2023 FECM / NETL Spring R&D Project Review Meeting
Project Update - DE-FE0031931 *(Emissions Control)*

Facilitating Implementation of High-Volume Fly Ash Use in Precast Concrete Construction to Increase Beneficial Utilization

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Review of
Project Background and Motivation

Fly ash (FA), a coal combustion residual (CCR), is one of the most commonly used supplementary cementitious materials (SCMs).

FA particles carried out of coal combustion chamber by exhaust gases and subsequently filtered out

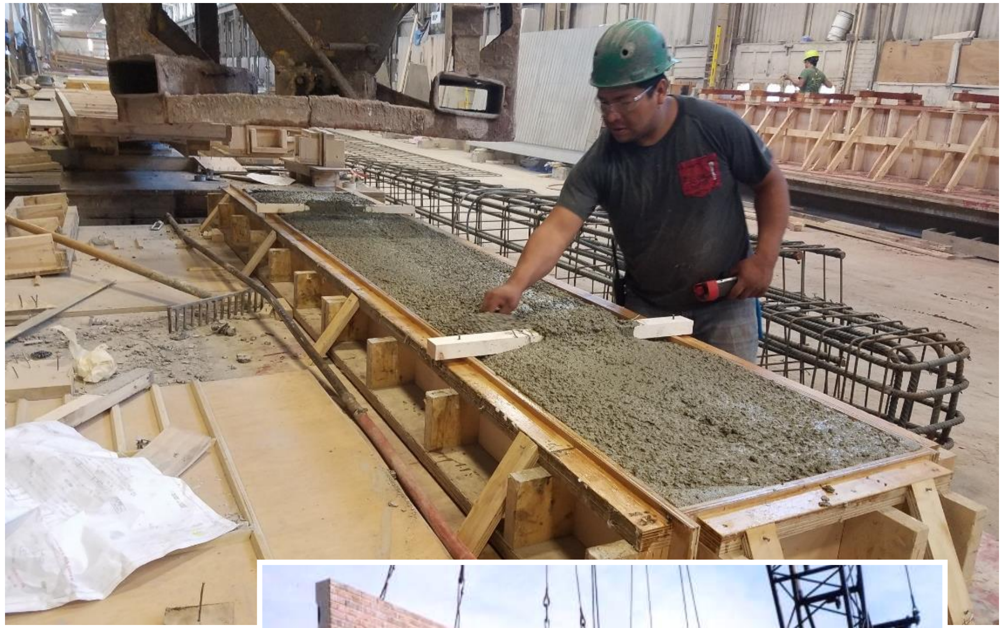
Two main classifications:
Class F → FA w/ pozzolan properties
Class C → FA w/ pozzolan & **cementitious** properties

Often used as a [partial] replacement of conventional Portland cement
→ With restrictions in precast construction

Precast Concrete → The process of fabricating concrete components in a location other than their final position.

Tilt-Up (site prefabricated)

Factory Precast



Precast Concrete Building Systems

+ Cost Effective
+ Energy Efficient
+ High Quality Control
+ Rapid Construction
+ New Technology

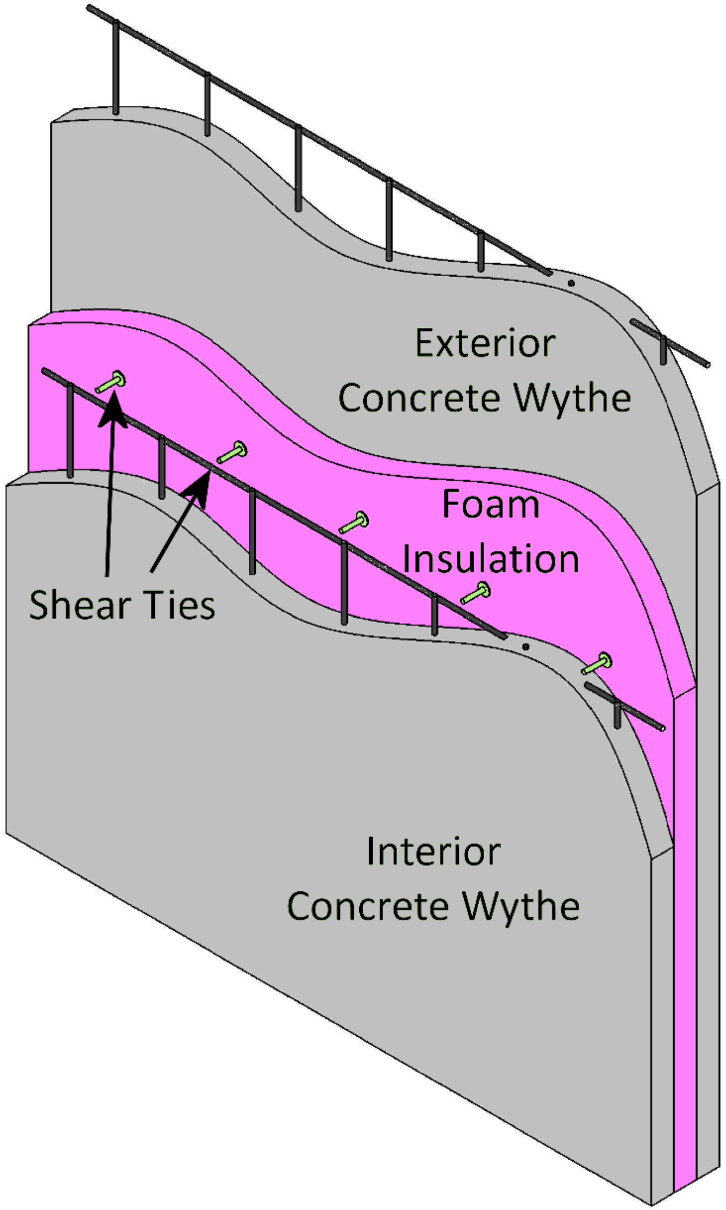
Parking Structures / Office Buildings
Residential / Manufacturing

Insulated precast concrete wall panels have grown in popularity due to **enhanced thermal properties**.

+ **Insulating foam layer** is sandwiched between **two concrete wythes**

+ **Shear ties** are used to connect the wythes and develop **composite action**

+ Further sustainability will be achieved using **HVFA concrete wythes** in conjunction with **insulating properties**.



(for Task 5)

HVFA use is more feasible in cast-in-place (CIP) concrete construction than **precast** concrete due to specialty **structural performance requirements**.

Development of **high early strength** is crucial for precast components

Maximizes operational efficiency of the facility by turning over casting beds rapidly

Components often stripped from formwork within ~24 hours of fresh concrete placement

Second photo source: “QUIKLIFT™ DTA Installation to Stripping (Precast Double Tee) by ALP Supply (formerly Patterson)” https://www.youtube.com/watch?v=sBCznhGwfFY&ab_channel=ALPSupply

Project **Objectives** and Expected **Outcomes**

1) Increase fly ash beneficial use by at least 15% in the precast concrete industry

2) Maintain or exceed stringent structural property requirements
(e.g., compressive strength at initial prestress, modulus of rupture, etc.)
Ex: 3500 psi compressive strength typical at initial prestress (~24 hrs.)

3) Exhibit little or no additional cost relative to conventional mixtures

4) Mitigate detrimental environmental consequences inadvertently caused by increased beneficial use

5) Facilitate diversion and harvesting of large fly ash quantities from landfills or impoundments

6) New design guidelines and code provisions for sustainability requirements for concrete mix designs

Project **Tasks**

Task 2 - Assessment of the state-of-the-art practices and initial materials procurement
(100% Complete)

Task 3 - Material formulation development
(85% Complete)

Task 4 - Performance testing of concrete mixtures
(80% Complete)

Task 5 - Design, fabrication, and experimental testing of full-scale specimens
(15% Complete)

Task 6 - Environmental impact study and life cycle assessments
(85% Complete)

Progress to Date

Development of **Optimized HVFA Binders** (Task 3)

Includes formulations for 40% fresh **Class C** and **F** & **harvested** F fly ashes

Evaluating mainly **compressive strength** and **flow** in this task

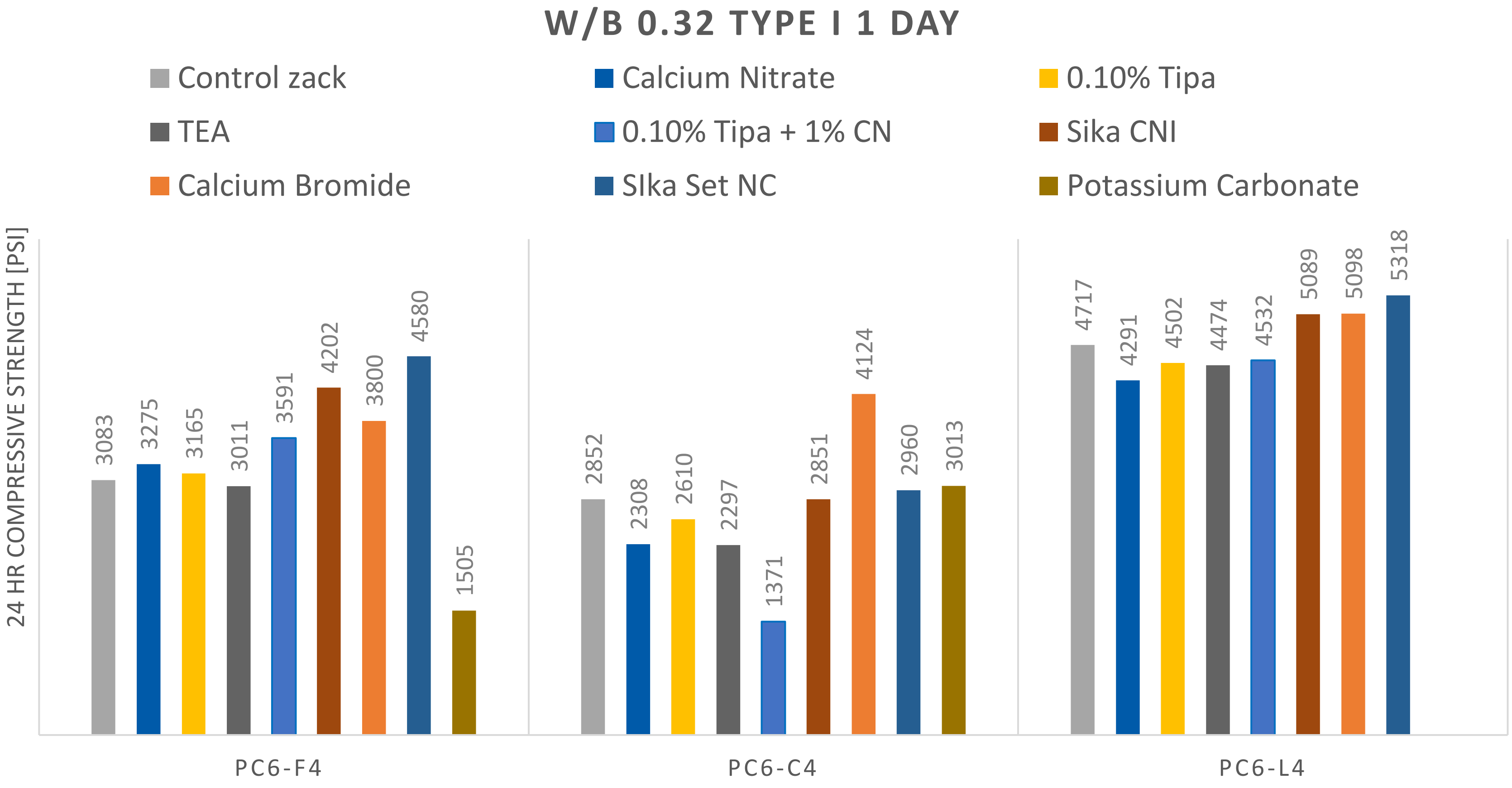
Binary Binders
→ HVFA & Type III Portland Cement w/ additional optimization

Ternary Binders
→ HVFA, Type III Portland Cement, [additional material] (w/ additional optimization)
→ Ex: CSA, slag, calcined clay, etc.

Evaluation of HVFA ***[binary]*** **binders** (Task 3)

→ **GOAL:** ~4000 psi compressive strength of mortar samples at 24 hrs.

→ NOTE: Slightly different than the overall goal of 3500 psi for concrete (discrepancy between mortar and concrete)



40% Fly ash, 60% Portland Cement Type I

Successful Accelerators:
1- Calcium Bromide
2- Tipa (Triisopropanolamine) + CN (Calcium nitrate)
3- Sika Set NC (Calcium Nitrate, Sodium Thiocyanate)
4- Sika CNI (Calcium Nitrite)

Gypsum optimization (Task 3)

Determine **SO_3** Content of Binder

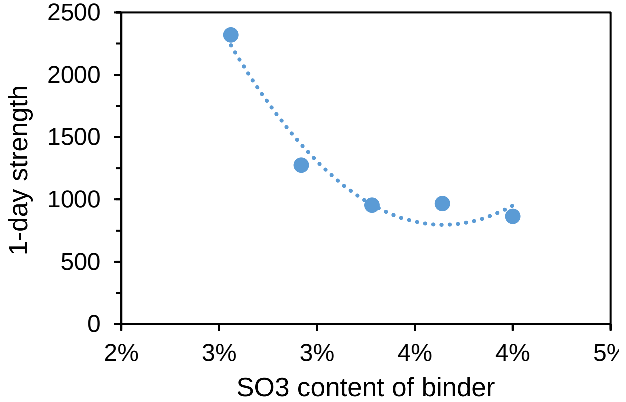
Material	SO_3 (XRF)
Type III	2.80%
Class F	2.20%
Class C	2.00%
Landfilled	0.46%
Gypsum	46.5%

ASTM - C563: Standard Guide For Approximation of Optimum SO_3 in Hydraulic Cement.

ASTM- C595: Standard Specification for Blended Hydraulic Cements determines the maximum sulfate reported as SO_3 as **"4%"**

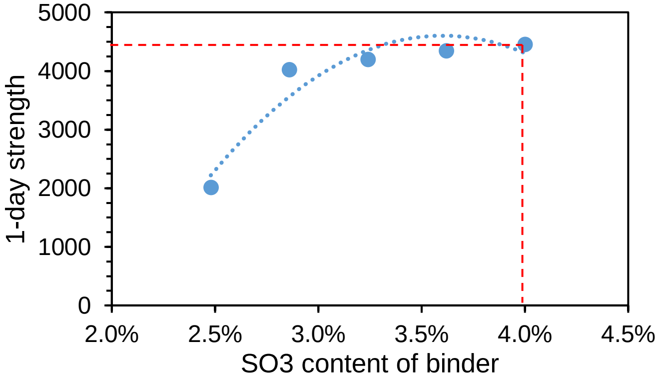
Class F

Mix	SO_3 Content	1 day strength
F-G0	2.56%	2319
F-G1	2.92%	1276
F-G2	3.28%	954
F-G3	3.64%	967
F-G4	4.00%	865



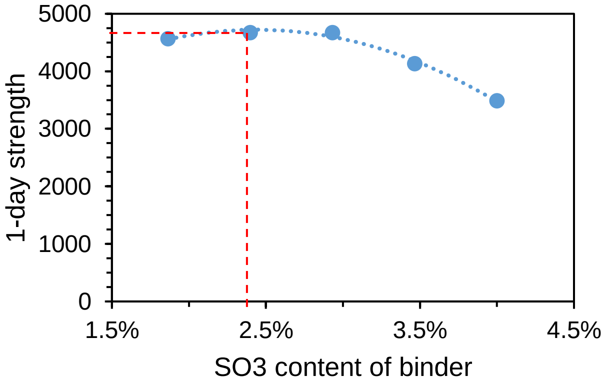
Class C

Mix	SO_3 Content	1 day strength
C-G0	2.48%	2017
C-G1	2.86%	4025
C-G2	3.24%	4200
C-G3	3.62%	4349
C-G4	4.00%	4455



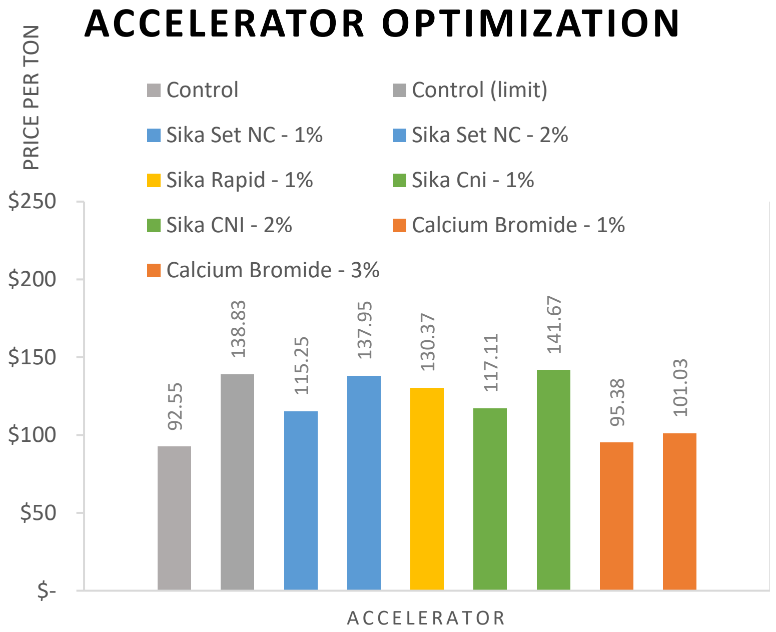
Landfilled

Mix	SO_3 Content	1 day strength
L-G0	1.86%	4563
L-G1	2.40%	4670
L-G2	2.93%	4671
L-G3	3.47%	4131
L-G4	4.00%	3483



Accelerator [admixture] **optimization** (Task 3)

→ **GOAL:** Balancing of optimized cost and 24-hour strength performance



	Class F				Class C				Landfilled			
	Sika Cni	Sika Set NC	Calcium Bromide	Sika Rapid 1	Sika Cni	Sika Set NC	Calcium Bromide	Sika Rapid 1	Sika Cni	Sika Set NC	Calcium Bromide	Sika Rapid 1
Optimal %	1%	1%	1.50%	0.50%	0%	0%	0.50%	0%	1%	1%	1.50%	0.50%
Strength	4688	4167	5505	4446	4455	4455	5156	4455	5476	5269	5554	5134

Scaling to **HVFA Concrete** (Task 4)

Optimization of 1) aggregate packing, 2) admixture dosage, and 3) w/c ratio was used to scale most promising binders to HVFA concretes

→ **Compressive** and **flexural strength** evaluated at several points during early-age period

(e.g., within ~12-24 hours & also at 28 days)

Select **Research Results** (Task 4)

40% Fresh Class C FA

Minimum Goal
3500 psi comp. strength
@ 24 hours

	Mix Design			
	C40-SCC-030-B	C40-G97-SCC-030-C	C40-G97-CABR2-SCC-030-A	C40-G97-FP20-SCC-030-A
Main Accelerators	None (control)	Optimized Gypsum	Opt. Gyp. w/ CaBr2	Opt. Gyp. w/ non-Cl Liq. Accel. A
Air Content (C231)	4.3%	6.8%	4.8%	5.5%
	12-hour Compressive Strength		16-hour Compressive Strength	
Average (psi)	1193.3	603	2903	3017
	18-hour Compressive Strength		20-hour Compressive Strength	
Average (psi)	2513.3	2750	**3837**	**3700**
	24-hour Compressive Strength			
Average (psi)	**3750**	**3760**	**4317**	**4210**

	Mix Design			
	C40-SCC-030-B	C40-G97-SCC-030-C	C40-G97-CABR2-SCC-030-A	C40-G97-FP20-SCC-030-A
Main Accelerators	None (control)	Optimized Gypsum	Opt. Gyp. w/ CaBr2	Opt. Gyp. w/ non-Cl Liq. Accel. A
Beam No.	12-hour Modulus of Rupture		16-hour Modulus of Rupture	
Average (psi)	202.7	161	515	526
ACI 318 f_r (psi)	259.1	184	404	412
Beam No.	18-hour Modulus of Rupture		20-hour Modulus of Rupture	
Average (psi)	336.0	463	562	556
ACI 318 f_r (psi)	376.0	393	465	456
Beam No.	24-hour Modulus of Rupture			
Average (psi)	439.9	565	599	607
ACI 318 f_r (psi)	459.3	460	493	487


C40-G97-SCC-030-B

Select **Research Results** (Task 4)

40% Harvested FA

<u>Minimum Goal</u>
3500 psi comp. strength
@ 24 hours

	Mix Design	
	L40-SCC-030-A	L40-G97-SR-SCC-030-A
Main Accelerators	Optimized Gypsum	Opt. Gyp. w/ non-Cl Liq. Accel. B
Air Content (C231)	6.4%	7.5%
	16-hour Compressive Strength	
Average (psi)	2183	3147
	20-hour Compressive Strength	
Average (psi)	3003	**3633**
	24-hour Compressive Strength	
Average (psi)	3373	**3977**

	Mix Design	
	L40-SCC-030-A	L40-G97-SR-SCC-030-A
Main Accelerators	Optimized Gypsum	Opt. Gyp. w/ non-Cl Liq. Accel. B
Beam No.	16-hour Modulus of Rupture	
Average (psi)	414	499
ACI 318 f_r (psi)	350	421
Beam No.	20-hour Modulus of Rupture	
Average (psi)	470	524
ACI 318 f_r (psi)	411	452
Beam No.	24-hour Modulus of Rupture	
Average (psi)	548	561
ACI 318 f_r (psi)	436	473

Slump flow test for an L40 mix.
High stability with no segregation was observed.

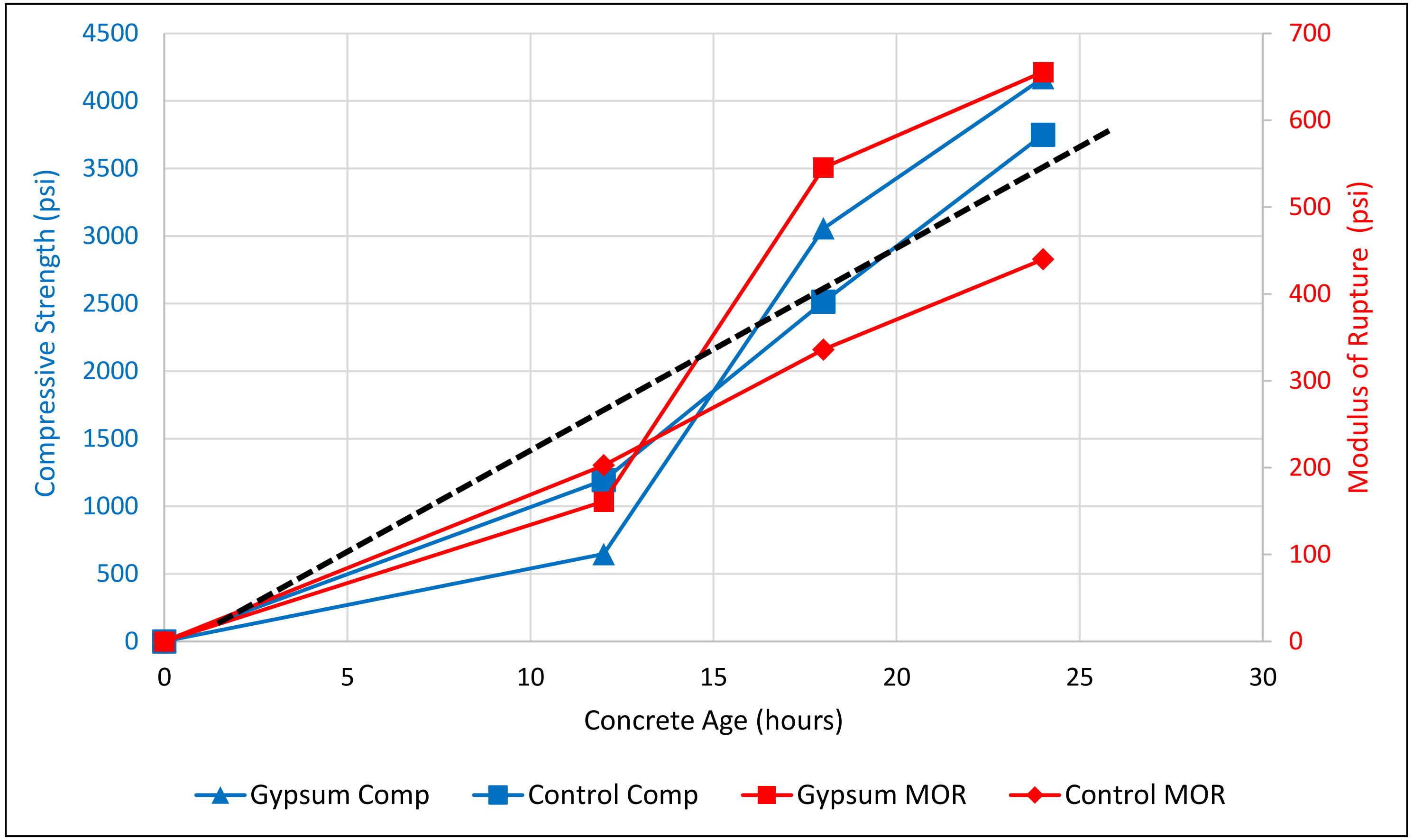
Select **Research Results** (Task 4)

40% Fresh Class F FA

<u>Minimum Goal</u>
3500 psi comp. strength
@ 24 hours

	Mix Design		
	F40-SR-SCC-030-F	F40-CI30-S40C-SCC-030-B2	F40-SR-S40C-SCC-030-G
Main Accelerators	non-Cl Liq. Accel. B	calcium nitrite Accel. (w/ Steam Curing @ 40°C)	non-Cl Liq. Accel. B (w/ Steam Curing @ 40°C)
Air Content (C231)	4.5%	3.3%	5.2%
	24-hour Compressive Strength		
Average (psi)	2913	**4481**	**4998**

Characterizing **HVFA Early Strength** Development (Task 4)



Also supplemented with projected **concrete strength-maturity curves** (ASTM C1074)

Testing of **Lifting Anchors** in **HVFA Concrete** (Task 5)

→Strength testing in Task 4 shows that tensile strength often matures at a different (slower) rate than compressive strength

→Concrete tensile strength is an important limit state for precast lifting anchors

→Testing results will report withdrawal capacity of anchors – as a function of concrete properties

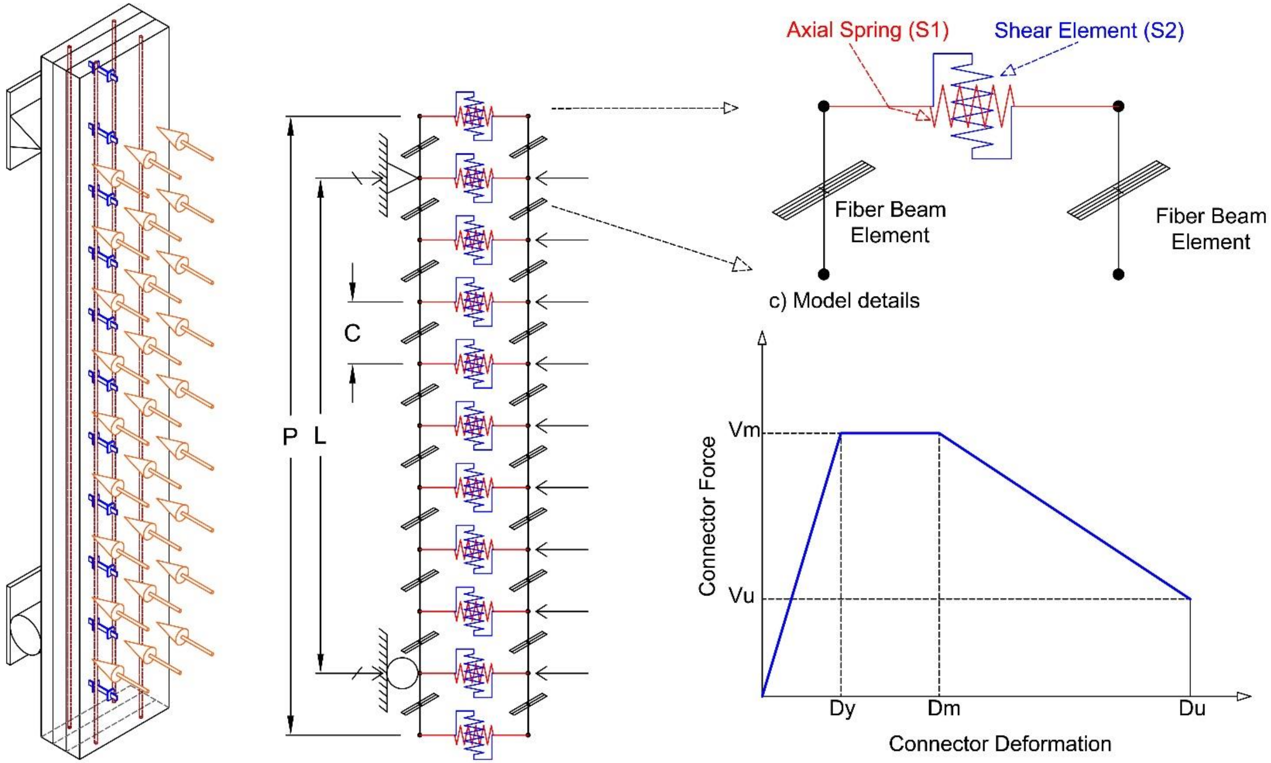
Example of Similar Previous Test

https://www.melbtest.com.au/wp-content/uploads/2020/01/Proof-Load-Test-On-Site.jpg

Preliminary Structural Modeling of **Precast Components** (Task 5)

→Serve as valuable link between material properties and predicting the performance of structural precast components

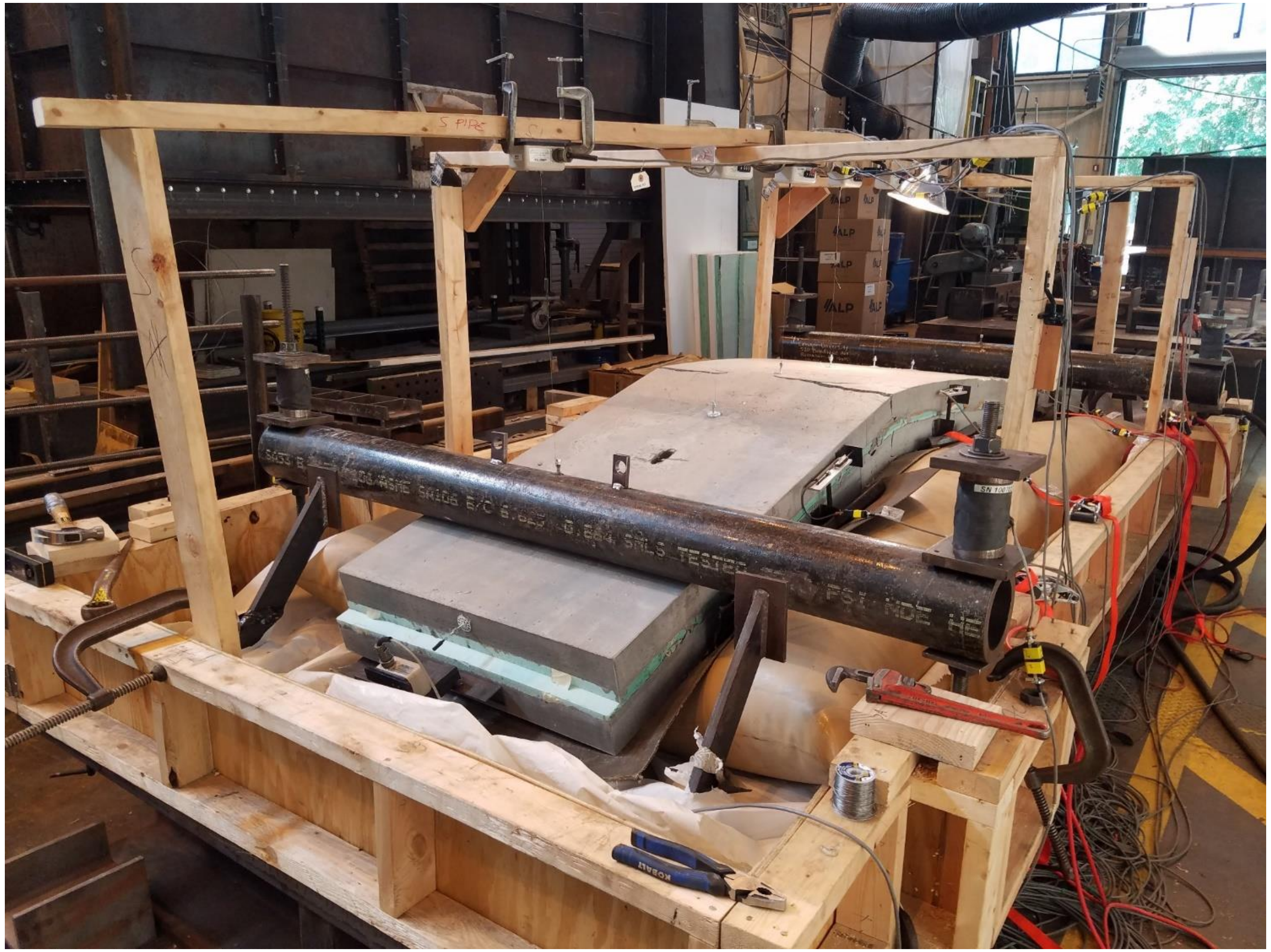
→Will be validated with experimental test data in Task 5



a) Loaded Panel b) Numerical model d) Shear element properties

Larger-Scale **Structural Testing** of **HVFA Members** (Task 5)

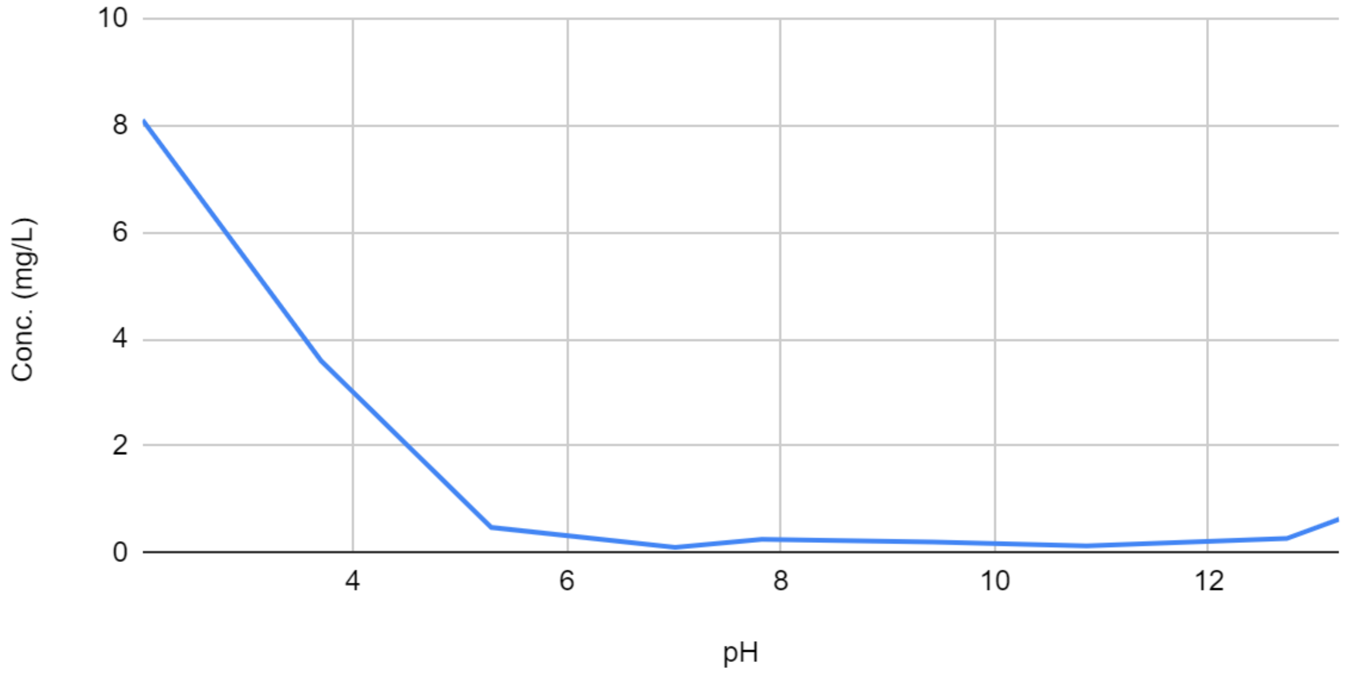
Examples of Similar Previous Tests



Nafadi et al. (2021). “Long-term behavior of precast, prestressed concrete sandwich panels reinforced with carbon-fiber-reinforced polymer shear grid” PCI Journal.

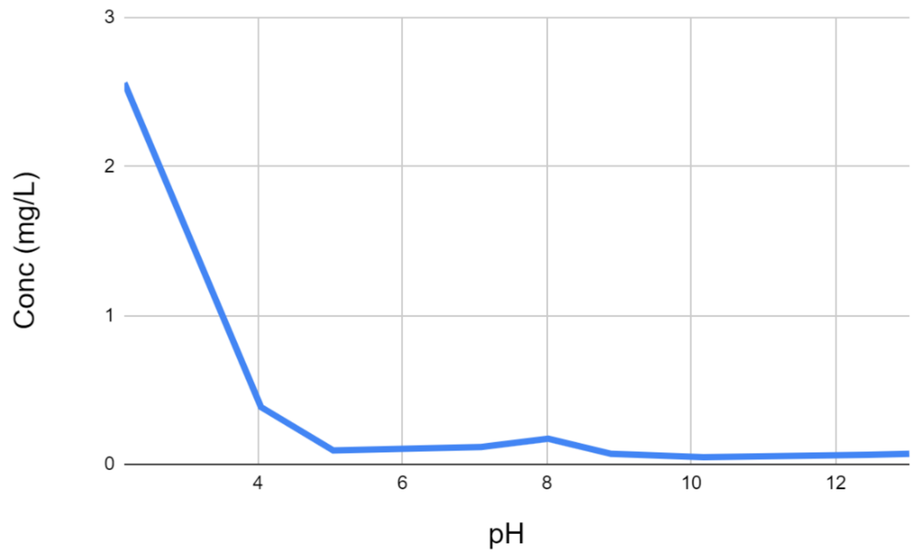
Environmental Performance (Task 6)

One of the fly ash samples exceeded the EPA drinking water limit for chromium. The general trends indicate that the chromium concentration increased as pH decreased. These results represent a maximum potential from the fly ash – once the samples are encapsulated in concrete the available COPCs are expected to be lower.

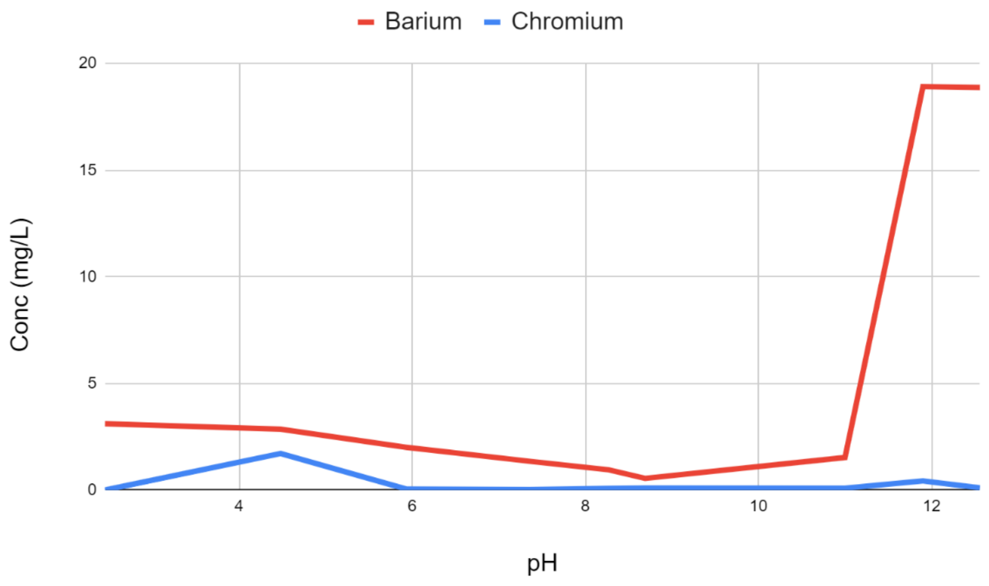


Chromium concentration from EPA Method 1313 for **fresh Class F** Fly Ash sample.

Environmental Performance cont… (Task 6)



Chromium concentration from EPA Method 1313 for **harvested Class F** Fly Ash sample.

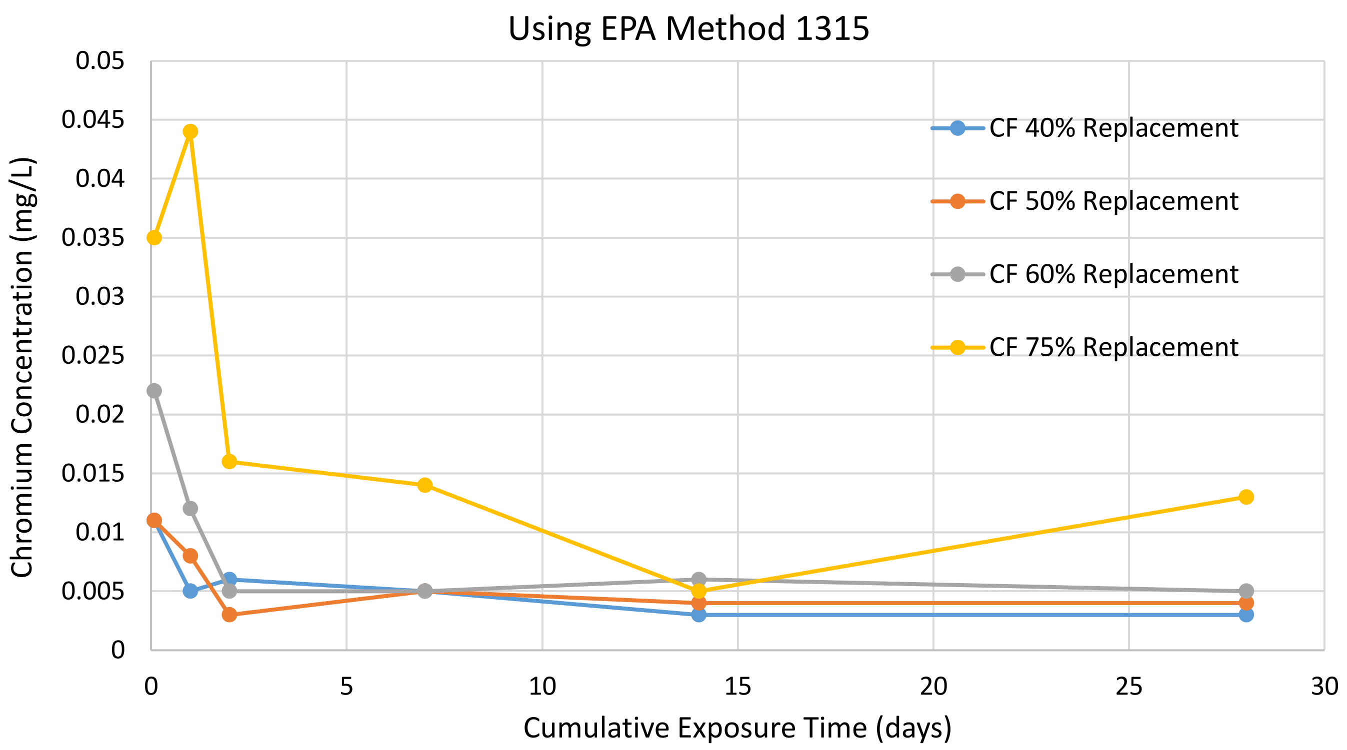


Chromium and Barium concentrations for EPA Method 1313 for **fresh Class C** Fly Ash.

These results show that the effluent increases with decreasing pH and barium increases with increasing pH.

Once again, these results represent a maximum potential from the fly ash – <u>once the samples are encapsulated in concrete the available COPCs are expected to be lower</u>.

Environmental Performance cont… (Task 6)



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Related Topics: Hazardous Waste Test Methods / SW-846 — CONTACT US

SW-846 Test Method 1315: Mass Transfer Rates of Constituents in Monolithic or Compacted Granular Materials Using a Semi-Dynamic Tank Leaching Procedure

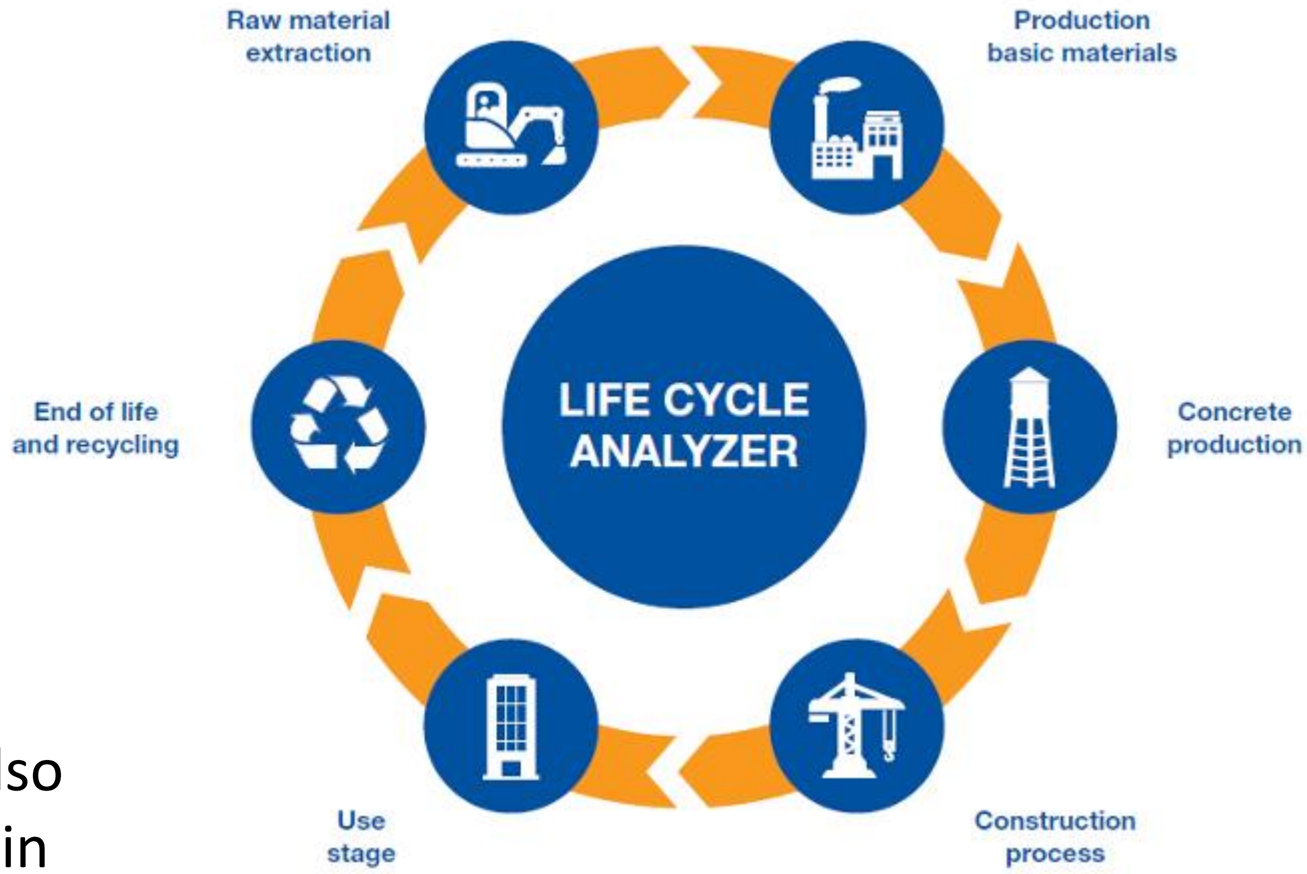
This method is one of four Leaching Environmental Assessment Framework (LEAF) methods. It is designed to provide the mass transfer rates (release rates) of inorganic analytes contained in a monolithic or compacted granular material, under diffusion-controlled release conditions, as a function of leaching time.

Environmental Life-Cycle Analyses (Task 6)

→LCA analysis framework has been built to quantify the environmental impact of using HVFA concretes

→The framework accounts for source of raw (or recycled) materials, transportation costs, end use of the concrete structure(s), etc.

→Global warming potential (GWP) will also be quantified to aid precast producers in meeting sustainable construction requirements with HVFA mixes



https://sphere-project.eu/wp-content/uploads/sites/10/2021/01/Picture-2.png

Upcoming Work

Remaining Research Tasks

Structural testing of HVFA precast members (remaining Task 5)

→ Effect of HVFA concrete on PS transfer, reinf. development, etc.
→ Non-prestressed RC beam as simple case
→ Insulated wall panel(s) [and other prototype precast component(s)]

Finish environmental life-cycle assessments (remaining Task 6)

→ Finalize GWP (CO_2e) metrics for novel HVFA mixes

Questions ?

Thank You!