SOLUTIONS FOR THE BUILT WORLD

Demonstrating Low Carbon Concrete for Tilt-Up Wall Panel Construction

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Acknowledgements

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- Collaborative effort between Amazon Web Services (AWS), Clayco, Concrete Strategies Inc., Ozinga, and Kienstra Ready Mix
  - All parties donated time and materials to make this a success
- Consulting team included Davies-Crooks Associates, Nichols Consulting Engineers (NCE), Sutter Engineering, Concrete Durability Assoc., Al Innis Consulting, and Wiss Janney Elstner (WJE)

Project Background

- Goal: Demonstrate the use of lower carbon concrete for the construction of tilt-up wall panels used for the construction of AWS data centers
  - Achieve desired concrete properties and the ability to “tilt” in three days
- Three full-scale mock-up tilt-up wall panels utilizing three concrete mixtures with varying degrees of embodied carbon
- Extensive laboratory and field data collected to be shared to facilitate broader adoption of low carbon concrete

Concrete Mixtures

- **Mix 1 – Control** was an ASTM C595 Type IL blended cement mix with proportions commonly used in tilt-up wall construction in AWS Data Centers
  - Estimated embodied carbon 209 kg CO_2 eq from draft EPD
- **Mix 2 – 25% Slag Cement** was identical to Mix 1, but 25% of the ASTM C595 Type IL cement was replaced with ASTM C989 slag cement
  - Estimated carbon reduction is 19% as compared to control from draft EPD
- **Mix 3 – C1157** contained a proprietary blend of cementitious materials which conforms to ASTM C1157, *Standard Performance Specification for Hydraulic Cement*
  - Estimated carbon reduction is 52% as compared to control from draft EPDs

Constituent	Description or Source	Units	Mix 1 - Control	Mix 2 - 25% SC	Mix 3 - C1157
Type IL Cement	Holcim St. Gen, MO	lbs/yd^3	564	423	--
Slag Cement	Holcim, Chicago, IL	lbs/yd^3	--	141	--
C1157 cement	Ozinga, Chicago, IL	lbs/yd^3	--	--	750
Coarse aggregate	Bluff City Materials	lbs/yd^3	1775	1780	1740
Fine aggregate	Madison County Sand	lbs/yd^3	1420	1400	1240
Water	n/a	lbs/yd^3	271	271	237
High-Range Water Reducer	ADVACAST 600, GCP	fl. oz.	26	26	30
Workability Enhancing Admixture	ADVA XT, GCP	fl. oz.	--	--	22
Rheology modifying Admixture	V-MAR F100, GCP	fl. oz.	--	--	45
Accelerating Admixture	OZ set	fl. oz.	--	--	262.5
w/cm (w/o admixtures)	--	--	0.48	0.48	0.32
w/cm (w/ admixtures)	--	--	0.48	0.48	0.34
Target Air Content	--	%	1.5	1.5	1.5

Laboratory Evaluation Program

- Fresh concrete properties
  - Slump (range: 6 to 8 in; ASTM C143), air content (< 2.5%; ASTM C231), unit weight (ASTM C138) and temperature (ASTM C1064)
- Setting time (ASTM C403), heat of hydration (ASTM C1702), bleeding potential (ASTM C232)
- Hardened concrete properties
  - Compressive strength (ASTM C39), splitting tensile strength (ASTM C469), elastic modulus (ASTM C469), drying shrinkage (ASTM C157), coefficient of thermal expansion (AASHTO T 336), bulk resistivity (AASHTO T 402), and maturity (ASTM C1074)

Laboratory Results: Fresh Properties

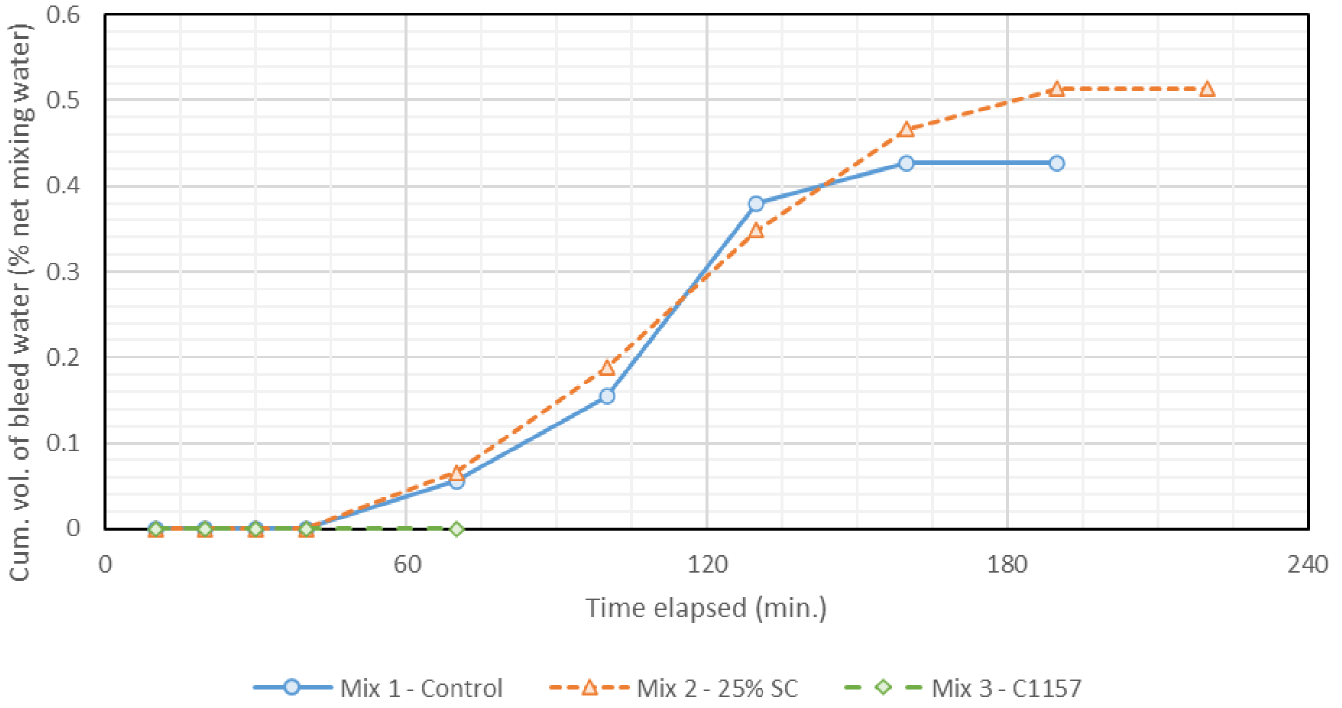
Test		Unit	Mix 1 - Control	Mix 2 - 25% SC	Mix 3 - C1157
Slump	ASTM C143	in.	7	8	9
Temperature	ASTM C1064	°F	74	74	77
Unit weight	ASTM C138	lb/ft^3	148.7	149.4	150.5
Air content	ASTM C231	%	2.0	2.0	2.1

Test		Unit	Mix 1 - Control	Mix 2 - 25% SC	Mix 3 - C1157
Setting time, Initial	ASTM C403	h:mm	3:20	3:15	2:55
Setting time, Final	ASTM C403	h:mm	4:40	4:40	7:10

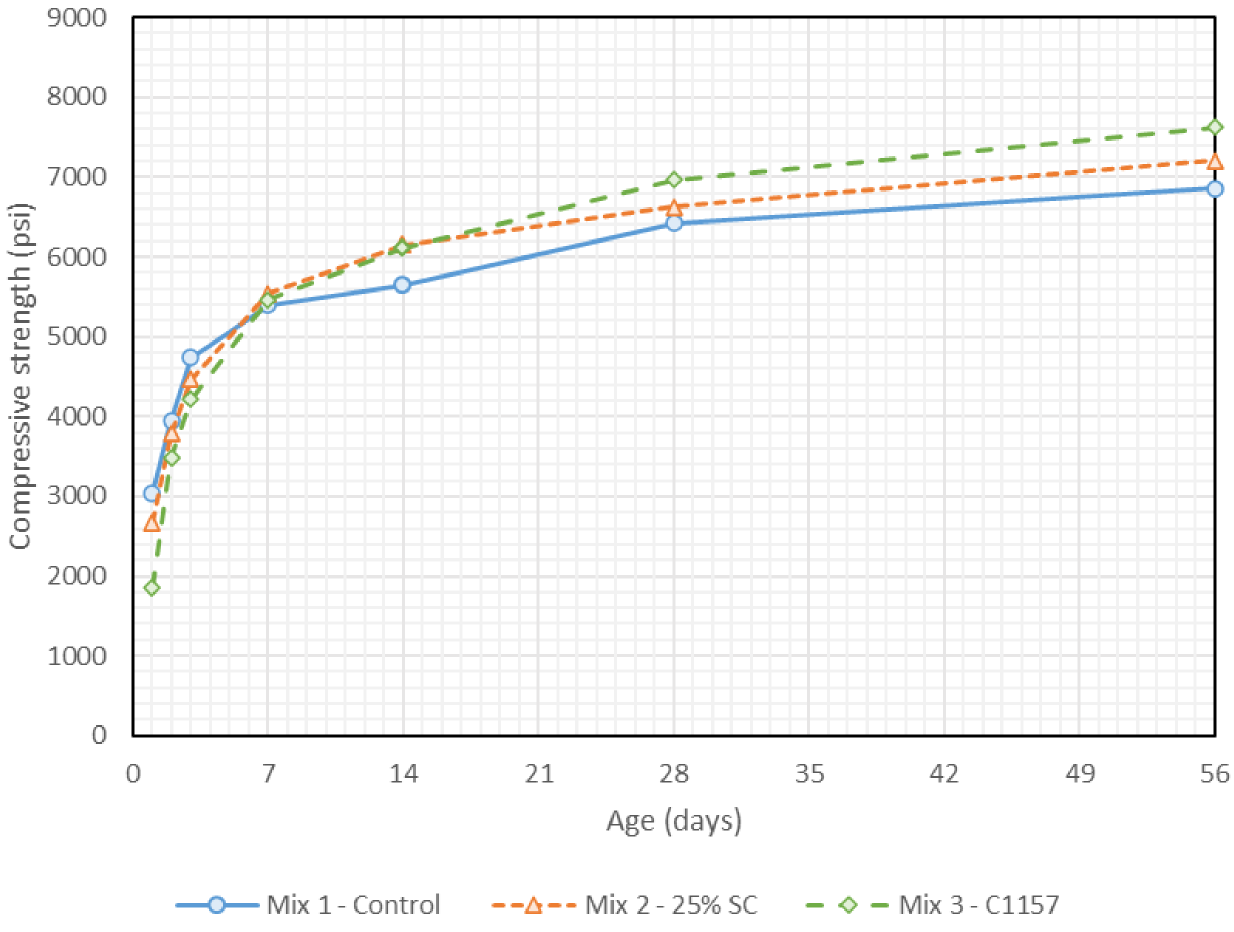
Laboratory Results: Total Heat Generated (J/g)

Sample ID	24 Hours	48 Hours	72 Hours	168 Hours
Mix 1 - Control	195	239	262	292
Mix 2 - 25% SC	165	207	232	269
Mix 3 - C1157	76	92	98	110

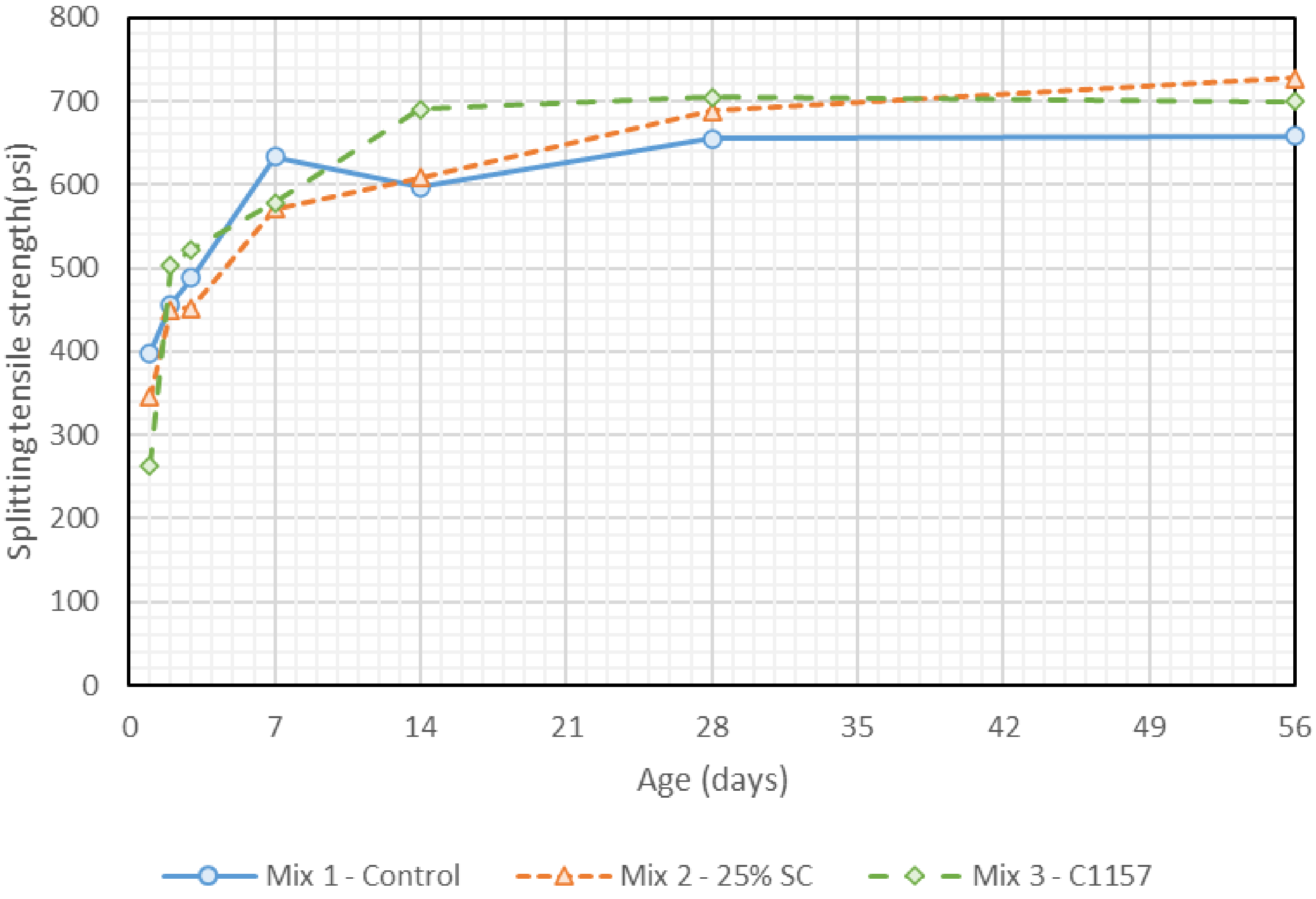
Laboratory Results: Bleeding



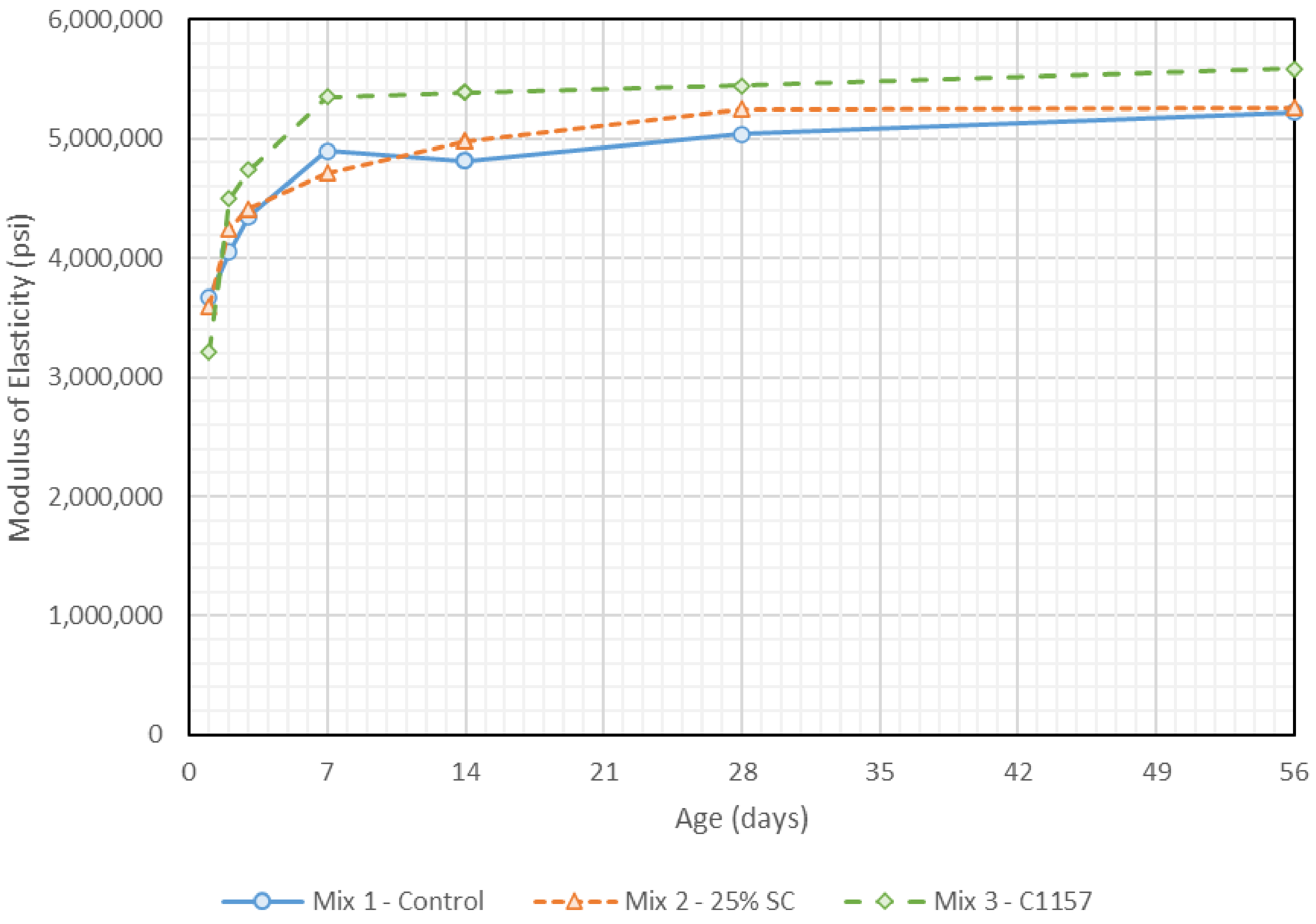
Compressive Strength



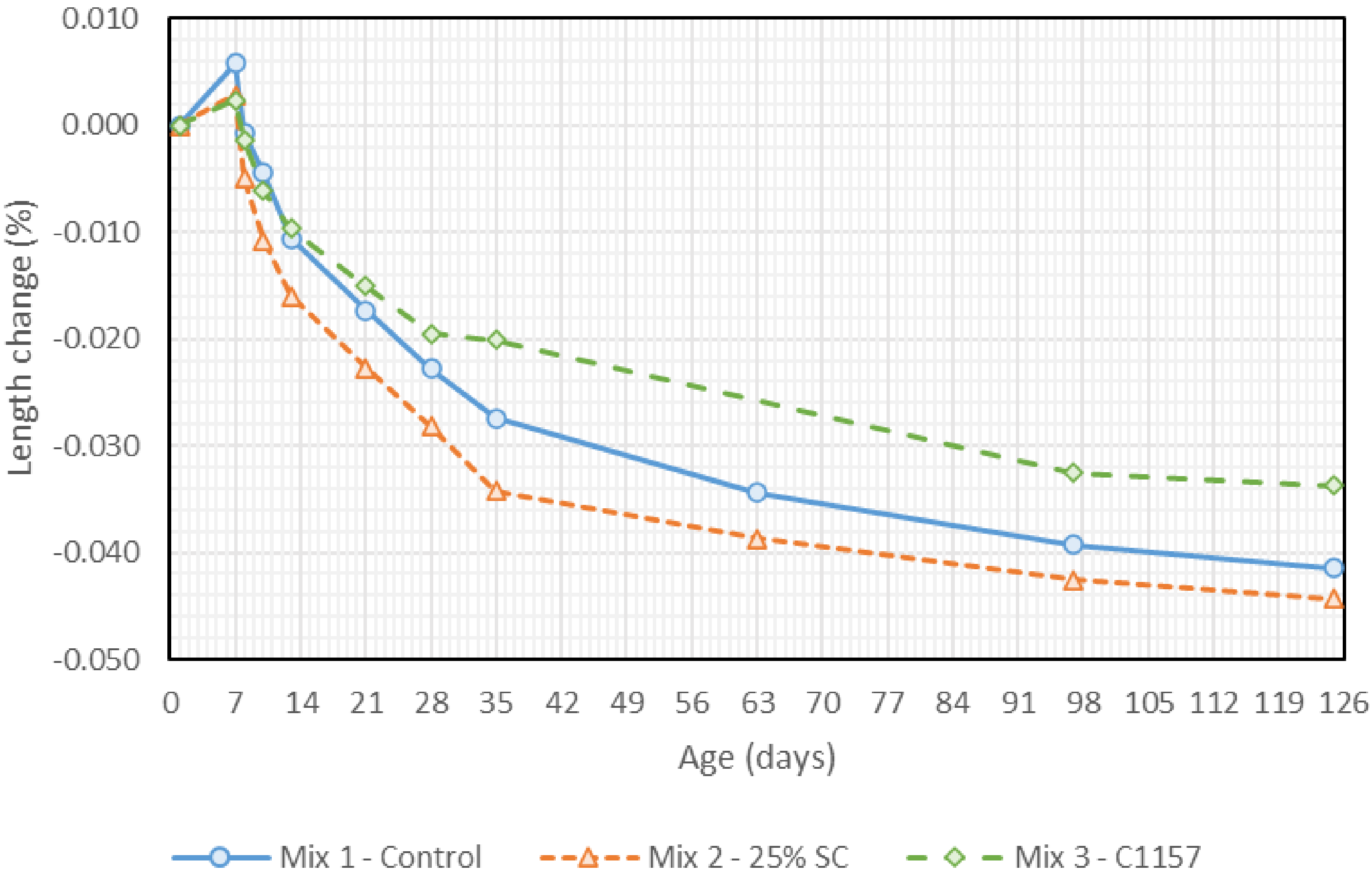
Splitting Tensile Strength



Modulus of Elasticity



Drying Shrinkage



Laboratory Test Results: Bulk Resistivity (Ohm-m)

Age (days)	Mix 1 - Control	Mix 2 - 25% SC	Mix 3 - C1157	Conditioning
28	64.9	103.1	992.3	100 % R.H (Moist room)
35	52.4	86.6	749.0	Submerged in SPS
56	53.8	92.1	920.2	Submerged in SPS
90	55.2	105.8	973	Submerged in SPS

Summary of Laboratory Properties

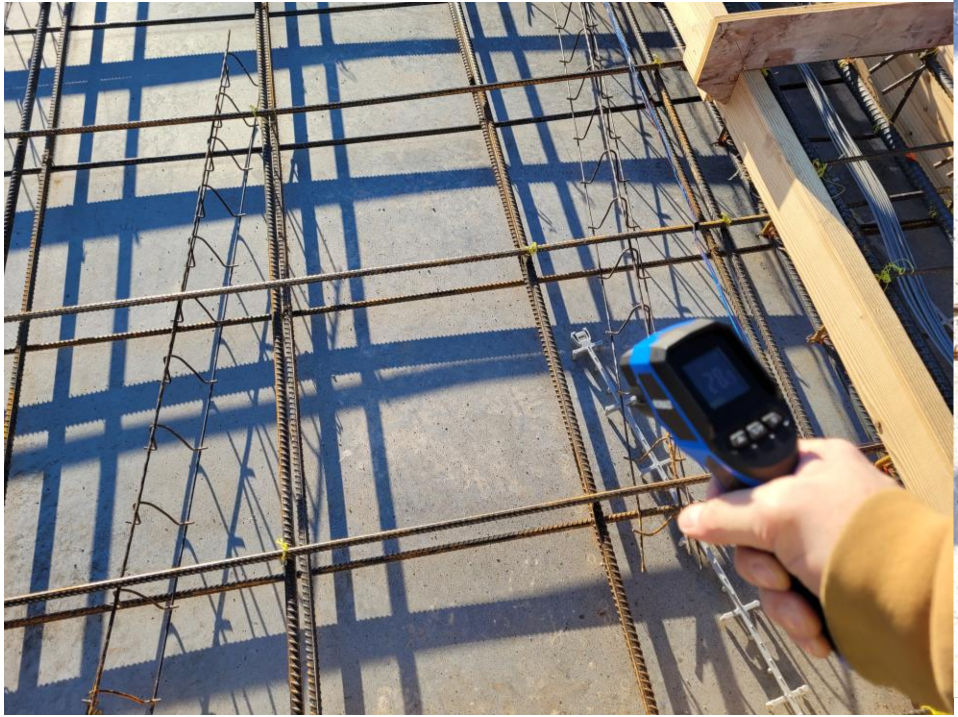
- All three mixtures are workable, but the thixotropic properties of Mix 3 would likely require more effort during placement and finishing
- The low bleed of Mix 3 means early curing will be needed to reduce the risk of plastic shrinkage cracking
- The heat of hydration and early strength gain characteristics suggest that Mixes 1 and 2 will behave similarly
  - Mix 3 may slow construction during cooler temperatures

Summary of Laboratory Results

- The lower early strength gain of Mix 3, coupled with higher stiffness and higher CTE, increases the risk of restrained thermal cracking at early ages
- The lower overall shrinkage of Mix 3 reduces the risk of drying shrinkage cracking at later ages
- Mix 2 has significantly higher resistivity compared to Mix 1, suggesting it is less permeable
  - Resistivity measurements suggest that Mix 3 is significantly less permeable than the other two mixes, although this would need to be further verified through more direct means

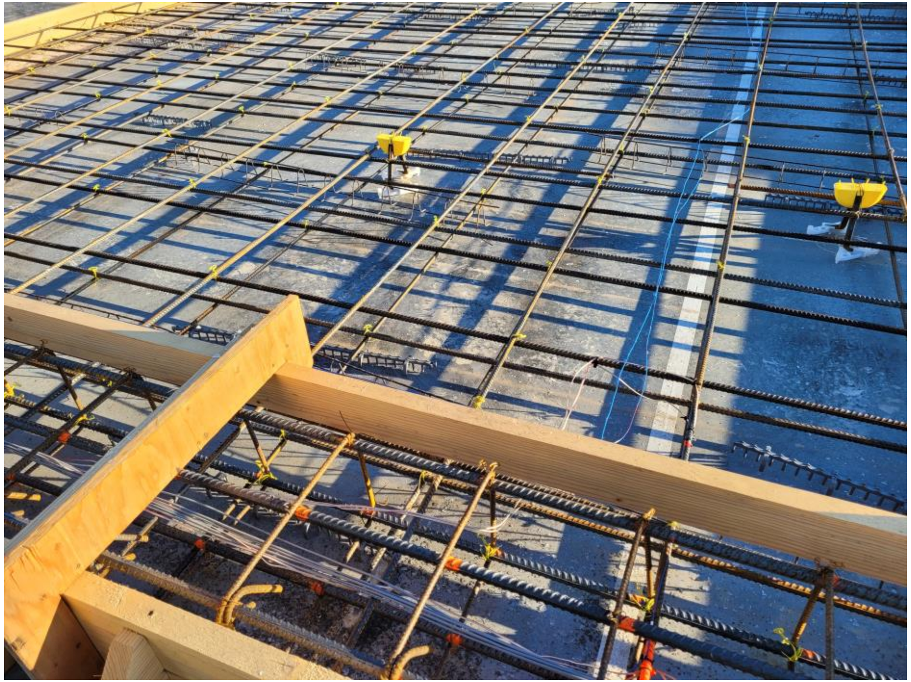
The Site

A Bit Cool



Blasting Ice Off of Slab

Instrumentation



And SmartRocks™

Fresh Concrete Properties

Property	Mix 1	Mix 2	Mix 3
Temperature (F)	79	80	73
Slump (in.)	3.5*	4.25*	9.0
Air Content (%)	2.3	2.3	3.5
Unit Weight (lb/ft^3)	152.0	148.2	142.8

Standard Construction Practices

Standard Construction Practices

Mix #3 Was A Bit Different

Finishing Sequence (in Minutes)

Activity	Mix 1	Mix 2	Mix 3
Screeding	+55	+60	+90
Bull-Floating	+65	+70	+100
1st Pass	+150	+155	+145
Last Pass	+255	+270	+265
Curing/Protection	+265	+280	+270

And Finishing

Blanket Curing – No Heat

Timing for the Tilt

- Based on compressive and flexural strength
  - Minimum compressive strength 2,500 psi and minimum flexural strength of 500 psi
  - Test cylinders and beams cured on top of panel under blankets
  - Maturity results available
- Targeting tilt for 3 days
  - Mixes #1 and #2 were tilted as planned
  - Mix #3 was tilted at 7 days

Compressive Strength (psi)

Test Age (days)	Mix 1			Mix 2			Mix 3*		
	Standard	Field	Maturity**	Standard	Field	Maturity**	Standard	Field	Maturity**
1	-	-	2,830	-	-	2,210	-	-	370
2	-	5,090	3,580	-	3,710	3,150	-	90	650
3	-	5,230	3,980	-	4,300	3,640	410	440	1,700
4	-	5,470	4,110	-	4,420	3,820	-	390	2,400
5	-	-	4,230	-	-	3,990	-	950	2,930
7	5,500	-	4,350	5,290	-	4,160	830	1,760	3,570
14	-	6,050	-	-	6,090	-	-	-	-
29	6,310	6,620	-	6,850	6,940	-	5,030	5,870	-

*Much colder temperatures at the southwest corner of the Panel 3 (location of the field cure cylinders) and inappropriate handling of the cylinders at early ages likely caused significant compromise in the measured compressive strength.

** Average of two maturity probes

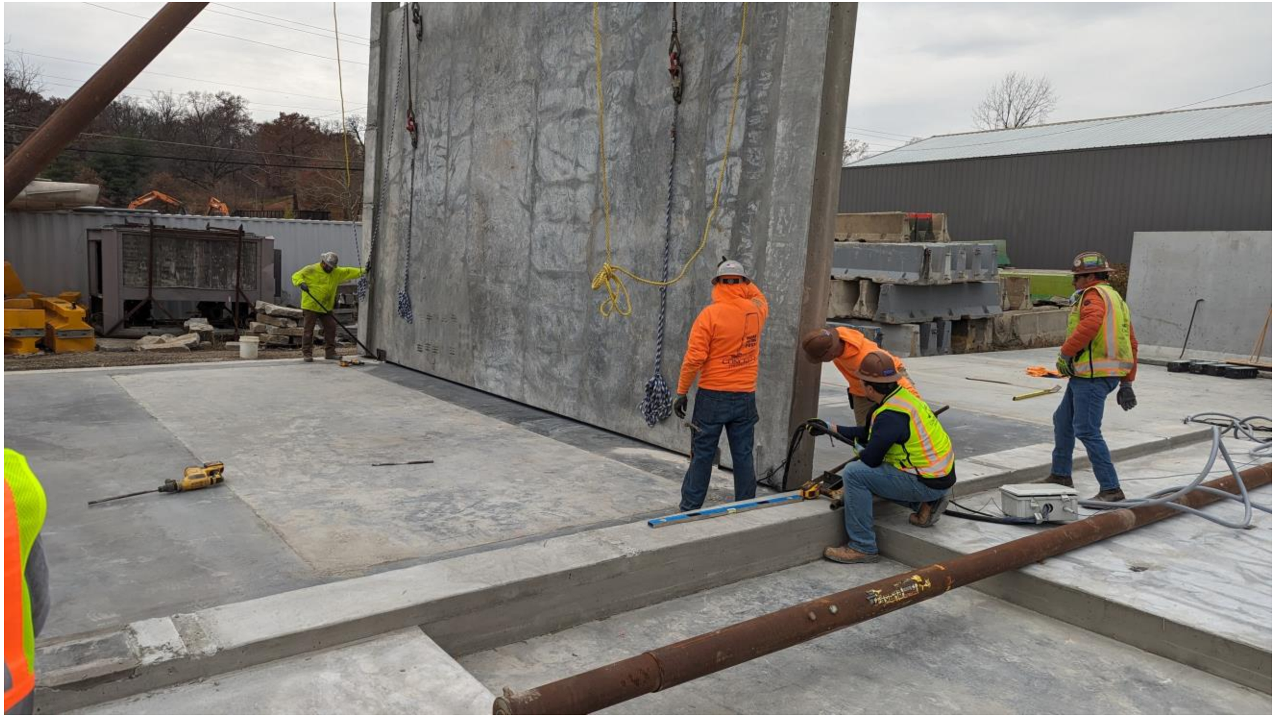
Flexural Strength (ASTM C78)(psi)

Test Age (days)	Mix 1			Mix 2			Mix 3*		
	Standard	Field	Maturity**	Standard	Field	Maturity**	Standard	Field	Maturity**
1	-	-	434	-	-	394	-	-	131
2	-	665	521	-	600	471	-	65	243
3	-	700	566	-	720	513	-	225	351
4	-	-	582	-	-	527	-	-	425
5	-	-	595	-	-	543	-	445	479
7	-	820	601	-	795	547	-	580	512

*Much colder temperatures at the southwest corner of the Panel 3 (location of the field cure cylinders)

** Average of two maturity probes

And Tilt



Takeaways

- Even though the temperatures at casting were not ideal, all mixtures could be pumped, placed, finished and tilted
  - Mix #2 was the favorite of the crew
  - Mix #3 was not popular
- Match curing was discussed as an alternative to placing test specimen on top of panels
- Maturity was considered successful
- Thought having summer and winter mixes might be needed as carbon reduction targets become more aggressive

Thanks

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