


American Concrete Institute  
Always advancing


## UHPC Innovations for Durability and Resiliency

ACI Fall 2013 Convention  
October 20 - 24, Phoenix, AZ




American Concrete Institute  
Always advancing

WEB SESSIONS



**Ben Graybeal** leads the Structural Concrete Research Program for the Federal Highway Administration at the Turner-Fairbank Highway Research Center in McLean, Virginia. He received his B.S. and M.S. degrees from Lehigh University and his Ph.D. from the University of Maryland. His research interests include structural application of advanced cementitious materials, concrete material characterization, experimental evaluation of highway bridge structures, and non-destructive evaluation techniques.



American Concrete Institute  
Always advancing

WEB SESSIONS

# DURABILITY OF ULTRA-HIGH PERFORMANCE CONCRETE

Ben Graybeal, Ph.D., P.E.  
Structural Concrete Research Program Mgr.  
Federal Highway Administration  
202-493-3122  
benjamin.graybeal@dot.gov





TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

## AFGC UHPC Recommendations: Chapter 3 Durability: Conclusion

...The values obtained for UHPFRC in general show a very marked improvement in durability compared with ordinary cementitious materials and corroborate the viability of long project life cycles with reduced concrete cover. This can be explained by their particular porous structure characterized by an absence of capillary porosity and non-interconnected porosity on a very small scale. ...

Association Française de Génie Civil  
Bétons Fibres À Ultra-Hautes Performances: Recommandations  
Revised Edition, June 2013  
Section 3.3.6




TURNER-FAIRBANK HIGHWAY RESEARCH CENTER


## 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.



Ultra-High Performance Concrete: A State-of-the-Art Report for the Bridge Community



<http://www.fhwa.dot.gov/publications/research/infrastructure/structures/hpc/13060/13060.pdf>


TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

## UHPC Material Property Characterization

- FHWA HRT-06-103
  - Published in August 2006
  - Extensive testing of a UHPC
  - Includes durability testing



Material Property Characterization of Ultra-High Performance Concrete




<http://www.fhwa.dot.gov/publications/research/infrastructure/structures/06103/06103.pdf>

TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

## Durability of UHPC

- ASCE Journal of Materials in CE
  - Published in October 2007
  - Graybeal and Tanesi
  - V. 19, No. 10, p. 848-854




U.S. Department of Transportation  
Federal Highway Administration

TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

## Grout Material Property Characterization


- NTIS PB2013-130231
  - Published in January 2013
  - Extensive testing of a grouts for PBES
  - Includes durability testing



U.S. Department of Transportation  
Federal Highway Administration  
<http://www.fhwa.dot.gov/publications/research/infrastructure/structures/bridge/13042/13042.pdf>

TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

## Rapid Chloride Penetration (ASTM C1202)



Total Charge Passed\*

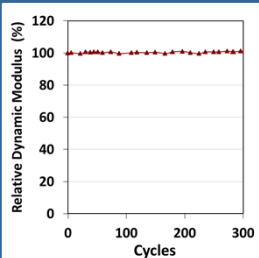
- Steam Treated (2006) 18 Coulombs
- Ambient Cure (2006) 360 Coulombs
- Ambient Cure (2012) 400 Coulombs

Charge Passed	Rating
< 100	Negligible
100 to 1000	Very Low
1000 to 2000	Low
2000 to 4000	Moderate
> 4000	High

U.S. Department of Transportation  
Federal Highway Administration

TURNER-FAIRBANK HIGHWAY RESEARCH CENTER


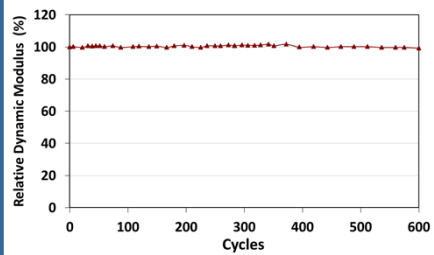
## Freeze-Thaw Resistance (ASTM C666)



U.S. Department of Transportation  
Federal Highway Administration

TURNER-FAIRBANK HIGHWAY RESEARCH CENTER


## Freeze-Thaw Resistance (ASTM C666)

U.S. Department of Transportation  
Federal Highway Administration

TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

## Freeze-Thaw Resistance (ASTM C666)



Relative Dynamic Modulus\*

- Steam Treated (2006, unsaturated) 97%
- Ambient Cure (2006, unsaturated) 112%
- Ambient Cure (2012, saturated) 99%

\* C666 Procedure A for 600 cycles

U.S. Department of Transportation  
Federal Highway Administration

TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

### Scaling Resistance (ASTM C672)



Initial Condition



After 50 Cycles

Surface Condition Rating: 0 (no scaling)



TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

### Abrasion Resistance (ASTM C944)



Weight Loss per Abrading\*

- Steam Treatment 0.18 grams
- Ambient Cure 1.18 grams



\* ASTM C944 with Ground Surface




TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

### Alkali-Silica Reaction (ASTM C1260)

14-day Expansion\*


- Steam Treated (2006) 0.01%
- 1-day Ambient Cure (2006) 0.00%
- 28-day Ambient Cure (2006) 0.01%

\* Expansion < 0.10% considered innocuous



TURNER-FAIRBANK HIGHWAY RESEARCH CENTER


### UHPC Durability: Very Good



TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

### UHPC Durability: Very Good


But what if it cracks...



TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

### Combined Structural/Environmental Loading

- NTIS PB2010-110331
  - Published in January 2010
  - Performance of Cracked UHPC



<http://www.fhwa.dot.gov/publications/research/infrastructure/structures/10055/10055.pdf>



TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

### Combined Structural and Environmental Effects



Load  
Salt Water




U.S. Department of Transportation  
Federal Highway Administration

TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

### Combined Structural and Environmental Effects




6 months continuous:  
• Cyclic Flexural Loading  
• Salt Solution Exposure

No degradation in flexural response


No indication of steel fiber reinforcement failure across cracks

TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

### Combined Structural and Environmental Effects



Prism extracted from flexural tensile face.  
Loaded in direct tension.  
Tensile failures at newly generated cracks.  
Tensile failures at 1.9, 2.3, and 2.6 ksi.



TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

### Combined Structural and Environmental Effects



"Old" cracks intersected, but generally not followed.

Salt residue visible near salted face.

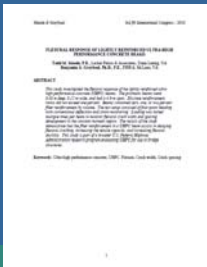
No indication of steel fiber deterioration.



TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

### Crack Widths in Steel Fiber Reinforced UHPC

- Proceedings of fib 2010
  - Meade and Graybeal
  - Flexural Response of Lightly Reinforced UHPC Beams



U.S. Department of Transportation  
Federal Highway Administration

TURNER-FAIRBANK HIGHWAY RESEARCH CENTER

### Crack Widths in Steel Fiber Reinforced UHPC

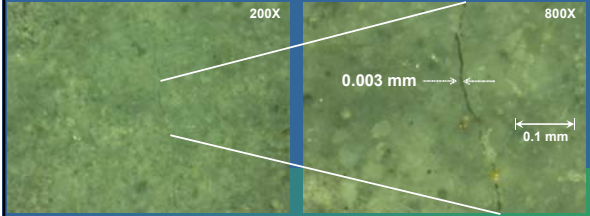


U.S. Department of Transportation  
Federal Highway Administration



### Crack Widths in Steel Fiber Reinforced UHPC

2 vol. % SF → Mean Crack Width = 0.006 mm  
1 vol. % SF → Mean Crack Width = 0.017 mm



## DURABILITY OF ULTRA-HIGH PERFORMANCE CONCRETE

Ben Graybeal, Ph.D., P.E.  
Structural Concrete Research Program Mgr.  
Federal Highway Administration  
202-493-3122  
benjamin.graybeal@dot.gov

