Slag Cement in Practice

Jeremy Reich - Technical Service Engineer
Ryan Betz - Technical Director

Argos USA

SCA
SLAG CEMENT ASSOCIATION

Game 4 of The Stanley Cup Playoffs: Lightning vs. Maple Leafs

A Historical Perspective

Beginnings of slag cement…In the South at least

Granulation of slag.—If slag be allowed to cool slowly it solidifies into a dense, tough material, which is not readily reduced to the requisite fineness for a cement mixture. If it be cooled suddenly, however, as by bringing the stream of molten slag into contact with cold water, the slag is "granulated," *i. e.*, it breaks up into small porous particles. This granulated slag or "slag sand" is much more readily pulverized than a slowly

cooled slag; its sudden cooling has also intensified the chemical activity of its constituents so as to give it hydraulic properties, while part of the sulphur contained in the original slag has been removed. The sole disadvantage of the process of granulating slag is that the product contains 20 to 40 per cent. of water, which must be driven off before the granulated slag is sent to the grinding machinery.

BULLETIN No. 8.

The Materials and Manufacture of Portland Cement.

BY

EDWIN C. ECKEL.

The Cement Resources of Alabama.

BY

EUGENE A. SMITH.

MONTGOMERY, ALABAMA
THE BROWN PRINTING COMPANY, PRINTERS AND BINDERS
1904

A Historical Perspective

From a 1912 publication

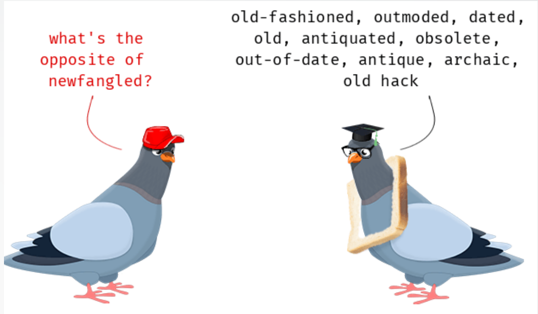
ALABAMA

Southern Cement Company.—The plant of the Southern Cement Company is located at North Birmingham, Ala., and was established in the year 1901.

The raw materials[2] consist of granulated furnace slag and hydrated lime. This company makes a Portland cement, "Alabama" brand, and also what they term a semi-Portland, "Magnolia" brand.

Analyses of the Slag and Portland Cement, North Birmingham,

Constituents	Slag	Cement
Silica (SiO_2)	32.40	30.00
Alumina (Al_2O_3)	14.60	13.20
Ferric oxide (Fe_2O_3)		.75
Lime (CaO)	50.37	52.00
Magnesia (MgO)	1.77	1.25
Sulphur trioxide (SO_3)	.86	1.00
Ignition		1.80



From a 1939 Publication

NON-PORTLAND CEMENTS

Puzzolan cement, similar to the old Roman cement, is made by mixing granulated blast furnace slag of suitable composition (high-calcium) with hydrated lime and grinding the mixture without calcining. Puzzolan nonstaining cements are made by two plants in Alabama. Lime for the manufacture of puzzolan cements is

Cheney Lime and Cement Company.—The plant of the Cheney Lime and Cement Company is at Allgood, Blount County, about 35 miles northeast of Birmingham on the Louisville and Nashville Railroad. (Pl. 1, Locality 3). Lime manufacture began here in 1903 and manufacture of puzzolan cement was started in 1929. Cordwood is used as fuel for drying the slag preliminary to mixing it with lime. The products of this plant are Vesuvius Slag Cement (nonstaining), and masonry cements branded Brixmortar, and Cheney's Mortar Mix. The annual capacity is reported to be 150,000 barrels of slag cement and 300,000 barrels of mortar cements.

Proportioning Concrete With Slag Cement

Proportioning Concrete With Slag Cement

Considerations when selecting a slag cement replacement level

- Need for early age strength
- Environmental impact (GWP)
- Ambient temperature / site conditions
- Type of placement and finishing
- Durability requirements
- Utilization with other SCMs
- Thermal control

Proportioning Concrete With Slag Cement

Typical Replacement Values

20% to 50%

- Precast / prestressed concrete
- Concrete masonry units
- Pavers

25% to 70%

- Walls and columns
- Paving
- Interior flatwork
- Exterior flatwork NOT exposed to deicer salts
- Exterior flatwork exposed to deicers with w/cm < 0.45
- Tilt-up panels
- High strength

25% to 50%

- ASR Mitigation
- Sulfate resistance
- Lower Permeability

50% to 80%

- Mass concrete

What Do Specs and Guides Say About Slag Cement

ACI 301: Specification for Concrete Construction

Supplementary cementitious material	Maximum percent of total cementitious material by mass*
Fly ash or natural pozzolans conforming to ASTM C618	25
Slag cement conforming to ASTM C989/C989M	50
Silica fume conforming to ASTM C1240	10
Total of fly ash or natural pozzolans, slag cement, and silica fume	50†
Total of fly ash or natural pozzolans and silica fume	35†

What Do Specs. and Guides Say About Slag Cement

ACI 318: Table 26.4.2.2(b) Limits for F3 Exposure Class (F/T)

Table 26.4.2.2(b)—Limits on cementitious materials for concrete assigned to Exposure Class F3

Supplementary cementitious materials	Maximum percent of total cementitious materials by mass
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Slag cement conforming to ASTM C989	50
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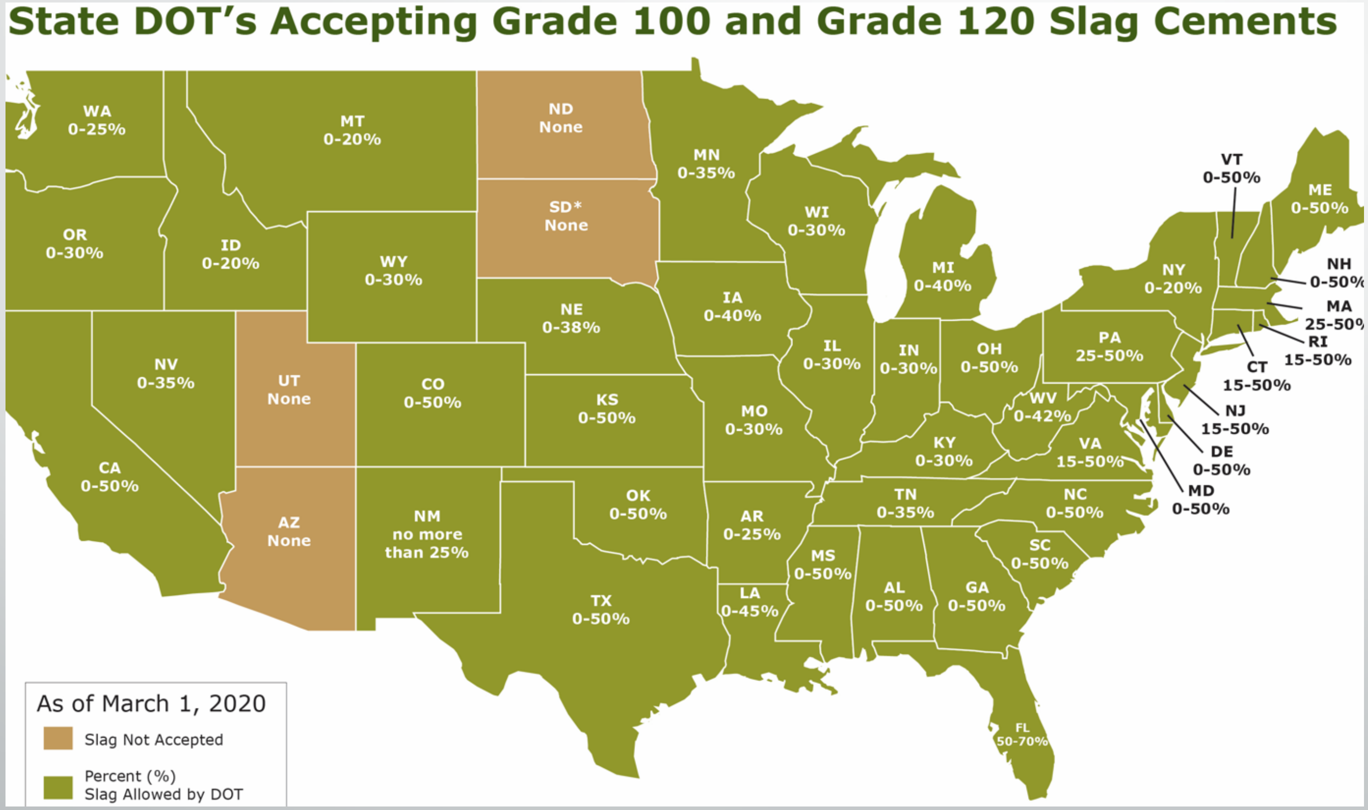
Total of fly ash or natural pozzolans and silica fume	35
Total of fly ash or natural pozzolans, slag cement, and silica fume	50

What Do Specs. and Guides Say About Slag Cement

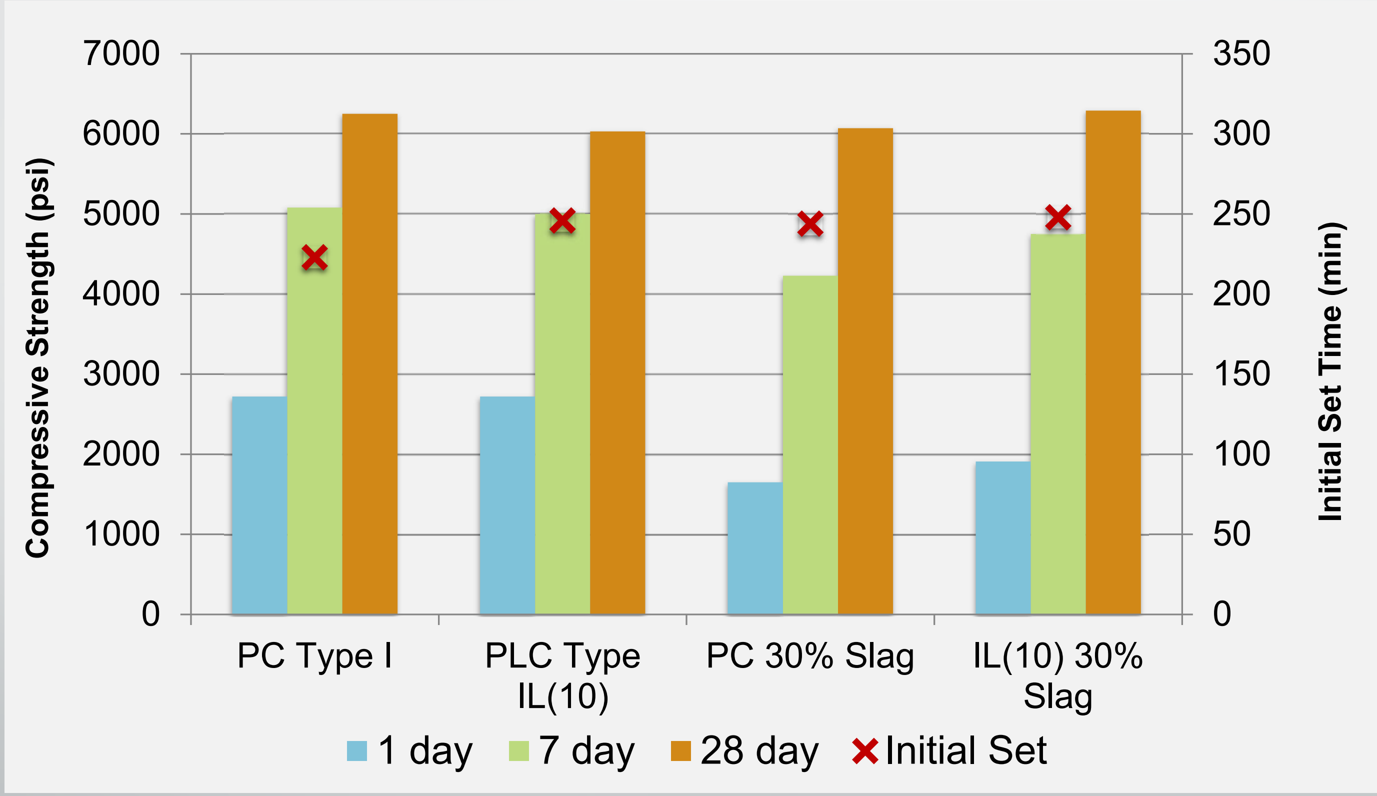
Departments of Transportation



Disclaimer: This data was complied in 2020 and may not reflect current requirements

Slag Cement and Concrete Hardened Properties

Compressive Strength and Time of Setting



Alkali Silica Reaction (ASR)

Concrete Growth?

US Army Corps of Engineers Nashville District Website

®

Chickamauga Navigation Lock

Chickamauga Lock is located at Tennessee River mile 471 only 6.9 miles above Chattanooga, Tennessee.

Concrete Growth

Chickamauga Lock has growing concrete in it's structure, which is a reaction between the alkali in the cement and the minerals in the stone. This growing concrete has brought many problems – in some places large chunks of concrete have broken loose from the lock walls – and because the massive blocks that make up the lock have expanded at different rates, the top of the structure is uneven. Lengthwise, the lock has actually grown five inches inside the lock chamber. The approach walls have grown even

Alkali Silica Reaction (ASR)

ASR risk evaluation starts with the aggregate

Aggregate-Reactivity Class	Description of Aggregate Reactivity	1-Year Expansion in CPT, %	14-Day Expansion in AMBT, %
R0	Non-reactive	≤0.04	≤0.10
R1	Moderately reactive	>0.04, ≤0.12	>0.10, ≤0.30
R2	Highly reactive	>0.12, ≤0.24	>0.30, ≤0.45
R3	Very highly reactive	>0.24	>0.45

Fist step:

Classify aggregate reactivity potential

Second step:

Identify risk level and manage ASR based on risk level

Third Step:

Utilize guidance in ASTM C1778 or AASHTO R80 (DOTs) to manage ASR risk.

Alkali Silica Reaction (ASR)

Mitigating ASR with slag cement

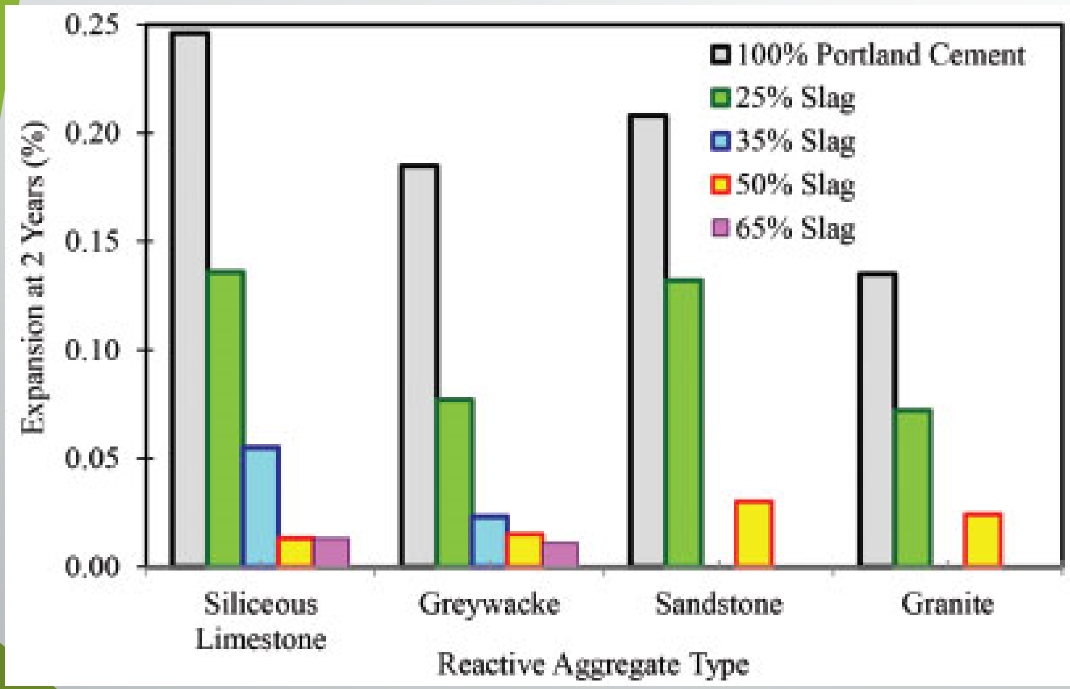


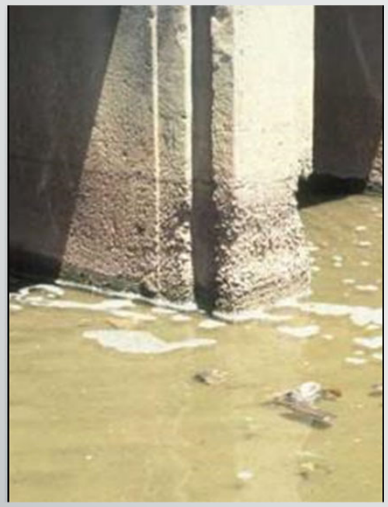
Figure shows the impact of slag on the 2-year expansion of concrete prisms (ASTM C1293) (CPT):

Aggregates: moderately to highly reactive

Cement: Very high alkali content 1.25%

Conclusion: More slag is better than less or none

Sulfate Resistance With Slag Cement



Stark PCA, Sacramento Site 1990

Sulfate Resistance With Slag Cement

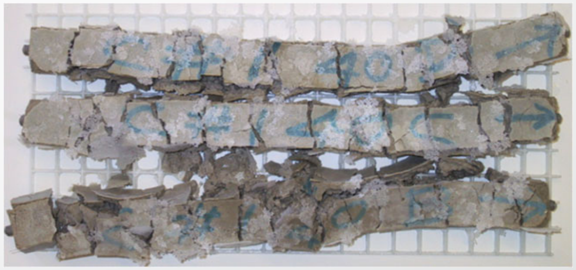
Evaluating Cement and SCM's – ASTM C1012

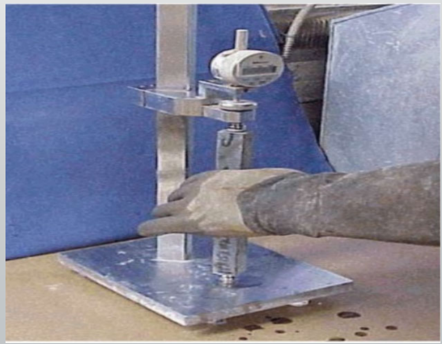
Test summary

Used to evaluate sulfate exposures (expansion) of combinations of Portland & blended cement, pozzolan, and slag cement

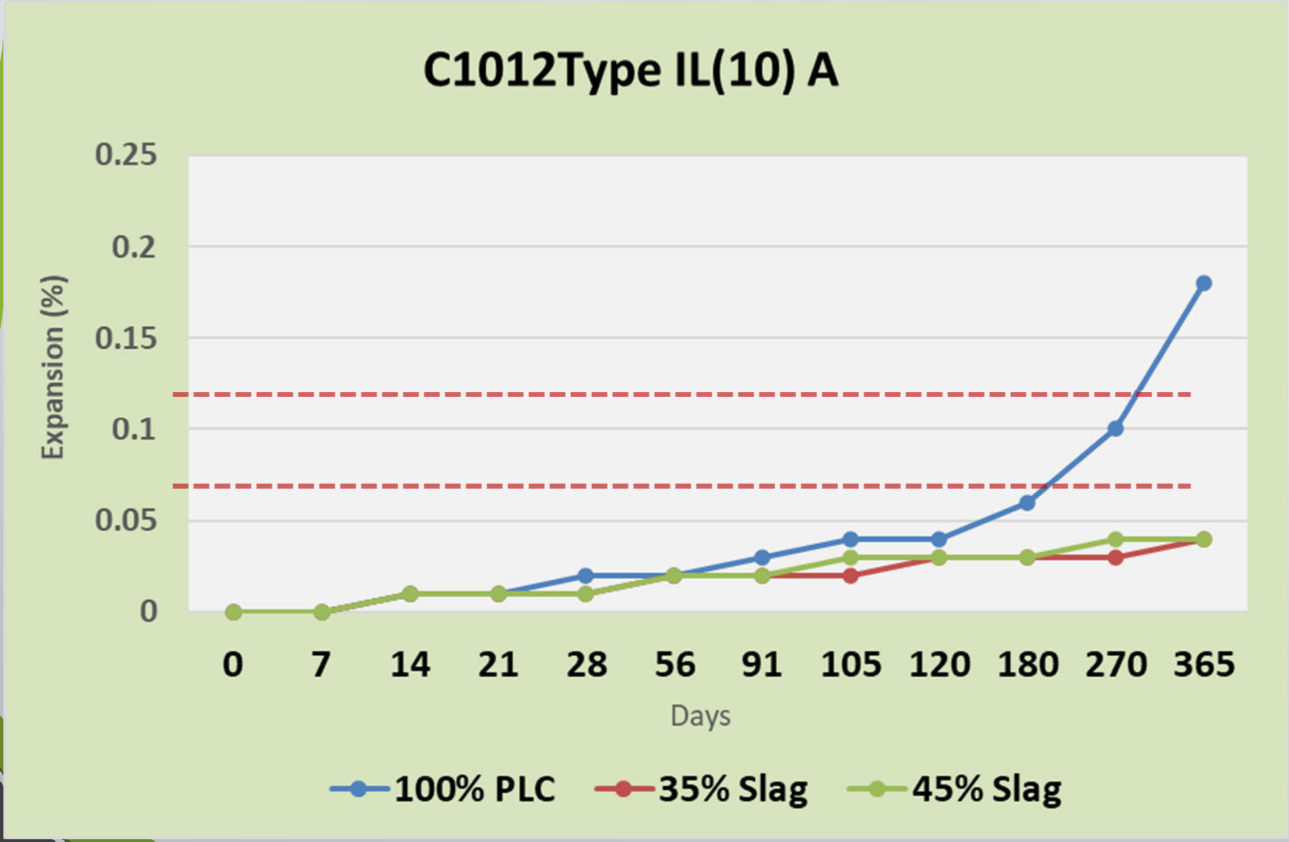
Mortar bar test with fixed W/C ratios
Air entrained concrete: 0.460
Non air entrained concrete: 0.485

Mortar bars stored in Na_2SO_4 solution and measured for length change over time (6 to 18 months)





Sulfate Resistance With Slag Cement



- Base cement C3A: 7.0%
- 35% & 45% Slag provided high sulfate resistance

Moderate Sulfate Resistance:

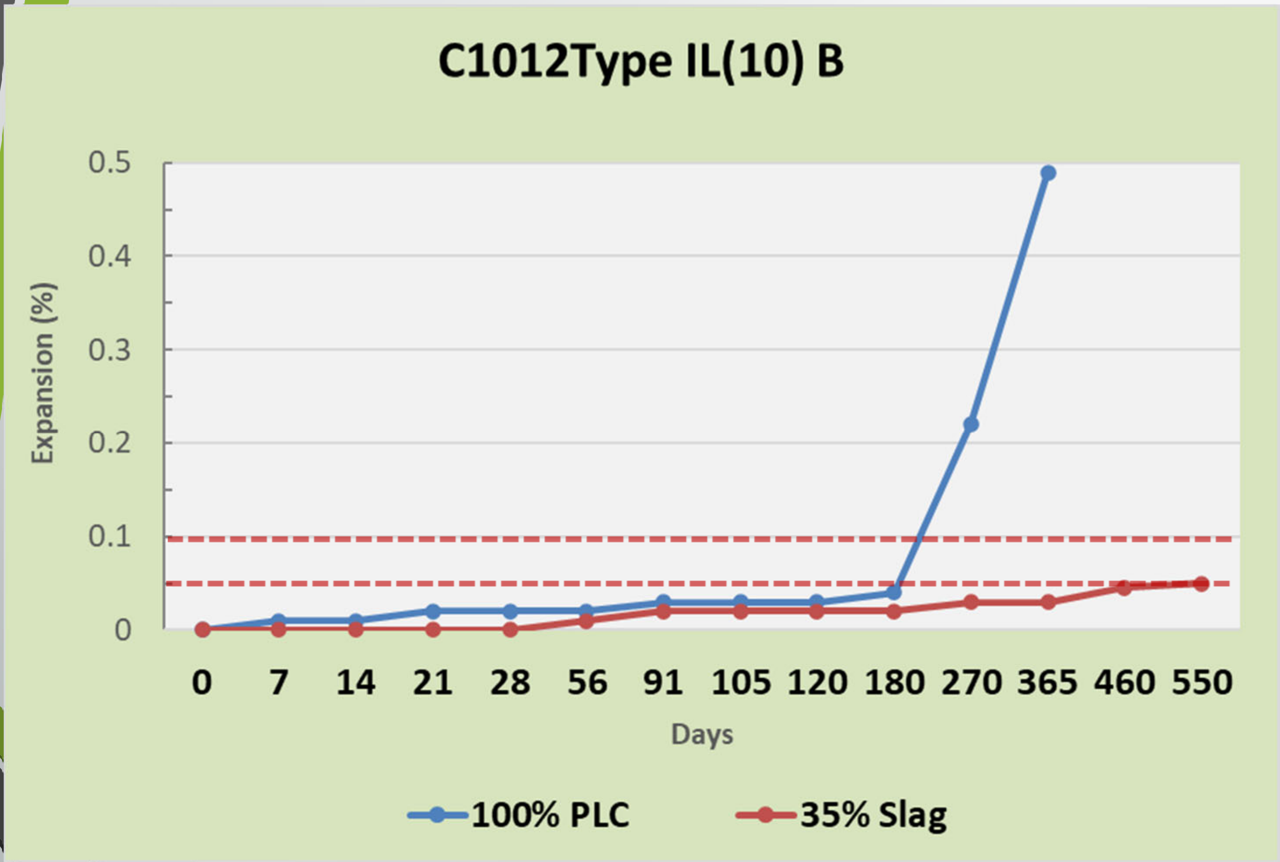
0.10% max @ 6 months

High Sulfate Resistance:

0.05% max @ 6 months **or**

0.10% max @ 12 months

Sulfate Resistance With Slag Cement



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Moderate Sulfate Resistance:

0.10% max @ 6 months

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0.05% max @ 6 months **or**

0.10% max @ 12 months or

0.10% max @ 18 months (S3 exposure class)

Sulfate Resistance With Slag Cement

How about 38 years worth of sulfate exposure?

Alapour & Hooton, 2017

Test Details:

- 4x8” cyls. submersed in 3,000 ppm & 50,000 ppm
- Visual inspection of samples
- Picture shows 38 years of exposure

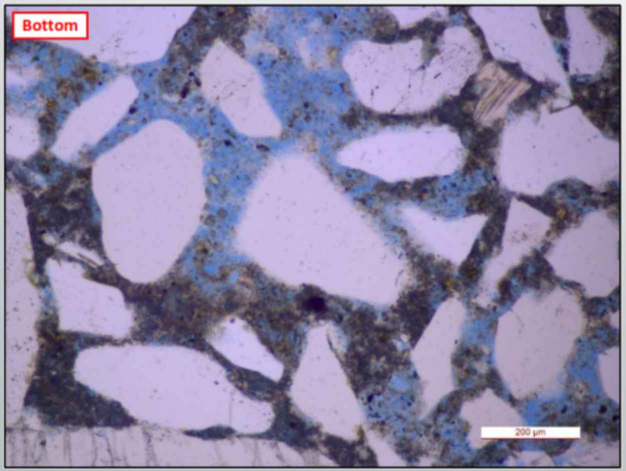
Mixture scenarios:

1) Type I & **65% Slag**, w/cm=0.45

2) HS, w/cm=0.50

3) MS-w/cm=0.50

Permeability Of Concrete



Permeability Of Concrete

What is permeability related to concrete?

- Measure of ease for moisture, air and other substances like chloride ions to enter concrete
- Commonly measured by RCPT, Bulk & Surface Resistivity or Chloride Diffusion

Why is it important?

- Reduced permeability slows the process of chloride ingress
- Increases life of concrete structures

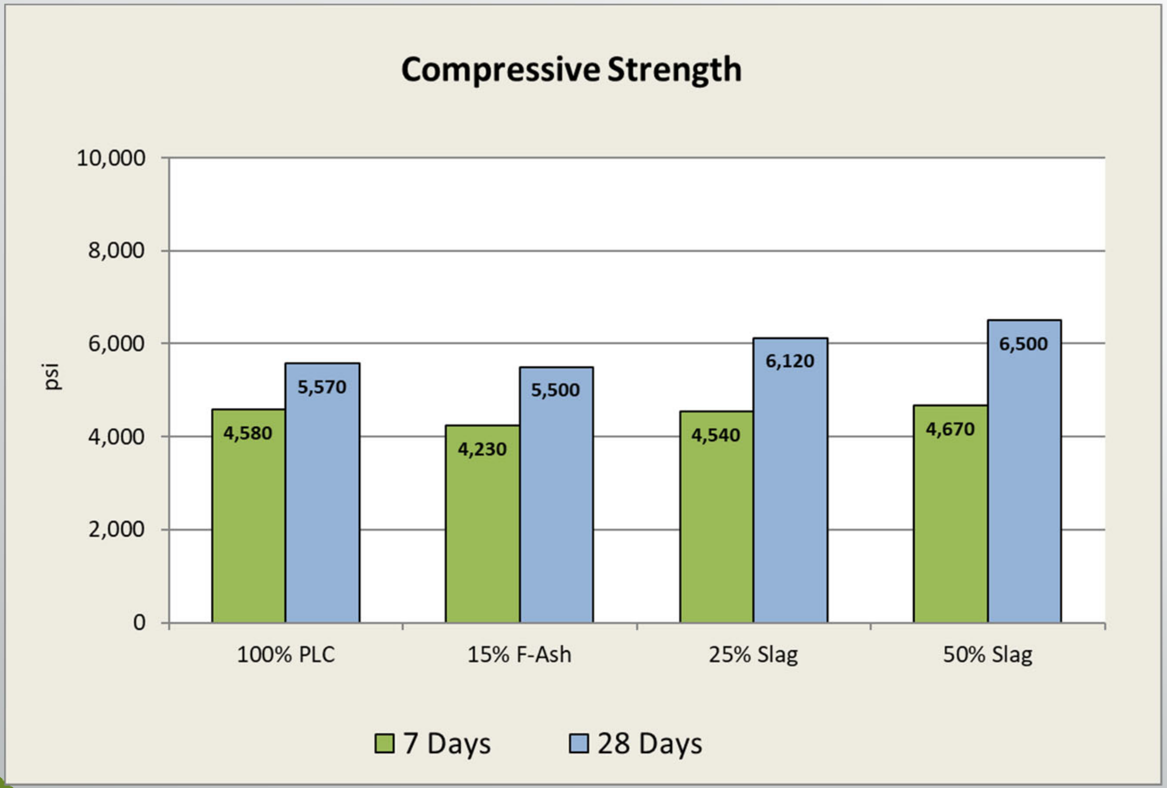
Lower permeability can be achieved, in binary or ternary mixtures, with **25 to 50% slag cement substitution**

Example – PLC Study (GDOT)

GDOT Class AA Concrete (Bridge Deck)	UOM	100% PLC	19% Class F	25% Slag	50% Slag
Cement					
Harleyville, SC Type IL(10)	lbs/yd³	635	540	476	318
Suplemental Cementitious Material					
Bowen Class F Fly Ash	lbs/yd³		125		
Port Canaveral Grade 120 Slag	lbs/yd³			159	318
Aggregate					
#57 Granite	lbs/yd³	1828	1828	1824	1815
Natural Sand	lbs/yd³	777	755	765	775
Washed Manufactured Sand	lbs/yd³	328	320	322	328
Water	lbs/yd³	275	262	279	285
W/C+P Ratio		0.433	0.394	0.439	0.448
Admixture					
Type A WR	oz/cwt	4.0	3.8	4.0	4.0
AEA	oz/cwt	0.60	1.30	1.00	1.80
Plastic Properties					
Slump	inches	3.75	4.00	3.75	3.25
Air	%	6.1	5.3	5.6	5.6
Density	lbs/ft³	141.4	141.9	141.7	141.3

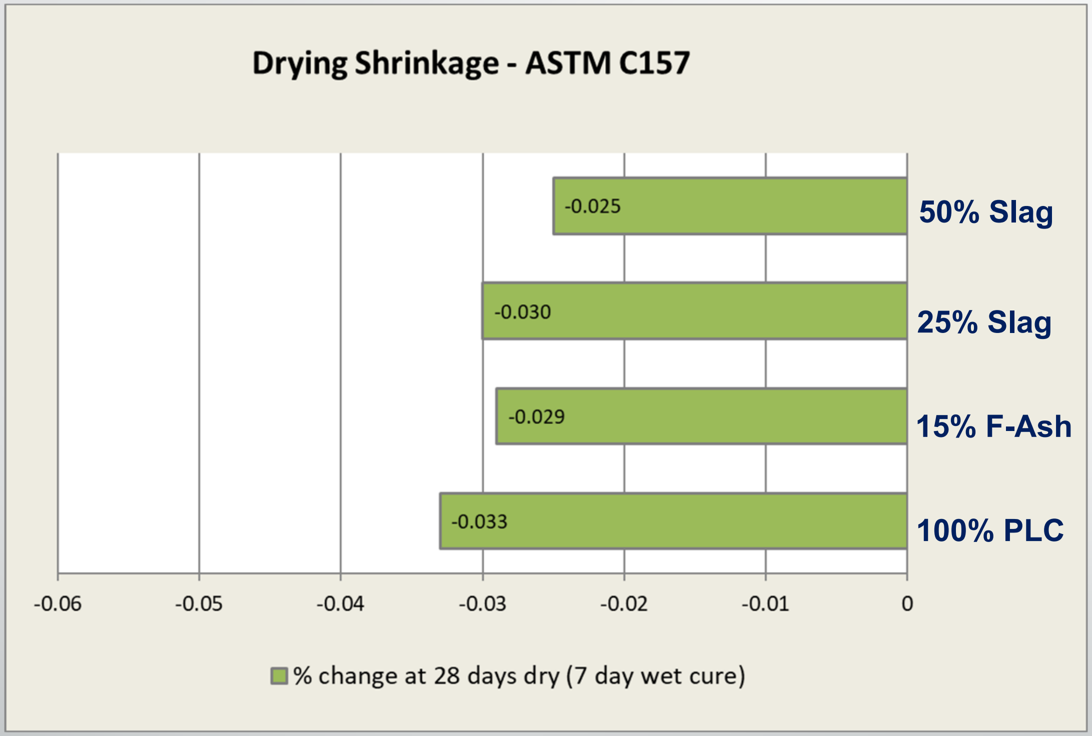
GDOT's primary focus was on PLC's impact on autogenous shrinkage

Compressive Strength



- 7 Day strength was comparable to 100% PLC in both slag mixes
- Improved 28-day strength observed with slag mixtures
- **+ 10%** with 25% slag
- **+ 17%** with 50% slag

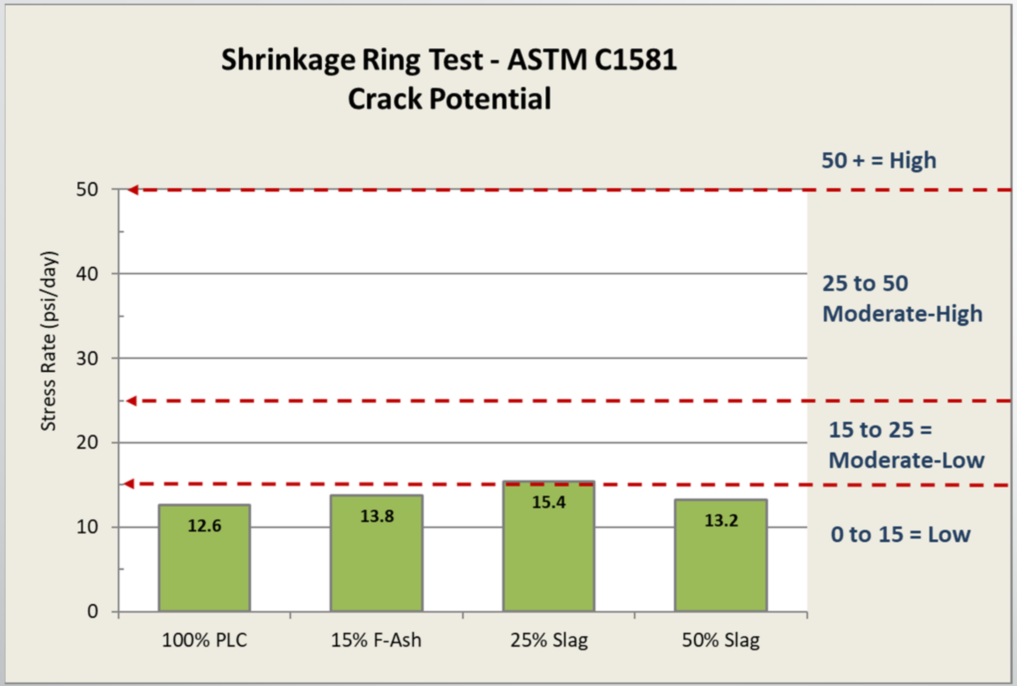
Drying Shrinkage In Concrete



- Impact to drying shrinkage utilizing slag cement range from neutral to a slight reduction.

Restrained Shrinkage

AKA: The Shrinkage Ring Test



- No Significant impact on restrained shrinkage at 25% and 50% replacement levels.

Shrinkage Ring is used to compare different mixtures to determine their susceptibility to early-cracking due to drying shrinkage, autogenous shrinkage, and heat of hydration. Source: www.worldoftest.com/

Permeability Of Concrete

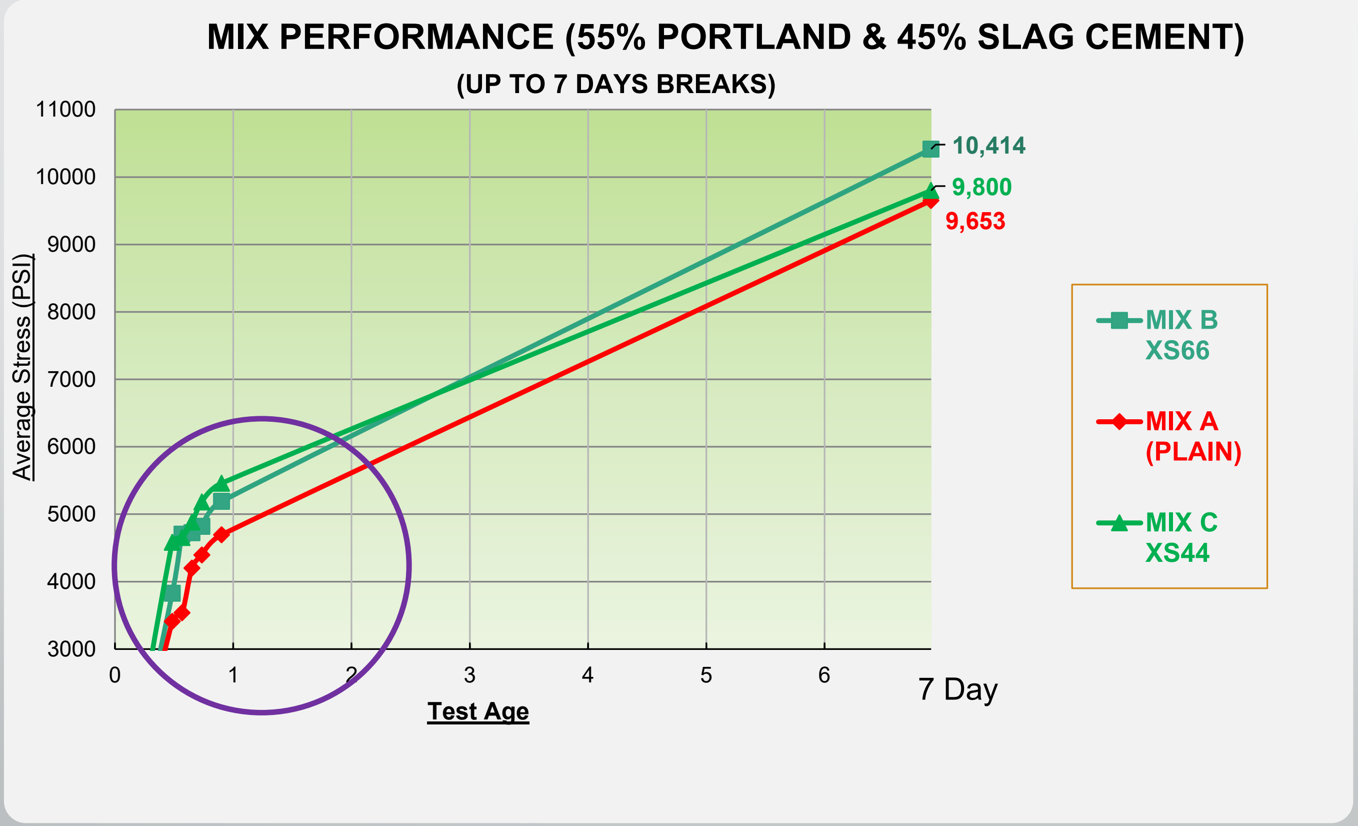
A visual of how slag cement reduces permeability

Permeability Of Concrete

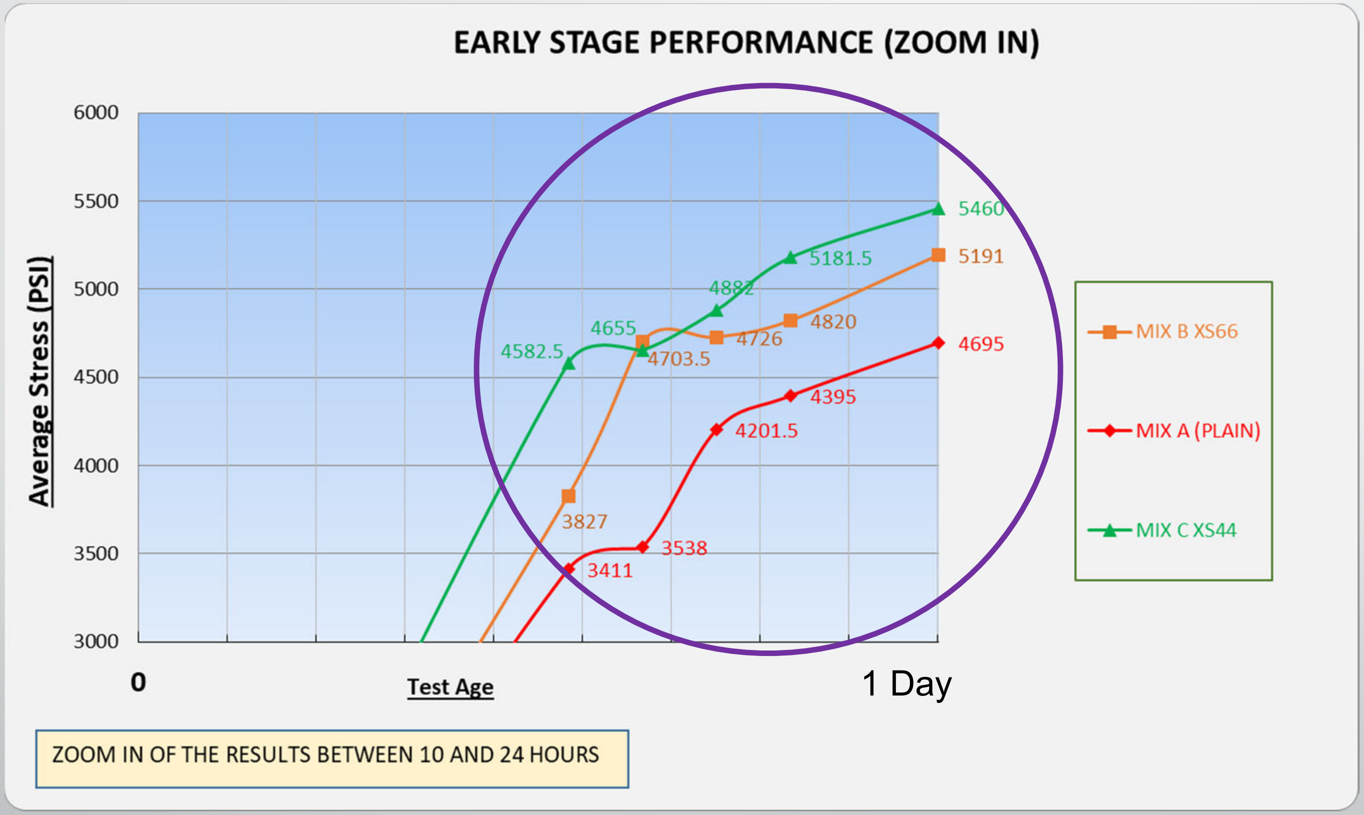
Time lapse shows the absorption of water into two prepared concrete sample, 100% OPC and 35% Slag over approx. a 9-day period.

Slag Cement In Precast / Precast Concrete?

Example: 45% slag cement mixtures



Slag Cement In Precast / Precast Concrete?



Customer was able to meet early age requirements utilizing 45% slag

Gordie Howe Bridge

- 125 year design life using Modeling Software
- Permeability Inputs
- Linear Shrinkage

Life-365™

Life-365 Service Life Prediction Model™ for reinforced concrete exposed to chlorides

Courtesy of Votorantim Cementos

Gordie Howe Bridge

Substructure/Caissons (Canada)

- 22,000 yd^3 of concrete
- 9 ft diameter, 195 ft deep
- Using GUbSF(8) with 65% Slag
- At surface 25% Slag
- Avg 37.6% Slag
- 40MPa (6000 psi)
- <1000 Coulombs permeability

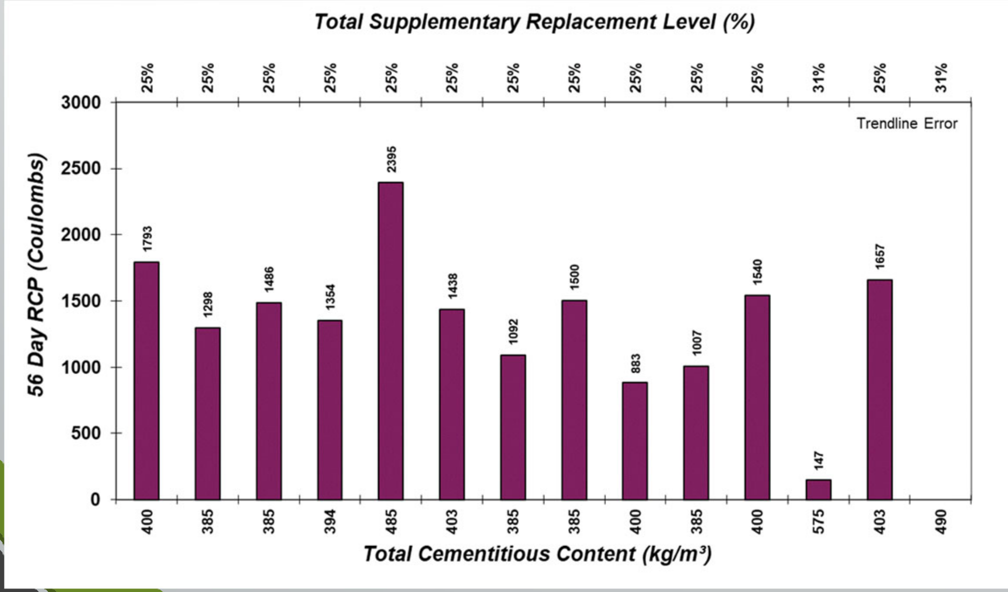
Substructure (US)

- Sulfate Resistance Concerns
- 50% Slag (min) required

Gordie Howe Bridge

<u>Superstructure</u>

- 22,000 yd^3 of concrete
- Using 4000T of GUbSF(8) with 25% Slag
- 70MPa (10,000 psi)
- <1000 Coulombs 300-500 Coulombs actual



Miami Port Access Tunnel

<u>Access between seaport and I-395 / I-95</u>

- 150 year design life
- f’c = 6,000 psi
- Slag cement used in soil stabilization at 70%
- Precast concrete liners at 51%
- Sulfate resistance and chloride penetration resistance critical for design life.

High Rise/High Performance Mass Concrete

- **Hudson Tower Detroit**
- **685 ft tall**
- **$980M**
- **13,000 psi**
  - **15% F-ash/ 40% Slag**
- **10,000 psi**
  - **40% Slag**

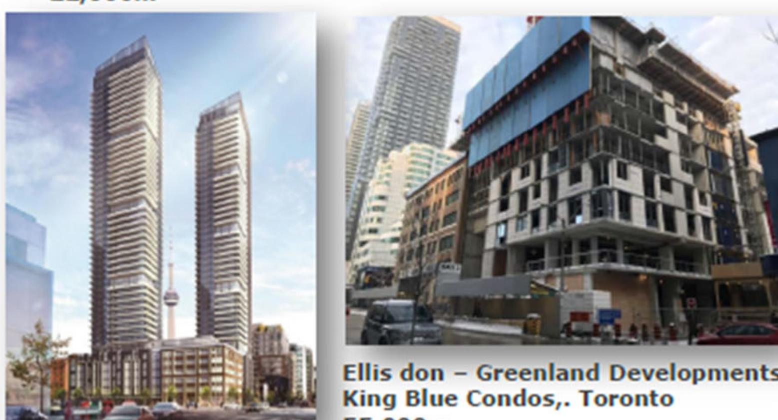
High Performance Mass Concrete

- 2nd Avenue Bridge
- 75% Slag
- 8000 psi
  - Heat
  - Shrinkage
  - Strength
  - ASR

High Rise/High Performance Mass Concrete

Ellis don – Grenadier Square,
Toronto
22,000m

Ellis don – King Portland Centre,
Toronto
24,000m



Ellis don – Greenland Developments
King Blue Condos,. Toronto
55,000m

Ellis don
Toronto Courthouse, University Avenue
55,000m

High Rise/High Performance Mass Concrete

Ellis don - York Region Annex; Newmarket, 40,000m3

Bowmanville GUL Job

Ellis Don - Concord Adex –TheLakeshore 50,000m3 SCC Columns

EllisDon

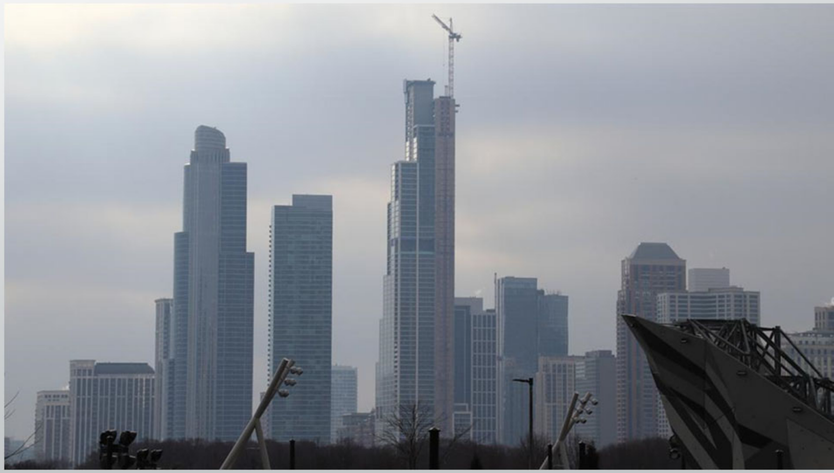
Ellis Don – The Well Mixed Use Development, Spadina & Front, Toronto 60,000m

70MPA C-1 / T10SF
Mass footings 50-60% Slag

Nema Project – Chicago (2019)

Formerly 1200 S Indiana

- 76 Stories- 893’ high
- Low heat – high slag replacement mixes were used for mat, caisson caps and massive grade beams
- Mix design: **57% slag replacement** with f’c of 8,000 psi @ 56 days and 10,000psi @ 91 days
- Mix needed stability and SCC flow due to rebar congestion of mat – Targeted 26” spread
- Center mass of mat reached temp of 102 F with 24 F differential
- Average Strengths exceeded 12,000psi at 91 days



Pinellas Bayway Bridge – Florida

- 65-ft clearance 4-lane bridge with 12-ft wide walkway replaced 2-lane drawbridge

- Slag cement used at 50% replacement in footings, columns, decks and barrier walls

- 5,500 psi f'c
- Provided reduced permeability as required by Florida DOT for this marine exposure

Thank You

QUESTIONS?