DEVELOPMENT OF NON-PROPRIETARY UHPC MIX

Quarterly Progress Report
For the period ending May 31, 2020

Submitted by:
PI- David Garber, PhD, PE
Graduate Student- Esmail Shahrokhinasab (PhD student)
Undergraduate Student- Cristhian Gutierrez De Pineres (Fall 2019)

Affiliation: Department of Civil and Environmental Engineering
Florida International University
Miami, FL

ABC UTC
ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

Submitted to:
ABC-UTC
Florida International University
Miami, FL

1. Background and Introduction

Ultra-high performance concrete (UHPC) is cementitious composite material with high compression strength (greater than 21 ksi), high tensile strength (greater than 1 ksi), and sustained post-cracking tensile strength. Proprietary UHPC mixes offer consistent quality and material properties but come at a premium compared to the cost of the individual components of the mix. Non-proprietary UHPC mixes have been previously investigated by several state DOTs and FHWA but are dependent on the type and quality of locally available materials.

The proposed study by FIU is part of a larger overall project including all five of the ABC-UTC partner universities. The main objective of this proposed study is to develop a non-proprietary UHPC mix design, labeled “ABC-UTC Non-Proprietary UHPC Mix,” made with local materials that can achieve the necessary mechanical properties and durability for use in bridge components, repair, and connections. The starting point for this mix will be non-proprietary UHPC mixes previously developed by the University of Oklahoma (OU). The ABC-UTC has partner universities covering most of the country, so the applicability of the previously developed mix design in different regions will be assessed or a set of regionally applicable non-proprietary UHPC mixes will be developed. One additional variable that will be considered during mix development is fiber content and fiber type.

The OU team will coordinate the overall effort of researchers at the five ABC-UTC partner universities to investigate material properties, bond strength, shear strength, and full-scale structural performance of the “ABC-UTC Non-Proprietary UHPC Mix” developed by the partner universities working together. Information and materials will be shared between the partner universities to investigate the repeatability of the proposed mix design. The combined efforts of the partner universities will lead to more significant results than could be obtained by any of the institutions working individually.

The study proposed by FIU will focus on evaluating the material properties of the “ABC-UTC Non-Proprietary UHPC Mix” and provide necessary information and materials to OU for the development of a “Guide for ABC-UTC Non-Proprietary UHPC.” FIU will also contribute to the planned technology transfer workshop at the 2019 International ABC Conference in Miami.

2. Problem Statement

Ultra-high performance concrete (UHPC) is cementitious composite material with high compression strength (greater than 21 ksi), high tensile strength (greater than 1 ksi), and sustained post-cracking tensile strength. Proprietary UHPC mixes offer consistent quality and material properties, but come at a premium compared to the cost of the individual components of the mix. Non-proprietary UHPC mixes have been previously investigated by several state DOTs and FHWA, but are dependent on the type and quality of locally available materials.

3. Objectives and Research Approach

The proposed research project will be part of a coordinated effort between researchers at the five ABC-UTC partner universities. The main objective of this proposed study is to develop a non-proprietary UHPC mix design, labeled “ABC-UTC Non-Proprietary UHPC Mix,” made with local materials that can achieve the necessary mechanical properties and durability for use in bridge components, repair, and connections. The mix design that was developed by OU will be shared with the other partner universities for comparative testing with other well-established

UHPC mix designs. The final mix design will be evaluated at OU and FIU by conducting a series of tests that has been recommended by FHWA for qualifying various mix designs as UHPC. The full list of FHWA recommended material tests are provided in this proposal. Fiber content will be one of the primary variables evaluated in this project. Fiber contents of 0%, 1.0%, 2.0%, 4.0%, and 6.0% by volume will likely be considered.

4. Description of Research Project Tasks

The research objectives will be accomplished through the following work plan. All research tasks will be conducted in collaboration with the other ABC-UTC universities.

Task 1. Review of Non-Proprietary UHPC Mix Designs

The objective of the first task is to obtain previously proposed non-proprietary UHPC mix designs and review previously completed research on non-proprietary UHPC performance. The primary non-proprietary UHPC mix design that will be used in this project will most likely be the mix developed by OU, shown in Table 1. Details from other non-proprietary UHPC mixes will be used if modifications to the OU mix design are needed to adapt the mix to locally available materials.

Table 1: Non-proprietary UHPC mix design proposed by OU

Type	Quantity
Type I Cement, lb/yd^3	1179.6
Slag, lb/yd^3	589.8
Silica Fume, lb/yd^3	196.6
w/cm	0.2
Fine Masonry Sand, lb/yd^3	1966
Steel Fibers, lb/yd^3	255.2
Steel Fibers, %	2.0
Glenium 7920, oz./cwt	15.77

Task 1 Update (6/1): Relevant literature is still being collected, evaluated, and summarized to guide the future mix design and testing.

Task 2. Mechanical Testing and Customization of Non-Proprietary Mix

The objective of this task will be to determine the effects of (1) UHPC constituent materials locally available to each partner university and (2) fiber content on the behavior of the "ABC-UTC Non-Proprietary UHPC Mix." This will be done by testing UHPC mixtures with locally available materials and fiber contents of 0%, 1.0%, 2.0%, 4.0% and 6.0% (by volume) using tests recommended by FHWA for qualifying UHPC mix designs. The recommended tests and the universities that will be conducting each of these tests are summarized in Table 2.

Table 2: Material property tests recommended by FHWA to be conducted on the "ABC-UTC Non-Proprietary UHPC Mix"

Property	Test Method	Institution
Flowability	ASTM C1437	All
Compressive Strength	ASTM C39 ASTM C109	All
Modulus of Elasticity and Poisson's Ratio	ASTM C469	All
Splitting Tensile Strength	ASTM C496	All
Flexural Strength	ASTM C78	All
Direct Tensile Strength	Various	All
Total and Drying Shrinkage	Embedded VWSG ASTM C157	All
Compressive Creep	ASTM C512	OU
Set Time	ASTM C403	All
Freeze-Thaw Resistance	ASTM C666	OU
Rapid Chloride Ion Permeability	ASTM C1202	All

The geometry and quantity of specimens for the testing of each different UHPC mix are provided in Table 3. These values may be modified to be consistent with the testing being performed at the partner universities.

Material properties will be measured using the relevant ASTM modified for UHPC using ASTM C1856 where applicable. Direct tension will be measured using FHWA recommended testing by Haber et al. (2018). Testing procedures will be discussed with OU to ensure that all tests are being conducted similarly at all the partner universities.

Total shrinkage will be measured from 24 hours after casting using 6" by 12" cylinders with embedded vibrating wire gages (VWGs). No environmental chamber or drying room is available at FIU, so shrinkage tests will be carried out in climate-controlled lab conditions. Temperature and relative humidity will be measured and documented at the time of strain measurements.

Creep tests will be conducted at OU and may be conducted at FIU pending available resources. Load levels for creep tests will be discussed with the partner universities. Previous testing conducted by FHWA (Haber et al., 2018) measured loads at two different load levels $0.4f'_c$ (low level) and $0.65f'_c$ (high level). These researchers cured their low-level creep samples for 56 days and high-level creep samples for less than 7 days. Each of their tests involved four 4" by 8" cylinders and three 3" by 6" cylinders. Vibrating wire gages (VWGs) will be mounted in the cylinders to measure the strain change over time. No environmental chamber is available at FIU, so if completed, creep tests will be carried out in climate-controlled lab conditions. Temperature and relative humidity will be documented at the time of strain measurements.

Table 3: Specimen geometry and quantity for mechanical testing of single UHPC mix

Property	Test Method	Specimen Geometry	Age for Testing (# specimens to test)
Flowability	ASTM C1437	n/a	tested during casting
Compressive Strength	ASTM C39 ASTM C109	3”x6” cylinders	3 days (3), 28 days (3), 56 days (3)
Modulus of Elasticity and Poisson’s Ratio	ASTM C469	4”x8” cylinders	28 days (3)
Splitting Tensile Strength	ASTM C496	3”x6” cylinders	28 days (3), 56 days (3)
Flexural Strength	ASTM C78/ASTM C1609	3”x3”x11” prisms	28 days (3), 56 days (3)
Direct Tensile Strength	Various	2”x2”x17” prisms	28 days (3)
Total and Drying Shrinkage	Embedded VWGs	6”x12” cylinders	Begin measuring after casting (3)
Set Time	ASTM C403	6”x6” cylinder	at time of casting (3)

A larger pan-style mixer with orbital mixing action is planned to be used for UHPC batches up to 4.0 cubic feet. It is estimated that the specimens required for each round of testing will require approximately 2.5 cubic feet of UHPC, so all the specimens required for each round of testing should be able to be cast at the same time.

The base mix design to be used for this task will be provided by the OU research team. Testing will be conducted by FIU using this mix design and locally available materials. Results from the testing will be discussed with OU. If needed, modifications will be made to the mix to adjust it for the locally available materials. The same ½-inch steel fibers produced by Bekaert will be used for all mixes for consistency.

Locally available materials will be shipped from FIU to OU and vice versa so that FIU and OU can investigate the repeatability of the mix designs and mechanical properties. The same FHWA recommended testing will be used to evaluate these mixes.

Task 2 Update (6/1): Small trial mixes (0.15cf) continue to be evaluated; each mix produces 6 3”x6” cylinders. The flowability and compressive strength are measured for each of these small trial mixes.

Property	Test Method	Specimen Geometry	Age for Testing (# specimens to test)
Flowability	ASTM C1437	n/a	tested during casting

Property	Test Method	Specimen Geometry	Age for Testing (# specimens to test)
Compressive Strength	ASTM C39 ASTM C109	3”x6” cylinders	3 days (2), 7 days (2), 28 days (2)

Flow

Compressive Strength

Over 100 different trial mixes have been completed to date. Variables that have been evaluated are: water-to-cement ratio, binder-to-aggregate ratio, binder proportions (cement, slag, silica fume), cement type, super plasticizer content, viscosity modifying admixture content, mixing procedure and time at which admixtures are added, moisture content of fine aggregates, steel fiber type and quantity, and curing type. Best results from these mixes have been between 15 and 17 ksi at 28 days. The testing has been slowed down due to COVID-19, but the large mixes (~2.2cf) will hopefully start early to mid-summer.

Task 3. UHPC Durability Property Testing

In addition to the mechanical testing conducted in Task 2, the durability of the developed UHPC mixes will be tested using bulk resistivity tests. The specimen geometries and quantities required for testing of a single UHPC mix are shown in Table 4.

Table 4: Specimen geometry and quantity for durability testing of single UHPC mix

Property	Test Method	Specimen Geometry	Age for Testing (# specimens to test)
Bulk Resistivity		4”x8” cylinders	28 days (4), 90 days (4)

Task 3 Update (6/1): Equipment was purchased to perform bulk resistivity on the proposed 4”x8” cylinders. Bulk resistivity will be measured for only the large-scale mixes.

Task 4. Technology Transfer Workshop

A technology transfer workshop will be held as part of the 2019 International ABC Conference in Miami to share the performance, observations, and recommendations for the “ABC-UTC Non-Proprietary UHPC Mix.” This workshop will be coordinated by OU and will involve presentations by each partner university. The workshop will also involve a lab demonstration of mixing and possibly testing of the UHPC mix. Details for the lab demonstration will be coordinated by OU and FIU.

Task 4 Update (6/1): Two four-hour workshops were held at the 2019 International ABC Conference on December 11th. Details on the workshop can be found in the conference archives (https://abc-utc.fiu.edu/2019-national-accelerated-bridge-construction-conference/). This task is complete.

Task 5. Final Report

A final report will be developed to summarize the research conducted by FIU and results from the testing done at FIU.

Task 5 Update (6/1): Chapters are still being developed summarizing the literature review and preliminary testing.

Task 6. "Guide for ABC-UTC Non-Proprietary UHPC"

A "Guide for ABC-UTC Non-Proprietary UHPC" will be developed incorporating the research results from all partner universities. OU will coordinate the development of this guide and all partner universities will contribute relevant sections.

Task 6 Update (6/1): This guide will be a compilation of work done by all the partner universities. FIU's contribution to this guide has been discussed with OU (the overall lead for this project).

5. Expected Results and Specific Deliverables

The work of this project is anticipated to result in an "ABC-UTC Non-Proprietary UHPC Mix" and recommendations for mixing and placing the mix. Quarterly progress reports will update the community on the progress of the research. A final report will be developed summarizing the work conducted at FIU. A "Guide for ABC-UTC Non-Proprietary UHPC" will be developed summarizing the findings and recommendations from all the partner universities.

6. Schedule

The approximate percentage of the project completed to date is shown below:

Item	% Completed
Percentage of Completion of this project to Date	60%

Progress of tasks in this project is shown in the table below:

	Month																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Task 1																		
	x	x	x															
Task 2																		
	x	x	x	x	x	x	x	x										
Task 3																		
Task 4																		
							x	x	x									
Task 5																		
Task 6																		

7. References

1. ASTM Standard C39 (2016) “Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens,” ASTM International, West Conshohocken, PA.
2. ASTM Standard C78 (2015) “Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading),” ASTM International, West Conshohocken, PA.
3. ASTM Standard C109 (2016) “Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50 mm] Cube Specimens,” ASTM International, West Conshohocken, PA.
4. ASTM Standard C157 (2014) “Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete,” ASTM International, West Conshohocken, PA.
5. ASTM Standard C469 (2014) “Standard Test Method for Static Modulus of Elasticity and Poisson’s Ratio of Concrete in Compression,” ASTM International, West Conshohocken, PA.
6. ASTM Standard C496 (2011) ‘Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens,” ASTM International, West Conshohocken, PA.
7. ASTM Standard C512 (2015) “Standard Test Method for Creep of Concrete in Compression,” ASTM International, West Conshohocken, PA.
8. ASTM Standard C666 (2015) “Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing,” ASTM International, West Conshohocken, PA.
9. ASTM Standard C672 (2012) “Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals,” ASTM International, West Conshohocken, PA.

10. ASTM Standard C1202 (2017) “Standard Test Method for Electrical Indication of Concrete’s Ability to Resist Chloride Ion Penetration,” ASTM International, West Conshohocken, PA.
11. ASTM Standard C1437 (2015) “Standard Test Method for Flow of Hydraulic Cement Mortar,” ASTM International, West Conshohocken, PA.
12. ASTM Standard C1856 (2017) “Standard Practice for Fabricating and Testing Specimens of Ultra-High Performance Concrete,” ASTM International, West Conshohocken, PA.
13. Haber, Z.B., De la Varga, I., Graybeal, B.A., Nakashoji, B., El-Helou, R. (2018) “Properties and Behavior of UHPC-Class Materials,” FHWA-HRT-19-036, March 2018, 151 pp.