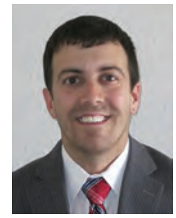

One Step Ahead: FHWA Investigates Commercially Available UHPCs

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Advances in concrete technology—such as high-strength steel, microfiber reinforcement, superplasticizers, gradation optimization, and supplementary cementitious materials—began to be packaged together into a new generation of cementitious composite materials in the 1970s and 1980s. In the 1990s, this new class of materials was brought to market and has become known as ultra-high-performance concrete (UHPC).

Today, UHPC is being adopted for a variety of different bridge construction and rehabilitation applications, including 100% UHPC structural elements, bridge deck overlays, jackets for columns and driven piles, and field-cast connections between prefabricated bridge elements. This last application has proven to be a common entry point for owners and an extremely popular solution across the United States and Canada.[1] Figure 1 depicts several applications where UHPC provided a solution to a design- or construction-related challenge.

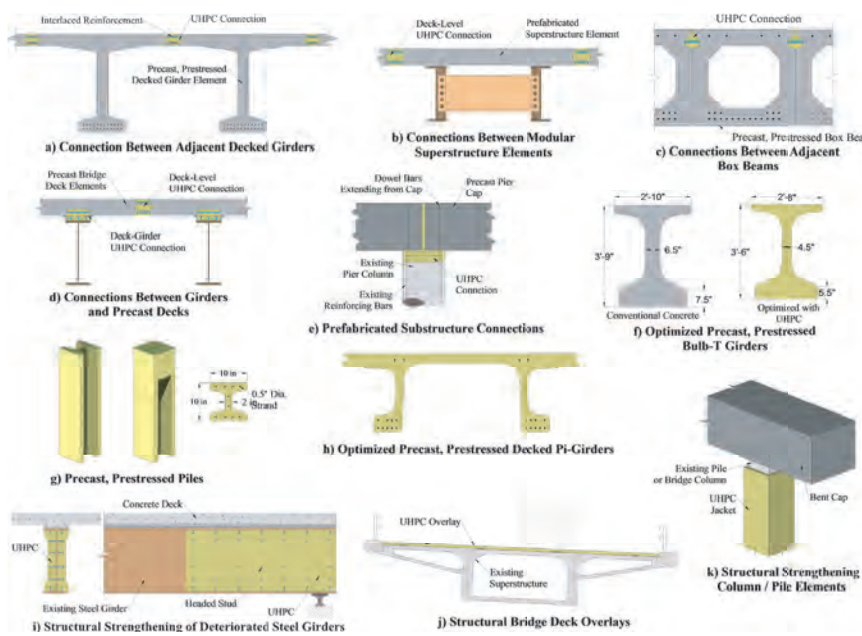

Figure 1. Bridge design and construction solutions using ultra-high-performance concrete. All Figures: Federal Highway Administration.

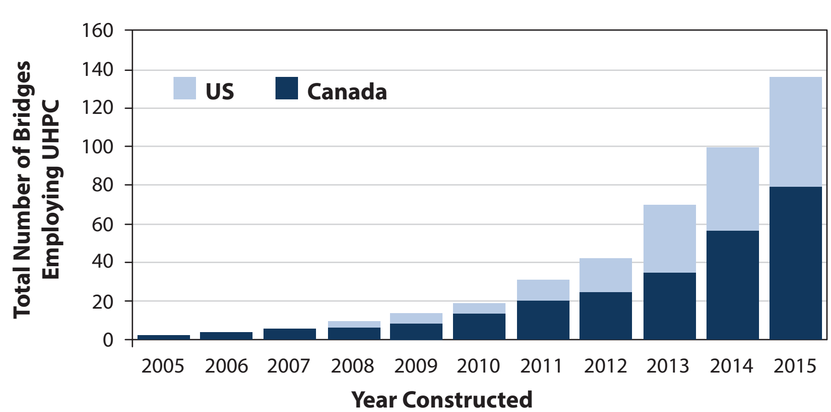

Figure 2. Chronology of bridge construction in North America with ultra-high-performance concrete.

The first North American deployment of UHPC in a bridge was in Canada in 1997; it would almost be a decade until the first U.S. bridge was constructed using UHPC in 2005. Now, just over a decade later, the growth in the total number of bridges constructed using this advanced material has increased significantly (Fig. 2). In fact, some state transportation agencies have or are planning to integrate UHPC into their standard practices and details.

As Demand Grows, FHWA Supplies Knowledge

As the demand for UHPC-class materials grows, so will the potential opportunities for suppliers of construction materials. These include current suppliers of UHPC-class

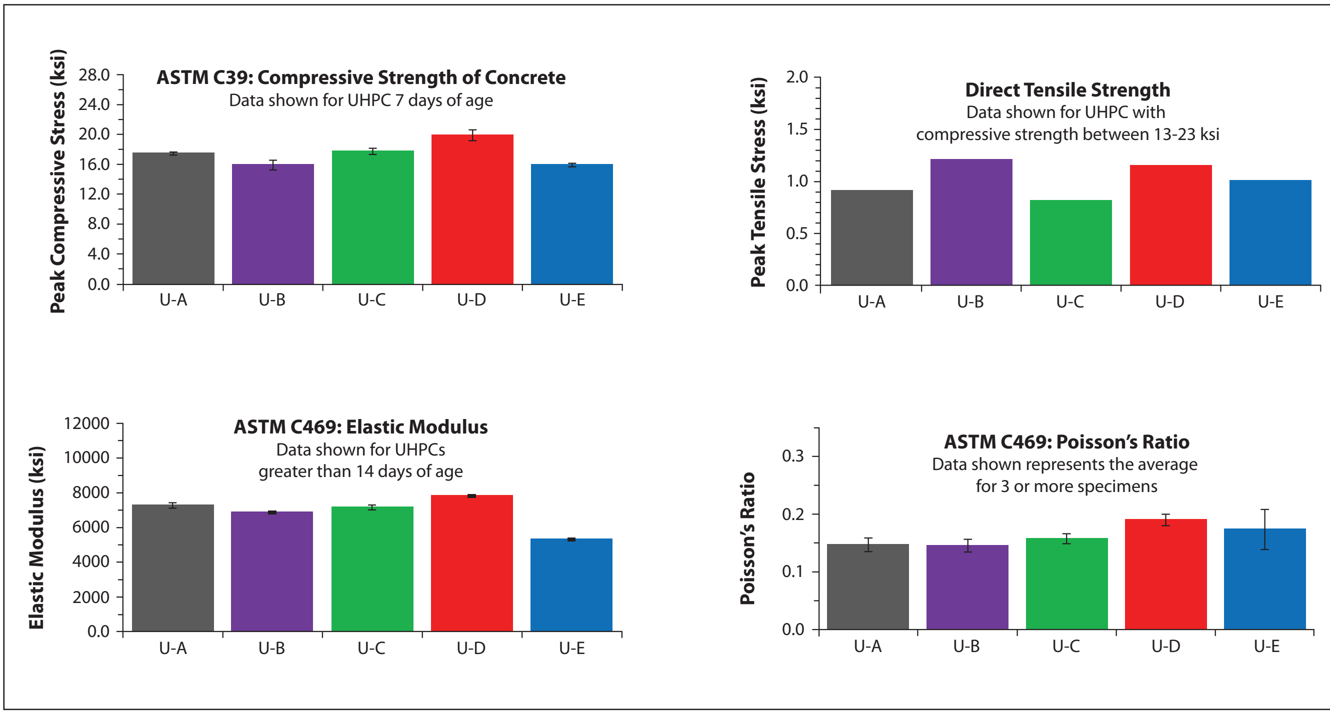

Figure 3A. Limited summary of test results on five different classes of ultra-high-performance concretes.

materials, emerging suppliers looking to bring a new product to the North American market, or small businesses looking to develop a locally-sourced product. As the demand for UHPC-class materials increases, so does the demand for knowledge. That is, the demand for a better understanding, from a general perspective, of the mechanical and durability properties of materials being marketed as "UHPC-class."

To fill this knowledge gap, researchers at the Federal Highway Administration's (FHWA) Turner-Fairbank Highway Research Center (TFHRC) executed an ambitious experimental study on five different commercially available materials that are marketed as UHPC-class. The goal of the research was to provide the bridge engineering community with a more comprehensive set of properties for this class of materials, which in turn could facilitate broader use within the bridge sector. Five materials, referred to as U-A through U-E, were tested. The experimental program included the following tests and associated test methods:

- Compressive Strength: ASTM C39, *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*
- Modulus of Elasticity and Poisson's Ratio: ASTM C469, *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression*
- Splitting Tensile Strength: ASTM C496, *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*
- Direct Tensile Strength: Per test methods developed at FHWA's TFHRC
- Shrinkage: ASTM C157, *Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete*
- Compressive Creep: ASTM C512, *Standard Test Method for Creep of Concrete in Compression*
- Flowability: ASTM C1437, *Standard Test Method for Flow of Hydraulic Cement Mortar*
- Fresh Height Change: ASTM C827, *Standard Test Method for Change in Height at Early Ages of Cylindrical Specimens of Cementitious Mixtures*
- Set Time: ASTM C403, *Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance*
- Freeze-Thaw Resistance: ASTM C666, *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*
- Chloride Penetration: ASTM C1202, *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*
- Surface Resistivity: AASHTO T358, *Standard Method of Test for Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration*
- Bond to Concrete in Flexure: modified from ASTM C78, *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*
- Interface Bond Strength of UHPC to Substrate Concrete: ASTM C1583, *Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)*
- Bond to Steel Reinforcing Bars: as described by Yuan and Graybeal[2]
- Behavior in Prefabricated Bridge Deck Connections: as described by Haber and Graybeal[3]

The researchers at TFHRC proportioned, mixed, and placed each material according to the manufacturer's specified procedures and conducted tests using both the manufacturer's recommended steel-fiber volume fraction and also a 2% volume fraction, which is common for field-cast UHPC applications. Researchers also cured the materials to simulate the conditions of field-cast UHPC. Heat or stream treatments were not applied. They mixed, placed, and cured the specimens under ambient laboratory conditions.

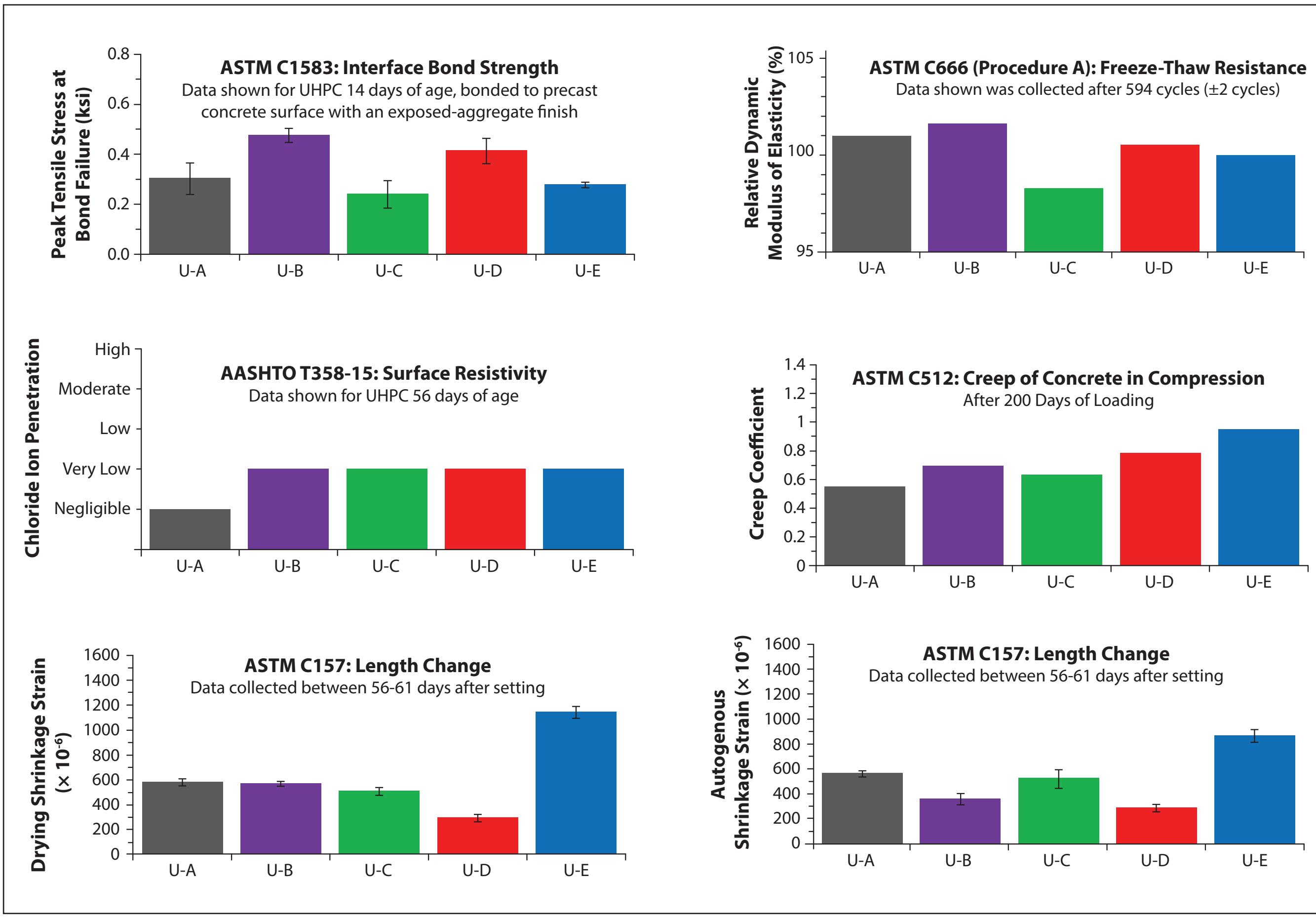

Figure 3B. Limited summary of test results on five different classes of ultra-high-performance concretes.

Findings

UHPC is known to have excellent durability properties, bond well to hardened concrete and deformed steel reinforcing bars, and have good resistance to compressive creep and good dimensional stability. As far as mechanical properties are concerned, FHWA defines UHPC to have a "*…compressive strength greater than 21.7 ksi and sustained post-cracking tensile strength greater than 0.72 ksi.*"

Figures 3A and 3B show a limited summary of results. With the exception of one type of UHPC (U-E), which did not exhibit compressive strengths greater than 21.7 ksi, the materials exhibited compression and tension properties consistent with FHWA's definition of a UHPC-class material. Each material exhibited very good durability in terms of surface resistivity and freezing and thawing resistance. The dimensional stability of the materials, which is also commonly associated with durability properties, as measured by ASTM C157, indicated a wide range of shrinkage properties among the different UHPCs. Lastly, the UHPCs exhibited some variation in the ability to bond to hardened concrete. However, this was likely a function of each material's fresh-state rheology, among other material properties. That is, materials exhibiting less flowability tended to exhibit lower bond strengths. A complete set of results and findings are currently being compiled into a final report and will soon be available to the bridge design and construction community.

Moving Forward

As the construction materials and bridge design communities strive to develop innovative and useful solutions using UHPC, FHWA intends to continue in its roles as both a technical resource and a visionary leader. Beyond assisting with the assessment of newly available UHPC materials, FHWA is initiating the process of developing a guide specification for bridge design and construction using UHPC. Through partnerships with state transportation agencies and the American Association of State Highway and Transportation Officials, the guide specification is expected to be an inflection point in the expanding use of UHPC for highway infrastructure.

References

1. Graybeal, B. 2014. *Design and Construction of Field-Cast UHPC Connections*. FHWA-HRT-14-084. McLean, VA: Federal Highway Administration Office of Infrastructure Research and Development.
2. Yuan, J., and B. A. Graybeal. 2015. "Bond of Reinforcement in Ultra-High-Performance Concrete." *ACI Structural Journal* 112 (6): 851–860.
3. Haber, Z. B., and B. A. Graybeal. 2016. "Performance of Different UHPC-Class Materials in Prefabricated Bridge Deck Connections." In *Proceedings of the First International Interactive Symposium on Ultra-High Performance Concrete: Proceedings, July 18-20, 2016.*, Des Moines, IA: Iowa State University.