Development of Non-Proprietary Ultra-High Performance Concrete (UHPC)

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Definition of UHPC

“UHPC is a cementitious composite material composed of an optimized gradation of granular constituents, a water-to-cementitious materials ratio less than 0.25, and a high percentage of discontinuous internal fiber reinforcement. The mechanical properties of UHPC include compressive strength greater than 17,500 psi and sustained post cracking tensile strength greater than 750 psi. Ultra-high performance concrete has a discontinuous pore structure that reduces liquid ingress, significantly enhancing durability compared to conventional and high-performance concretes.” – Federal Highway Administration
About UHPC

Conventional Concrete

Matrix density

Surface quality

UHPC

Permeability

Strength

> 90%

> 17,500 psi

4000-5000 psi

Water      cement    SCM        sand        gravel

Water      cement    SCM        sand        fibers    Admixtures

Conventional Concrete

UHPC

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Federal Highway Administration
Research Objectives

Develop non-proprietary UHPC mix design formulations using locally available materials based on laboratory and small-scale mockup testing.

1. Characterize and select right fibers
   - Fiber types of fibers
     - Tensile strength
     - Modulus
     - Elongation rate
     - Microstructure

2. Improve mix design of UHPC
   - Particle packing
     - A two-step method
     - Seven UHPC mixes
     - Six cementitious materials

3. Property of UHPC
   - Mechanical and physical properties
     - Compressive strength
     - Bending strength
     - Tensile strength
     - Permeability & durability

4. Long-term cyclic performance
   - Mock-up tests on PCI Northeast closure joints
     - Narrow, longitudinal closure pour connection
     - Straight bars, rather than hooped bars

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Fibers

(a) PVA fiber, (b) AR glass fiber, (c) basalt fiber, and (d) steel fiber

(length: 0.5 in.)
A novel two-step particle packing optimization method:

**Step 1:** identify the ranges of optimal contents (dosages) for the studied materials based on strength development of UHPC.

**Step 2:** use the identified material contents as constrains for particle packing maximization in the Modified Andersen-Andreasen model.
Autogenous shrinkage

![Graph showing autogenous shrinkage with time (hours) for different mixtures](image)

- PC
- M1
- M2
- M3
- M5
- M6
- M7

**Autogenous Shrinkage (μm/m)**

**Time (hours)**

**Autogenous Shrinkage (μm/m)**

- PC
- M1
- M2
- M3
- M5
- M6
- M7

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Permeability

Bulk resistivity measurement (ASTM C1876/AASHTO TP119)

<table>
<thead>
<tr>
<th>Chloride penetration</th>
<th>56-day rapid chloride permeability charge passed (Coulombs)</th>
<th>28-day bulk electrical resistivity of saturated concrete (kΩ-cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>&gt;4,000</td>
<td>&lt;4</td>
</tr>
<tr>
<td>Moderate</td>
<td>2,000 to 4,000</td>
<td>4-8</td>
</tr>
<tr>
<td>Low</td>
<td>1,000 to 2,000</td>
<td>8-16</td>
</tr>
<tr>
<td>Very Low</td>
<td>100 to 1,000</td>
<td>16-190</td>
</tr>
<tr>
<td>Negligible</td>
<td>&lt;100</td>
<td>&gt;190</td>
</tr>
</tbody>
</table>

High particle packing density
Dense structure /low porosity
High resistivity/low permeability
High durability
Compressive strength

Lime Water Curing

Steam Curing

Compressive Strength (PSI)

Mix

M 1
M 2
M 3
M 4
M 5
M 6
M 7

Mix

M3
M5
M6
M7

3D
7D
28D
60D
Compressive strength – influence of fibers

Mix 5 containing 2 vol.%:
- PVA: PVA fiber,
- GF: glass fiber,
- BS: basalt fiber
- SF: micro-steel fiber

The UHPC with micro-steel fiber yielded the highest strength.
Beam Bending Tests

**Dimensions:** 1-in. by 2.25-in. by 12-in. beams; 3-point bending test (ASTM C1609)

**Test span:** 9.75 in.

**Loading rate:** 0.003 in./min. up to displacement of 0.065 in.; 0.009 in./min to failure.

**Tested groups:** Mix 1, Mix 3, Mix 5, and Mix 6

**Two ages:** 7 days and 28 days

Two curing conditions: lime water curing and steam curing

**Four Fibers:** Mix 5 with PVA, glass, basalt, and micro-steel fibers
Crack Opening at End of Test – Micro-steel Fiber

Lime water curing – 28-day test

Steam curing – 28-day test
Flexural Strength -- Micro-Steel Fiber

Regular Lime Water Curing

Steam Curing
Response of UHPC Beams – Mix 5 with glass fiber

7-day test

28-day test

Failure Surface
Mix 5 containing 2 vol.%:
PVA: PVA fiber,  
GF: glass fiber,  
BS: basalt fiber  
SF: micro-steel fiber  

The UHPC with micro-steel fiber yielded the highest strength.
Dogbone Tests

Dogbone Test Specimen from Zhou and Qiao (2020)

Test specimen and apparatus used in this study
Dogbone Test Results

M1

M3

M5

M6

Tensile Stress, ksi

Tensile Strain

Tensile Stress, ksi

Tensile Strain

Tensile Stress, ksi

Tensile Strain
Tensile Test (Dogbone) Results

**Tensile strength**

**Tangent elastic modulus**
PCI Northeast Closure Joint Details

1. HOOKED BARS WITH 4 KSI CONCRETE
A similar narrower joint made with 6 KSI grout may also be used. See next b beam details at www.pcine.org.

2. STRAIGHT BARS WITH 4 KSI CONCRETE
Size and spacing of longitudinal bars as per AASHTO LRFD Bridge Design Specifications

3. STRAIGHT BARS WITH UHPC
Minimum strength of UHPC = 14 KSI

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Details of Closure Joint Panel Specimens

Plan view of test specimens
Specimen 1 - 8 in. joint width
Specimen 2 - 6 in. joint width

Joint Detail (Section)

No. 4 @ 6 in.
No. 5 @ 9 in.
2 ft – 10 in.
or 2 ft – 11 in.
8 in. or 6 in.
Closure Joint Panel Specimen Casting
Closure Joint Test Setup
Panel 2 – 6 in. Joint Width
Load-Deflection Response – Closure Joint Specimens

Specimen 1 – 8 in. joint width

Specimen 2 – 6 in. joint width

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Nominal strength</th>
<th>Strength using material strength</th>
<th>Laboratory failure load</th>
<th>Nominal /Experiment (%)</th>
<th>Measured /Experiment (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>53.9 kip</td>
<td>64.4 kip</td>
<td>76.25 kip</td>
<td>41.5%</td>
<td>18.4%</td>
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<tr>
<td>2</td>
<td>52.0 kip</td>
<td>62.1 kip</td>
<td>74.75 kip</td>
<td>43.8%</td>
<td>20.4%</td>
</tr>
</tbody>
</table>
References, Publications, and Information