Low Carbon Concrete Case Study: Amrize Sulfated Slag

Parking Garage Column Encasement

Bellevue, WA

Executive Summary

Advancing industry experience developing and working with next generation lower-carbon materials is part of Amazon's continuous efforts to decarbonize its buildings. As part of this effort, Amazon challenged the design, construction, and material supply teams of the Bellevue 600 project to pilot new materials. The result is a novel near-zero Portland cement concrete that exceeded concrete strength and placement expectations. The material was developed in partnership with the project's General Contractor Sellen Construction, concrete supplier Stoneway, and concrete materials supplier Amrize. It was tested through physical mock-ups and placed in a series of non-structural concrete column encasements in the below-grade garage. The innovative concrete mixture uses sulfated granulated blast furnace slag (GBFS) that replaces the more typical Portland cement, which is the most carbon intensive aspect of producing concrete. GBFS is a recycled byproduct of blast-furnace steel and iron production. The 99.2% clinker free cement resulted in a Global Warming Potential (GWP) of 100 kg/m^3 (76 kg/yd^3); a 62% reduction against the National Ready Mix Concrete Association (NRMCA) Pacific Northwest regional benchmark. The concrete met project requirements, was workable after some mix adjustments, and met aesthetic expectations. This materials pilot allowed the team to experience working with this next generation lower carbon concrete, and to responsibly advance its use on this project and future applications.

Project Team

amazon

SENECA GROUP

nbbj

MAGNUSSON KLEMENCIC ASSOCIATES
Structural + Civil Engineers

Sellen

STONEWAY CONCRETE
A MERLINO COMPANY

AMRIZE
BUILD YOUR AMBITION

climateworks FOUNDATION

INSIGHTS

Amrize Sulfated Slag

ASTM C1157 Cement

62% GWP Reduction

3886 psi @ 28 days

4806 psi @ 90 days

Project Goal

Mock-up and field placement testing of an ASTM C1157 lower carbon and near zero clinker cement within a non-structural self-consolidating concrete (SCC) vertical column encasement.

Abstract

Responding to a lower carbon material challenge from Amazon's Bellevue 600 team, Amrize brought forward a novel concrete solution resulting from an extensive internal research and development effort. The new mixture uses sulfated granulated blast furnace slag (GBFS) resulting in a 99.2% clinker-free cement. In collaboration with the project's General Contractor Sellen Construction and concrete supplier Stoneway, and the development and design teams of Seneca Group, NBBJ and MKA, this material was put into truck trial mock-up tests, approved, and then ultimately placed on the project.

After mixture development and testing at Amrize's Seattle, WA facility, the team completed two different truck trials and physical mockups of both slab and column encasements, utilizing this ASTM C1157 cement. This testing occurred at the Sellen Construction warehouse in Mountlake Terrace, WA. These tests resulted in the team selecting and approving a concrete mixture utilizing this C1157 cement for use in non-structural placements (Mixture #3). A comparative in-field project testing was then developed to compare this mixture against both a regional baseline (Mixture #1), and current market lower carbon concrete (Mixture #2) use. Placement was at concrete column encasements around steel wide-flange columns inside a below grade composite steel parking garage and for an extensive topping slab designed to protect the at grade water-proofing. All placements occurred via a pump truck with a 4" line. The level P5 column encasements also used a pump truck and 200 lineal feet of slickline. Final strength, shrinkage, and other criteria for all tested concretes comfortably exceeded the 3000psi at 28day self-consolidating concrete specification, which included exposure classifications of F0, S0, W0, C0.

Mixture 1 is a zero-slag mix, representative of the regional average mixture often used when pumping is required, but lower carbon requirements are not asked for. Mixture 2 is a 50% slag concrete mixture that was originally planned and used for this project, which is an aggressive but "market and project ready" lower carbon concrete for the area. Mixture 3 is a first of its kind "novel material" use of a sulfated slag mixture that is 99.2% clinker free cement concrete.

Truck Trial Mock-up Testing at the Sellen Construction Warehouse

Mixture #1 — Regional Baseline

ASTM C595 Type 1L Cement, No Slag



Testing of Truck Trial Mixtures

Placement

Interior Slabs, Columns and Walls, Misc. Concrete

Design Mixture GWP

253 $kgCO_2e/m^3$ (based upon Stoneway EPD)

Design Criteria

3.0ksi @ 28 days; Exposure Criteria F0, S0, W0, C0

Contractor and Finisher Comments

- This is a basic 6 sack mixture frequently used in the local market for many different applications, when pumping is required and no lower carbon requirements are specified. This mixture has no SCM's, with cement content controlled by minimum pumpability requirements and not the 3.0 ksi @ 28-day strengths.
- A very consistent mix that pumps and finishes as you would expect for normal concrete.
- This mixture is often placed at a 3-5 in slump for slab pours, or dosed with superplasticizer to bring it to a self-consolidating-concrete (SCC) mixture for use in vertical formwork of columns and walls.

Mixture Design

Material	Source	Description	Volume (cu.ft)	Weight (lb)
Cement	Ashgrove	C 595, Type IL(13)MS	2.916	564
Aggregate	Pit #: B335	C33, AASHTO #57 (3/4)	11.484	1935
	Pit #: B335	C 33, Concrete Sand	8.484	1408
Water	City	C 1602, Water	3.974	248
Air			0.351	
			TOTAL	4155 lb

Specified F'c	3000 psi @28 days	Estimated Fresh Density:	152.71 lb/ft³
		Designed W/C+P Ratio:	0.44
Specified Air:	1-1.75\1.3	Designed Volume:	27.21 ft³

Compression Tests

Date Tested	Slump (in)	7-day Strength (psi)	28-day Strength (psi)
03/05/17	5.5	4440	5500
07/07/20	3	4470	6050
05/05/21	4.5	5120	6480
05/28/21	3.5	3970	5160
Average	**4.44**	**4604**	**6111**

Mix avg % air – 2.6%

All test data not shown, averages are based upon a total of 44 tests over time.

Standard Deviation on strength Avg – 1.91 (737 psi)

Mixture #2 – Current Market Lower Carbon Concrete

ASTM C595 Type 1L Cement, 50% Slag Replacement

Testing, Placement, and Final Column Encasement for Pumped Column Concrete

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Placement

Columns and Walls, Self Consolidating Concrete Mixture

Design Mixture GWP

159 $kgCO_2e/m^3$ (based upon Stoneway EPD)

Design Criteria

3.0ksi @ 28 days; Exposure Criteria F0, S0, W0, C0

Contractor and Finisher Comments

- We use this mix frequently on our projects. It is a preferred wall and column SCC mix, when carbon reduction is a goal and a flowable self-consolidating mix is required. Similar to Mixture #1, minimum cement and SCM amounts used are required for pump-ability and placing characteristics, not the final f'c at 28 days.
- No pump-ability challenges with this mix. From a planning and logistics perspective, we have no major differences in our efforts with this mix compared to the Mixture #1.
- Finishes like normal concrete, no significant differences in finish ability relative to the Mixture #1.

Mixture Design

Material	Source	Description	Volume (cu.ft)	Weight (lb)
Cement	Ashgrove	C595, Type IL(13) MS	1.458	282
Additive	Amrize	C989, Amrize GGBFS	1.575	282
Aggregate	Pit #: B335	C 33, AASHTO #8 (3/8)	10.648	1787
	Pit #: B335	C 33, Concrete Sand	9.037	1500
Water	City	C 1602, Water	4.087	255
Admixture	GCP Applied	C 494, ADVA, Dosage: 22.56 fl oz/yd³		
	GCP Applied	C 494, Concera, Dosage: 22.56 fl oz/yd³		
	GCP Applied	C 494, Zyla 630, Dosage: 25.38 fl oz/yd³		
Air			0.405	
			TOTAL	4106 lb

Specified F'c	3000 psi @28 days	Estimated Fresh Density:	150.92 lb/ft³
		Designed W/C+P Ratio:	0.45
Specified Air:	0-3%	Designed Volume:	27.21 ft³

Compression Tests

Date Tested	Slump (in)	7-day Strength (psi)	28-day Strength (psi)
03/18/24	23	5240	7490
04/05/24	23	4070	7280
04/09/24	27	4690	7650
4/11/24	23	4690	7450
4/17/24	24	4990	7260
4/26/24	24	4050	7400
5/7/24	24	5620	8230
5/17/24	20	4220	7110
6/10/24	23.5	4630	7030
Average	**23.5**	**4588**	**7432**

Mix avg % air – 2.5%

All test data not shown, averages are based upon a total of 30 tests over time.

Standard Deviation on strength Avg – 2.81 (449 psi)

Mixture #3 – Next Generation Lower Carbon Concrete

ASTM C1157 Sulfated Slag Concrete (99.2% Slag Replacement)

Testing, Placement, and Final Encasement for Pumped Column Concrete

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Placement

Parking Column Covers, Self Consolidating Concrete Mixture

Design Criteria

3.0ksi @ 28 days; Exposure Criteria F0, S0, W0, C0

Design Mixture GWP

100 $kgCO_2e/m^3$ (based upon Stoneway EPD , with Lafarge EPD for cement included)

Contractor and Finisher Comments

- Surface had a chalkier finish when form-work was removed prematurely, especially when temperatures were low. It is more sensitive to curing procedures, which need to be refined by project teams in mock-up trials prior to in-field placements.
- First column encasements required pumping through 400 linear feet of slickline. This mix is stickier than mixture #2. The pump was working harder but it pumped. The worst-case condition was a 9ft tall encasement pumped from below.
- Noticeably fewer pinholes, lighter color, chamfered edge is a little soft after placement, but firms up with time.
- They look beautiful, finishes the same as regular concrete.
- Good for use at column encasements.
- Mixture is slower setting in cold weather conditions, which could have schedule impacts if not otherwise accounted for.

Mixture Design

Material	Source	Description	Volume (cu.ft)	Weight (lb)
Additive	Amrize	C989, Sulfated Slag	4.467	800
Aggregate	Pit #: B231	C 33, AASHTO #57 (3/4)	8.629	1470
	Pit #: B231	C 33, AASHTO #8 (3/8)	1.638	275
	Pit #: B231	C 33, Concrete Sand	7.312	1200
Water	City	C 1602, Water	4.487	280
Admixture	GCP Applied	C 494, ADVA, 40 fl oz/yd^3		
	GCP Applied	C 494, Recover, 16 fl oz/yd^3		
	GCP Applied Technologies	ASTM C494, Vmar 3, 16 fl oz/yd^3		
Air			0.540	
			TOTAL	4025 lb

Specified F'c	3000 psi @28 days	Estimated Fresh Density:	148.67 lb/ft^3
		Designed W/C+P Ratio:	0.35
Specified Air:	0-3%	Designed Volume:	27.07 ft^3

Compression Tests

Date Tested	Age at Test (days)	Max Load (lbs)	Comp Strength (psi)
05/10/24	7	38,785	3088
05/31/24	28	48,805	3886
06/28/24	56	56,320	4484
08/02/24	90	60,365	4806

Modulus of Rupture (MOR) Tests

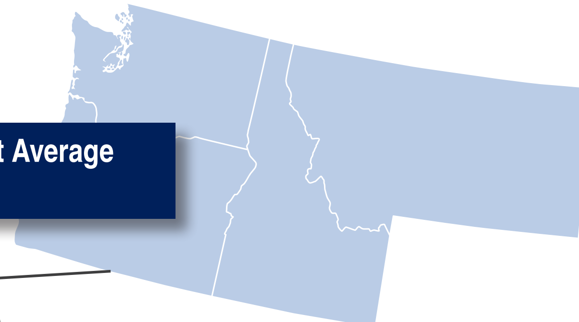
Criteria for 3000psi concrete = 7.5 sqrt (f'c) = **411psi**

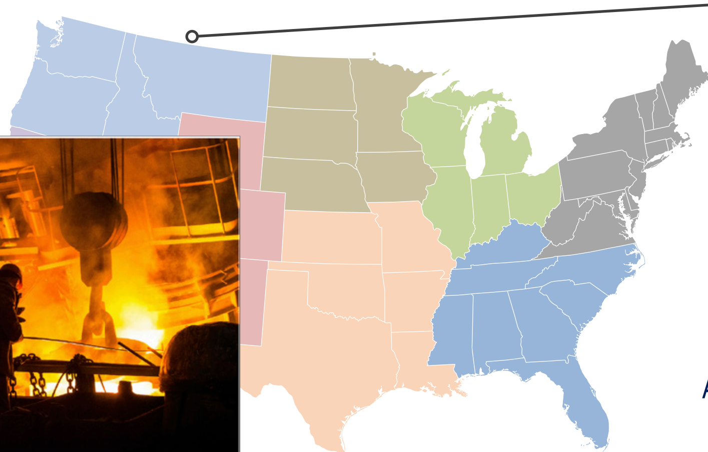
Date Tested	Age at Test (days)	Max Load (lbs)	Modulus of Rupture (psi)	MOR Avg (psi)
08/14/24	28	7,149	575	
08/14/24	28	6,386	515	
08/14/24	28	6,905	555	**548**

GWP Comparison Between Mixtures

NRMCA Averages:

261 $kgCO_2e/m^3$ – NRMCA Pacific Northwest Average for 3000 psi Concrete, 07/2022





Mixture #1
253 $kgCO_2e/m^3$

ASTM C150 Type 1L Cement, No Slag

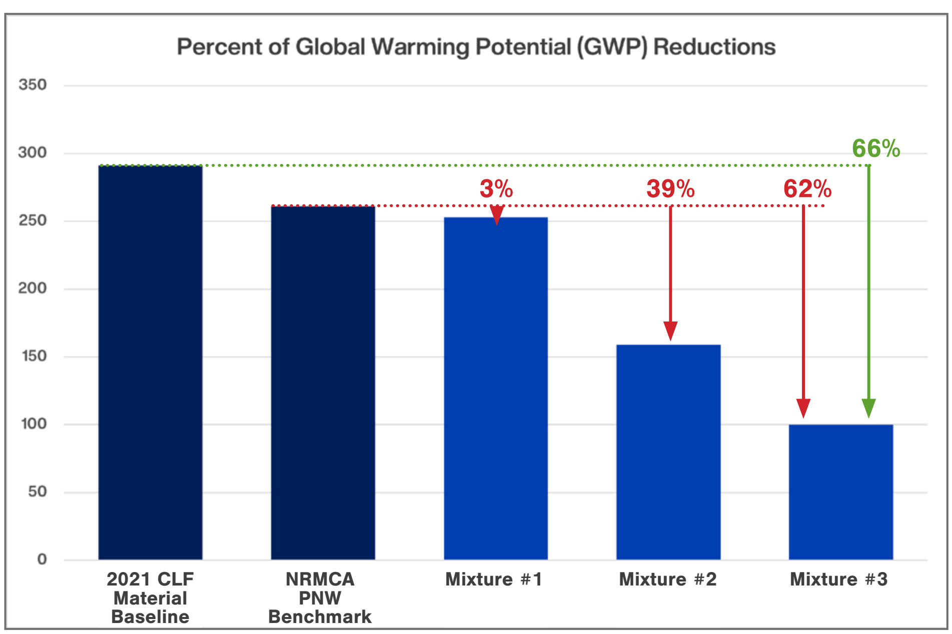
Mixture #2
159 $kgCO_2e/m^3$

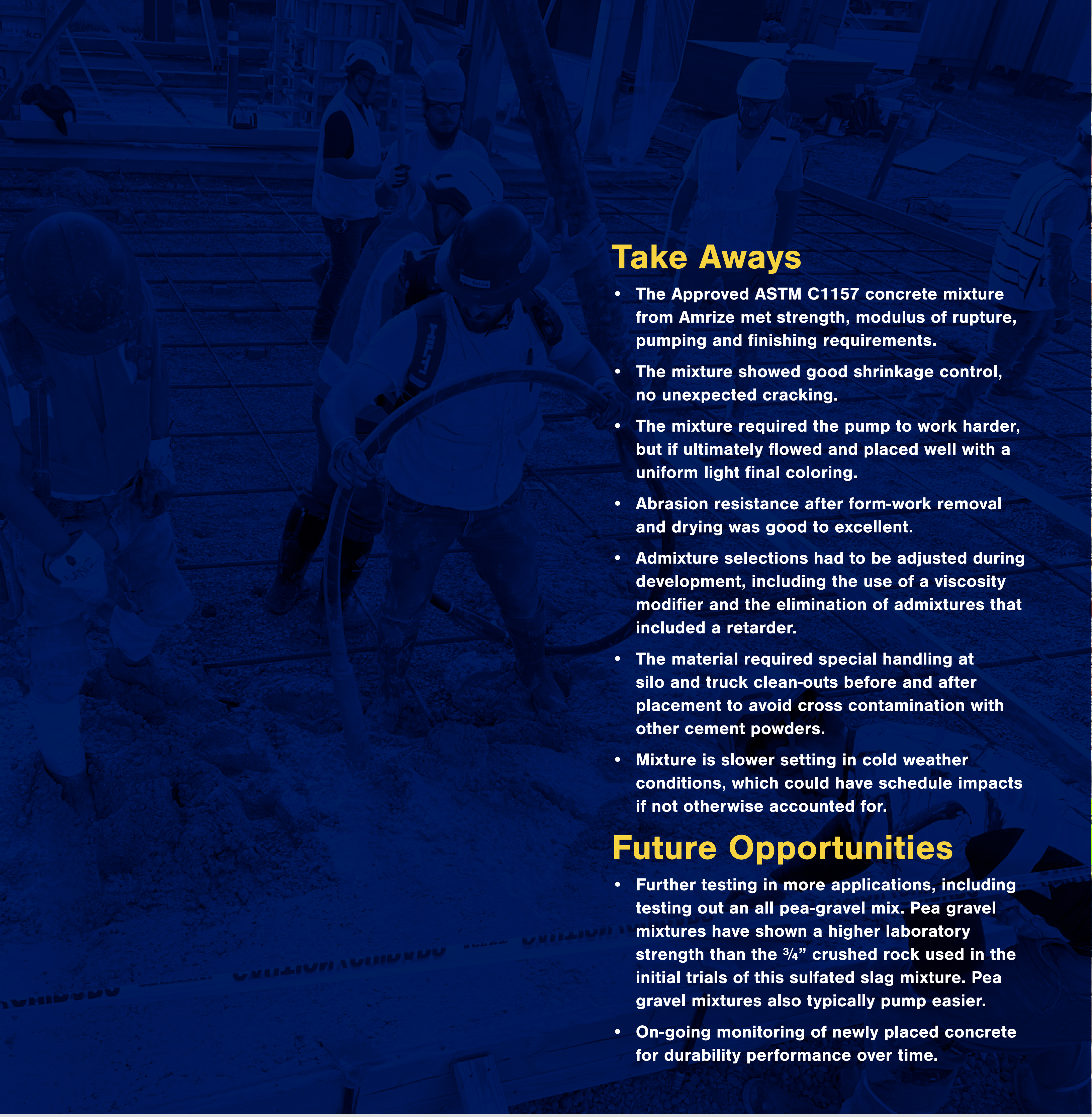
ASTM C595 Type 1L Cement, 50% Slag Replacement

Mixture #3
100 $kgCO_2e/m^3$

ASTM C1157 Concrete (99.2% Slag Replacement)

291 $kgCO_2e/m^3$ – 2021 CLF Materials Baseline Report for 3000 psi – Median





Take Aways

- The Approved ASTM C1157 concrete mixture from Amrize met strength, modulus of rupture, pumping and finishing requirements.
- The mixture showed good shrinkage control, no unexpected cracking.
- The mixture required the pump to work harder, but if ultimately flowed and placed well with a uniform light final coloring.
- Abrasion resistance after form-work removal and drying was good to excellent.
- Admixture selections had to be adjusted during development, including the use of a viscosity modifier and the elimination of admixtures that included a retarder.
- The material required special handling at silo and truck clean-outs before and after placement to avoid cross contamination with other cement powders.
- Mixture is slower setting in cold weather conditions, which could have schedule impacts if not otherwise accounted for.

Future Opportunities

- Further testing in more applications, including testing out an all pea-gravel mix. Pea gravel mixtures have shown a higher laboratory strength than the ¾” crushed rock used in the initial trials of this sulfated slag mixture. Pea gravel mixtures also typically pump easier.
- On-going monitoring of newly placed concrete for durability performance over time.

CONTACT US

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