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Ultra-high-performance concrete: A game changer in the precast concrete industry

- Ultra-high-performance concrete (UHPC) has the potential to replace conventional concrete in large-scale applications.
- UHPC benefits include longer life cycles, more efficient materials use, improved safety and space utilization, and longer spans.
- PCI has devoted resources to study ways to meet UHPC implementation challenges, which include cost and the development of UHPC structural systems to capitalize on its unique capabilities.

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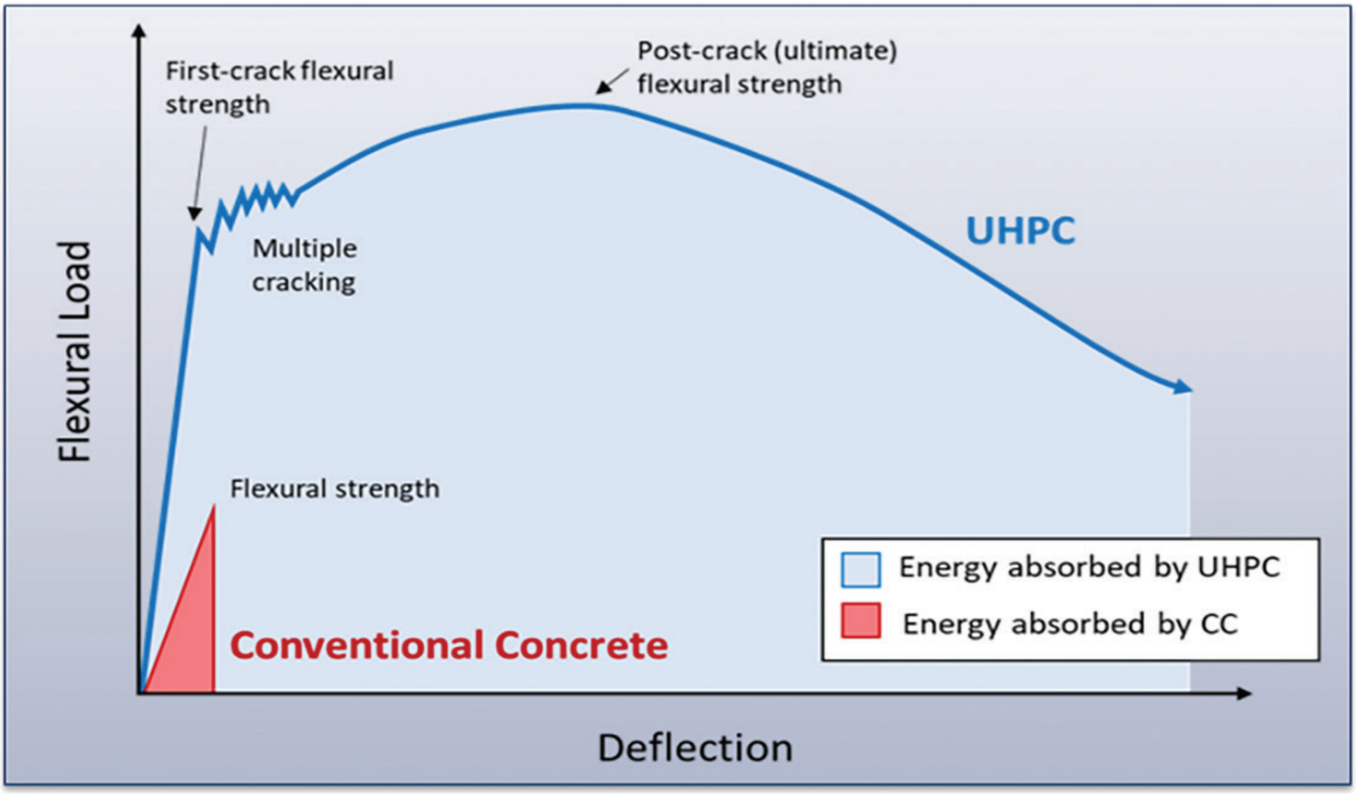
Ultra-high-performance concrete (UHPC) was first introduced as reactive powder concrete in the early 1990s by employees of the French contractor Bouygues. Since then, France, Japan, Malaysia, South Korea, and several other countries have made significant progress in using this material for bridge construction and other applications. The first roadway bridge with UHPC beams was built in France in 2001 and comprised five double tees with a beam section referred to as a pi shape.

In the United States, several state departments of transportation, with support from research conducted by the Federal Highway Administration (FHWA) and their local universities, are exploring applications of UHPC for their bridge projects. Most notably, Virginia has produced I-beams with UHPC, and Iowa has built two bridges with UHPC beams and one with a UHPC deck in the past 10 years. Several companies market prepackaged UHPC mixtures in the United States. However, due to the high cost of these prebagged mixtures, UHPC has mostly been limited to use in the FHWA-subsidized demonstration projects in Virginia and Iowa and in limited quantities in the joints between precast concrete members.

To advance UHPC applications in the United States, two conditions need to be met: the cost of UHPC raw materials must be reduced to less than $1000/yd^3, compared with a cost of about $2500/yd^3 for prebagged materials, and structural systems must be developed to capitalize on the unique capabilities of UHPC to allow for reduction of member

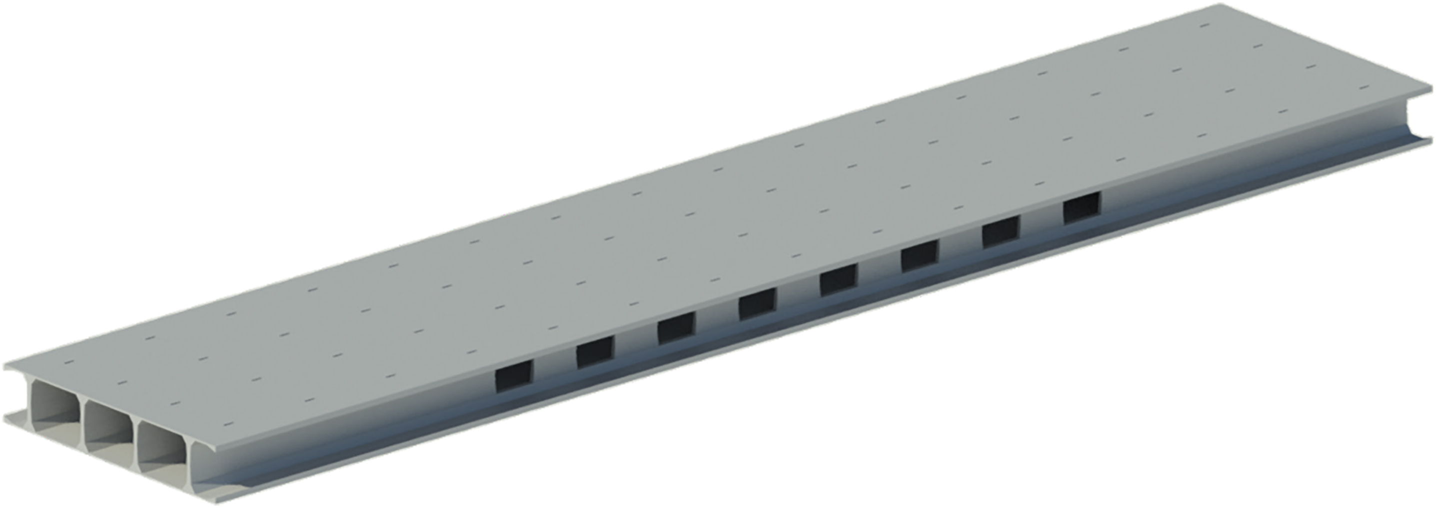


Ultra-high-performance concrete (UHPC) and conventional concrete (CC) tensile behavior differs greatly under flexural loading. Courtesy of e.construct USA.

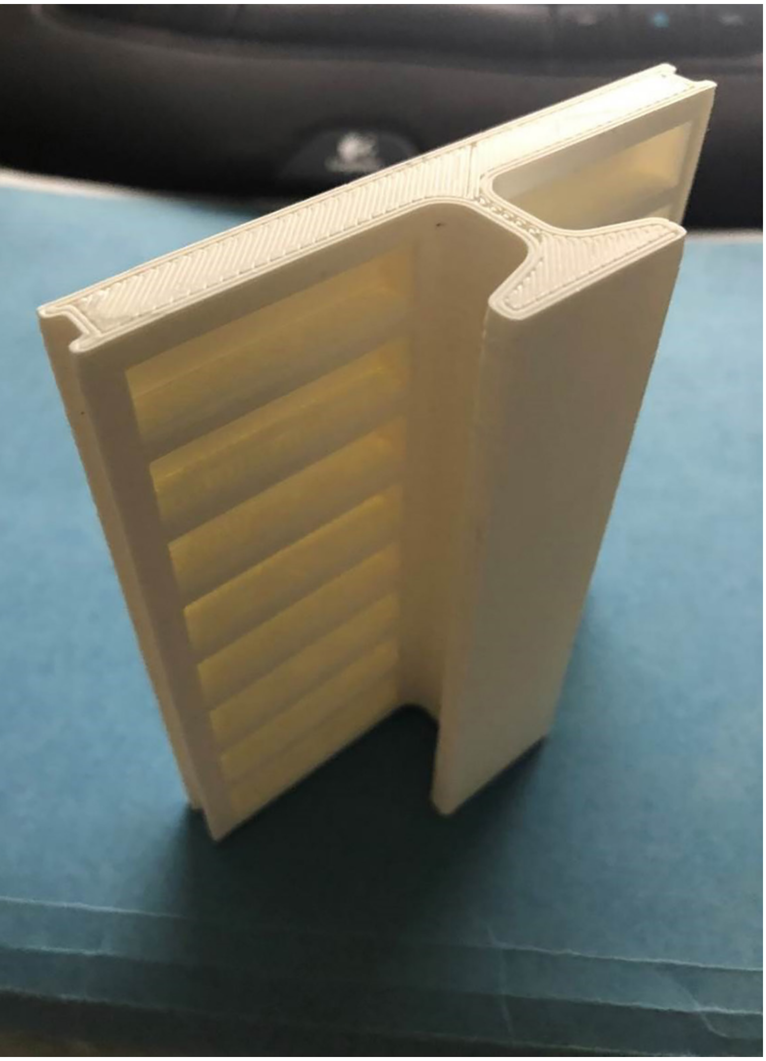
weight by about 50% while maintaining acceptable strength and stiffness and preserving the high durability of the material. PCI is devoting resources to help meet these conditions by awarding an implementation project led by e.construct and including Wiss, Janney, Elstner Associates; the University of Nebraska–Lincoln; North Carolina State University; and Ohio State University.

The first phase of this ongoing PCI project is complete, and a comprehensive report has been posted for PCI producer members. Both goals of achieving cost-effective locally mixed and produced UHPC mixtures and optimized structural members for buildings and bridges were successfully achieved. When the project findings are implemented, it is expected that the UHPC products targeted in the PCI project will be competitive based on initial cost. Several full-scale bridge and building elements have been produced and tested. Most of the products failed at loads much higher than required in service. In addition, the material is like ceramic. It has nearly zero porosity and has an expected service life of several hundred years, as opposed to conventional concrete, which is designed for a 75-year service life. The second phase of the PCI project is ongoing and includes full-scale testing of components and full members. It is intended to verify, refine, and confirm the tentative design guidelines drafted in phase 1.

The primary constituents of ultra-high-performance concrete mixtures are portland cement, supplementary cementitious materials, fine sand, fiber reinforcement, and high-range water-reducing admixtures. Courtesy of Wiss, Janney, Elstner Associates.



The example above shows a design concept for an ultra-high-performance concrete voided slab system for residential applications. Courtesy of e.construct USA.



This isometric view shows an optimized ultra-high-performance-concrete-decked I-beam for accelerated bridge construction. Courtesy of e.construct USA.

UHPC qualities

Currently, there is not a universally accepted definition of UHPC. Typically, the design compressive strength ranges from 17 to 22 ksi (117 to 152 MPa), which is nearly five times the compressive strength of conventional concrete.

Compressive strength is not the most important property. Tensile strength and tensile ductility are the keys to success with UHPC. The high tensile strength allows for significantly higher shear resistance, with the possibility of total elimination of the stirrups. When stirrups are eliminated, significant simplification of design and precast concrete production results. Also, member web (stem) width is greatly reduced, which results in significant weight reduction. There is a great difference between the tensile behavior of UHPC and that of conventional concrete. For example, 4 ksi (28 MPa) conventional concrete has a flexural tensile strength of about 0.450 ksi (3 MPa), while the corresponding UHPC value can be as high as 10 times that value. UHPC also deflects in the standard ASTM C1609 prism test an amount larger than span/150 without losing much of its strength. This behavior demonstrates tremendous toughness and ability to absorb energy even without the help from reinforcing bars.

UHPC applications

Shown is a design concept for use in buildings. The voided slab is a two-piece precast, prestressed concrete floor that allows for a 60 ft (18 m) span using a depth of 22 in. (0.6 m). No steel, other than the prestressing strands, is needed for this design. The top flange is only 1 in. (25.4 mm) thick, and the stems are only 2 in. (50 mm) wide. The stems have openings to allow for integration of utilities. The overall weight corresponds to a solid slab less than 4 in. (102 mm) thick. With this long-span product, residential multistory buildings can have column-free parking in the lower floors, which enhances the safety of the residents. Also shown is an isometric view of an optimized decked I-beam to be used in accelerated bridge construction (ABC) applications. It has a 4 in. (102 mm) wide web and a ribbed (waffle) slab top flange with a top skin of only 2 to 3 in. (50 to

76 mm) and total flange depth of 8 in. (203 mm). As a result, the product has about 50% of the concrete and less than 30% of the reinforcing bars compared with conventional concrete. Not having reinforcing bars for stirrups in the webs greatly simplifies design and precast concrete production. A total depth of 9 ft (2.7 m) can be shown to span up to 250 ft (76.2 m).

Conclusion

The information presented in this article shows that UHPC has an excellent potential to replace conventional concrete (CC) in many large-scale applications. UHPC has the ability to be cost-competitive on a first-cost basis while being far more valuable than CC on a long-term life cycle basis.

By taking advantage of the key properties of UHPC, bridge and building members will become more efficient in the use of materials, while also being able to span farther, improving space utilization and enhancing safety of people and vehicles. Lower consumption of construction materials will be good for the environment as it reduces carbon dioxide emission and global warming potential.

About the authors

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Abstract

The information presented in this article details UHPC's potential to replace conventional concrete in many large-scale applications. UHPC has the ability to be cost-competitive on a first-cost basis while being far more valuable than conventional concrete on a life-cycle basis. By taking advantage of the key properties of UHPC, bridge and building members will use materials more efficiently while also being able to span farther, improving space utilization and enhancing the safety of people and vehicles. Lower consumption of construction materials will be good for the environment because of its potential to reduce carbon dioxide emissions.

Keywords

Bridge, I-beam, parking structure, UHPC, ultra-high-performance concrete.

Reader comments

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