FTBA Orlando February 2020

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Lead Materials Research Engineer

COR-TUF UHPC
the future of concrete

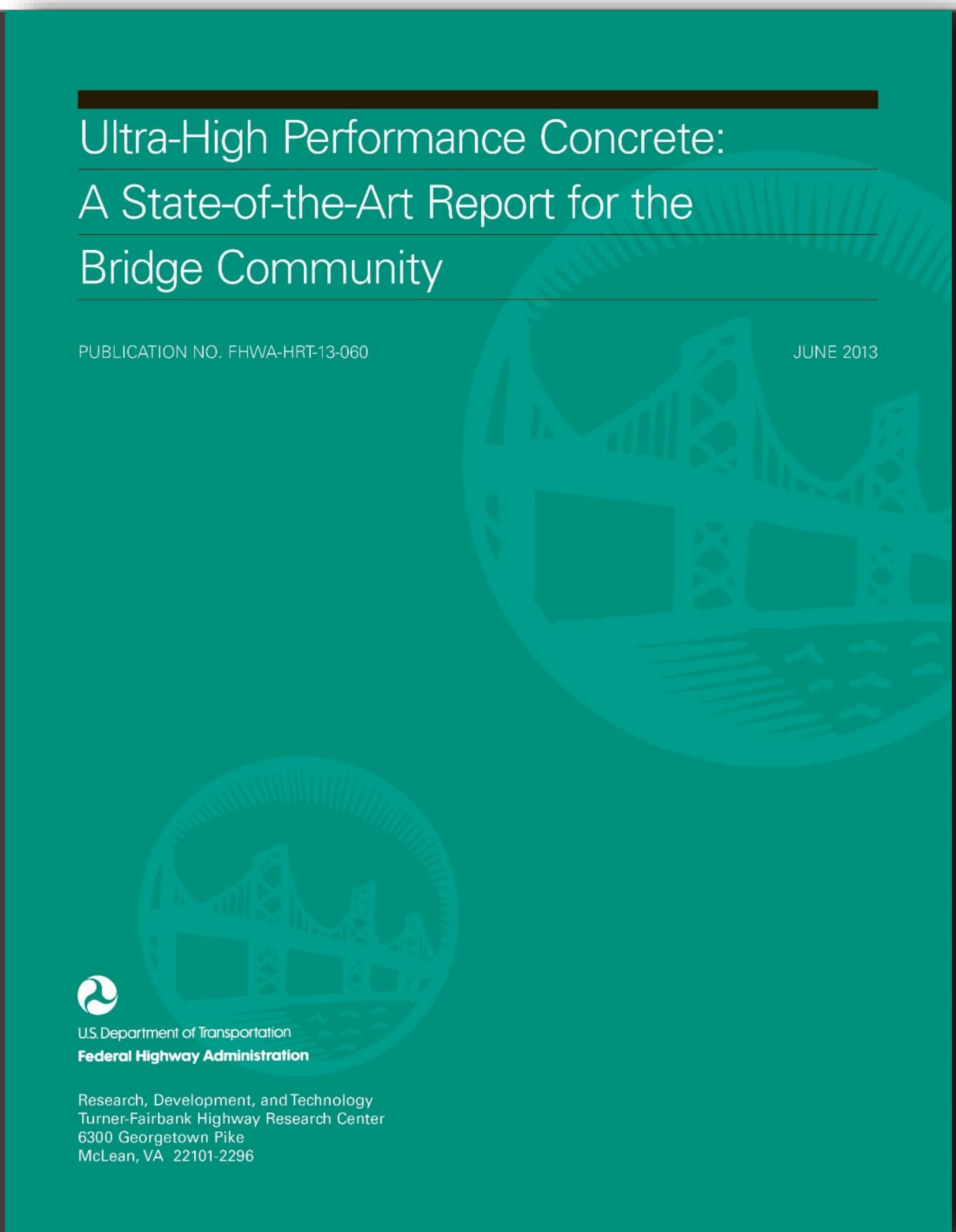
- WHAT IS ULTRA HIGH PERFORMANCE CONCRETE
- ABOUT COR-TUF
- INTRODUCTION TO COR-TUF UHPC
- PRODUCT APPLICATIONS AND COMPARISONS
- PRODUCT DEMOSTRATION VIDEOS

PRESENTATION AGENDA

What is UHPC

Federal Highway Administration

- **Defined by Federal Highway Publication FHWA HRT-13-060**
- **Published in June 2013**


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

PUBLICATION NO. FHWA-HRT-13-060 JUNE 2013

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

What is UHPC

Federal Highway Administration

- **UHPC is a cementitious composite material composed of an optimized gradation of granular constituents, a water-to-cementitious materials ratio of less than 0.25, and a high percentage of discontinuous internal fiber reinforcement.**
- **The mechanical properties of UHPC include compressive strengths greater than 21.7 KSI(150 MPa)**
- **Sustained post-cracking tensile strength greater than 0.72 KSI (5 MPa)**

Originally presented by Ben Graybeal (FHWA) on 6/18/16 at the 1st International Interactive Symposium on UHPC

What is UHPC

- Mixture of
  - Supplementary Cementitious Materials
  - Superplasticizers
  - Fiber Reinforcement

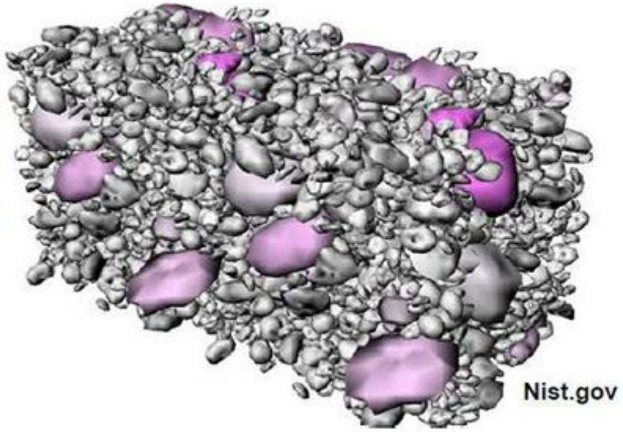
- Utilizes the particle packing theory to decrease interstitial void spaces to the absolute minimal size possible.

Supplementary Cementitious Materials

Superplasticizers

Fiber Reinforcement

Particle Packing Theory



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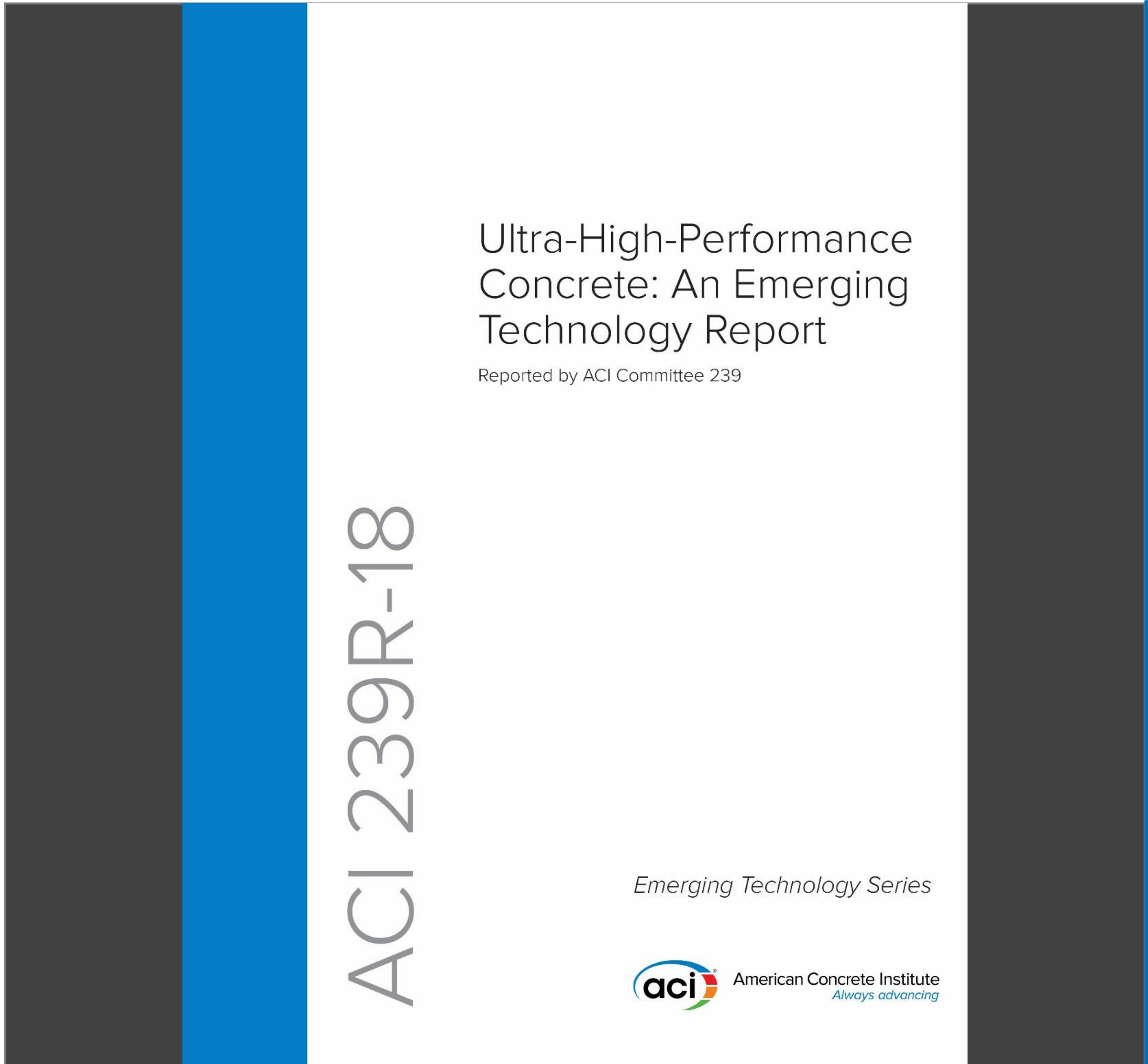


Ultra-High-Performance Concrete: An Emerging Technology Report

Reported by ACI Committee 239

ACI 239R-18

Emerging Technology Series

American Concrete Institute
Always advancing

What is UHPC

American Concrete Institute

- **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.**

Originally presented by Ben Graybeal (FHWA) on 6/18/16 at the 1st International Interactive Symposium on UHPC

About Cor-Tuf

- Company founded by Douglas Darling in 2016

- Product was originally developed for defense applications by the Army Corps of Engineers. Concrete needed to be tough and light weight.

- 10 times the compressive strength of conventional concrete and an estimated longevity of more than 100 years.

About Cor-Tuf

Cor-Tuf exceeds FHWA / ACI UHPC definitions through the following typical material properties

***All data has been verified by independent laboratory CTL Group. Project #059330 Client: Cor-Tuf UHPC**

COR-TUF UHPC

the future of concrete

PRODUCT DATA SHEET

CT25

CTL Group Material Testing Results*

Concrete Performance	Test Method	Curing Conditions at CTL Group	Age	Test Result
Compressive Strength	ASTM C 39	73°F/100% RH	at 1 day	9,050 psi
Compressive Strength	ASTM C 39	73°F/100% RH	at 3 days	11,140 psi
Compressive Strength	ASTM C 39	73°F/100% RH	at 14 days	20,780 psi
Compressive Strength	ASTM C 39	73°F/100% RH	at 28 days	22,920 psi
Compressive Strength	ASTM C 39	73°F/100% RH	at 56 days	24,770 psi
Compressive Strength	ASTM C 1856	Controlled Curing	at 28 days	25,500 psi
Length Change	ASTM C 157	73°F/50% RH	28 days (26 days Dry)	-0.033%
Chloride Penetrability	ASTM C 1202 AASHTO T277	73°F Limewater	28 days	>=100 (Negligible)
		190°F water 5 days; 190°F air 2	28 days	>=100 (Negligible)
First-Peak Strength	ASTM C 1609	73°F/Limewater	28 days	1,811 psi
Residual Strength (L/600)	ASTM C 1609	73°F/Limewater	28 days	1,653 psi
Residual Strength (L/500)	ASTM C 1609	73°F/Limewater	28 days	940 psi
Abrasion Resistance, Ave Loss	ASTM C 944	73°F/Limewater	58 days	0.016 oz

About Cor-Tuf

What availability options exist for UHPC?

- Proprietary versions – Cor-Tuf, Ductal etc..
- Non-Proprietary version
- Non-Proprietary versions of UHPC are still under development. FHWA-HRT-13-100

Example Proprietary Versions

Non-Proprietary Versions

TECHBRIEF

Development of Non-Proprietary Ultra-High Performance Concrete for Use in the Highway Bridge Sector

FHWA Publication No.: FHWA-HRT-13-100

FHWA Contact: Ben Graybeal, HRDI-40, (202) 493-3122, benjamin.graybeal@dot.gov.

This document is a technical summary of the unpublished Federal Highway Administration (FHWA) report, *Development of Non-Proprietary Ultra-High Performance Concrete for Use in the Highway Bridge Sector*, available through the National Technical Information Service at www.ntis.gov.

NTIS Accession No. of the report covered in this TechBrief: PB2013-110587

US Department of Transportation
Federal Highway Administration
Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296
www.fhwa.dot.gov/research

Objective

The long-term goals of this study are to facilitate the use of ultra-high performance concrete (UHPC) among U.S. suppliers and contractors, accelerate its application in U.S. construction, and promote a more resilient and sustainable future U.S. infrastructure. In pursuit of these goals, the objective of this research was to develop a non-proprietary cost effective UHPC characterized by compressive strength exceeding 20 ksi (138 MPa), pre- and post-cracking tensile strength above 0.72 ksi (5 MPa), and sufficient durability properties. The mix designs were optimized in their efficiency considering workability, mechanical performance, and cost effectiveness. In support of cost effectiveness, locally available materials were used from selected areas in the United States. The results of the research effort are summarized herein, and mix designs are suggested for the following three regions: the Northeast area in the vicinity of New York, Connecticut, and New Jersey; the upper Midwest area in the vicinity of Iowa, Minnesota, and Michigan; and the Northwest area in the vicinity of Washington and Oregon.

Introduction

UHPC has attracted the growing interest of researchers in academia, engineers in the public and private sectors, and contractors across the world due to its highly enhanced mechanical and durability properties in comparison to conventional

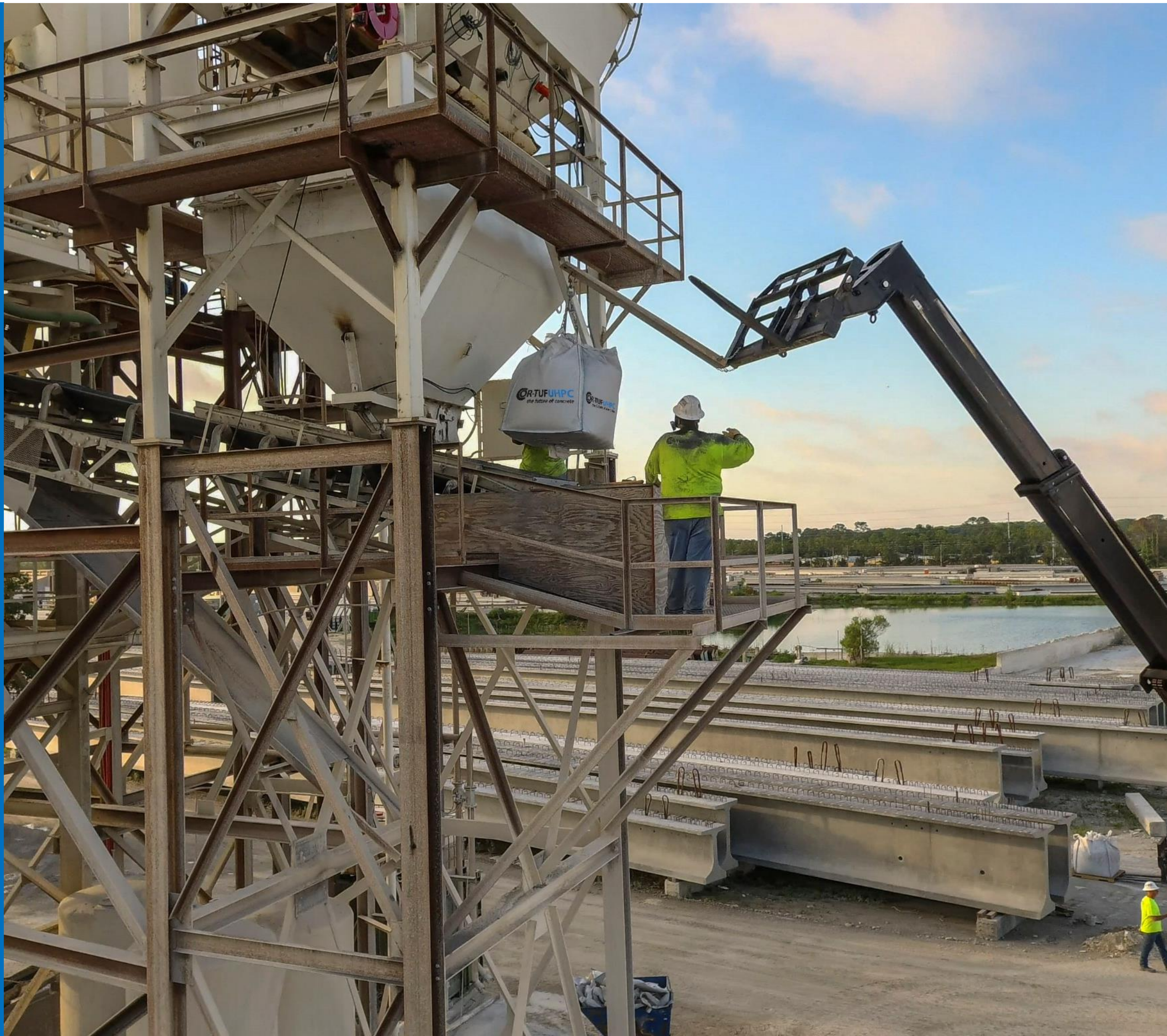
FHWA-HRT-13-100:
Dr. Kay Willie at UCONN

Originally presented by Ben Graybeal (FHWA) on 6/18/16 at the 1st International Interactive Symposium on UHPC

About Cor-Tuf

How is Cor-Tuf packaged?

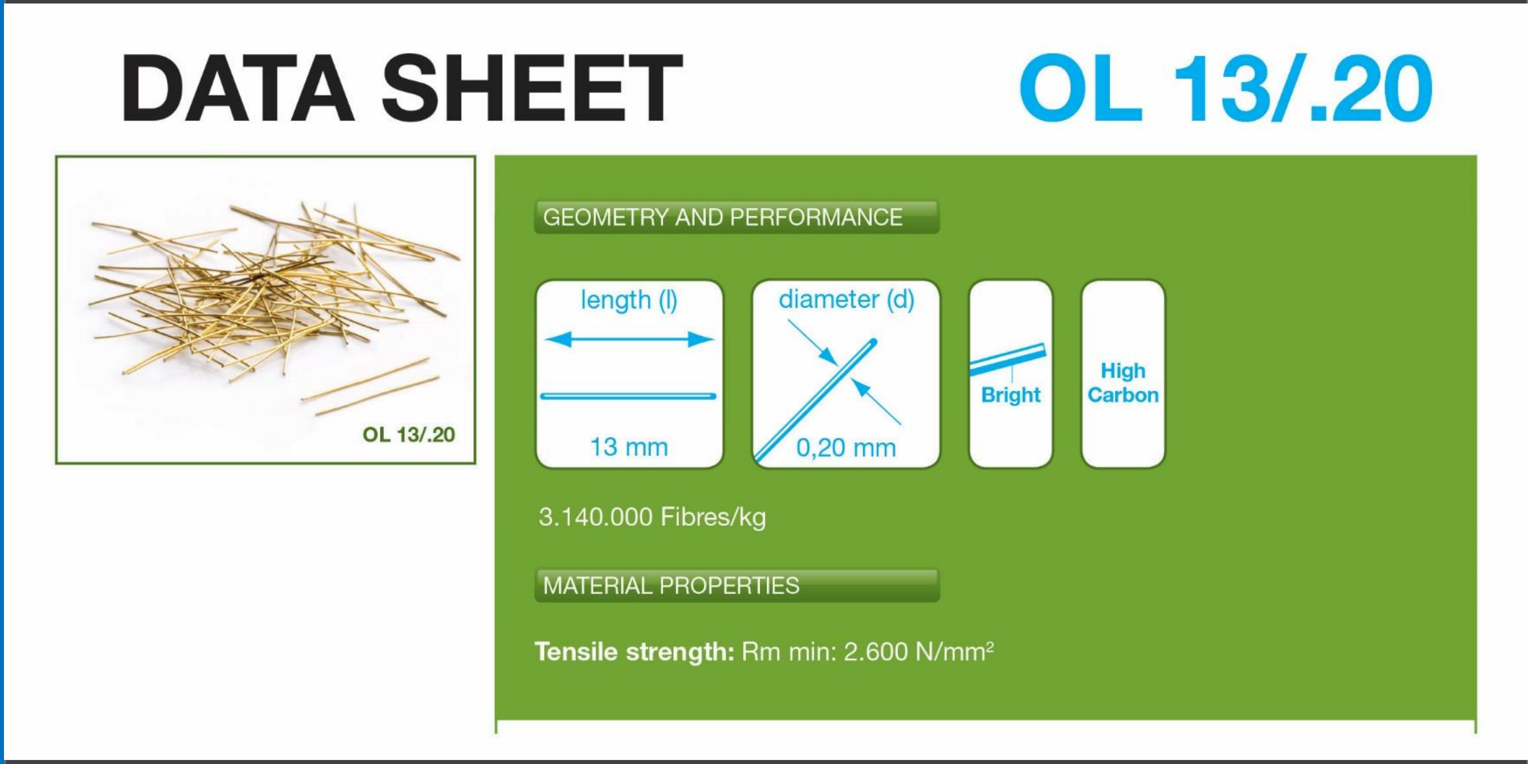
- Individual 50 Lb. bags
- 1-yard super sacks
  - Can be mixed with or without fiber, sand and cement (complete mix)
- Full pneumatic tanker

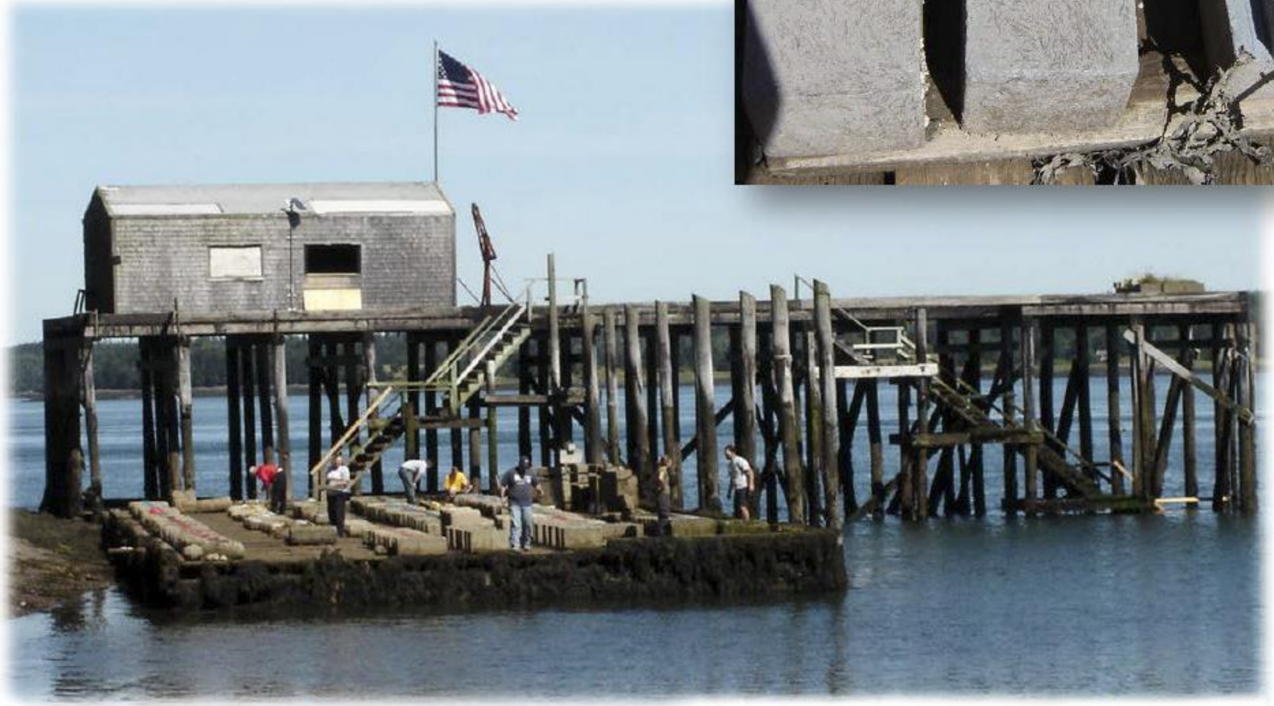


About Cor-Tuf

Fiber Reinforcement

- Steel fiber is used for reinforcement
- 13 mm x .20mm
- Minimum tensile strength of 2.6 N/mm² is required





Introduction to Cor-Tuf UHPC

US Army Core of Engineers Testing Facility at Treat Island

- Statement from US Army Corps of Engineers –
- Cor-Tuf UHPC is a class of concrete that is exceptionally strong and durable.
- Originally developed by the U.S. Army Corps of Engineers, it combines form and function with strength, resiliency.
- It also has the ability to be prepared and poured in mass quantities via conventional means and methods common to the concrete industry.

Originally presented by Ben Graybeal (FHWA) on 6/18/16 at the 1st International Interactive Symposium on UHPC

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

INTERNATIONAL

Designation: C1556 – 11a (Reapproved 2016)

Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Mixtures by Bulk Diffusion[1]

This standard is issued under the fixed designation C1556; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method covers the laboratory determination of the apparent chloride diffusion coefficient for hardened cementitious mixtures.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field

C42/C42M Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete

C125 Terminology Relating to Concrete and Concrete Aggregates

C192/C192M Practice for Making and Curing Concrete Test Specimens in the Laboratory

C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

C1152/C1152M Test Method for Acid-Soluble Chloride in Mortar and Concrete

C1202 Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration

2.2 *NORDTEST Standards:*

NT BUILD 443 Approved 1995-11, Concrete, Hardened: Accelerated Chloride Penetration (in English)[3]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this test method, refer to Terminology C125.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *apparent chloride diffusion coefficient, D_a, n*—a chloride transport parameter calculated from acid-soluble chloride profile data obtained from saturated specimens exposed to chloride solutions, without correction for chloride binding, that provides an indication of the ease of chloride penetration into cementitious mixtures.

3.2.2 *chloride binding, v*—the chemical process by which chloride ion is removed from solution and incorporated into cementitious binder hydration products.

3.2.2.1 *Discussion*—Chloride binding is primarily associated with hydration products formed by the aluminate phase of cement and mixtures containing ground granulated blast furnace slag.

3.2.3 *chloride penetration, v*—the ingress of chloride ions due to exposure to external sources.

3.2.4 *exposure liquid, n*—the sodium chloride solution in which test specimens are stored prior to obtaining a chloride profile.

3.2.5 *exposure time, n*—the time that the test specimen is stored in the solution containing chloride ion.

3.2.6 *initial chloride-ion content, C_i, n*—the ratio of the mass of chloride ion to the mass of concrete for a test specimen that has not been exposed to external chloride sources.

3.2.7 *profile grinding, v*—the process of grinding off and collecting a powder sample in thin successive layers from a test specimen using a dry process.

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.66 on Concrete's Resistance to Fluid Penetration.

Current edition approved April 1, 2016. Published May 2016. Originally approved in 2003. Last previous edition approved in 2011 as C1556 – 11a. DOI: 10.1520/C1556-11AR16.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Published by NORDTEST, P.O. Box 116 FIN-02151 ESPOO Finland, Project 1154-94, e-mail: nordtest @vtt.fi, website: http://www.vtt.fi/nordtest

*A Summary of Changes section appears at the end of this standard

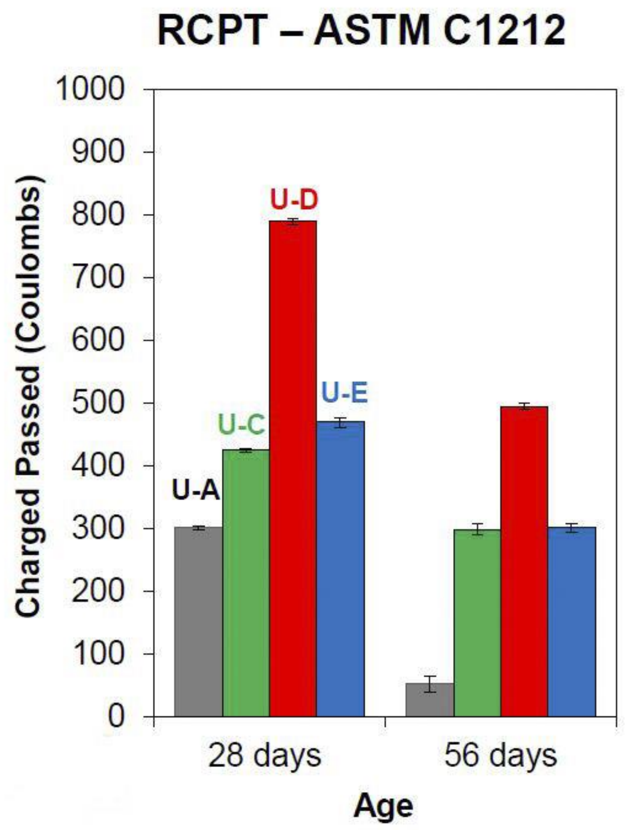
Introduction to Cor-Tuf UHPC

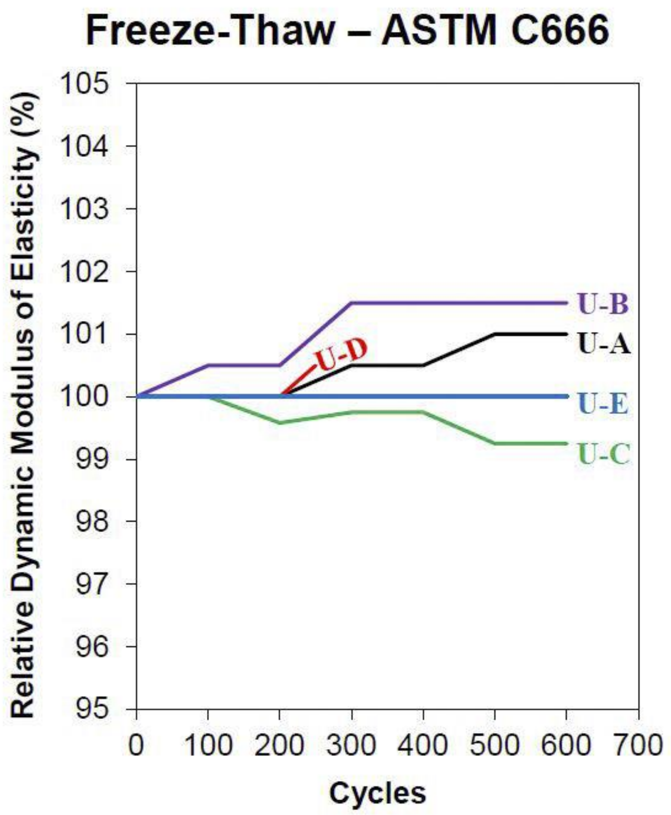
UHPC Permeability

- **ASTM C1556 – 11**
- **Chloride Ion Diffusion Coefficient**
  - **2x10^{-11} m²/s for conventional concrete**
  - **2x10^{-12} m²/s for HPC**
  - **2x10^{-13} m²/s for UHPC**
- **Less than 100 coulombs of permeability versus 1800 in regular concrete**

Originally presented by Ben Graybeal (FHWA) on 6/18/16 at the 1st International Interactive Symposium on UHPC

Introduction to Cor-Tuf UHPC





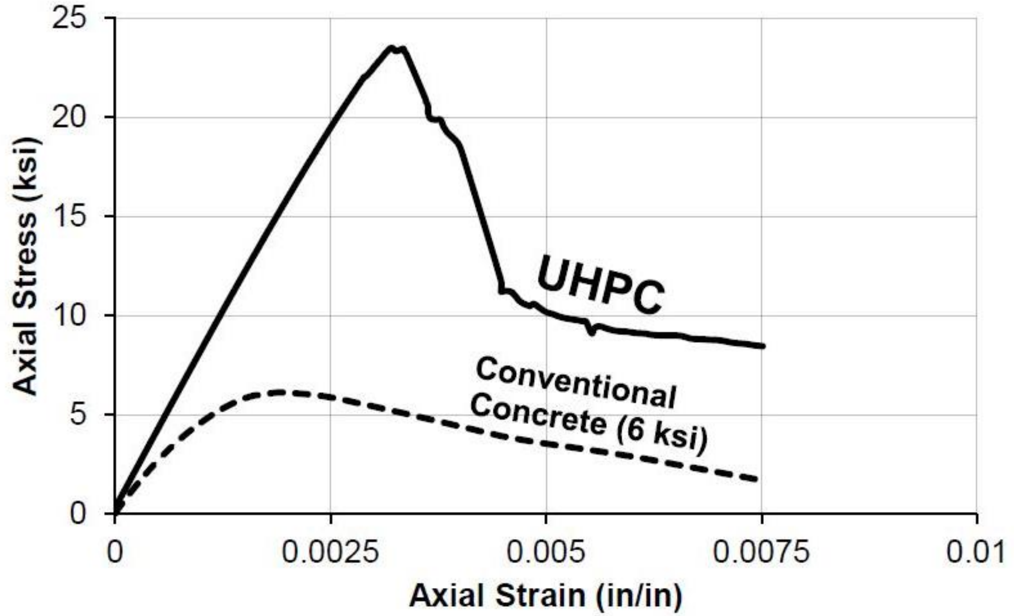
UHPC Durability

- **Can withstand more than 1,000 freeze/thaw cycles with no damage versus 27 for traditional concrete**
- **Particle packing principle reduces void spaces to prevent penetration by water and other chemicals.**

Originally presented by Ben Graybeal (FHWA) on 6/18/16 at the 1st International Interactive Symposium on UHPC

Introduction to Cor-Tuf UHPC

UHPC Compression Behavior



- Typical values range between 18 and 35 KSI
  - Cor-Tuf has demonstrated consistent values in excess of 28,000 PSI
- UHPC typically exhibits 10x the compressive strength of conventional concrete

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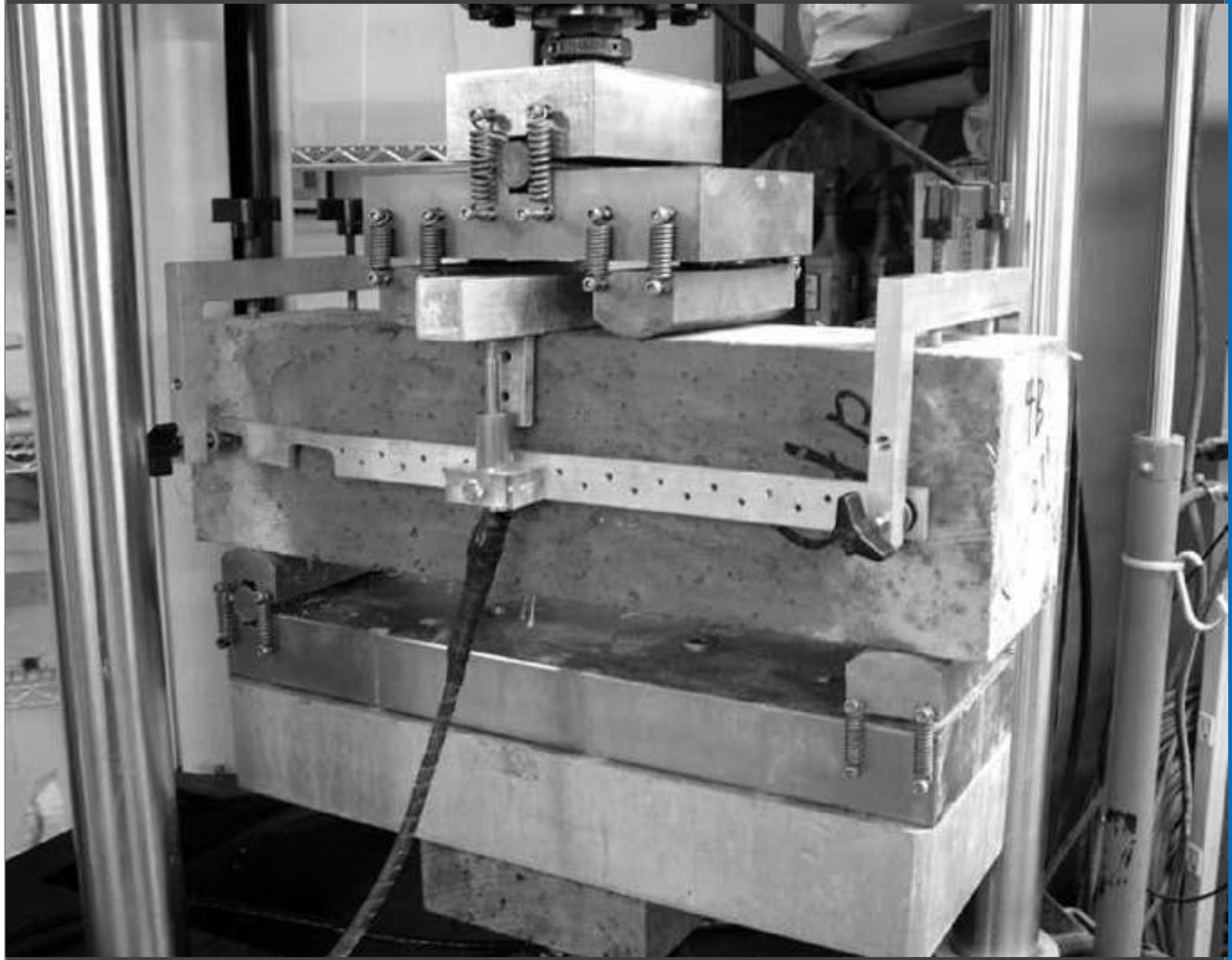
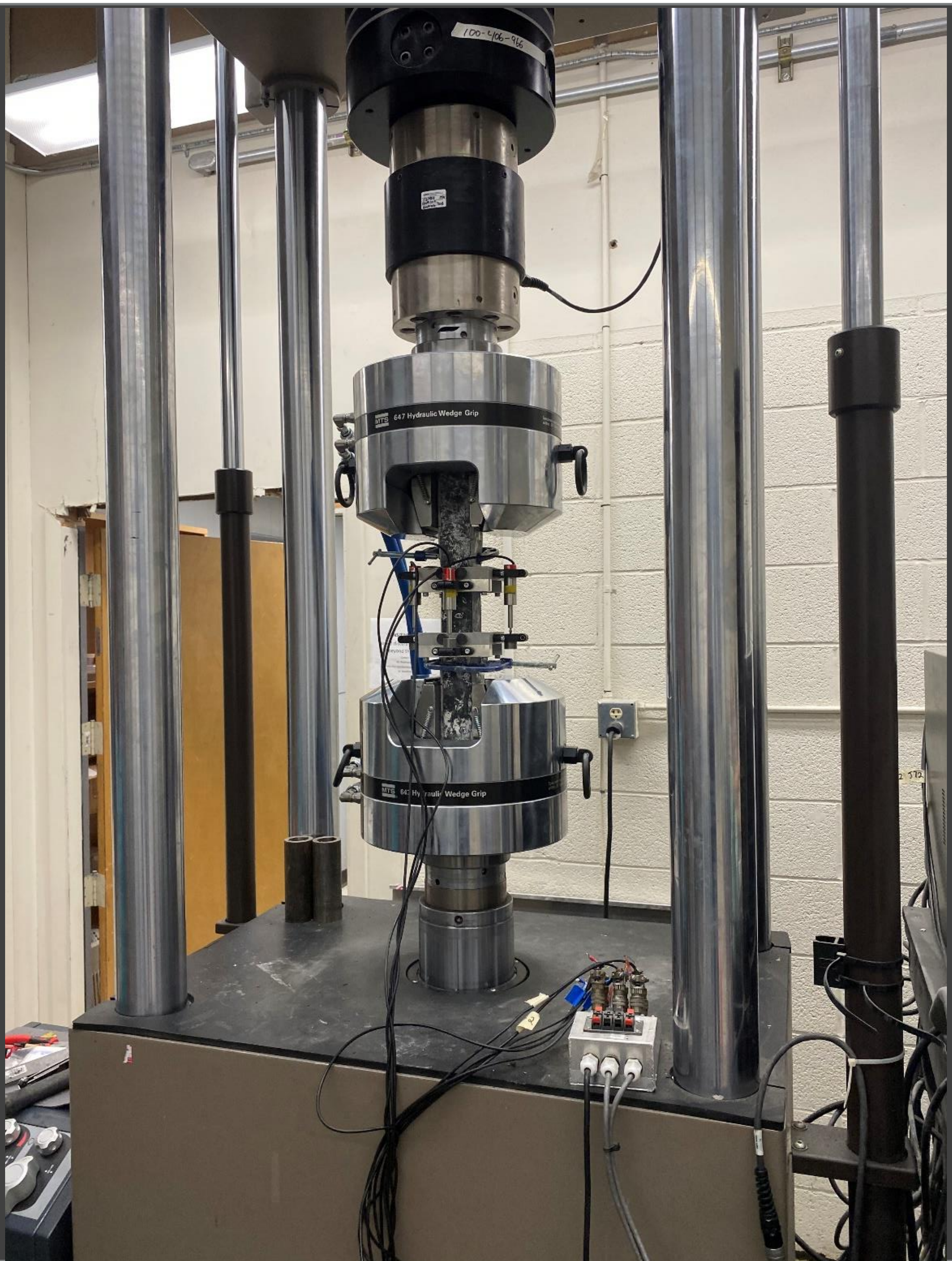


Introduction to Cor-Tuf UHPC

UHPC Flexure Standards

- C1609/C1609M
- Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)
- NOT ASTM C78 - Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

Originally presented by Ben Graybeal (FHWA) on 6/18/16 at the 1st International Interactive Symposium on UHPC



Introduction to Cor-Tuf UHPC

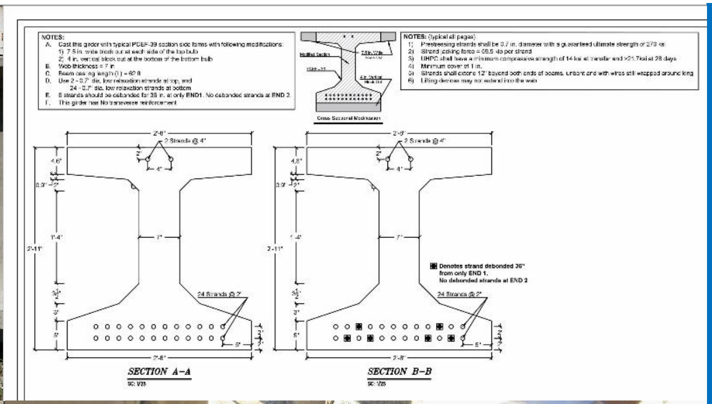
UHPC Flexure Standards

- Recent development of "Direct Tension Test" (Pull Up Test) with FHWA - Ben Graybeal, Ph.D., University of Florida - Kyle Riding Ph.D. and University of Alabama – Sriram R. Aaleti Ph.D.

Introduction to Cor-Tuf UHPC

UHPC Mixing

- Cor-Tuf can be mixed using a variety of industry standard means and methods.
  - Small stationary field mixers
  - Large central batching facilities
  - Skid-steer Auger Bucket
- Cor-Tuf can be pumped using conventional concrete pumping solutions.
  - Cleans using only water
- Can be transported and placed using Tucker-built or ready- mix trucks



Introduction to Cor-Tuf UHPC

Benefits of Cor-Tuf UHPC

- **Precast pouring of larger and longer structural components**
- **Reduced structural design criteria in reinforcing components**
- **Compatible with extrusion and extraction techniques**
- **Compatible with pre- and post-tensioning**
- **Can be used to create precast beams and deck panel**
- **Can link slabs between adjacent spans**
- **Precast parapets and side barriers**
- **Can be used in Tilt-up construction**
- **Cast in place joints between precast beams, deck panels and stud pockets**

How Cor-Tuf UHPC Replaces Traditional Concrete

1

Strength – 10 times the compressive strength of conventional concrete, achieves half strength in 5-7 days

2

Durability – Can withstand more than 1,000 freeze/thaw cycles with no damage versus 27 for traditional concrete

3

Impermeable – Less than 100 coulombs of permeability versus 1800 in regular concrete

4

Ductile – Has a demonstrated tensile strength in excess of 1,800 psi versus 600-800 of standard concrete

5

Versatile – Hardens according to mix design variability and can be handled in as little as 8 hours

How Cor-Tuf UHPC Replaces Traditional Concrete

6

Blast and Impact Resistant – Originally developed by the US Army Corps of Engineers, **Cor-Tuf is an ideal defense material**

7

Superior Adhesive – Unlike standard concrete, **no special surface preparation** is required to use Cor-Tuf.

8

Lighter Weight – Panels are **25-33% thinner** than those of equivalent size made with conventional concrete

9

Chemical Resistance – Due to its impermeability Cor-Tuf is **highly resistant to salt and chemical penetration**

10

Longer Lifespan – Cor-Tuf has much longer useful lifespan in **excess of 100 years** versus 15-25 for traditional concrete

Additional Benefits

- Off-site manufacturing
- Accelerated Bridge Construction via critical path savings
- Elimination of primary and/or secondary reinforcement
- Retrofit and modification projects
- Architectural design implications
- Structures exposed to harsh elements
- Accent the vertical and horizontal shear values

Cost Savings with Cor-Tuf UHPC

- Lower lifecycle cost
- Expediently reduces overall structural maintenance
- Expedites critical path method (CPM)
- Less material required for projects
- Lower gross weight reduces support and footing requirements
- Faster construction
- Reduced maintenance requirements
- Pumpable, cleans from equipment with only water

Aerial view of the VDOT crew pouring the bridge panel connections

Pre-tensioned piling being removed from its form during Florida Dot tests at Dura Stress Inc.

Cor-Tuf designated batch plant at Dura-Stress Inc. – Leesburg, Florida

Cor-Tuf being poured via ready mix truck during H-piling casting at Dura Stress Inc.

Pre-tensioned H-piling after casting at Dura Stress Inc.

Cor-Tuf UHPC beam prepared for transportation to the Turner-Fairbank Highway Testing facility - FHWA


Cor-Tuf UHPC security planters prepared
for DOD / LBM Research Associates

Installation of 18”x18”x100’ square piling in Leware Construction Yard, Leesburg FL.

Piling showed 100% integrity throughout installation.

Product Demonstration Videos

- Cor-Tuf Piling Lifecycle
- Cor-Tuf UHPC H-Piling Production

References

- UHPC 101, An Introduction to Ultra-High-Performance Concrete
  - Written and presented by Ben Graybeal, PH.D., P.E.

- Ballistic Penetration Test Results For Ductal® And Ultra-High-Performance Concrete Samples
  - Written by Tom F. Thornhill, William D. Reinhart
  - Sandia Report Sand 2010-2222 Unlimited Release Printed March 2010

- Federal Highway Administration – Ultra-High-Performance Concrete
  - https://highways.dot.gov/bridges-and-structure/ultra-high-performance-concrete/ultra-high-performance-concrete

- Cor-Tuf
  - https://cor-tuf.com/

THANK YOU !

COR-TUF UHPC

the future of concrete

Proudly made in America