UHPC 101

An Introduction to Ultra-High Performance Concrete

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UHPC State-of-the-Art Report

- FHWA HRT-13-060
  - Published in June 2013
  - 300+ references
  - 600+ item bibliography

Mix Designs, Material Properties, Design Guidelines, Deployment, etc.
FHWA UHPC Web Resources

- Web Search: **FHWA UHPC**
- [https://www.fhwa.dot.gov/research/resources/uhpc/](https://www.fhwa.dot.gov/research/resources/uhpc/)
UHPC Deployments Across US and Canada

http://usdot.maps.arcgis.com/apps/webappviewer/index.html?id=41929767ce164eba934d70883d775582
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http://usdot.maps.arcgis.com/apps/webappviewer/index.html?id=41929767ce164eba934d70883d775582
What is Ultra-High Performance Concrete?
What is Ultra-High Performance Concrete?

- Fiber Reinforcement
- Superplasticizers
- Supplementary Cementitious Materials
- Particle Packing Theory

Nist.gov
American Coal Ash Association

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February 2017
What is Ultra-High Performance Concrete?

• ACI 239 – Ultra-High Performance Concrete
  – Concrete, ultra-high performance - concrete that has a minimum specified compressive strength of 150 MPa (22,000 psi) with specified durability, tensile ductility and toughness requirements; fibers are generally included to achieve specified requirements.
What is Ultra-High Performance Concrete?

- FHWA
  - 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 21.7 ksi (150 MPa) and sustained post-cracking tensile strength greater than 0.72 ksi (5 MPa).
What is Ultra-High Performance Concrete?

Highly durable, strain-hardening concrete
What is Ultra-High Performance Concrete?

Micro-Reinforced Concrete
What is Ultra-High Performance Concrete?

Resilient Cementitious Composite
Availability of UHPC-Class Materials

Example Proprietary Versions

Non-Proprietary Versions

FHWA-HRT-13-100:
Dr. Kay Willie at UCONN
## Example Composition of a UHPC

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Amount (lb/yd³)</th>
<th>Amount (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement</td>
<td>1235</td>
<td>733</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>388</td>
<td>230</td>
</tr>
<tr>
<td>Ground Quartz</td>
<td>308</td>
<td>183</td>
</tr>
<tr>
<td>Fine Sand</td>
<td>1699</td>
<td>1008</td>
</tr>
<tr>
<td>Steel Fibers</td>
<td>327</td>
<td>194</td>
</tr>
<tr>
<td>Superplasticizer</td>
<td>56</td>
<td>33</td>
</tr>
<tr>
<td>Water</td>
<td>271</td>
<td>161</td>
</tr>
</tbody>
</table>

* Teichmann and Schmidt report titled “Mix Design and Durability of UHPC” from the Proceedings of the 4th Intl Ph.D. Symposium in Civil Engineering
## Example Composition of a UHPC

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<th>Amount (lb/yd³)</th>
<th>Amount (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement</td>
<td>1331</td>
<td>790</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>334</td>
<td>198</td>
</tr>
<tr>
<td>Fly Ash (Class F)</td>
<td>324</td>
<td>192</td>
</tr>
<tr>
<td>Fine Basalt</td>
<td>1923</td>
<td>1141</td>
</tr>
<tr>
<td>Steel Fibers</td>
<td>199</td>
<td>118</td>
</tr>
<tr>
<td>Superplasticizer</td>
<td>47</td>
<td>28</td>
</tr>
<tr>
<td>Water</td>
<td>246</td>
<td>146</td>
</tr>
</tbody>
</table>

* Wille and Boisvert-Cotulio report titled “Development of Non-Proprietary UHPC for Use in the Highway Bridge Sector” (FHWA NTIS-PB2013-100587)
Fiber Reinforcement
Compression Behavior

![Graph showing compression behavior of UHPC and conventional concrete. The graph plots Axial Stress (ksi) against Axial Strain (in/in). The UHPC curve is indicated by a solid line and the conventional concrete curve by a dashed line. The UHPC curve reaches a peak stress of approximately 25 ksi at a strain of about 0.005. The conventional concrete curve, labeled "Concrete (6 ksi)", reaches a peak stress of 6 ksi at a strain of about 0.005. A photo of a UHPC sample is also shown.](image-url)
Tensile Behavior

![Graph showing the relationship between average axial stress (ksi) and average axial strain (in/in).]
Tensile Behavior

- 2% Steel Fiber Reinforcement
- 13 ksi $\leq f_c' \leq$ 16 ksi

Average Axial Stress (ksi) vs. Average Axial Strain graph with different curves labeled A, B, C, D, E.
**Tensile Behavior**

![Graph showing tensile behavior with different curves labeled A, B, C, D, and E.](image)

- **Average Axial Stress (ksi)**
- **Average Axial Strain**
- **Average Axial Stress (MPa)**

- **Key Points:**
  - D (4%)
  - E (3.25%)
  - B (3.25%)
  - D (3%)
  - C (4.5%)

- **Condition:**
  - 13 ksi \( \leq f_c' \leq 19 \text{ ksi} \)

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**February 2017**
Tensile Behavior

Average Axial Stress (MPa)

Average Axial Strain

- F0 (0 degrees)
- F45 (45 degrees)
- F90 (90 degrees)
- FEC (Mold Cast)

Individual
Average
Compression Strength Gain

![Graph showing the compression strength gain over days after mix initiation for different curing regimes. The graph compares the compressive strength in ksi and MPa for 105°F (40°C), 73°F (23°C), and 50°F (10°C) curing regimes. The data points and trend lines are clearly marked for each curing regime.](image-url)
Interface Bond

Age of UHPC During Test: 14-Days

Load

Supports

Precast Concrete

UHPC

Interface

Tensile Stress at Bond Failure (ksi)

U-A

U-B

0

0.1

0.2

0.3

0.4

0.5

0.6

Load

Pull-Off Disc

Saw Cut

Precast Concrete

Base Slab

UHPC Topping

Interface
Shrinkage Behavior

Autogenous deformation (µε) vs. Time (days)

-1200 -1000 -800 -600 -400 -200 0 10 20 30 40 50 60

U-D  U-B  U-C  U-A  U-E

Inset: Sample UHPC slabs.
Durability

USACE Facility at Treat Island
UHPC Permeability

• Chloride Ion Diffusion Coefficient

  \[ 2 \times 10^{-11} \text{ m}^2/\text{s} \text{ for conventional concrete} \]

  \[ 2 \times 10^{-12} \text{ m}^2/\text{s} \text{ for HPC} \]

  \[ 2 \times 10^{-13} \text{ m}^2/\text{s} \text{ for UHPC} \]
Bond to Steel Reinforcing Bars

TEST CONFIGURATION

EXAMPLE RESULT

Gr. 120 Bars (Uncoated)
Side Cover: $c_{so} = 3d_b$
Embedment Length: $l_d = 8d_b$
Splice Length: $l_s = 6.4d_b$

1 ksi = 6.89 MPa

Manufacturer-Recommend Fiber Vol.
UHPC Properties: Some Ballpark Values

- Compressive Strength – 18 to 35 ksi
- Modulus of Elasticity – 6000 to 8000 ksi
- Sustained Tensile Capacity – 0.9 to 1.5 ksi
- Interface Bond – Can surpass substrate tensile strength
- Permeability – 100x less than conventional concrete
- Freeze/Thaw Resistance – RDM > 95%
- Rebar Bond – $8d_{b}$ embedment can deliver yield
UHPC Mixing
UHPC Mixing

![Image of UHPC Mixing]

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UHPC Casting
UHPC Casting (Video)
UHPC Casting (Video)
UHPC Structural Design

Specifications Published
- France
- Switzerland

Development Underway
- Canada
- US
Design and Construction of UHPC Field-Cast Connections

- FHWA-HRT-14-084
- What is UHPC?
- Example Connections
- Structural Design
- Construction
- Quality Assurance
- Deployments
UHPC Structural Behavior

#5 Rebar Lap Splice
Mars Hill Bridge
Mars Hill Bridge

Iowa 45” Bulb Tee
SW ≈ 0.7 kip/ft

Modified Bulb Tee
SW ≈ 0.56 kip/ft
π-Girder

- 33” depth spans 80’; weight = 932 lb/ft
- Family of girders up to 47” depth
Mars Hill Bridge
Wapello County, Iowa

Jakway Bridge
Buchanan County, Iowa

Jakway Bridge
Buchanan County, Iowa
UHPC for Bridge Decks

Dahlonega Road Bridge in Wapello County, Iowa
Footbridge - Marseille, France
Foot Bridge of Peace – Seoul, South Korea
MuCEM - Marseille, France
Pulaski Skyway
Newark, New Jersey
Precast Deck Panel Connections

Pulaski Skyway
Newark, New Jersey
Franklin Avenue Bridge
Minneapolis, Minnesota
Deck Panel Connections

Franklin Ave. Bridge
Minneapolis, MN
UHPC for Pile Foundations

Without Taper

With Taper – Minimize Driving Stresses

0.5" Dia. Strand

UHPC Pile Design – Vande Voort et al. 2008, Iowa State University
UHPC for Seismic Retrofit

Image Credit: Proceedings, 2009 UHPFRC, Marseille

Bruno Massicotte, Polytechnique Montreal
UHPC Connection for Substructures

Hooper Road over US 17C in Union, New York

(14) #9 DWLS – CAST INTO PRECAST PIER CAP – EXTEND 11" BELOW BOTTOM OF PIER CAP

3" DIA. GROUT PLACEMENT TUBE – TYP. AT EACH Pier

PRECAST PIER CAP – REINFORCING NOT SHOWN

(2) 3/4" VENT TUBE – TYP. AT EACH Pier

EXISTING TIE TO REMAIN – REPLACE TO MATCH
EXISTING IF DAMAGED DURING CONCRETE REMOVAL

EXISTING 42" DIA. PIER

GROUT JOINT WITH UHPC

EXISTING (28) #9 BARS TO REMAIN
Pier Column to Cap Connection

Hooper Road over Route 17C
Union, New York
UHPC for Replacing Failing Expansion Joints

SR 96 over I-86 near Owego, NY
UHPC for Steel Girder Rehabilitation

Photos from Rose & Picard, NYSDOT

Tested by Zmetra, 2015 at UCONN

Concrete Deck

UHPC

Steel Girder

Studs

UHPC
UHPC for Bridge Deck Rehabilitation

Chillon Viaduct near Lausanne, Switzerland
UHPC for Bridge Deck Rehabilitation

Chillon Viaduct near Lausanne, Switzerland
UHPC for Bridge Deck Rehabilitation

CR L over Mud Creek near Brandon, Iowa
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Capable Solution for Today’s Challenges and Tomorrow’s Opportunities
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Mid-Atlantic Quality Assurance Workshop – February 2017