ABC-UTC Non-Proprietary UHPC Workshop

Material Properties

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Outline

- Overview
- Flow and Setting Time
- Compressive and Tensile Strength
- Creep and Shrinkage
- Durability
- Bond Behavior
- Conclusions

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Objectives

- Develop an UHPC mix using materials local to Oklahoma, then modify as ABC-UTC Non-Proprietary UHPC Mix with guidance for use in different regions
- Evaluate ABC-UTC Non-Proprietary UHPC Mix performance and repeatability using FHWA recommended tests
- Examine the effect of fiber content on material properties and structural behavior

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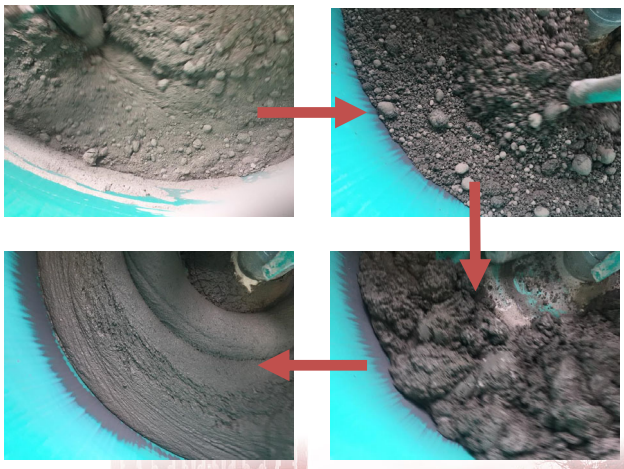
Mix Development

Final ABC-UTC Mix Design

Constituent	Mix Proportion
Type I Cement	0.6
Silica Fume	0.1
Slag Cement	0.3
Masonry Sand (1:1 agg/cm)	1.0
w/cm	0.2
Steel Fibers	2% by Volume
HRWR	18 oz/cwt



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Material Properties

Property	Test Method
Flowability	ASTM C1437
Compressive Strength	ASTM C39 ASTM C109
Modulus of Elasticity and Poisson's Ratio	ASTM C469
Splitting Tensile Strength	ASTM C496
Flexural Strength	ASTM C78/C1609
Direct Tensile Strength	FHWA (Graybeal and Baby, 2013)
Total and Drying Shrinkage	Embedded VWSG ASTM C157
Compressive Creep	ASTM C512
Set Time	ASTM C403
Freeze-Thaw Resistance	ASTM C666
Rapid Chloride Ion Permeability	ASTM C1202

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Material Properties

- Tests run using ASTM procedures with modifications for available testing equipment and modifications of ASTM C1856 for UHPC
- Examined local Oklahoma materials and Florida materials shipped from FIU
- Unless otherwise specified, steel fibers were 0.008 in. (0.2 mm) diameter, 0.5 in. (13 mm) long smooth steel fibers (Dramix® OL 13/0.2)
- All specimens cured in approximate 73 °F water bath after removing from forms at approximately 3 days

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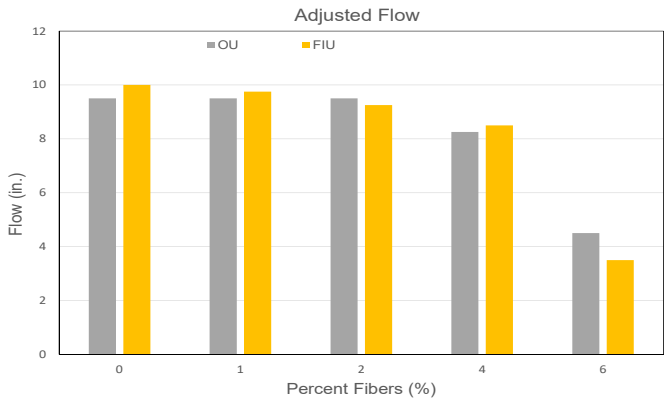
Flowability



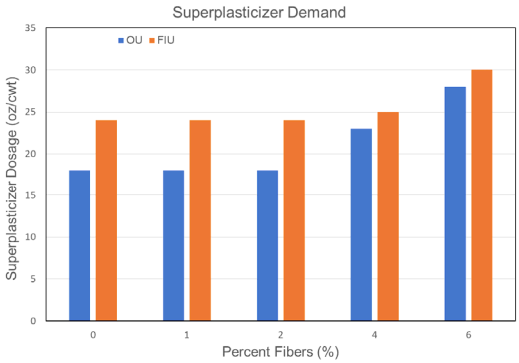
Measured flow for batches cast with OU and FIU materials

0% Fibers

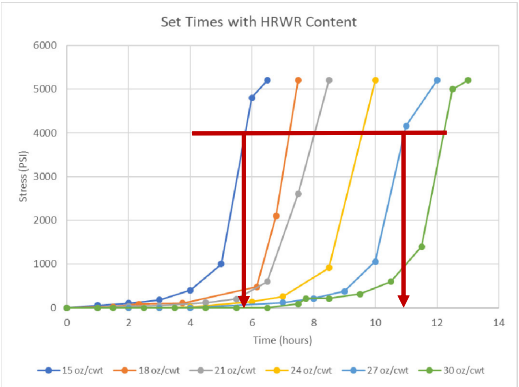
4% Fibers

6% Fibers

Setting Time and HRWR Demand



HRWR dosages required to achieve flow results for OU and FIU materials



ASTM C403 penetration resistance results for batches cast with OU materials

Flowability and Setting Time

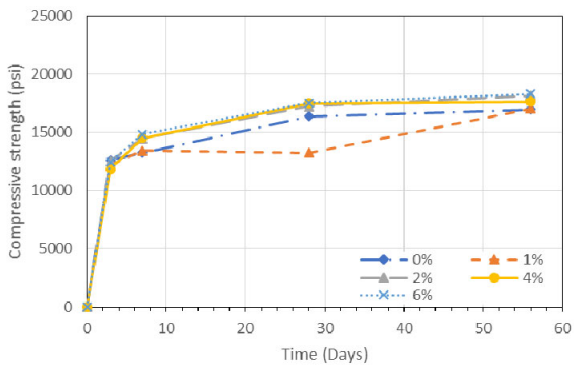
- Setting time increased with high range water reducer (HRWR) dosage
- The same HRWR dosage provided adequate flow for 0%, 1%, and 2% fibers
- Even with an increased HRWR dosage, the 4% fibers batch had a lower flow and the 6% fibers batch did not achieve adequate flowability
- FIU materials required a generally higher HRWR dosage for the same flow

Compressive Strength

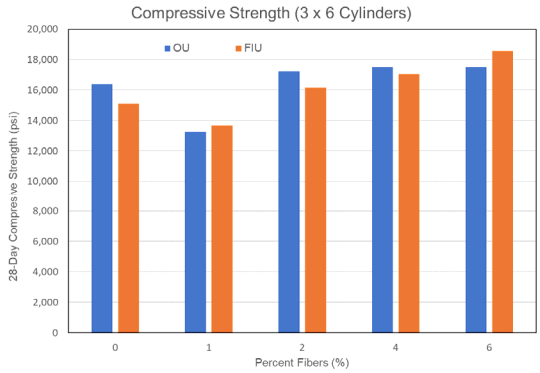
Tested specimens with no fibers

Tested specimens with 2% fibers by volume

Compressive Strength



Compressive strength over time for OU materials



28-day compressive strength results for OU and FIU materials

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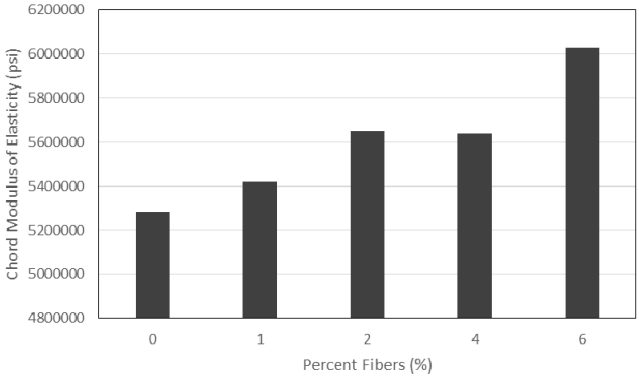
Modulus of Elasticity

Modulus of elasticity testing using 4 in. by 8 in. cylinders



ASTM C469 modulus of elasticity results for batches cast with OU materials

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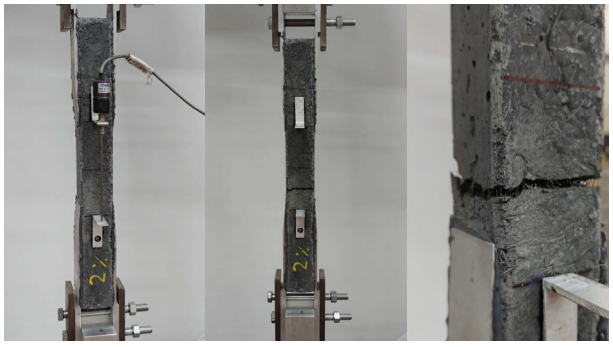
Compressive Strength and Modulus

- Compressive strength generally increased with increasing fiber percentage
- The 1% fiber content batches exhibited lower compressive strength for unknown reasons – not seen in subsequent testing
- Modulus of elasticity increased with increasing fiber content, but all specimens were in the range of 5200 to 6000 ksi

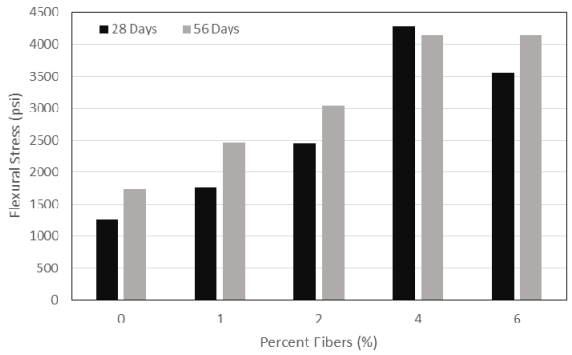
Tension Strength

Modified ASTM C1609 flexural test specimen

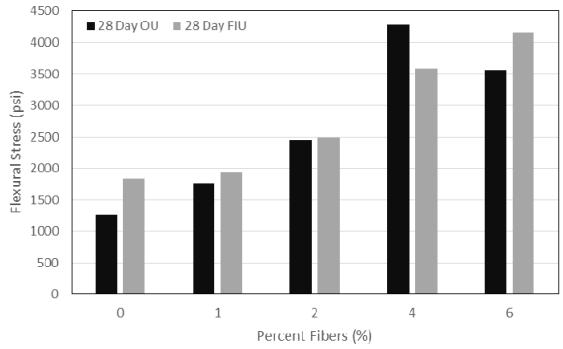


Modified direct tension test specimen with 2% steel fibers

Flexural Strength



Maximum flexural strength results at 28 and 56 days of age for OU materials



Maximum flexural strengths for OU and FIU materials at 28 days

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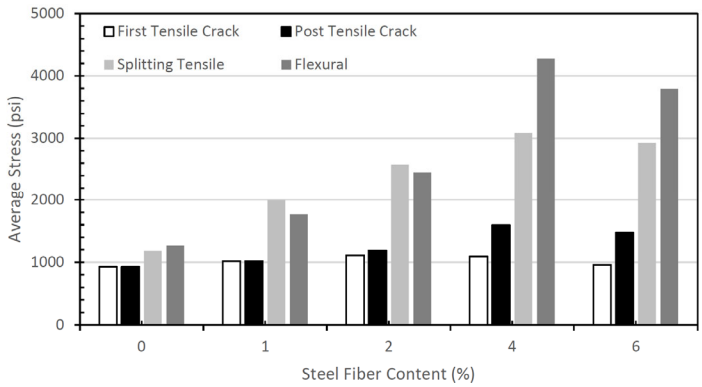
Tensile Strength Comparison



Comparison of results from direct tension, splitting tension, and flexural tension tests for batches with OU materials at 28 days

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Compressive and Flexural Strength

- Flexural strengths generally increased with increasing fiber content
- For OU materials the maximum flexural strength was observed with 4% fibers
- OU and FIU materials has similar flexural strengths
- Direct tension strength at first cracking was between 800 and 1000 psi and larger post-cracking tensile strength was observed for specimens with more than 2% fibers
- The highest direct tension strength was observed with 4% fibers

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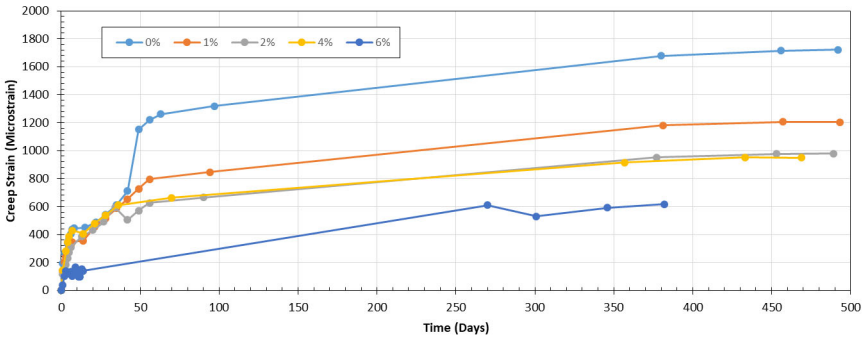
Compressive Creep



Compressive creep strain over time

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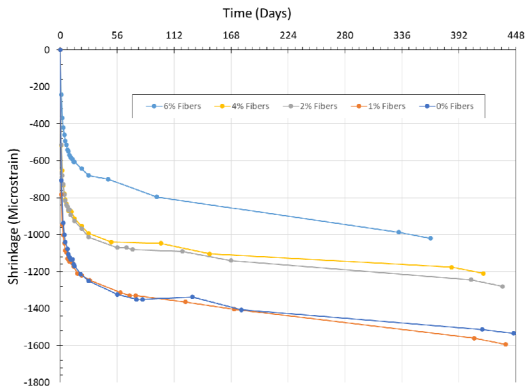
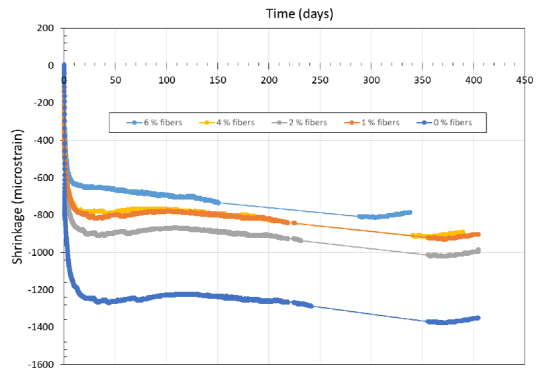
Shrinkage



ASTM C157 shrinkage measurements over time



Shrinkage measurements using vibrating wire strain gauges in 6 in. x 12 in. cylinders over time

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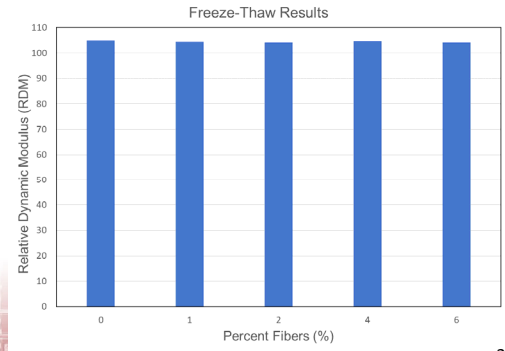
Durability

- Freeze-thaw testing with different fiber contents
- Compare to proprietary UHPC
- Rapid chloride (RCIP) testing
- Composite specimens to examine durability of interface

Property	AA	Proprietary (2% fibers)	Non-Proprietary (2% fibers)
Rapid Chloride (28 day)	2465 C	61 C	251 C
	Moderate	Negligible	Very Low
Freeze-Thaw RDM (350 cycles)	99.1%	102.5%	103.1%



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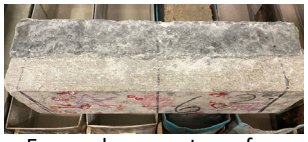
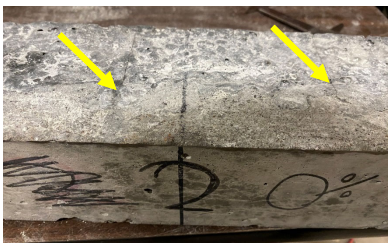
Durability

- Freeze-thaw durability
  - Composite UHPC and conventional concrete specimens
  - Varying fiber content



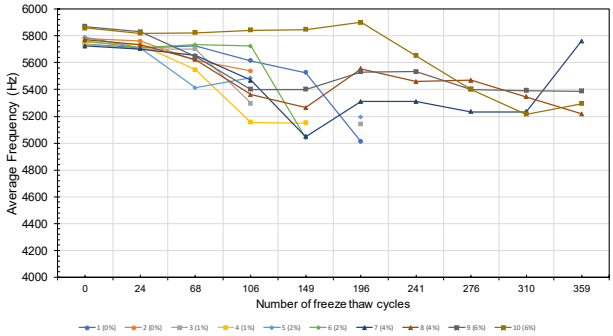
Exposed aggregate surface and completed specimen



0% fibers specimen after 150 cycles showing transverse cracks

0% fibers specimen after 350 cycles

Freeze-Thaw



Change in composite specimen resonant frequency over time

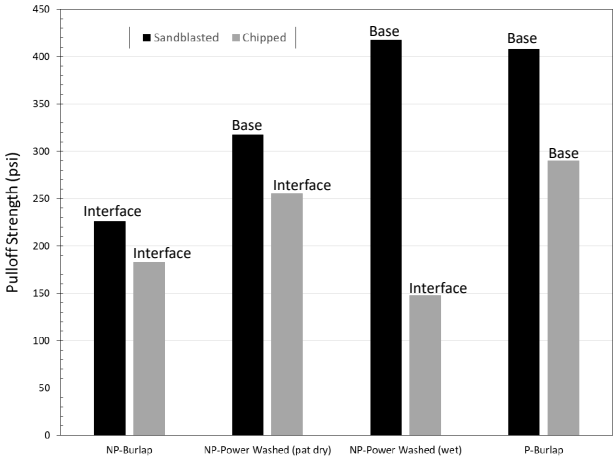
Close-up showing no damage at interface after freeze-thaw testing

Bond to Conventional Concrete

Sandblasted surface

Chipped surface

ASTM C1583 pulloff test



Pulloff test results – labels indicate failure location

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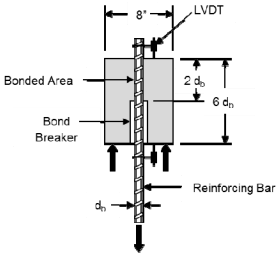
Bond Strength

- Comparative pull-out tests
- Beam splice tests



Pullout specimen details and test setup

Splice beam testing arrangement

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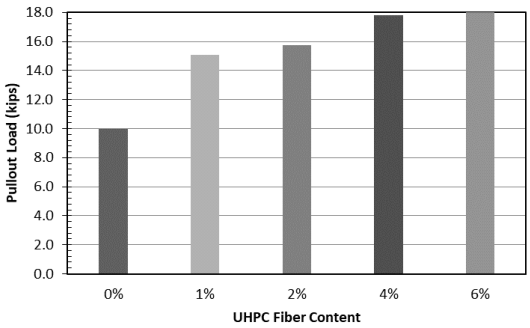
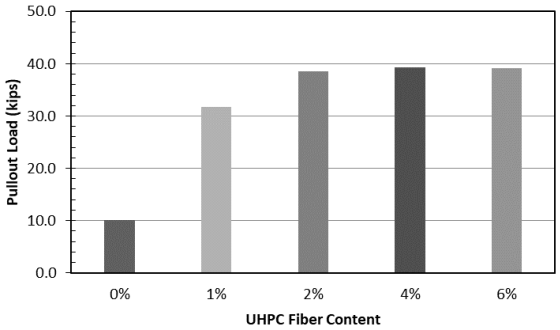
Bond Strength – Black Steel



Maximum pullout loads for No. 5 bar black steel specimens



Maximum pullout loads for No. 8 bar black steel specimens

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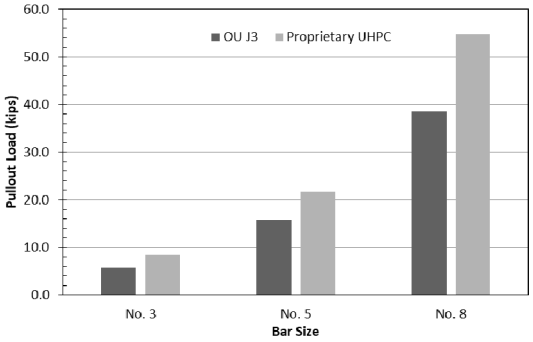
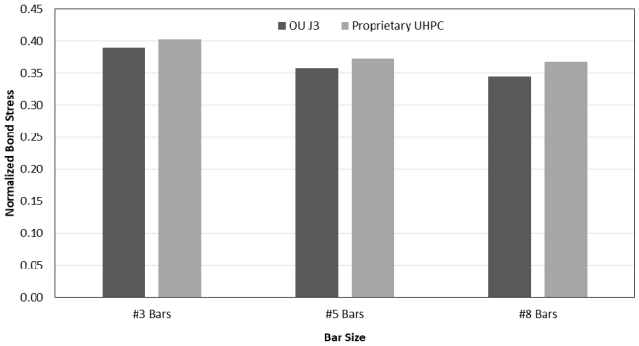
Bond Strength – Black Steel



Maximum pullout loads for black steel specimens with 2% steel fibers



Normalized bond stress for black steel specimens with 2% steel fibers

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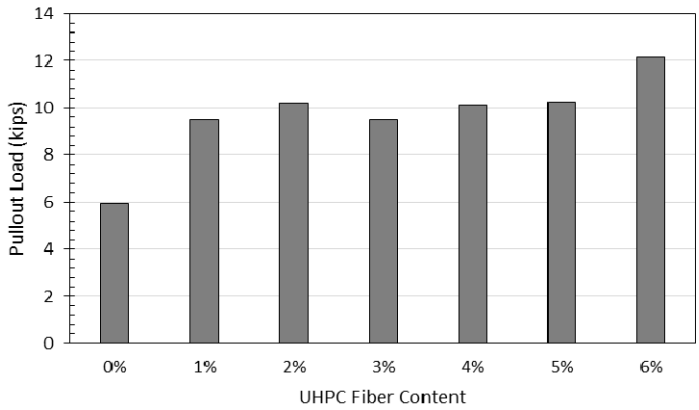
Bond Strength – Epoxy Coated



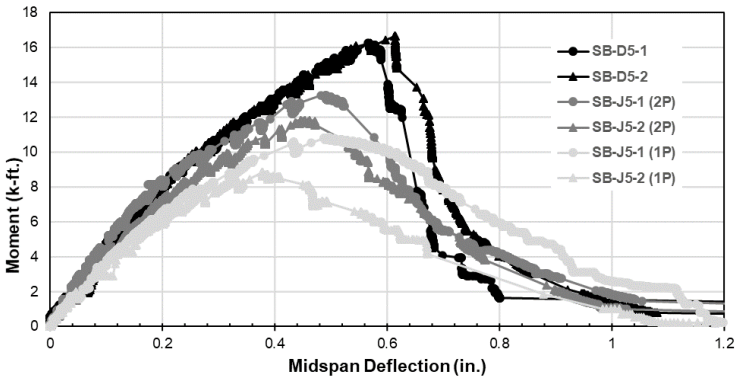
Maximum pullout loads for No. 4 epoxy coated steel specimens

Beam Splice Tests

Non-proprietary UHPC specimen showing distributed cracking at failure

Proprietary UHPC specimen showing limited cracking at failure

Beam Splice Tests



Comparison of beam splice test results for No. 5 bar specimens

Conclusions

- Non-proprietary UHPC can achieve superior properties desired for many applications and similar properties to commercial UHPC
- Adequate properties for some applications achieved with 1% steel fibers
- Freeze-thaw resistance was excellent including at interface of UHPC and conventional concrete
- Little increase in pullout strength was observed after 2% steel fibers for black steel and after 1% fibers for epoxy-coated bars
- Non-proprietary UHPC exhibited more cracking during bar splice test and bar splices performed better with 2% steel fibers by volume

References

- Campos, R. (2020) "Effect of Fiber Content on Tensile Strength of Non-proprietary Ultra-High Performance Concrete, M.S. Thesis, University of Oklahoma, Norman, OK.
- Dyachkova, Y. (2020) "Effect of Steel Fiber Content on Mechanical Properties of Non-proprietary Ultra-High Performance Concrete, M.S. Thesis, University of Oklahoma, Norman, OK.
- Looney, T., Leggs, M., Volz, J., and Floyd, R. (2022) "Durability and Corrosion Resistance of Ultra-High Performance Concretes for Repair," *Construction and Building Materials*, 345, 12 pp., https://doi.org/10.1016/j.conbuildmat.2022.128238
- Looney, T., Coleman, R., Funderburg, C., Volz, J., and Floyd, R. (2021) "Concrete Bond and Behavior of Non-Proprietary Ultra-High Performance Concrete Bridge Slab Joints," *ASCE Journal of Bridge Engineering*, 26(2), 11 pp., doi: 10.1061/(ASCE)BE.1943-5592.0001669.
- Looney, T., McDaniel, A., Volz, J., and Floyd, R. (2019) "Development and Characterization of Ultra-High Performance Concrete with Slag Cement for Use as Bridge Joint Material", *British Journal of Civil and Architecture Engineering*, 1(2): 1-14.

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