High Performance Icelandic Alternative Cementitious Material

February 21, 2020

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

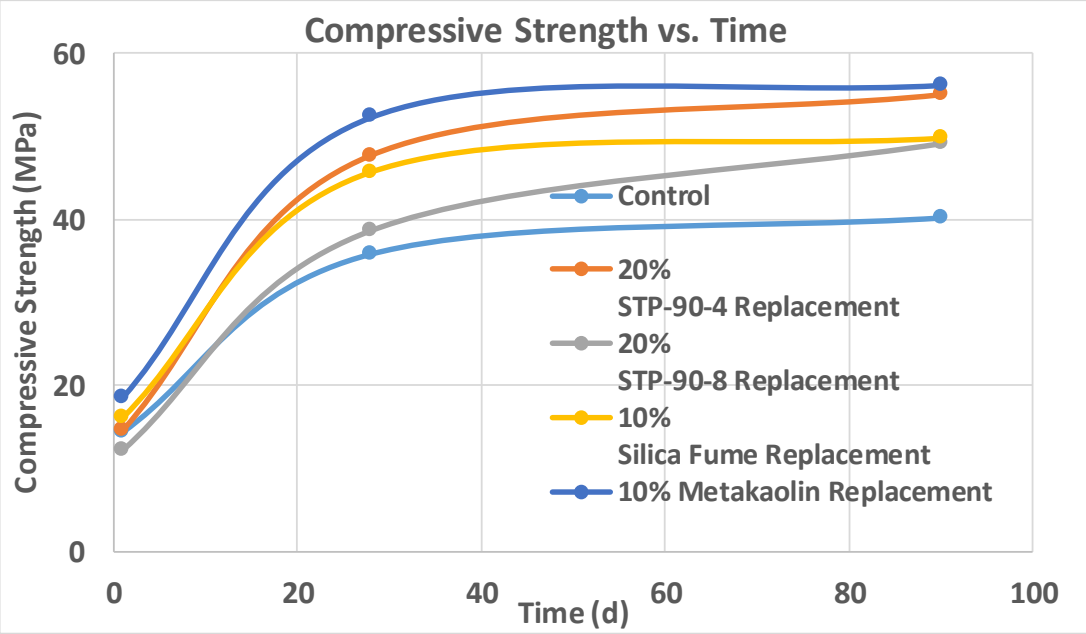
- STP 90-4 and STP 90-8 have workability is similar to the cement only control
- Silica fume and Metakaoline require more than **two times** the superplasticizer dosage

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

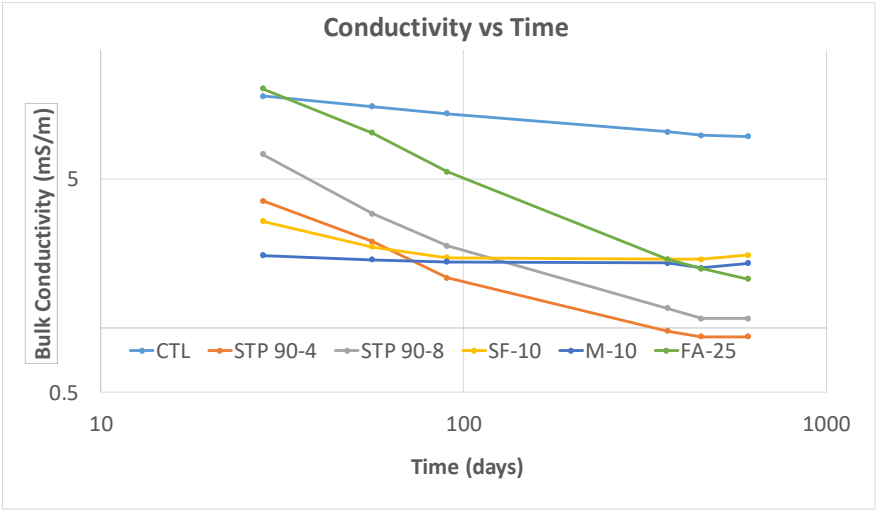
Freezing and Thawing

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

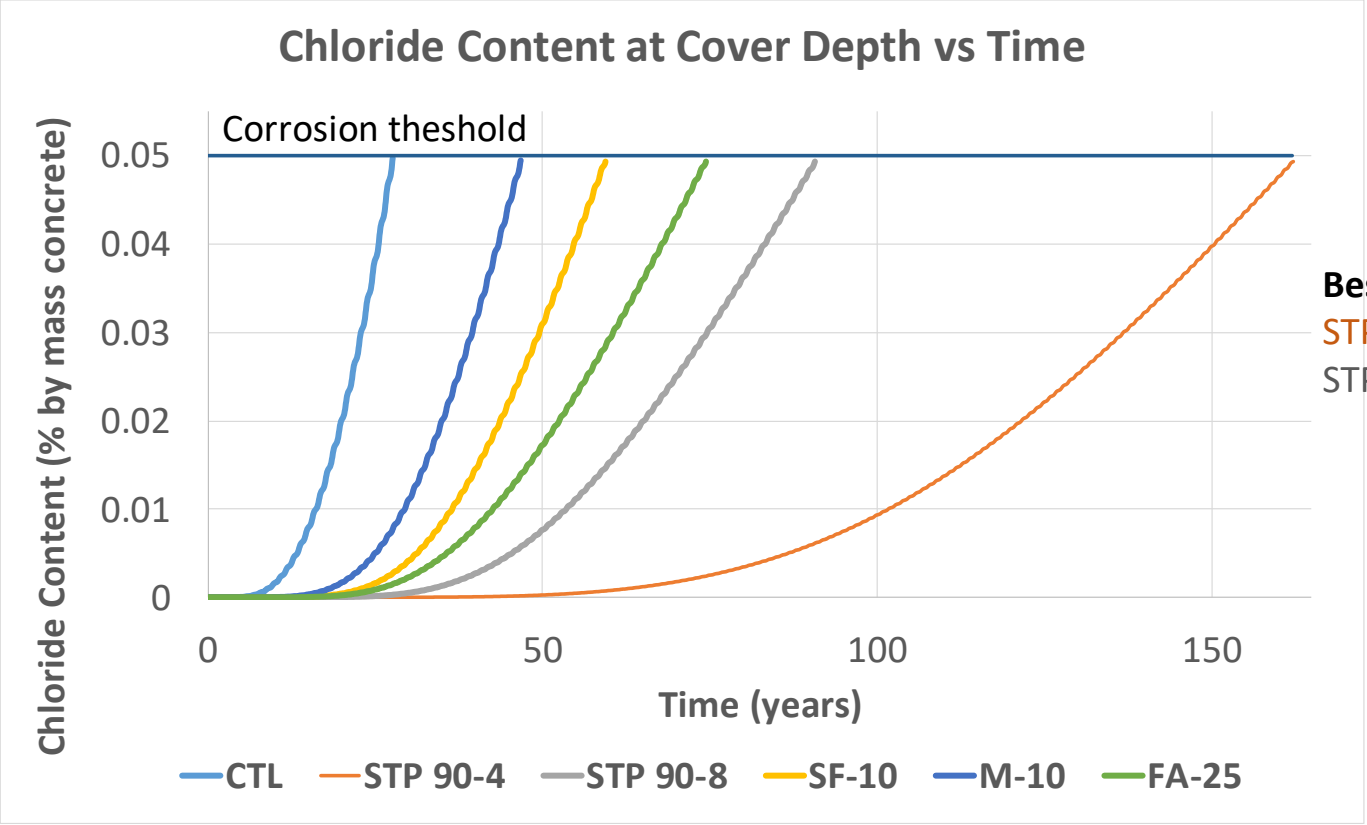


- Low permeability at early ages (low diffusion, conductivity, Coulombs)
- Continues to improve over time (more so than silica fume or metakaolin)

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

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

Preliminary Results with Icelandic Cements:

Mix Description:	Control kg/m^3	0% STP-2-4 Replacement kg/m^3	
Aalborg Type III Cement	296	237	
20% Replacement SRA2- **4**-Micron	0	59	
Agg. Resource Midway Pit **Natural Fine** Agg SSD	880	873	
Caremuse Cedarville Limestone 3/4" Crushed **Coarse** Agg SSD	1036	1036	
Total Water	133	133	
Designed Air %	6.5%	6.5%	
Water/Cement Ratio	0.45	0.45	
Admixtures			
Grace Daravair 1000 AEA mL/kg	0.33	0.59	
Grace WRDA 82 WR mL/kg	1.3	1.3	
Grace ADVA 575 HRWR mL/kg	3.3	2.6	
Physical Properties			
Slump (mm) ASTM C31	114.3	146.1	
Air % As Tested ASTM C231	6.1	8.0	
Density kg/m^3 ASTM C138	2366.1	2321.4	
Concrete Temp °C ASTM C1064	20	20	
Yield m^3	0.99	1.01	
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 101.6 x 203.2 mm cyl. 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

CO_2 Footprint:

less than $2kgCO_2/ton$

From: Sandra Rán Ásgrímsdóttir <sandra@mannvit.is>
Sent: Thursday, February 20, 2020 3:35 AM
To: Romeo Ciuperca
Cc: Sigurður Páll Steindórsson; Þorbjörg Hólmgeirsdóttir; Stefanía Lára Bjarnadóttir
Subject: RE: Fundur

Dear Romeo,

Preliminary results form our CO2 calculations give us the following results.

CO2 emissions from production of 1 tonn og 4 micron	1,80 $kgCO_2/ton$
CO2 emissions from production of 1 tonn og 8 micron	1,36 $kgCO_2/ton$

I will send you some further clarifications later today.

Kveðja / Regards,
Sandra Rán Ásgrímsdóttir
Sjálfbærni verkfræðingur
Sustainability Engineer
Sími / Tel: +354 422 3180
GSM / Mobile: +354 866 0995

MANNVIT

www.mannvit.is / www.mannvit.com

Iceland Carbon Footprint Reduction Benefits:

- A 20% ACM replacement of Portland Cement will eliminate over 32,000 tons CO2 per year (1,2)
- A 20% OPC replacement will reduce CO2 equivalent to planting 1,440,000 trees (3)
- A 30% ACM replacement of Portland Cement will eliminate over 48,000 tons CO2 per year (1,2)
- A 30% OPC replacement will reduce CO2 equivalent to planting 2,160,000 trees (3)

1. Based on Portland Cement CO2 emissions of approx. 800 kg/ton
2. CO2 reduction estimate calculated based on 2018 Iceland cement use of 200,000 tons/year
3. Based on an average tree absorption of 22 kg per year of CO2 Iceland tree absorption may vary.

Reactive Silica requirement of min 25%:

46.1%
46.3%

Analysenbericht

Berichtnummer	ZL-20-009
Prüfauftrag ZL	2020-TEC-01
Auftraggeber	Holcim (Schweiz) AG, TEC

Holcim

Analysenergebnisse

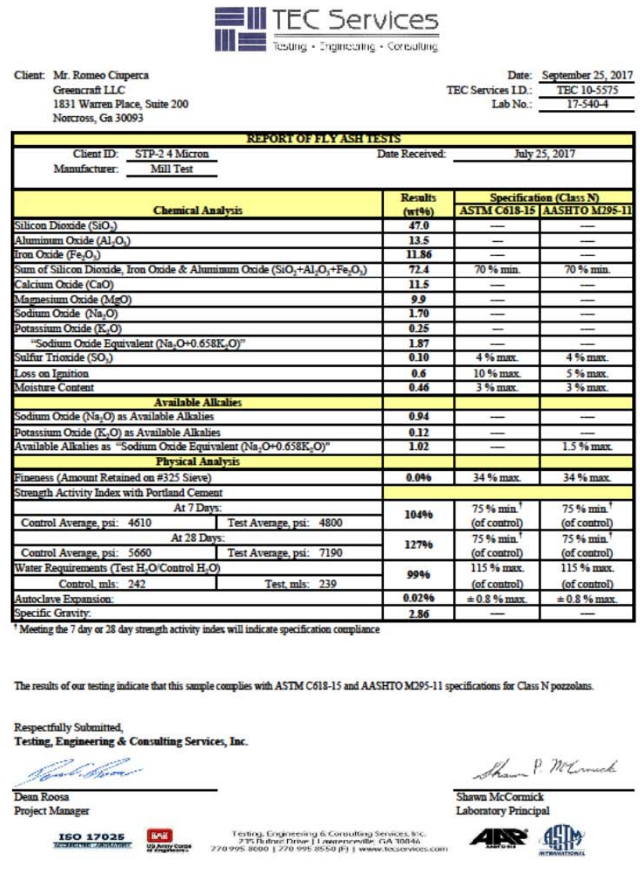
Reaktionsfähiges SiO_2 nach AW-048*

LIMS Nr.	MTD190076	MTD190080
Externe Nr.	P.1572M	P.1583M
Analysendatum	03.02.2020	03.02.2020
Reaktions-fähiges SiO_2 in %	46.1	46.3

Holcim (Schweiz) AG
Zentral-Labor
Zementweg 1
CH-5303 Würenlingen

Telefon
+41 58 850 55 15
zl-chei@lafargeholcim.com
www.holcim.ch
Akkreditiert nach
ISO/IEC 17025
STS Nummer 0555

ASTM C 618
Meets Class N



TEC Services
Testing • Engineering • Consulting

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

Date: September 25, 2017
TEC Services I.D.: TEC 10-5575
Lab No.: 17-540-4

REPORT OF FLY ASH TESTS

Client ID: STP-2 4 Micron
Manufacturer: Mill Test
Date Received: July 25, 2017

Chemical Analysis	Results (wt%)	Specification (Class N) ASTM C618-15	Specification (Class N) AASHTO M295-11
Silicon Dioxide (SiO_2)	47.0	—	—
Aluminum Oxide (Al_2O_3)	13.5	—	—
Iron Oxide (Fe_2O_3)	11.86	—	—
Sum of Silicon Dioxide, Iron Oxide & Aluminum Oxide (SiO_2+Al_2O_3+Fe_2O_3)	72.4	70 % min.	70 % min.
Calcium Oxide (CaO)	11.5	—	—
Magnesium Oxide (MgO)	9.9	—	—
Sodium Oxide (Na_2O)	1.70	—	—
Potassium Oxide (K_2O)	0.25	—	—
"Sodium Oxide Equivalent (Na_2O+0.658K_2O)"	1.87	—	—
Sulfur Trioxide (SO_3)	0.10	4 % max.	4 % max.
Loss on Ignition	0.6	10 % max.	5 % max.
Moisture Content	0.46	3 % max.	3 % max.
Available Alkalies			
Sodium Oxide (Na_2O) as Available Alkalies	0.94	—	—
Potassium Oxide (K_2O) as Available Alkalies	0.12	—	—
Available Alkalies as "Sodium Oxide Equivalent (Na_2O+0.658K_2O)"	1.02	—	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:	104%	75 % min.† (of control)	75 % min.† (of control)
Control Average, psi: 4610 — Test Average, psi: 4800			
At 28 Days:	127%	75 % min.† (of control)	75 % min.† (of control)
Control Average, psi: 5660 — Test Average, psi: 7190			
Water Requirements (Test H_2O/Control H_2O)	99%	115 % max. (of control)	115 % max. (of control)
Control, mls: 242 — Test, mls: 239			
Autoclave Expansion:	0.02%	± 0.8 % max.	± 0.8 % max.
Specific Gravity:	2.86	—	—

† Meeting the 7 day or 28 day strength activity index will indicate specification compliance

The results of our testing indicate that this sample complies with ASTM C618-15 and AASHTO M295-11 specifications for Class N pozzolans.

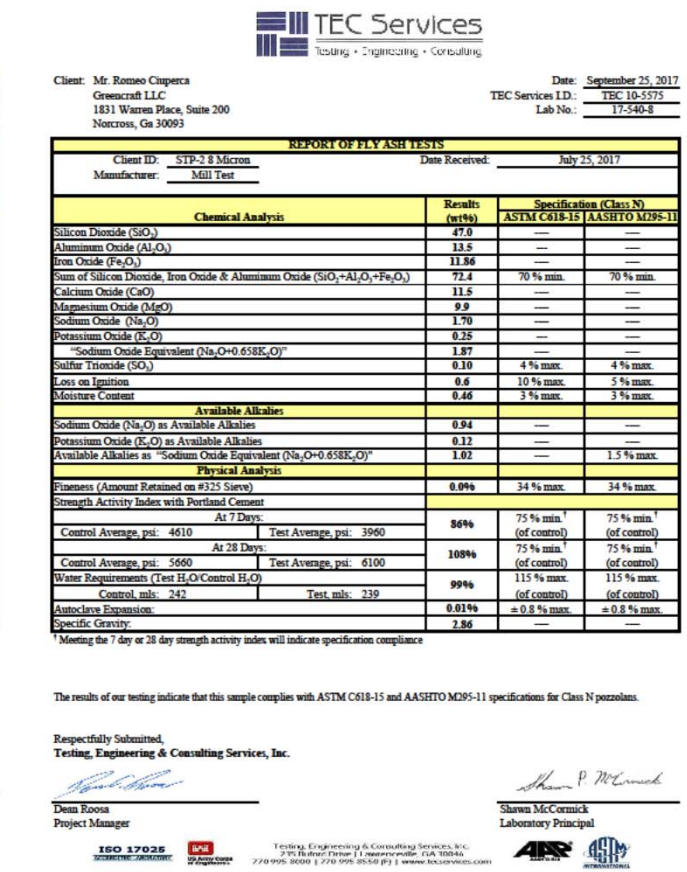
Respectfully Submitted,
Testing, Engineering & Consulting Services, Inc.

Dean Roosa
Project Manager

Shawn McCormick
Laboratory Principal

ISO 17025

Testing, Engineering & Consulting Services, Inc.
275 Rubinet Drive | Lawrenceville, GA 30046
770 995 8000 | 770 995 8550 (F) | www.tecservices.com



TEC Services
Testing • Engineering • Consulting

Client: Mr. Romeo Ciuperca
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1831 Warren Place, Suite 200
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Date: September 25, 2017
TEC Services I.D.: TEC 10-5575
Lab No.: 17-540-8

REPORT OF FLY ASH TESTS

Client ID: STP-2 8 Micron
Manufacturer: Mill Test
Date Received: July 25, 2017

Chemical Analysis	Results (wt%)	Specification (Class N) ASTM C618-15	Specification (Class N) AASHTO M295-11
Silicon Dioxide (SiO_2)	47.0	—	—
Aluminum Oxide (Al_2O_3)	13.5	—	—
Iron Oxide (Fe_2O_3)	11.86	—	—
Sum of Silicon Dioxide, Iron Oxide & Aluminum Oxide (SiO_2+Al_2O_3+Fe_2O_3)	72.4	70 % min.	70 % min.
Calcium Oxide (CaO)	11.5	—	—
Magnesium Oxide (MgO)	9.9	—	—
Sodium Oxide (Na_2O)	1.70	—	—
Potassium Oxide (K_2O)	0.25	—	—
"Sodium Oxide Equivalent (Na_2O+0.658K_2O)"	1.87	—	—
Sulfur Trioxide (SO_3)	0.10	4 % max.	4 % max.
Loss on Ignition	0.6	10 % max.	5 % max.
Moisture Content	0.46	3 % max.	3 % max.
Available Alkalies			
Sodium Oxide (Na_2O) as Available Alkalies	0.94	—	—
Potassium Oxide (K_2O) as Available Alkalies	0.12	—	—
Available Alkalies as "Sodium Oxide Equivalent (Na_2O+0.658K_2O)"	1.02	—	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:	86%	75 % min.† (of control)	75 % min.† (of control)
Control Average, psi: 4610 — Test Average, psi: 3960			
At 28 Days:	108%	75 % min.† (of control)	75 % min.† (of control)
Control Average, psi: 5660 — Test Average, psi: 6100			
Water Requirements (Test H_2O/Control H_2O)	99%	115 % max. (of control)	115 % max. (of control)
Control, mls: 242 — Test, mls: 239			
Autoclave Expansion:	0.01%	± 0.8 % max.	± 0.8 % max.
Specific Gravity:	2.86	—	—

† Meeting the 7 day or 28 day strength activity index will indicate specification compliance

The results of our testing indicate that this sample complies with ASTM C618-15 and AASHTO M295-11 specifications for Class N pozzolans.

Respectfully Submitted,
Testing, Engineering & Consulting Services, Inc.

Dean Roosa
Project Manager

Shawn McCormick
Laboratory Principal

ISO 17025

Testing, Engineering & Consulting Services, Inc.
275 Rubinet Drive | Lawrenceville, GA 30046
770 995 8000 | 770 995 8550 (F) | www.tecservices.com

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

For More Information Contact:
Romeo Ciuperca
Greencraft LLC
1831 Warren Place, Suite 200
Norcross, GA 30093 USA
Email: romeo@greencraft.com
Tel: +1-404-787-6221