BOND BEHAVIOR AND PETROGRAPHY OF ULTRA-HIGH-PERFORMANCE CONCRETE

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Project Overview

Background/Introduction

- Ultra-High-Performance Concrete (UHPC) is not a readily available concrete product due to its high manufacturing cost and use of rare material.
- The goal of this research was to find a cost-effective means of developing a concrete mixture that met the criteria of UHPC (22,000 psi compressive strength at 28 days of curing as stated in ACI 239R-18).
- Petrographic analysis was used to observe the effect of each mixing method on particle and fiber distributions, packing density of aggregate, and mineralogy of aggregate.

Materials/Methods

Vertical high-shear orbital mixer (as opposed to a rotating gravity mixer).

Steam/submergence apparatus made using ovens and bowls/buckets of water.

Materials/Methods

Caps for cylinders.

Power saw to create smooth surfaces for samples.

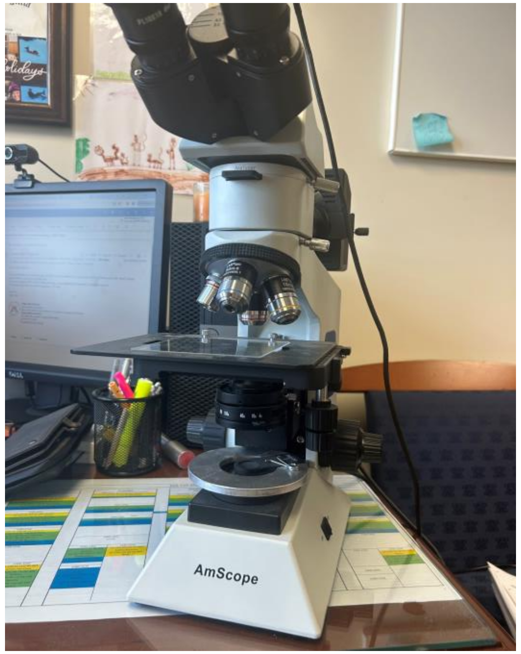
Materials/Methods

Hydraulic press to test for the compressive strength of samples.

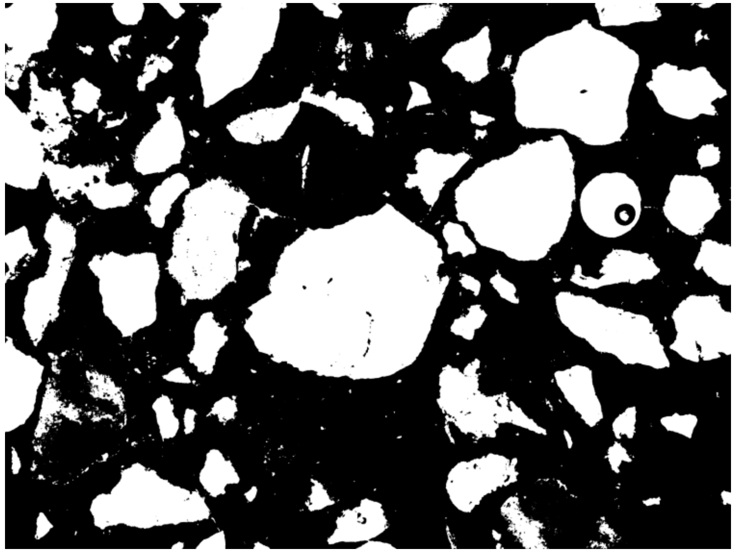
Vibrating table used for consolidating samples.

Standard micron thin sections using high pressured fluorescent epoxy impregnation.

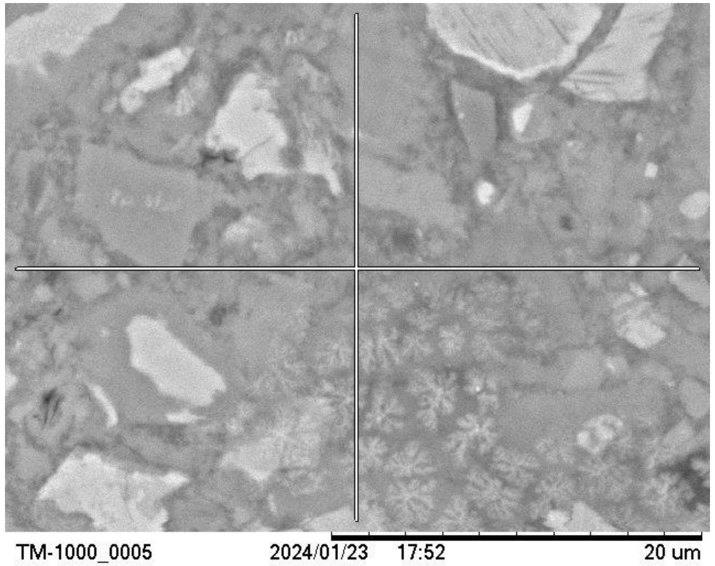
Materials/Methods



AmScope Polarizing Light Microscope



ImageJ



Electron Scanning Microscope

Part 1: Mix Design

Mix Design Development

- Started with a control mix developed by Colin Butler, a former VMI Cadet.
- Manipulated the water content of each batch.
- Added silica fume to later mixes.
- Consolidation using vibrating table.
- Changes in types of samples
  - Cast in 3x6 cylinders, 4x8 cylinders, and 2x2 cubes
- Tested various curing methods
  - Steam curing
  - Submerged curing
  - Plastic covering

Mix Design Development

Original Mix 1

- 9 2x2 Cubes
  - 4 submerged/steamed
  - 5 using plastic covering
- 8 4x8 Cylinders
  - 4 submerged/steamed
  - 4 using plastic covering
- Submerged for 5 days
- Steamed for up to 28 days

Original Mix Design		
Component	**lb/yd^3**	**lb**
Water	350	6.490
Superplasticizer	40	0.742
Sand	1687	31.284
Cement	1750	32.452
Steel Fibers	264	4.896
Silica Fume	0	0.000

Mix Design Development

Original Mix 2

- 18 3x6 Cylinders
  - 9 submerged/steamed
  - 9 using plastic covering
- 2 4x8 Cylinders
  - 1 submerged/steamed
  - 1 using plastic covering
- Soupy consistency
- Unequal fiber distribution and scaling on top of samples
- Led to the usage of petrographic analysis
- No tests were performed on these samples

Original Mix Design		
Component	**lb/yd^3**	**lb**
Water	350	6.490
Superplasticizer	40	0.742
Sand	1687	31.284
Cement	1750	32.452
Steel Fibers	264	4.896
Silica Fume	0	0.000

Mix Design Development

SF Mix 1

- 15 3x6 Cylinders
    - 15 submerged/steamed
- 1 4x8 Cylinder
    - 1 using plastic covering
- Soupy consistency
- 20% Silica Fume Replacement
- Submerged for 5 days
- Steamed for up to 28 days
- Crushing present at the top of samples after breaks
- Used caps that were too large for the samples

SF Mix - 1		
Component	**lb/yd^3**	**lb**
Water	350	6.490
Superplasticizer	40	0.742
Sand	1687	31.284
Cement	1400	25.962
Steel Fibers	264	4.896
Silica Fume	350	6.490

Mix Design Development

SF Mix 2

- 12 3x6 Cylinders
  - 6 submerged/steamed
  - 6 using plastic covering
- 1 4x8 Cylinder
  - 1 using plastic covering
- Stiff mix
- Submerged for 5 days
- Vibrating table could not consolidate it
- Low workability
- No tests were performed on this mix

SF Mix - 2		
Component	**lb/yd^3**	**lb**
Water	375	6.954
Superplasticizer	25	0.464
Sand	1687	31.284
Cement	1400	25.962
Steel Fibers	264	4.896
Silica Fume	350	6.490

Mix Design Development

SF Mix 3

- 11 3x6 Cylinders
  - 6 submerged completely
  - 5 using plastic covering
- 1 4x8 Cylinder
  - 1 using plastic covering
- Switched Super Plasticizer from Sica to Lafarge
- Did not sieve the cement before leading to cement clumps present
- Soupy consistency without fiber separation
- 3/16” shaved off each sample for a smooth surface
- Lubricated with WD-40 before breaks
- Changed to a more precise loading apparatus

SF Mix - 3		
Component	**lb/yd^3**	**lb**
Water	350	6.490
Superplasticizer	15	0.278
Sand	1687	31.284
Cement	1400	25.962
Steel Fibers	264	4.896
Silica Fume	350	6.490

Mix Design Development

SF Mix 4

- 6 3x6 Cylinders
    - 6 submerged completely
- 1 4x8 Cylinder
    - 1 using plastic covering
- Sieved sand and cement
- Voids present
- 3/16” shaved off each sample for a smooth surface
- Lubricated with WD-40 before breaks
- Stiff but vibrated and consolidated
- Possible repair application
- Good workability

SF Mix - 4		
Component	**lb/yd^3**	**lb**
Water	353	6.546
Superplasticizer	19	0.352
Sand	1687	31.284
Cement	1400	25.962
Steel Fibers	264	4.896
Silica Fume	350	6.490

Mix Design Development

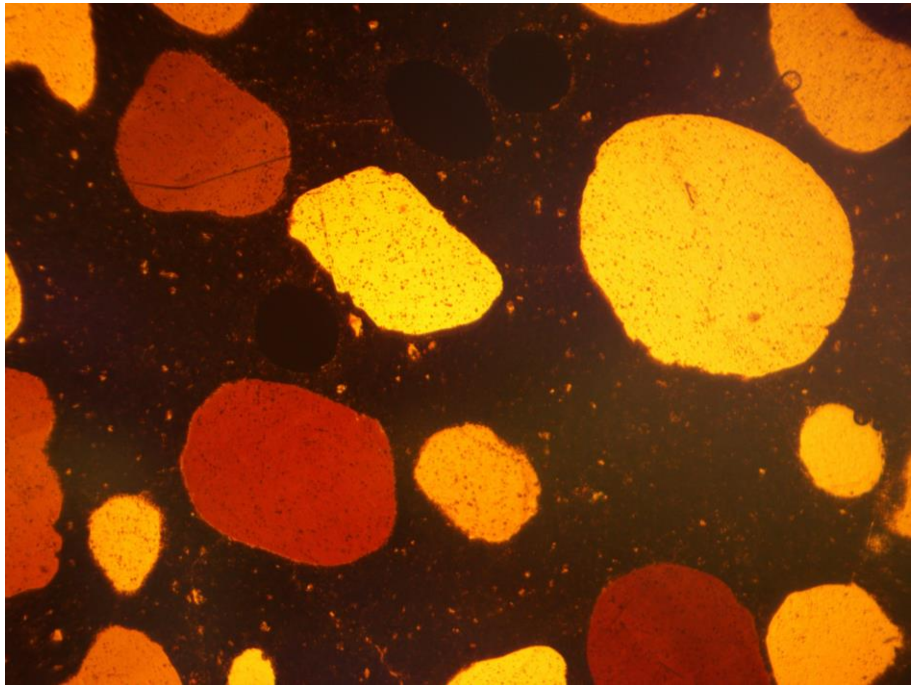
Mix Design Table	Average 28 Day Compressive Strength (psi)	
Mixes	Submerged/Steamed	Plastic Covering
Original Mix 1	23075	14632
Original Mix 2	N/A	N/A
SF-1 Mix	11186	N/A
SF-2 Mix	N/A	N/A
SF-3 Mix	15685	13110
SF-4 Mix	16504	N/A

Note: The “Submerged/Steamed” and “Plastic Covering” labels denote the curing method used for the samples. “N/A” denotes mixes that did not create samples that were ideal for testing and/or data that does not exist as a particular curing method was not utilized for that mix.

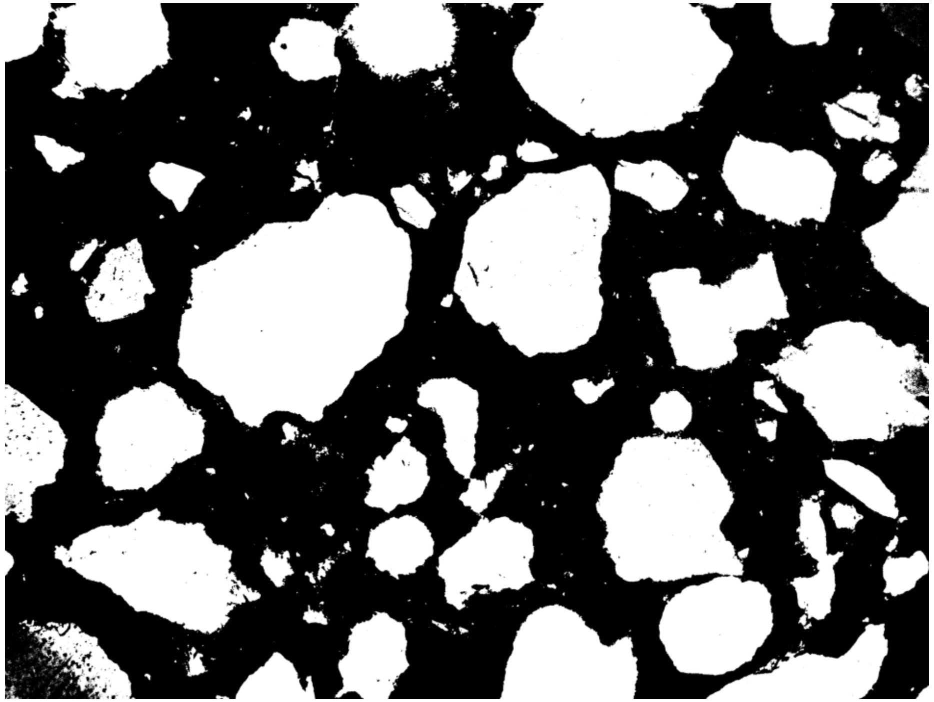
Mix Design Development

Part 2: Petrographic Analysis

Petrographic Analysis – ImageJ

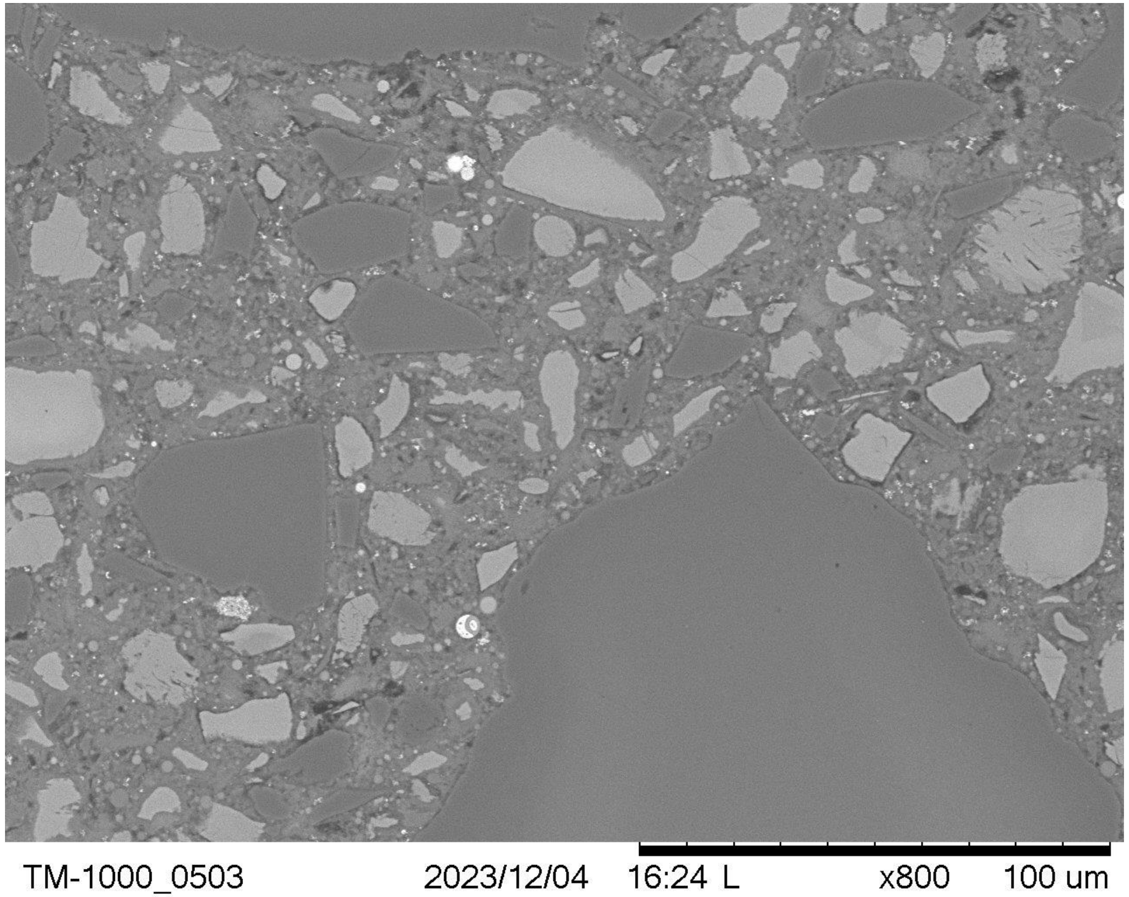


Standard Image Example



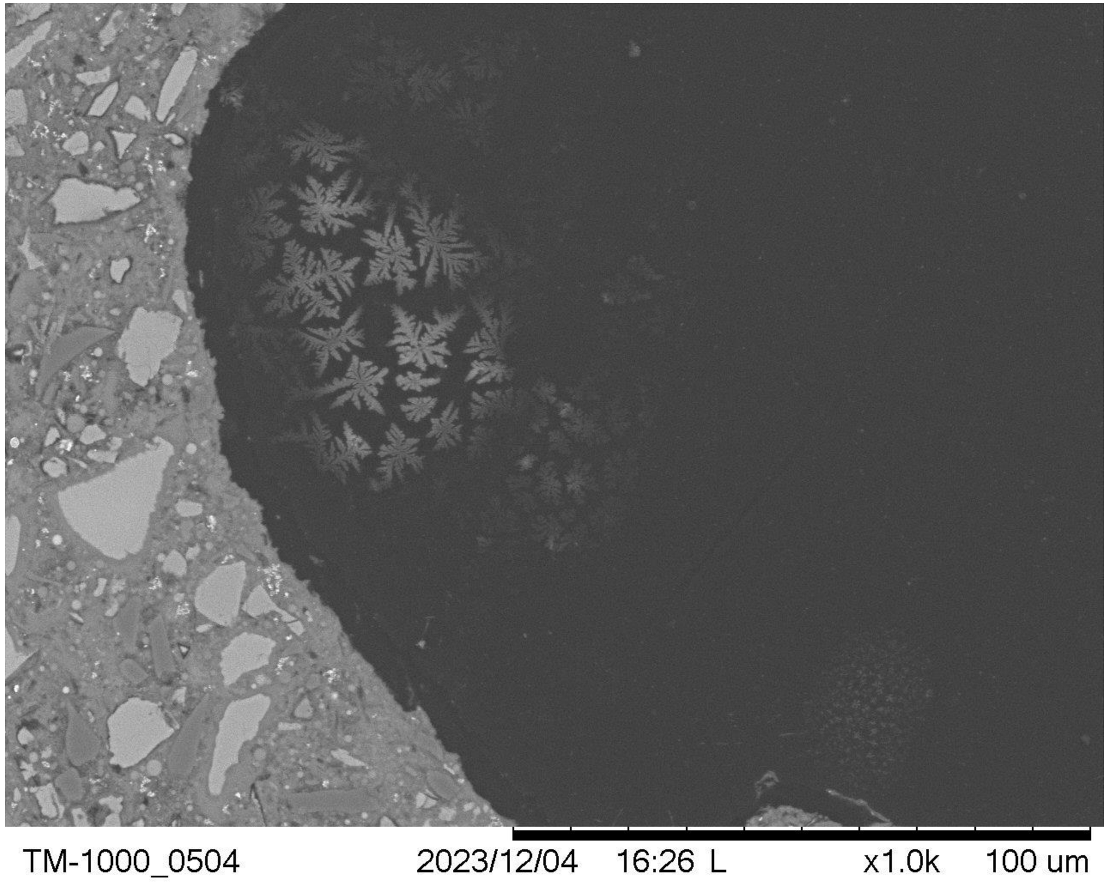
Binary Image Example

Petrographic Analysis - ESM



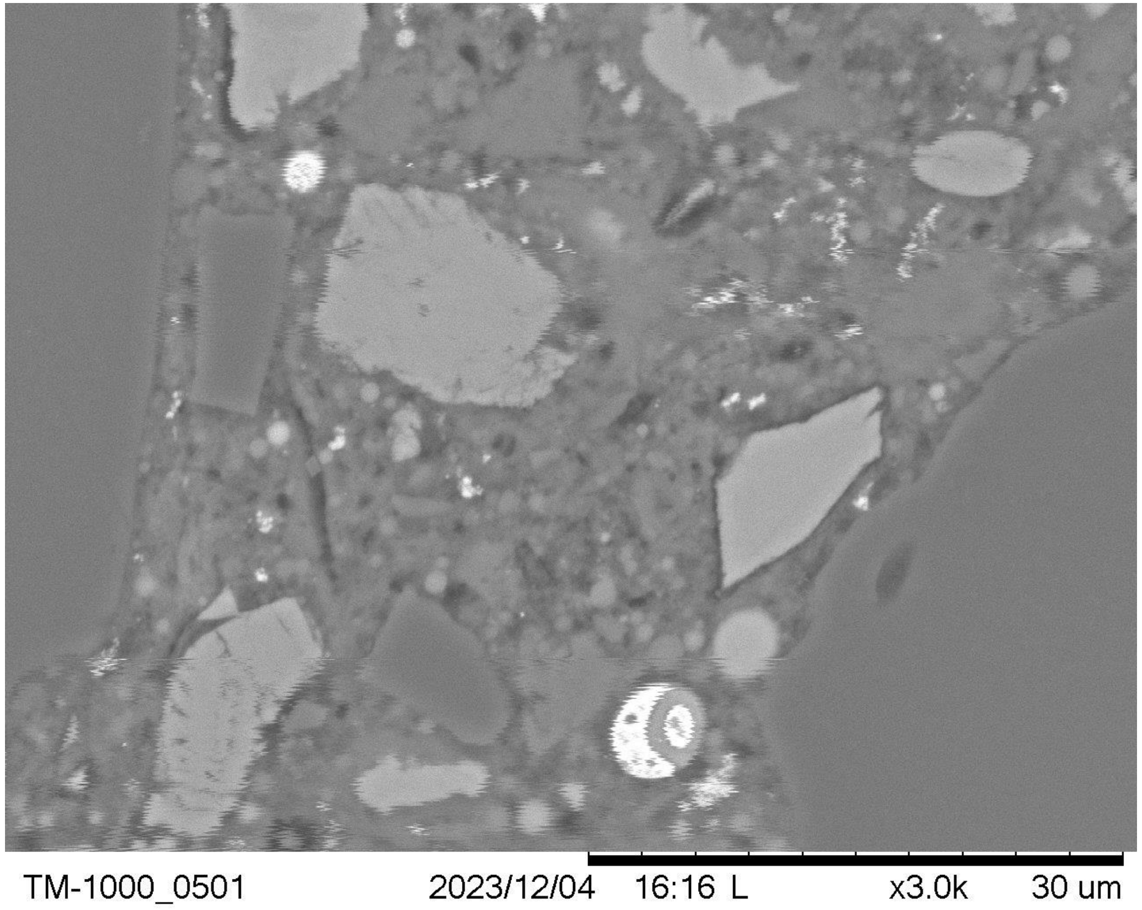
x800 Magnification

Petrographic Analysis - ESM



x1k Magnification

Petrographic Analysis - ESM

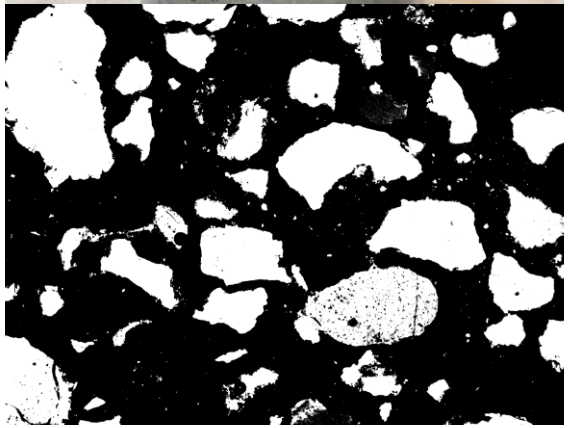


x3k Magnification

Recommendations and Conclusion

Recommendations and Conclusion

- More data needs to be gathered and a mix needs to developed where results are consistently repeatable.
- Finding the most ideal method to break cylinders prior to mixing (i.e. using WD-40)
- Utilizing steam curing and submergence yielded the best results. (Is this practical in the field?)



What Next?

- Further mixing, testing, and petrographic analysis is required in order to find and understand the most effective curing method and mix design.
- After determining the most ideal mix and the most effective curing method, the bonding between the UHPC mix and a normal concrete mix will be tested using a push-off shear test.

References

ACI Committee 239. (2018). Ultra-High-Performance Concrete: An Emerging Technology Report (ACI 239R-18). Farmington Hills, MI: American Concrete Institute.

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Questions?