Ultra-high-performance concrete research at PCI

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The theme of this issue of *PCI Journal* is "Materials." This Research Corner presents an overview of the work that led up to the recently completed PCI specially funded research on ultra-high-performance concrete (UHPC).

Additives to concrete mixtures to improve workability, as well as to maintain high early strengths while limiting water demand, have been researched for decades. Fly ash was the subject of a study published in 1990[1] that showed benefits that have prompted widespread use within the industry ever since. Studies were later done in specific product applications where the density of the cementitious matrix was augmented by adding silica fume, thereby increasing strength and resistance to chloride and moisture penetration.

Laboratory research by French and Mokhtarzadeh[2] determined the effect of various material and test parameters on uniaxial compressive strength. Parameters included mold size, mold material, type of aggregate, type of curing, age, and specimen end condition. When using Type III portland cement by itself as well as in combination with fly ash and silica fume, compressive strengths ranging from 9000 to 15,000 psi (62 to 103 MPa) were achieved. Through the 1990s, several projects examined bridge girders using high-performance concrete with 10,000 psi (69 MPa) compressive strength, primarily to prove structural performance under fatigue loading. One finding was that for uncracked conditions, designing for an extreme fiber tensile stress between 750 and 860 psi (5.2 and 5.9 MPa) would be applicable.[3]

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.

Research refining the matrix of cementitious materials continued over the past 25 years. This refined matrix in combination with steel fiber reinforcement has led to modern UHPC, which has high compressive strength, high durability, and perhaps most significantly, high tensile strength and postcracking ductility. To date, UHPC has seen limited commercial use, such as for thin shells for architectural applications and in deck connections for the transportation sector. These projects have typically involved material of a proprietary nature.

In the November–December 2016 issue of *PCI Journal*, Geisler, Applegate, and Weldon[4] published a paper titled, "Implementing Nonproprietary Ultra-high-performance concrete in a Precasting Plant," which was partially funded by a PCI Daniel P. Jenny Research Fellowship and partially funded by the New Mexico Department of Transportation. The study successfully showed that concrete capable of achieving high compressive strengths on the order of what would be considered UHPC could be produced by adapting laboratory methods on a large scale with no significant changes to the plant facilities. In addition, it showed that locally available materials could be used to produce this concrete.

The works noted above and research by other entities led to a PCI specially funded project on UHPC that took place between 2018 and 2021.[5,6] The focus of this research was twofold. The first objective was to facilitate implementation of UHPC materials. This involved proving that consistent production of concrete mixtures with a compressive strength of 18,000 psi (124 MPa) and a tensile strength of 1700 psi (12 MPa) using regionally available materials was feasible and capable of providing an alternative to proprietary mixtures. Using regionally available materials also reduces the material cost per cubic yard, which improves the commercial viability. This work also produced material and quality control guidelines and a draft specification, subsequently published as PCI TR-9-22, *Guidelines for the Use of Ultra-High-Performance Concrete (UHPC) in Precast and Prestressed Concrete*.[7] The second objective was to define design parameters for use in structural flexural elements, both for bridge and building applications, seeking to optimize member cross section by gaining maximum benefit of the material properties. Of necessity, this study was limited to steel fibers of a certain size and the target design strengths, rather than a broader more encompassing study.

There is discussion underway about extrapolating more from this study, such as using nonmetallic fibers and targeting lower strengths for architectural applications. More research is likely to come as it relates to refining mixtures for the sake of carbon reduction, either through the reduction of cement usage through more-efficient mixture designs or through efficient and smaller cross sections needing significantly less volume. The expected service life of UHPC members exceeding several hundred years makes this material that much more desirable when viewed on a life cycle basis.

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