat (minutes)	45 / 375	45 / 375	45 / 375	Min / Max 125
Air Entrainment (% Volume)	12	12	12	Max. 7.4
C1702 Heat of Hydration at 7 Days (J/g)	—	—	—	[a] 352
False Set, %	50	50	50	Min. 88
Color, (L value)	—	—	—	55

Compressive Strength Test:

	Type I MPA	psi	Type II MPA	psi	Type V MPA	psi		MPA	PSI
1 Day	—	—	—	—	—	—		15.0	2170
3 Day	12.0	1740	10.0	1450	8.0	1160	Min.	26.8	3890
7 Day	19.0	2760	17.0	2470	15.0	2180	Min.	35.9	5200
28 Day July 2021	—	—	—	—	21.0	3050	Min.	40.1	5810

This cement has been sampled and tested in accordance with ASTM standard methods and procedures. All tests results are certified to comply with the type specification designated above. No other warranty is made or implied. We are not responsible for improper use or workmanship. The MCC laboratory is AASHTO accredited. [a] For information only. [b] Adjusted per ASTM C150 A1.6.

MITSUBISHI CEMENT CORPORATION
Cushenbury plant
Evan Coss
Quality Control Superintendent

Meets ASTM C 618 Class N

and

AASHTO M295

SGS TEC SERVICES
Testing • Engineering • Consulting

Client: Mr. Romeo Ciuperca
Greencraft LLC
1831 Warren Place, Suite 200
Norcross, Ga 30093

Date: July 31, 2020
TEC Services I.D.: TEC 10-5575
Lab No.: 20-745-2

REPORT OF NATURAL POZZOLAN TESTS

Client ID: PVT1-70-4
Manufacturer: Mill Test
Date Received: June 16, 2020

Chemical Analysis	Results (wt%)	Specification (Class N) ASTM C618-19	Specification (Class N) AASHTO M295-19
Silicon Dioxide (SiO_2)	48.7	—	—
Aluminum Oxide (Al_2O_3)	13.0	—	—
Iron Oxide (Fe_2O_3)	12.71	—	—
Sum of Silicon Dioxide, Iron Oxide & Aluminum Oxide (SiO_2+Al_2O_3+Fe_2O_3)	74.5	70 % min.	70 % min.
Calcium Oxide (CaO)	9.6	—	—
Magnesium Oxide (MgO)	6.0	—	—
Sodium Oxide (Na_2O)	2.91	—	—
Potassium Oxide (K_2O)	1.11	—	—
"Sodium Oxide Equivalent (Na_2O+0.658K_2O)"	3.64	—	—
Sulfur Trioxide (SO_3)	0.15	4 % max.	4 % max.
Loss on Ignition	1.5	10 % max.	5 % max.
Moisture Content	0.22	3 % max.	3 % max.
Available Alkalies			
Sodium Oxide (Na_2O) as Available Alkalies	1.33	—	—
Potassium Oxide (K_2O) as Available Alkalies	0.46	—	—
Available Alkalies as "Sodium Oxide Equivalent (Na_2O+0.658K_2O)"	1.65	—	1.5 % max.
Physical Analysis			
Fineness (Amount Retained on #325 Sieve)	0.0%	34 % max.	34 % max.
Strength Activity Index with Portland Cement			
At 7 Days: Control Average, psi: 4930 / Test Average, psi: 4630	94%	75 % min.† (of control)	75 % min.† (of control)
At 28 Days: Control Average, psi: 6430 / Test Average, psi: 6990	109%	75 % min.† (of control)	75 % min.† (of control)
Water Requirements (Test H_2O/Control H_2O) Control, mls: 242 / Test, mls: 244	101%	115 % max. (of control)	115 % max. (of control)
Autoclave Expansion:	0.03%	± 0.8 % max.	± 0.8 % max.
Specific Gravity:	2.83	—	—

† Meeting the 7 day or 28 day strength activity index will indicate specification compliance
* Does not meet Available Alkalies as Na_2O requirements for AASHTO M295-19.

The results of our testing indicate that this sample complies with ASTM C618-119 specifications for Class N pozzolans.

Respectfully Submitted,
SGS TEC Services

Dean Roosa
Project Manager

Shawn McCormick
Laboratory Principal

ISO 17025

SGS TEC SERVICES
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770-995-8000 | www.tecservices.com

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Client: Mr. Romeo Ciuperca
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1831 Warren Place, Suite 200
Norcross, Ga 30093

Date: July 31, 2020
TEC Services I.D.: TEC 10-5575
Lab No.: 20-745-4

REPORT OF NATURAL POZZOLAN TESTS

Client ID: PVT1-70-12
Manufacturer: Mill Test
Date Received: June 16, 2020

Chemical Analysis	Results (wt%)	Specification (Class N) ASTM C618-19	Specification (Class N) AASHTO M295-19
Silicon Dioxide (SiO_2)	48.7	—	—
Aluminum Oxide (Al_2O_3)	13.0	—	—
Iron Oxide (Fe_2O_3)	12.71	—	—
Sum of Silicon Dioxide, Iron Oxide & Aluminum Oxide (SiO_2+Al_2O_3+Fe_2O_3)	74.5	70 % min.	70 % min.
Calcium Oxide (CaO)	9.6	—	—
Magnesium Oxide (MgO)	6.0	—	—
Sodium Oxide (Na_2O)	2.91	—	—
Potassium Oxide (K_2O)	1.11	—	—
"Sodium Oxide Equivalent (Na_2O+0.658K_2O)"	3.64	—	—
Sulfur Trioxide (SO_3)	0.15	4 % max.	4 % max.
Loss on Ignition	1.5	10 % max.	5 % max.
Moisture Content	0.22	3 % max.	3 % max.
Available Alkalies			
Sodium Oxide (Na_2O) as Available Alkalies	1.33	—	—
Potassium Oxide (K_2O) as Available Alkalies	0.46	—	—
Available Alkalies as "Sodium Oxide Equivalent (Na_2O+0.658K_2O)"	1.65	—	1.5 % max.
Physical Analysis			
Fineness (Amount Retained on #325 Sieve)	0.0%	34 % max.	34 % max.
Strength Activity Index with Portland Cement			
At 7 Days: Control Average, psi: 4930 / Test Average, psi: 4030	82%	75 % min.† (of control)	75 % min.† (of control)
At 28 Days: Control Average, psi: 6430 / Test Average, psi: 5700	89%	75 % min.† (of control)	75 % min.† (of control)
Water Requirements (Test H_2O/Control H_2O) Control, mls: 242 / Test, mls: 251	104%	115 % max. (of control)	115 % max. (of control)
Autoclave Expansion:	0.02%	± 0.8 % max.	± 0.8 % max.
Specific Gravity:	2.78	—	—

† Meeting the 7 day or 28 day strength activity index will indicate specification compliance
* Does not meet Available Alkalies as Na_2O requirements for AASHTO M295-19.

The results of our testing indicate that this sample complies with ASTM C618-119 specifications for Class N pozzolans.

Respectfully Submitted,
SGS TEC Services

Dean Roosa
Project Manager

Shawn McCormick
Laboratory Principal

ISO 17025

SGS TEC SERVICES
235 Buford Drive | Lawrenceville GA 30046
770-995-8000 | www.tecservices.com

Tests performed by Tourney Consulting Group:

Property	Test Method	Notes
Mortar Mixtures		
ASR	ASTM C1260	For 28 days
	ASTM C1567	For 28 days
Concrete Mixtures		
Slump	ASTM C31	
Air Content	ASTM	
Density	C231	
Temperature	ASTM C1064	
Setting Time	ASTM C403	
Compressive Strength	ASTM C39	Several Ages
Conductivity	ASTM C1760	28, 90 days
Non Steady-State Diffusion	NT Build 492	28 days
Bulk Diffusion	ASTM C1556	28 days
Capiillary Absorption	ASTM C1585	28 days
Freezing and Thawing	ASTM C666	Method A
Isothermal Calorimetry		
Data at 23.0 °C		7 days

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Isothermal Calorimetry		
Data at 23.0 °C		7 days

ASR Performance:

- Evaluated in ASTM C1260/C1567 (Accelerated mortar bars) (TCG)

Mix Identification :	**CTL**	**FA-25**	**SF-10**	**M-10**	**FA-20**	**70-4**	**70-8**
% Replacement	---	25	10	10	20	20	20
Linear Expansion % @ 14 d	**0.15**	0.02	0.08	0.03	0.08	0.03	0.03
Linear Expansion % @ 28 d	**0.31**	0.04	**0.19**	0.05	**0.15**	0.04	0.04
% Reduction @ 14 d	---	87	47	80	47	80	80
% Reduction @ 28 d	---	87	39	84	52	87	87

Concrete Mixes

Mix Description:	Control	25% Class F Fly Ash Replacement	10% Silica Fume Replacement	10% Metakaolin Replacement	Control	20% PVT-70-4 Replacement	20% PVT-70-8 Replacement
Mix Number:	**CTL**	**FA-25**	**SF-10**	**M-10**	**CTL-0522**	**70-4**	**70-8**
Units	lb/yd^3	lb/yd^3	lb/yd^3	lb/yd^3	lb/yd^3	lb/yd^3	lb/yd^3
Lafarge Alpena Type I/II	658	494	592	592	658	526	526
20% Replacement **PVT-70-4**						132	
20% Replacement **PVT-70-8**							132
Class F Fly Ash Boral St Johns River Park Plt.		165					
Silica Fume Norchem			66				
Metakaolin				66			
Agg. Resource Midway Pit MI **Natural Fine** Agg SSD DOT #39-64	1280	1239	1266	1262	1280	1273	1273
Vulcan Lithia Springs GA Pit 3/4" Crushed **Coarse** Agg SSD	1680	1680	1680	1680	1680	1680	1680
Total Water	250	250	250	250	250	250	250
Designed Air %	6%	6%	6%	6%	6%	6%	6%
Water/Cement Ratio	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Admixtures							
Sika Air 260 Air Entrainment oz./cwt	0.35	0.50	0.35	0.42	0.30	0.35	0.35
Sika Viscocrete 2100 HRWR oz./cwt	1.1	0.8	3.1	3.1	1.1	4.0	2.2

Concrete Plastic Properties

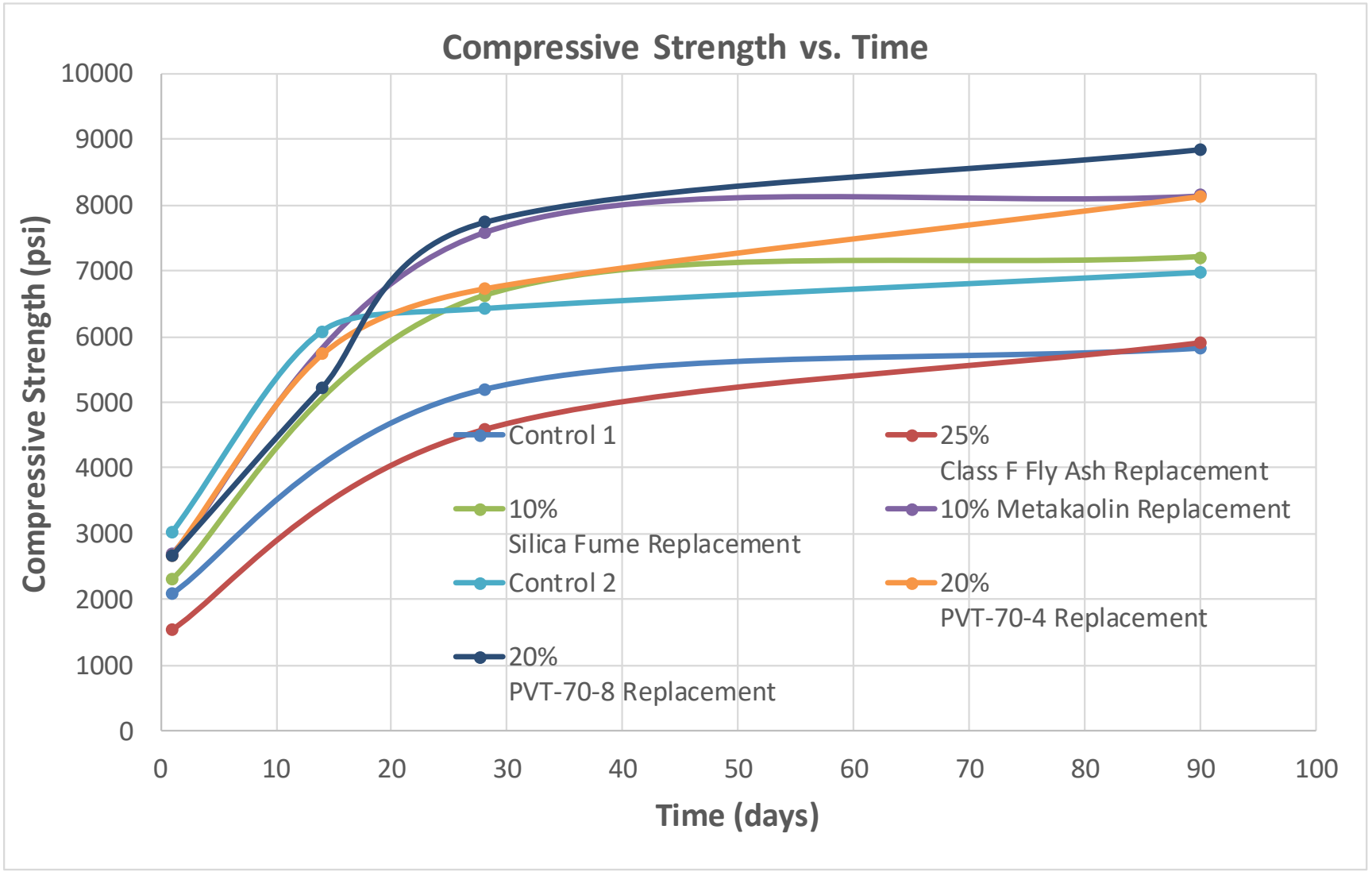
Mix Description:	Control	25% Class F Fly Ash Replacement	10% Silica Fume Replacement	10% Metakaolin Replacement	Control	20% PVT-70-4 Replacement	20% PVT-70-8 Replacement
Mix Number:	**CTL**	**FA-25**	**SF-10**	**M-10**	**CTL-0522**	**70-4**	**70-8**
Plastic Properties							
Slump (in.) ASTM C31	6.00	6.25	3.50	6.75	4.00	4.50	5.50
Air % As Tested ASTM C231	7.4	6.4	6.5	6.8	7.0	5.0	5.5
Density lb/ft^3 ASTM C138	138.3	139.4	140.9	140.0	141.5	143.9	143.1
Concrete Temp °F ASTM C1064	72	71	71	71	72	72	72
Initial Set hours:min	4:55	5:21	4:42	5:13	4:12	4:27	4:11
Final Set hours:min	6:27	7:04	6:11	6:39	5:23	5:42	5:40

- Equivalent setting time to control
- Good workability and air entrainable

Mechanical properties:

Days	Control 1	25% Class F Fly Ash Replacement	10% Silica Fume Replacement	10% Metakaolin Replacement	Control 2	20% PVT-70-4 Replacement	20% PVT-70-8 Replacement
1	2090	1540	2320	2690	3020	2660	2670
14					6080	5730	5230
28	5200	4580	6620	7590	6420	6730	7740
90	5830	5900	7210	8150	6970	8140	8850

- Compressive Strength significantly higher than control and comparable to or better than silica fume or metakaolin


Compressive Strength vs. Time
Compressive Strength (psi)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
10
20
30
40
50
60
70
80
90
100
Time (days)
Control 1
25% Class F Fly Ash Replacement
10% Silica Fume Replacement
10% Metakaolin Replacement
Control 2
20% PVT-70-4 Replacement
20% PVT-70-8 Replacement

Freezing and Thawing

ASTM C666 Freeze Thaw Method A	CTL-0522	70-4	70-8
Durability Factor Percent	94	93	95
Weight Loss Percent	0.30	1.10	1.30

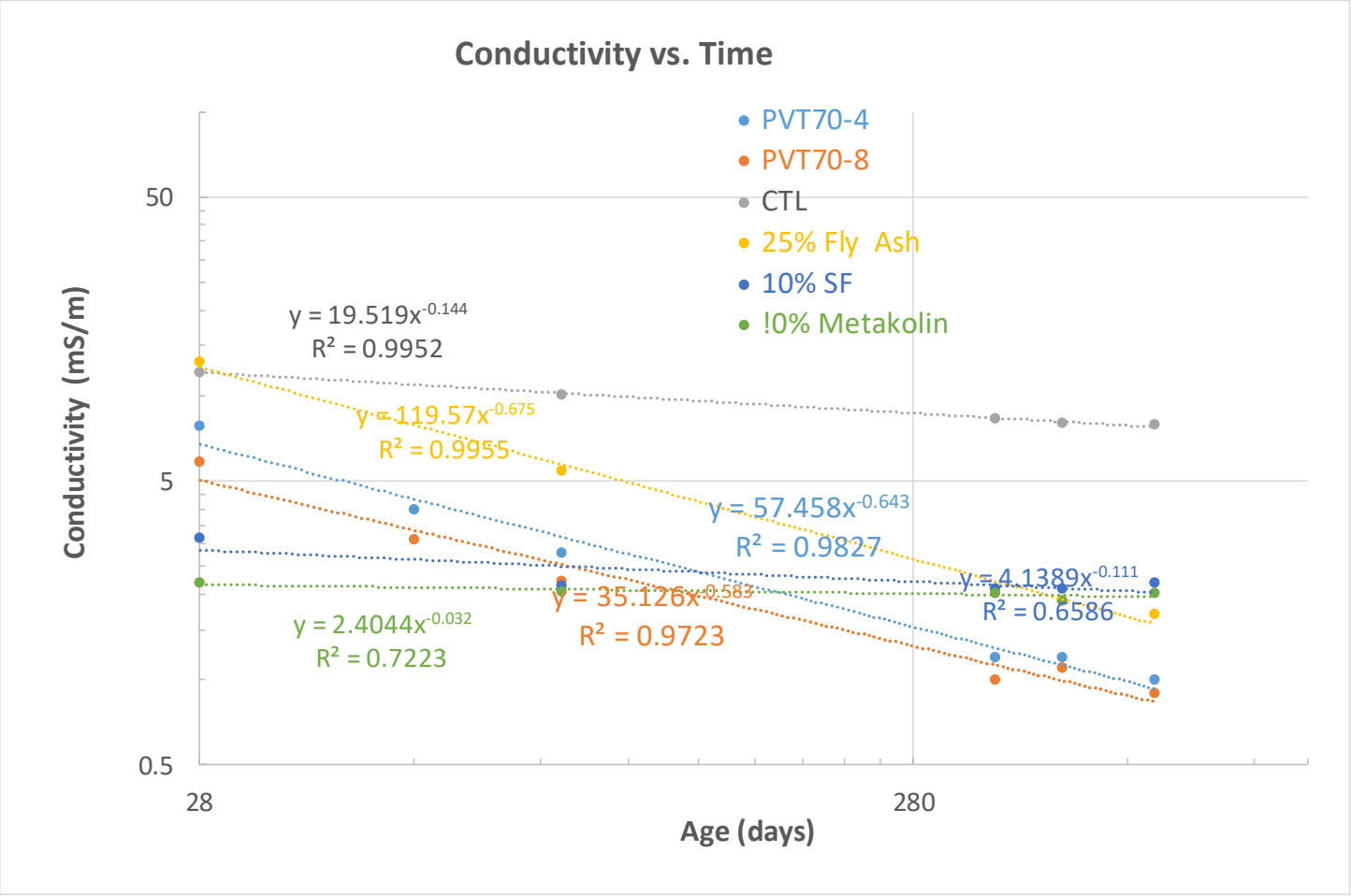
- Excellent Freeze/Thaw Resistance

Transport Properties

Mix Identification :	CTL	FA-25	SF-10	M-10	70-4	70-8
ASTM C1760 Conductivity 4" x 8" cyl.						
28 d Bulk Elect Conductivity (mS/m) C1760	12.18	13.15	3.17	2.19	7.79	5.86
28d STDev (mS/m) C1760	0.16	0.20	0.00	0.03	0.07	0.03
28 d Coulombs C1760	2214	2391	576	397	1415	1065
90 d Bulk Elect Conductivity (mS/m) C1760	10.11	5.43	2.14	2.04	2.81	2.22
90 d STDev (mS/m) C1760	0.18	0.10	0.04	0.04	0.001	0.07
90 days Coulombs C1760	1837	988	389	371	511	404
365 d Bulk Elect Conductivity (mS/m) C1760	8.30	2.10	2.10	2.02	1.20	1.00
365 d STDev (mS/m) C1760	0.32	0.06	0.02	0.04	0.00	0.03
453 d Bulk Elect Conductivity (mS/m) C1760	8.00	1.90	2.10	1.91	1.20	1.10
453 d STDev (mS/m) C1760	0.28	0.02	0.01	0.01	0.01	0.01
609 d Bulk Elect Conductivity (mS/m) C1760	7.90	1.70	2.20	2.01	1.00	0.90
609 d STDev (mS/m) C1760	0.33	0.04	0.00	0.02	0.04	0.02
NT Build 492 Non Steady State Diff. Coeff.						
28 days D_{NSS} (x 10^{-12} m^2/s)	18.2	17.3	6.4	3.3	11.3	6.8
ASTM 1556 Bulk Diffusion						
Surface Concentration (ppm)	9572	9180	10450	10572	12644	13590
Diffusion Coefficient (D_a), (x 10^{-12} m^2/s)	3.9	4.9	1.6	1.1	2.35	2.0
ASTM C1585 Capillary Absorption						
Initial absorption ($mm/s^{0.5}$)	0.00030	0.00194	0.00058	0.00050	0.00029	0.00049
Secondary absorption ($mm/s^{0.5}$)	0.00023	0.00064	0.00022	0.00022	0.00020	0.00022

- Low permeability at early ages (low diffusion, conductivity, Coulombs)
- Continues to improve over time (more so than silica fume or metakaolin)

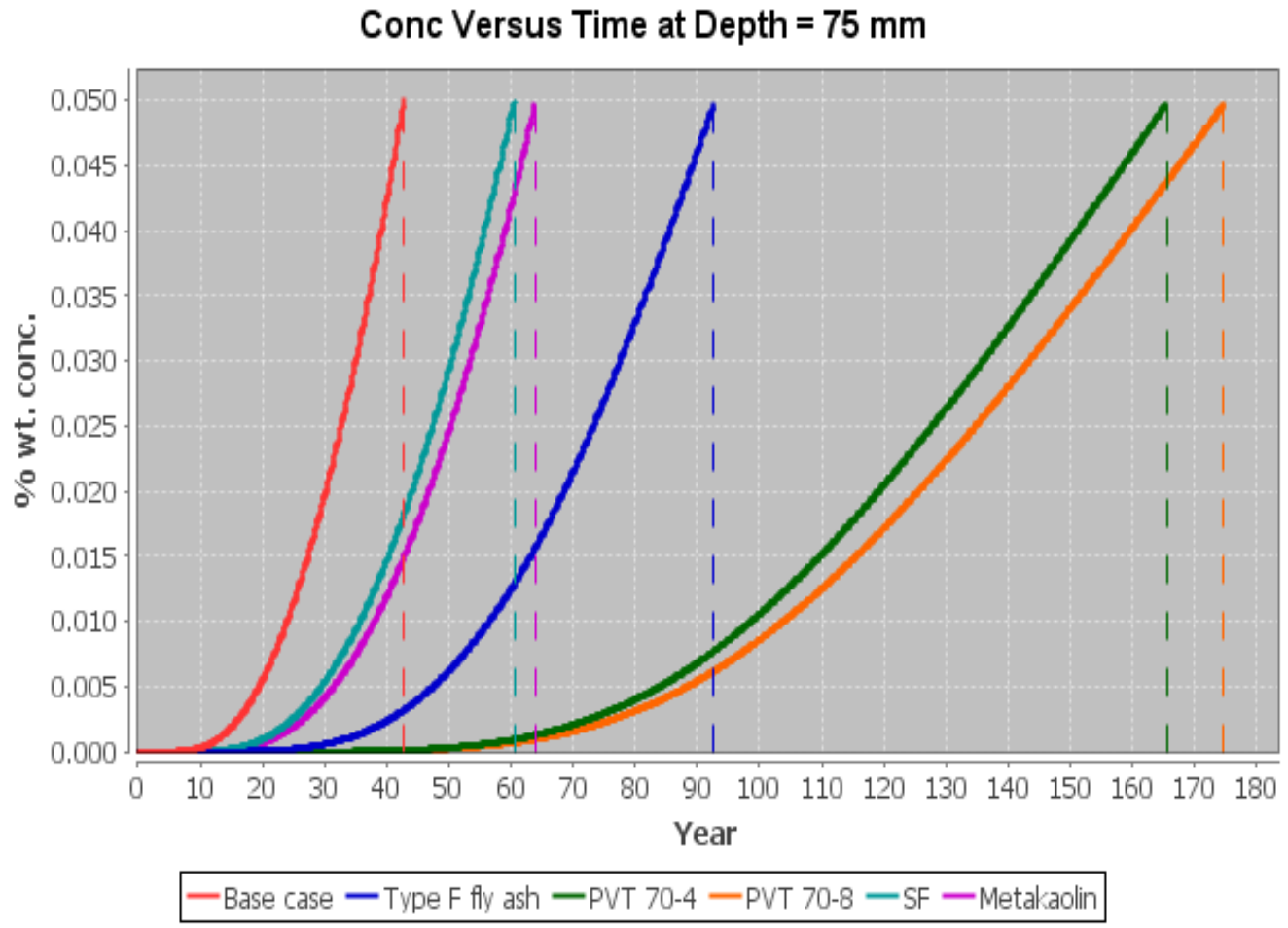
Transport Properties



Predicted Times to Corrosion for Bridge Deck

- Used Salt Lake City as a severe example
- 3” (75 mm) concrete cover
- 250 mm deck thickness
- Modified Life 365™ to be consistent with new data
  - Aging constant and hydration time, based on ASTM 1760 conductivity data
  - Aging factor was limited to a maximum of 0.6 which is a constraint in the Life-365 software.
  - Diffusion Coefficients, based on ASTM C1556
  - Surface buildup, based on ASTM C1585 capillary absorption results
  - This series of tests indicated that the hydration period did not extend beyond 3 years.

Predicted Time to Corrosion Initiation Curves



Best Predicted Performance

PVT 70-8

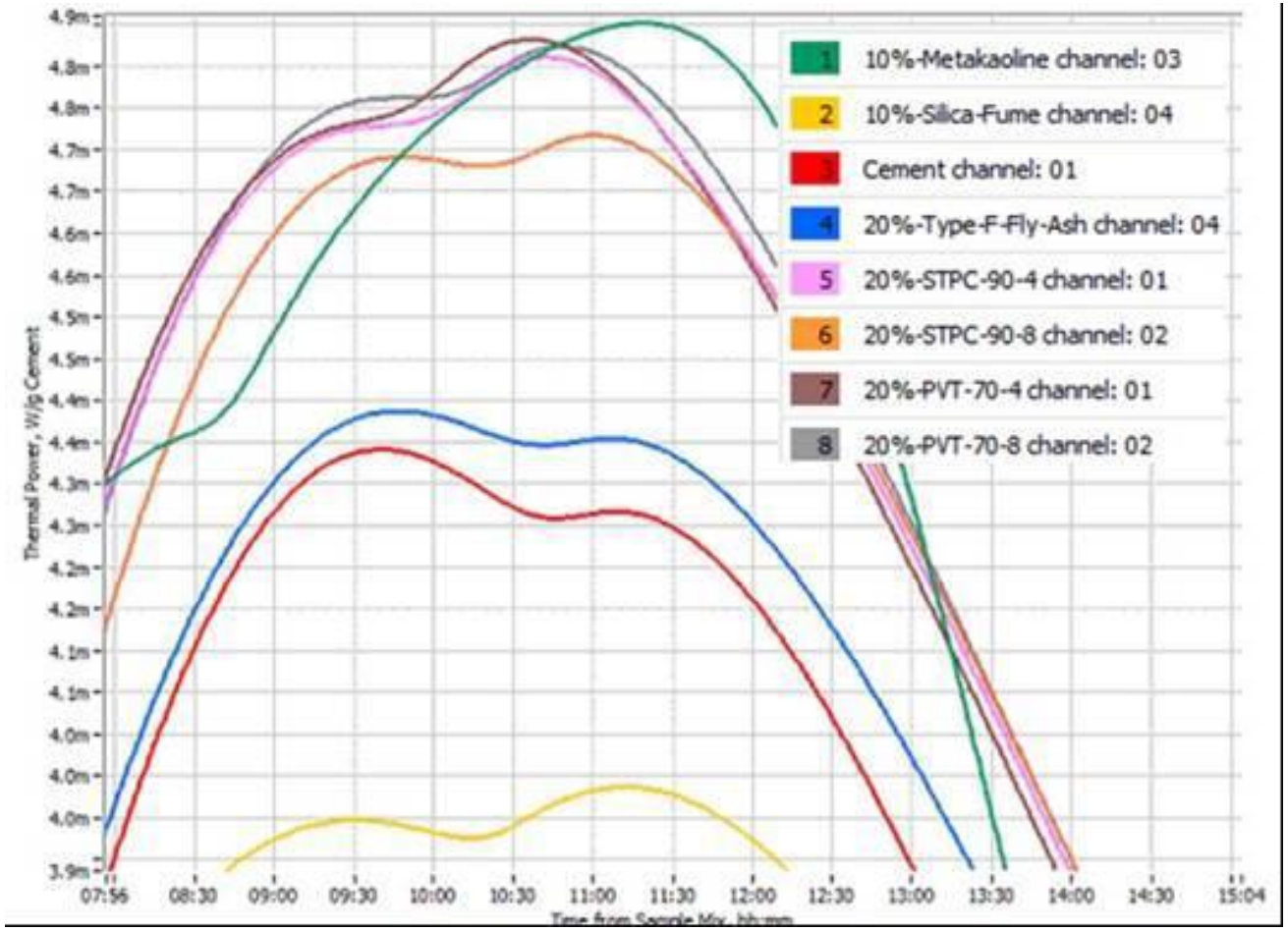
PVT 70-4

Isothermal Calorimetry Results

Mix	Peak watts	Peak mw/g cement	Peak Time H:min	Total J	Total J/g cement
Cement	0.44	4.4	9:45	33700	337
20%Fly Ash	0.35	4.4	9:40	29040	363
20%PVT-70-4	0.38	4.8	10:35	30160	377
20%PVT-70-8	0.38	4.8	10:50	30400	380
10%Metakaolin	0.44	4.9	11:15	36360	404
10%SF	0.36	4.0	11:15	31770	353

- Improves cement efficiency but lowers overall heat output
- In contrast to metakaolin which will increase heat produced

Isothermal Calorimetry Curves



Icelandic High Performance Alternative Cementitious Material

- STP is natural pozzolan that is 90% amorphous and meets the requirements of ASTM C618 Class N.
- STP at particle sizes of 4 µm and 8 µm were compared to Class F fly ash, silica fume and metakaolin for the following properties:
  - ASR Performance (TEC and TCG)
  - Mortar Cube Strength Versus Time (TEC)
  - Concrete Testing (TCG)
    - Plastic properties
    - Compressive strength versus time
    - Freezing and thawing resistance
    - Transport properties related to water and chloride ingress
  - Calorimetry (TCG)
- The results in the following slides show that it outperforms fly ash and is comparable to or better than silica fume or metakaolin.

ASR Performance

- Evaluated in ASTM C441 (Ground Pyrex Glass) by TEC Services
- Evaluated in ASTM C1260/C1567 (Accelerated mortar bars) (TCG)

ASTM C441

Mix Identification :	Control	STP 90-4	STP 90-8
% Replacement	---	25	25
Expansion % at 14 d	0.027	-0.001	0.005
% Reduction at 14 d	---	103.7	81.5

ASTM C1260/C1567

Mix Identification :	Control	STP 90-4	STP 90-8	FA-25	SF-10	M-10	FA-20
% Replacement	---	20	20	25	10	10	20
Linear Expansion % at 14 d	**0.15**	0.02	0.03	0.02	0.08	0.03	0.08
Linear Expansion % at 28 d	**0.31**	0.05	0.04	0.04	**0.19**	0.05	**0.15**
% Reduction at 14 d	**---**	85.3	82.7	86.7	46.7	80.0	46.7
% Reduction at 21 d	**---**	85.5	86.1	87.1	38.7	83.9	51.6

FA=Type F fly ash, SF=Silica Fume, M=Metakaolin

Mortar Cube Results ASTM C618

	Strength (psi)			% Increase	
	Control	**STP-90-4**	**STP-90-8**	**STP-90-4**	**STP-90-8**
1 Day	2430	2340	2110	96	87
3 Day	3960	3620	3390	91	86
7 Day	4930	4520	3820	92	77
14 Day	5320	5720	4770	108	90
21 Day	5750	7160	5810	125	101
28 Day	6460	7500	6310	116	98
56 Day	6390	8000	7680	125	120
90 Day	6220	8640	7870	139	127
120 Day	6450	9020	8370	140	130
180 Day	6490	9060	8230	140	127
Water Req % of control	242	242	242	100	100

Concrete Mixes

Mix Description:	Control	20% STP-90-4 Replacement	20% STP-90-8 Replacement	10% Silica Fume Replacement	10% Metakaolin Replacement
Mix Number:	**CTL**	**90-4**	**90-8**	**SF-10**	**M-10**
Units	lb/yd3	lb/yd3	lb/yd3	lb/yd3	lb/yd3
Lafarge Alpena Type I/II	658	526	526	592	592
20% Replacement 90% Amorphous **4**-Micron		132			
20% Replacement 90% Amorphous **8**-Micron			132		
20% Replacement **50%** Amorphous **4**-Micron					
20% Replacement **50%** Amorphous **8**-Micron					
Class F Fly Ash Boral St Johns River Park Plt.					
Silica Fume Norchem				66	
Metakaolin					66
Agg. Resource Midway Pit MI **Natural Fine** Agg SSD DOT #39-64	1280	1273	1273	1266	1262
Vulcan Lithia Springs GA Pit 3/4" Crushed **Coarse** Agg SSD	1680	1680	1680	1680	1680
Total Water	250	250	250	250	250
Designed Air %	6%	6%	6%	6%	6%
Water/Cement Ratio	0.38	0.38	0.38	0.38	0.38
Admixtures					
Sika Air 260 Air Entrainment oz./cwt	0.35	0.35	0.36	0.35	0.42
Sika Viscocrete 2100 HRWR oz./cwt	1.1	1.3	1.5	3.1	3.1

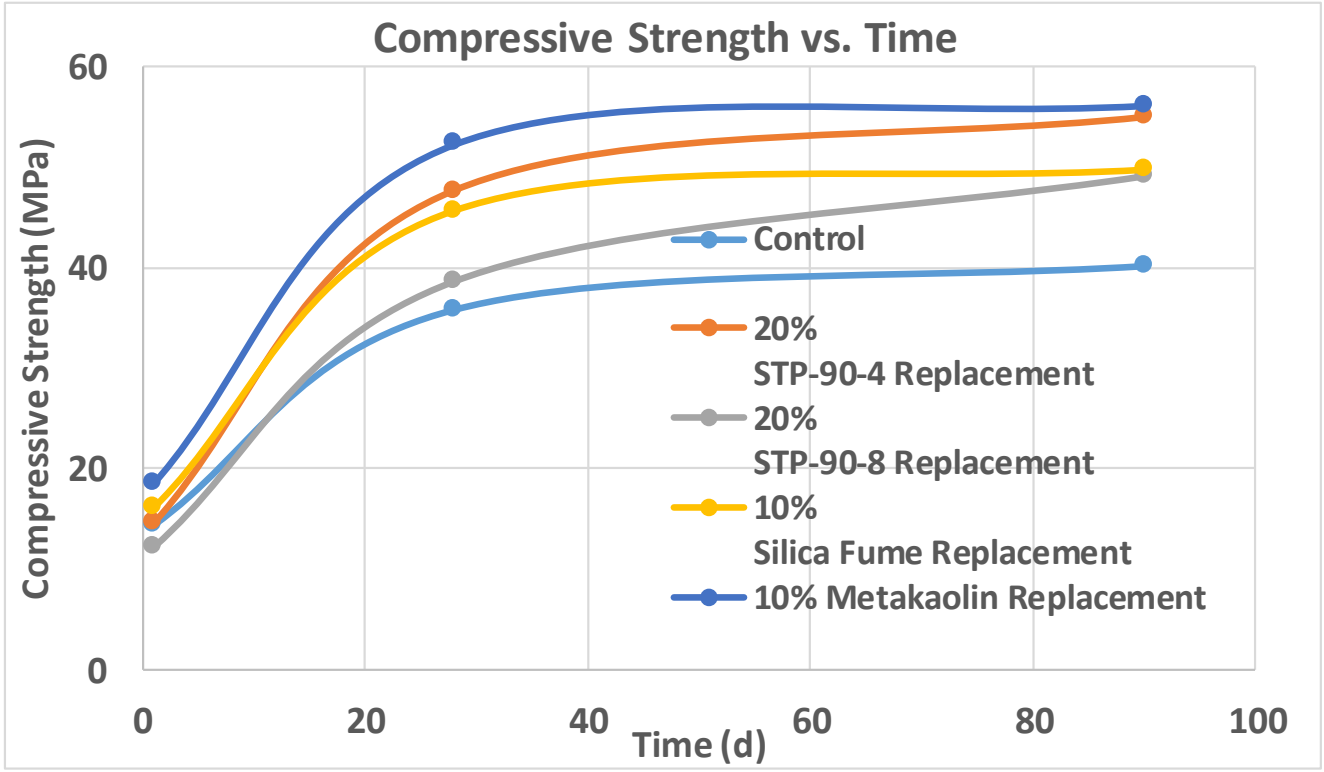
- STP 90-4 and STP 90-8 have workability is similar to the cement only control
- Silica fume and Metakaoline require more than **two times** the superplasticizer dosage

Concrete Plastic Properties

Mix Description:	Control	20% STP-90-4 Replacement	20% STP-90-8 Replacement	10% Silica Fume Replacement	10% Metakaolin Replacement
Plastic Properties					
Slump (in.) ASTM C31	**6.00**	**7.00**	**7.00**	**3.50**	**6.75**
Air % As Tested ASTM C231	7.4	5.8	6.8	6.5	6.8
Density lb/ft3 ASTM C138	138.3	140.7	139.6	140.9	140.0
Concrete Temp °F ASTM C1064	72	71	71	71	71
Initial Set hours:min	4:55	5:00	5:02	4:42	5:13
Final Set hours:min	6:27	6:19	6:43	6:11	6:39

- Equivalent setting time to control
- Good workability and air entrainable

Compressive Strength



- Compressive Strength significantly higher than control and comparable to or better than silica fume or metakaolin

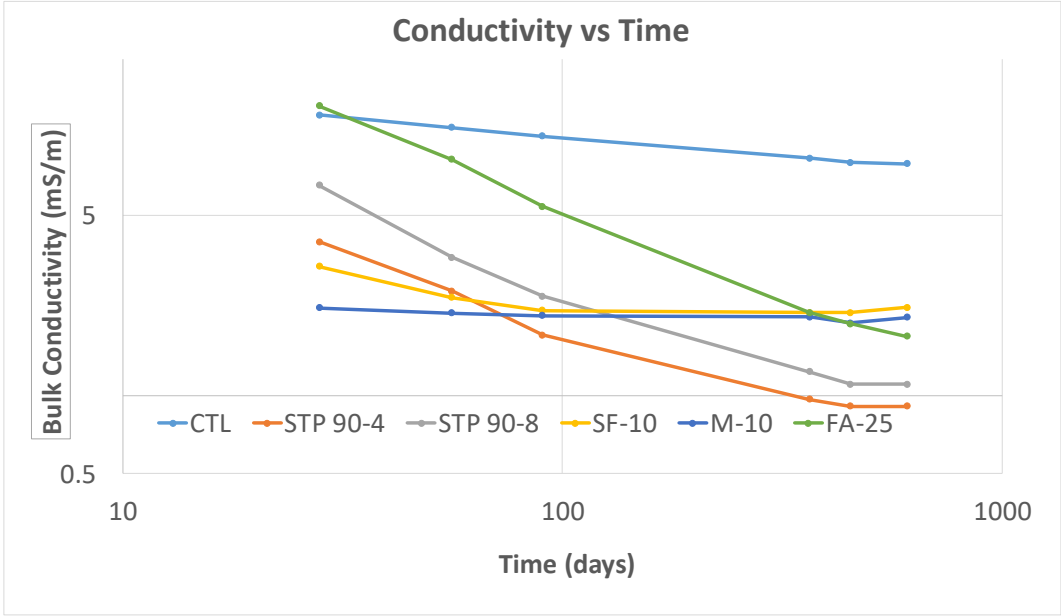
Freezing and Thawing

ASTM C666 Freeze Thaw Method A	Control	STP 90-8
Slump (in.) ASTM C31	4.50	5.00
Air % As Tested ASTM C231	6.7	5.6
Super Air Meter Number	0.23	0.17
Durability Factor Percent	97	97
Weight Loss Percent	0.10	0.50

- Excellent Freeze/Thaw Resistance

Transport Properties

Mix Identification :	CTL	STP 90-4	STP 90-8	SF-10	M-10	FA-25
ASTM C1760 Conductivity 4" x 8" cyl.						
28 d Bulk Elect Conductivity (mS/m) C1760	12.20	3.94	6.52	3.17	2.19	13.20
28d STDev (mS/m) C1760	0.16	0.08	0.00	0.00	0.03	0.20
28 d Coulombs C1760	2214.00	716.50	1185.50	576.50	397.00	2390.50
56 d Bulk Elect Conductivity (mS/m) C1760	10.90	2.54	3.43	2.40	2.09	8.20
56 d STDev (mS/m) C1760	0.10	0.31	0.02	0.06	0.04	0.10
90 d Bulk Elect Conductivity (mS/m) C1760	10.10	1.72	2.43	2.14	2.04	5.40
90 d STDev (mS/m) C1760	0.18	0.03	0.01	0.04	0.04	0.10
365 d Bulk Elect Conductivity (mS/m) C1760	8.30	0.97	1.24	2.10	2.02	2.10
365 d STDev (mS/m) C1760	0.32	0.02	0.00	0.02	0.04	0.06
453 d Bulk Elect Conductivity (mS/m) C1760	8.00	0.91	1.11	2.10	1.91	1.90
453 d STDev (mS/m) C1760	0.28	0.01	0.01	0.01	0.01	0.02
609 d Bulk Elect Conductivity (mS/m) C1760	7.90	0.91	1.11	2.20	2.01	1.70
609 d STDev (mS/m) C1760	0.33	0.01	0.01	0.00	0.02	0.04
NT Build 492 Non Steady State Diff. Coeff.						
28 days D_{NSS} (x 10^{-12} m^2/s)	18.2	6.8	9.6	6.4	3.3	17.3
ASTM 1556 Bulk Diffusion						
Surface Concentration (ppm)	9572	12606	12844	10450	10572	9180
Diffusion Coefficient (D_a), (x 10^{-12} m^2/s)	3.9	1.1	2.1	1.6	1.1	4.9
ASTM C1585 Capillary Absorption						
Initial absorption ($mm/s^{0.5}$)	0.00030	0.00014	0.00082	0.00058	0.00050	0.00194
Secondary absorption ($mm/s^{0.5}$)	0.00023	0.00017	0.00019	0.00022	0.00022	0.00064

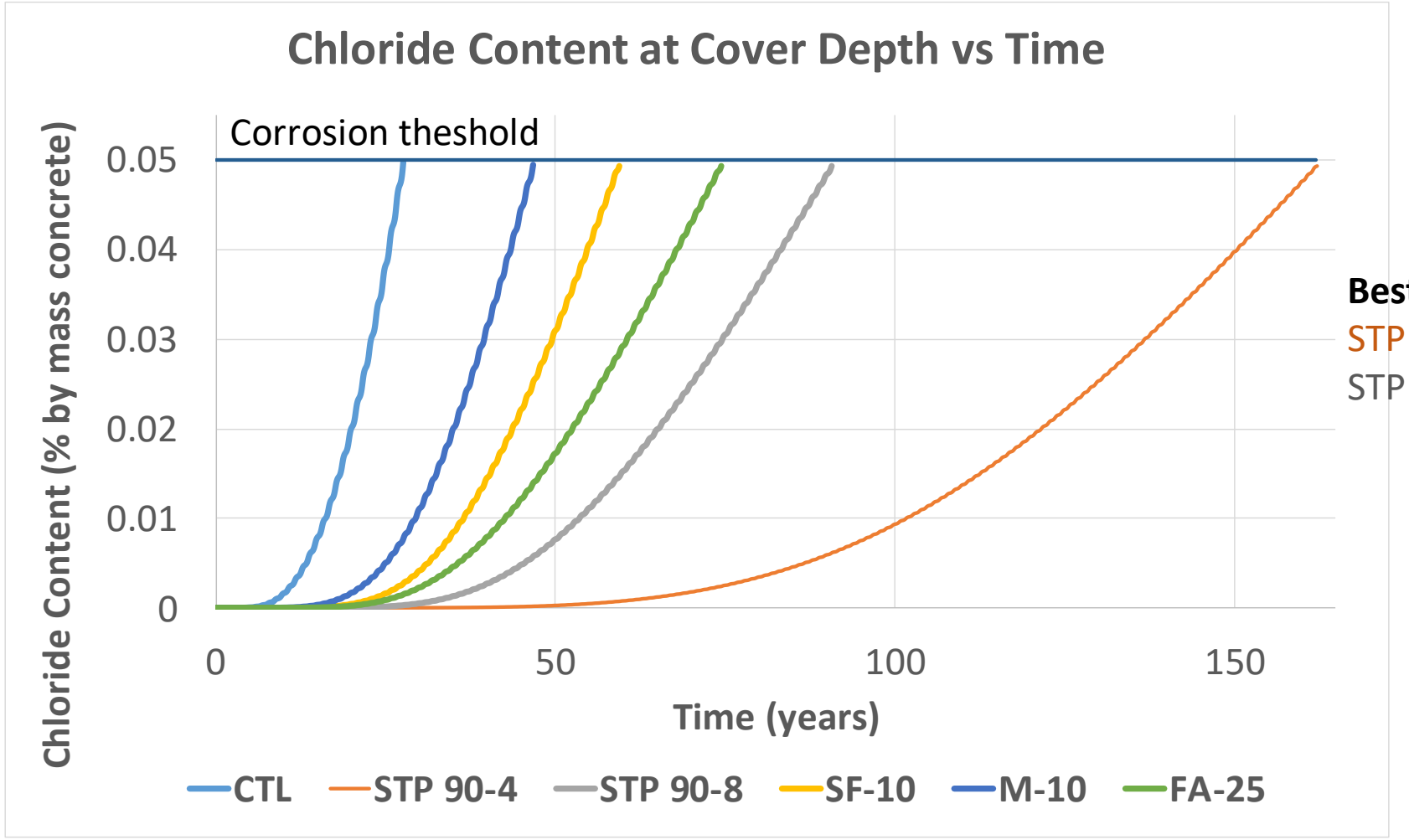


- Low permeability at early ages (low diffusion, conductivity, Coulombs)
- Continues to improve over time (more so than silica fume or metakaolin)

Predicted Times to Corrosion for Bridge Deck

- Used Detroit, MI USA as a severe example
- 70 mm concrete cover
- 250 mm deck thickness
- Modified Life 365™ to be consistent with new data
  - Aging constant and hydration time, based on ASTM 1760 conductivity data
  - Diffusion Coefficients, based on ASTM C1556
  - Surface buildup, based on ASTM C1585 capillary absorption results

Predicted Time to Corrosion Initiation Curves

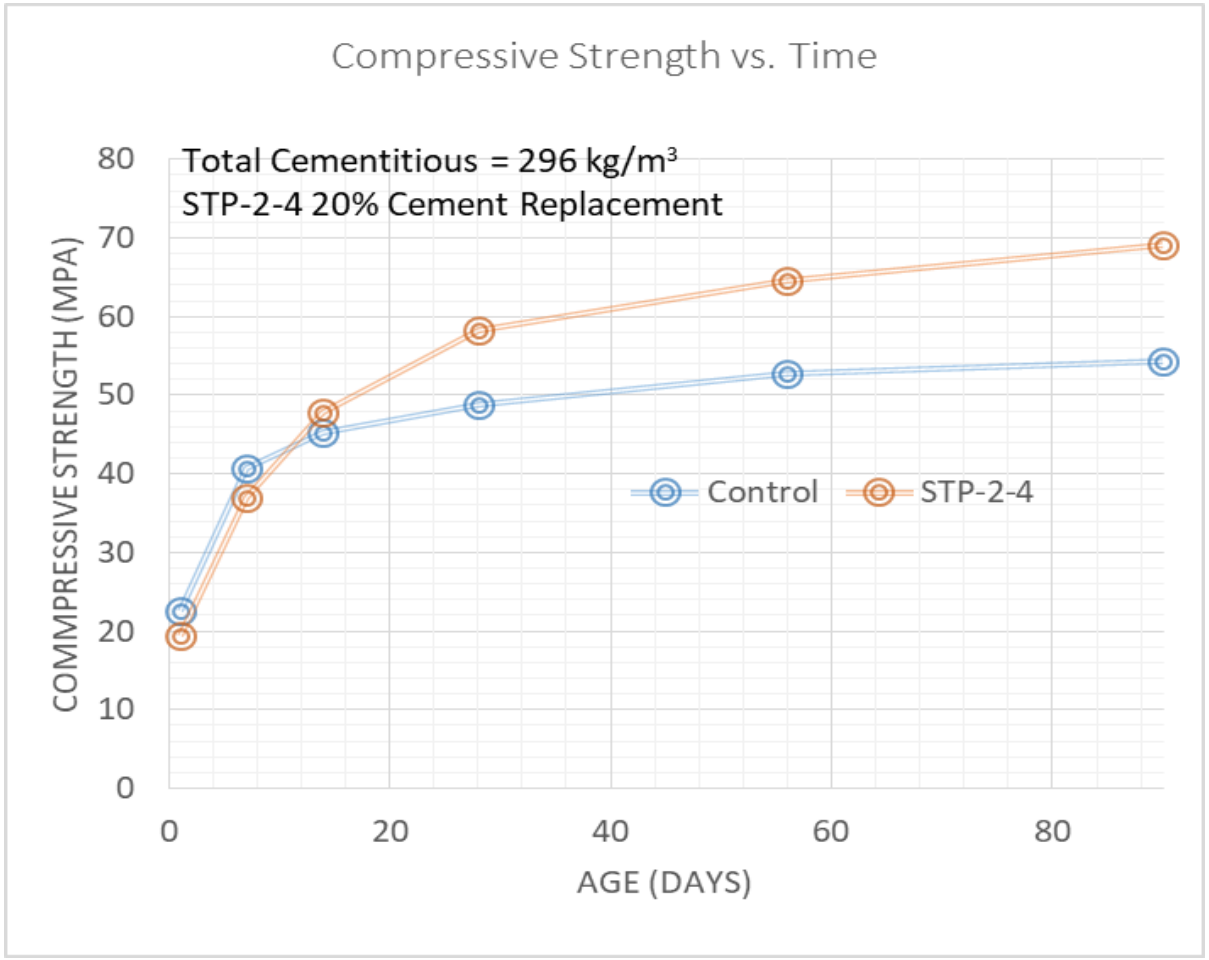


Best Predicted Performance

STP 90-4

STP 90-8

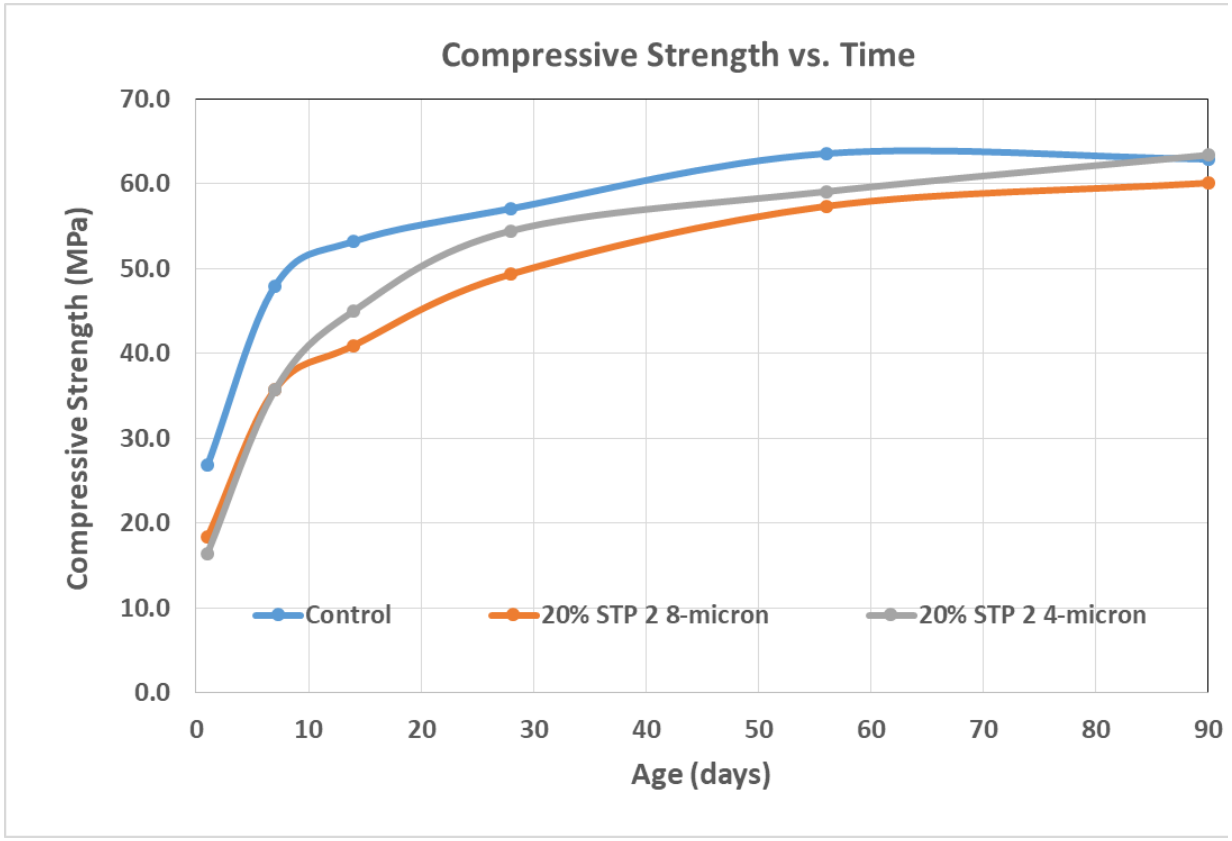
4 micron d50 testing with Aalborg Rapid Cement at 0.45 w/c ratio:



Project Description:	**Evaluation of STP-2-4**				
TCG Project Number:	20001				
Mix Description:	Control	20% STP-2-4 Replacement		Control	20% STP-2-4 Replacement
Mix Number:	G-CTL	STP-2-4		G-CTL	STP-2-4
Mix Date:	1/30	1/30		1/30	1/30
	lb/yd³	lb/yd³		kg/m³	kg/m³
Aalborg Type III Cement	500	400		296	237
20% Replacement SRA2- 4-Micron		100		0	59
Agg. Resource Midway Pit **Natural Fine** Agg SSD	1487	1476		880	873
Caremuse Cedarville Limestone 3/4" Crushed **Coarse** Agg SSD	1750	1750		1036	1036
Total Water	224	224		133	133
Designed Air %	6.5%	6.5%		6.5%	6.5%
Water/Cement Ratio	0.45	0.45		0.45	0.45
Admixtures					
Grace Daravair 1000 AEA oz./cwt	0.50	0.90	ml/kg	0.33	0.59
Grace WRDA 82 WR oz./cwt	2.0	2.0	ml/kg	1.30	1.30
Grace ADVA 575 HRWR oz./cwt	5.0	4.0	ml/kg	3.25	2.60
Physical Properties					
	in.	in.		mm	mm
Slump ASTM C31	4.50	5.75		114	146
Air % As Tested ASTM C231	6.1	8.0		6.1	8.0
Density lb/ft3 ASTM C138	148.1	145.3	kg/m³	2366	2321
Concrete Temp °F ASTM C1064	68	68	°C	20	20
Yield ft3	26.75	27.19	m³	0.9907	1.007037

ASTM C403 Time of Set			Difference
Initial Set hours:min	4:39	5:23	0:44
Final Set hours:min	6:14	6:50	0:36
ASTM C39 Comp. Strength 4" x 8" cyl.	**psi**		
1 Day Strength (1 each)	3270	2830	-440
7 Day Strength (2 each)	5895	5370	-525
14 Day Strength (2 each)	6555	6940	385
28 Day Strength (2 each)	7080	8450	1370
56 Day Strength (2 each)	7640	9370	1730
90 Day Strength (2 each)	7890	10010	2120
	MPa		
1 Day Strength (1 each)	22.5	19.5	-3.0
7 Day Strength (2 each)	40.6	37.0	-3.6
14 Day Strength (2 each)	45.2	47.9	2.7
28 Day Strength (2 each)	48.8	58.3	9.5
56 Day Strength (2 each)	52.7	64.6	11.9
90 Day Strength (2 each)	54.4	69.0	14.6

4 and 8 micron d50 testing with Aalborg Rapid Cement at 0.50 w/c ratio:



Project Description:	Evaluation of STP-2-4 & STP-2-8						
TCG Project Number:	20001						
Mix Description:	Control	20% STP-2-8 Replacement	20% STP-2-4 Replacement		Control	20% STP-2-8 Replacement	20% STP-2-4 Replacement
Mix Number:	G-CTL	STP-2-8	STP-2-4		G-CTL	STP-2-8	STP-2-4
Mix Date:	3/2	3/2	3/2		3/2	3/2	3/2
	lb/yd^3	lb/yd^3	lb/yd^3		kg/m^3	kg/m^3	kg/m^3
Aalborg Type I Rapid Set Cement	556	445	445		329	263	263
20% Replacement STP 2- 8-Micron		111			0	66	0
20% Replacement STP 2- 4-Micron			111		0	0	66
Agg. Resource Midway Pit Natural Fine Agg SSD	1490	1480	1480		882	876	876
Caremuse Cedarville Limestone 3/4" Crushed Coarse Agg SSD	1775	1775	1750		1050	1050	1036
Total Water	278	278	278		164	164	164
Designed Air %	2.0%	2.0%	2.0%		2.0%	2.0%	2.0%
Water/Cement Ratio	0.50	0.50	0.50		0.50	0.50	0.50
Admixtures							
Grace WRDA 82 WR oz./cwt	2.0	2.0	2.0	ml/kg	1.30	1.30	1.30
Grace ADVA 575 HRWR oz./cwt	1.5	0.8	0.8	ml/kg	0.98	0.52	0.52
Physical Properties							
	in.	in.	in.		mm	mm	mm
Slump inches ASTM C31	6.25	7.00	5.25	mm	159	178	133
Air % As Tested ASTM C231	------	2.7	------	%	------	2.7	------
Density lb/ft3 ASTM C138	152.5	150.5	151.1	kg/m^3	2436	2404	2414
Concrete Temp °F ASTM C1064	73	73	71	°C	22.778	22.778	21.667
Yield ft3	26.88	27.17	27.06	m^3	0.996	1.006	1.002

ASTM C39 Comp. Strength 4" x 8" cyl.	psi			MPa		
1 Day Strength (2 each)	3895	2660	2390	26.9	18.3	16.5
7 Day Strength (2 each)	6955	5190	5180	48.0	35.8	35.7
14 Day Strength (2 each)	7720	5940	6530	53.2	41.0	45.0
28 Day Strength (2 each)	8280	7160	7900	57.1	49.4	54.5
56 Day Strength (2 each)	9220	8320	8570	63.6	57.4	59.1
90 Day Strength (2 each)	9123	8717	9195	62.9	60.1	63.4

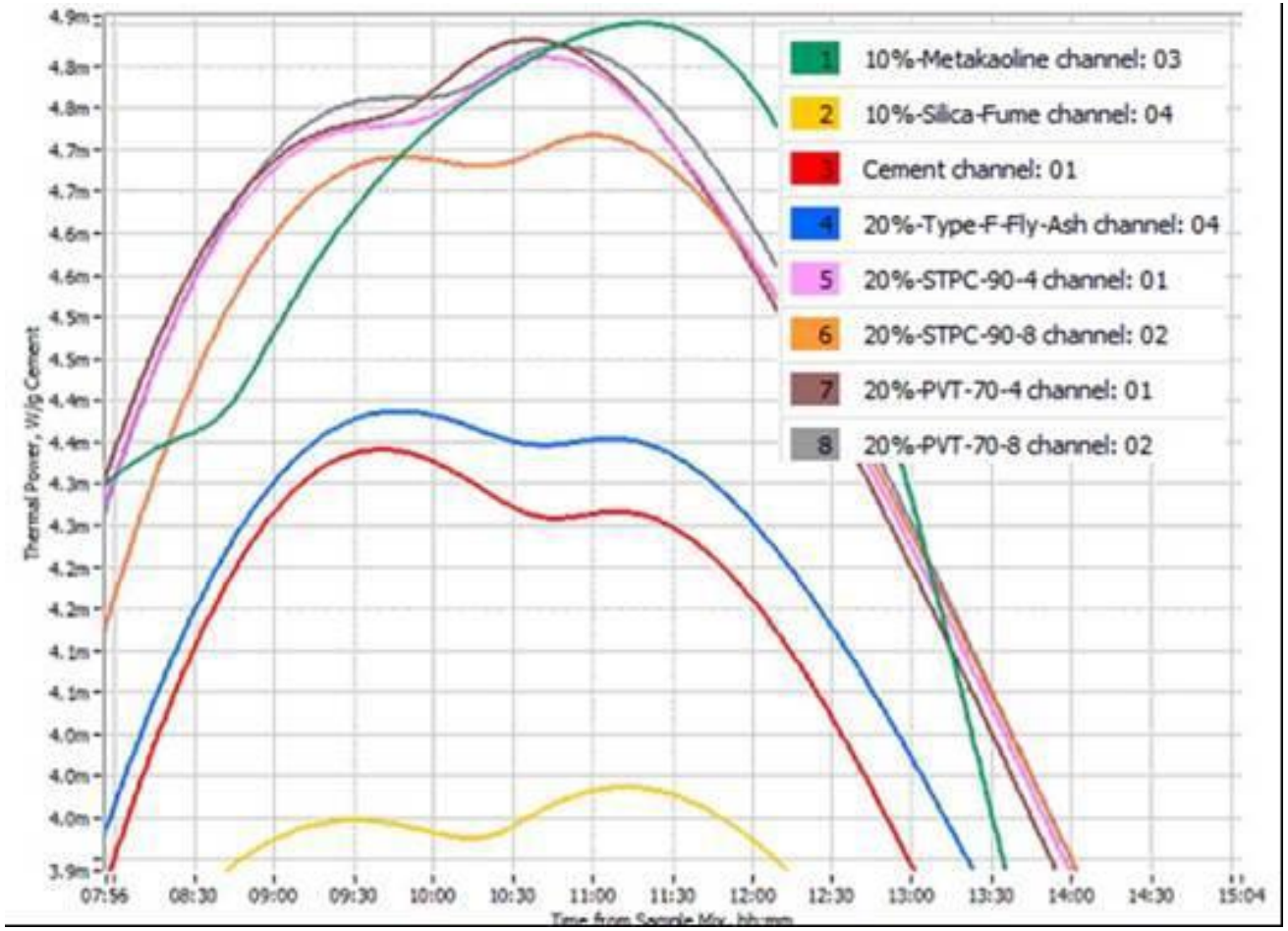
ASTM C157 Length Change 3" x3" x11.25"						
7 days wet , 28 days Air Dry %	-0.032	-0.043	-0.042	-0.032	-0.043	-0.042
28 days wet , 28 days Air Dry %	-0.022	-0.026	-0.022	-0.022	-0.026	-0.022
ASTM C1760 Bulk Electrical Conductivity						
56 Day Bulk Conductivity mS/m (Avg 2)	11.4	5.7	3.4	11.4	5.7	3.4
Standard Deviation	0.303	1.027	0.058	0.303	1.027	0.058
56 d Coulombs C1760	2079	1045	617	2079	1045	617

Isothermal Calorimetry Results

Mix	Peak watts	Peak mW/g cmt	Peak Time H:min	Total Heat J	Total J/g cement
Cement	0.44	4.4	9:45	**33700**	**337**
20% STP 90-4	0.38	4.8	10:50	**30560**	**382**
20% STP 90-8	0.38	4.7	11:00	**30240**	**378**
10% Metakaolin	0.44	4.9	11:15	**36360**	**404**
10% Silica Fume	0.36	4.0	11:15	**31770**	**353**

- Improves cement efficiency but lowers overall heat output
- In contrast to metakaolin which will increase heat produced

Isothermal Calorimetry Curves



CO_2 Footprint:

less than $2kgCO_2/ton$

Interpretation

Table 6 shows the estimated greenhouse gas emission from the production of 1 ton of 4 µm and 8 µm size ACM.

Table 6: Estimated greenhouse gas emission from the production phase of the ACM.

Product	GHG emissions (kg CO2 eq./ton)
ACM - 4 µm	1,80
ACM - 8 µm	1,36

5.3 Assumptions

The energy requirements listed in Chapter 4 are all based on information provided by 3rd party. This data has not been quality checked and were used as provided.

The official emission factor for electricity from the Icelandic grid was provided by the Environment Agency of Iceland and used to estimate the GHG emission from electricity. Information on other GHG emission factors was provided by the relevant suppliers. For example, the emission factor for electricity provided by HS Orka is 43 gCO2eq/kWh (Sigurbergsson, J. S, personal communication, March 9, 2019). Therefore, if electricity were to be provided directly by HS Orka it would increase the GHG emission to 6,45 gCO2eq/kWh for 4 µm size ACM and 4,3 g CO2eq/kWh for 8 µm.

No official emission factor has been set for the methane produced by Sorpa but after personal communication with SORPA the emission was determined to be zero (Hjarðar B, personal communication, March 11, 2020). SORPA holds a swan certificate for its methane production which means emissions from the methane are at least 60% less than a corresponding fossil fuel but no formal LCA has been published.

Carbon Footprint Reduction Benefits:

- Increase clinker replacement RATIO to decrease overall CO2 footprint
- Unconsolidated mineral deposit ZERO CO2 footprint associated with the natural deposit.
- Total CO2 footprint dependent on the distance to market, type of electricity and mining

Estimated less than 100kg/ton compared to 700-800 kg/ton for OPC

Neal S. Berke, Ph.D., FACI, FASTM,FNACE

Dr. Neal S. Berke, FACI, is the Vice President, Research at Tourney Consulting Group, in Kalamazoo, MI. He has over 35 years of experience, at Bethlehem Steel and Grace Construction Products in the corrosion and durability of infrastructure materials and the properties of concrete as well as service life modeling. He has conducted extensive research on silica fume, fly ash, slag, metakaolin and other pozzolanic materials with an emphasis on irmproving both the durability and sustainability of concrete. He is the October 2012 recipient of the J.C. Roumain Innovation in Concrete Award.

He has written and presented over one hundred papers on his research activities, has 45 U. S. patents, and is a frequent reviewer for several technical organizations and journals.

Neal serves on several ACI, NACE, ASTM, and TRB committees, and is Immediate Past Chairman of ASTM Committee G01 On the Corrosion of Metals, and is chairman of ASTM Section C.09.03.08 on Durability Enhancing Admixtures.

Dr. Berke has a bachelor's degree in Physics from the University of Chicago and a Ph.D. in Metallurgical Engineering from the University of Illinois at Urbana-Champaign.

Dr. Diego Rosani, Chemist

Mr. Rosani is a consultant and is the former Team Leader at the Heidelberg Cement Technology Center in Germany. He has over 35 years of experience at Heidelberg Cement, Holcim, and Ecodesco S.p.A, in cement and SCM technology. In these roles he developed several innovative products and developed new applications for cementitious materials.

He participates in several society and standards groups related to cement technology. He is frequent lecturer on various aspects of cement technology and CO_2 initiatives.

Mr. Rosani received his degree in Chemistry at Università degli Studi Trieste.

The research reported was performed at Tourney Consulting Group, LLC. (TCG), and at TEC Services. Both companies are AASHTO Accredited.

TCG specializes in the testing of materials durability and volume stability of construction materials, providing research and development for companies of all sizes, and in providing Engineering Service Life solutions for structures. Recent projects include the Goethals Bridge (award winner), Tappen Zee Bridge, New Bridge over the St. Lawrence. TCG was and is involved in several major projects in the Middle East and Asia.

Thank You

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