Development of Non-Proprietary Ultra-High Performance Concrete (UHPC) for Iowa Bridges

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RESEARCH PROJECT TITLE
Development of Non-Proprietary Ultra-High Performance Concrete (UHPC) for Iowa Bridges

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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This project details a study performed on the design of non-proprietary UHPC mixtures that deliver comparable strength and durability properties to those of commercially available mixtures and provides recommendations for preparation of cost-effective, non-proprietary UHPC mixtures that can be used for various transportation infrastructure applications.

Problem Statement

While ultra-high performance concrete (UHPC) provides superior properties in strength and durability—which are desirable in bridges and potentially applicable in the majority of projects—UHPC is still not widely used. The major contributing factor that limits the use of UHPC for bridges is the cost associated with it.

Goal and Objectives

The goal of this work was to develop and characterize economically viable, non-proprietary UHPC mixtures made with readily available materials in Iowa.

Given that UHPC is known not only for its high strength but its superior durability, this project details the efforts made to maintain and improve these factors in non-proprietary UHPC mixtures.

Background

Disruption in the functionality of highway transportation infrastructure as a result of deterioration of concrete structures has been a growing concern for transportation agencies. This has required the identification of strategies to enhance the performance of concrete to reduce the deterioration of concrete structures and lengthen their service lives.

Research Description

For this project, the researchers developed non-proprietary UHPC mixtures by using ordinary portland cement, regular sand, widely available masonry sand, silica fume, and steel fibers. The mixtures that were developed were tested for both strength and durability, and, as a result, service life of concrete structures. The mixtures were then evaluated for the effect of individual constituents on the properties of the UHPC.

The set of non-proprietary UHPC mixtures developed were based on the theoretical model for particle packing (the Andreasen and Andersen packing model) and the findings from available literature. The mixtures obtained were further improved by optimizing the parameters of the theoretical model, i.e., maximum particle size and the distribution modulus. A set of further investigations were performed to evaluate the effect of the sand-to-cement ratio, silica fume-to-cement ratio, and types of silica fume.

This study also explored the effects of various dosages, shapes, and sizes of steel fibers on the flexural response characteristics of UHPC. The dosage of steel microfibers was varied from 1.0% to 3.0% (with increments of 0.5%). Two additional mixtures were prepared using two macrofibers, twisted wire and hooked, without any microfibers.

Upon understanding the main characteristics of the UHPC mixtures made with either micro- or macrofibers, a set of six UHPC mixtures were prepared using various combinations of the micro- and macrofibers. The mixtures were tested for their workability, compressive strength, and flexural strength, while detailed digital image correlation (DIC) analyses were conducted in parallel.

Since the flexural response characteristics of UHPC greatly depend on the type and dosage of fibers included in the mixture, in the absence of any holistic investigations in the literature, this study evaluated the flexural performance of UHPC mixtures made with five different synthetic fibers: nylon, polypropylene (PP), polyvinyl alcohol (PVA), alkali-resistant (AR) glass, and carbon. The scope of this investigation covered workability, compressive strength, and flexural strength of several combinations of synthetic and steel fibers.

Key Findings

- The initial efforts focused on the development of a base mixture utilizing locally available materials that resulted in a mixture with one-third the cost of the proprietary UHPC mixtures and a promise to provide comparable strength and resistivity.

- The results obtained from further testing of a set of selected mixtures—for transport properties, volume stability, and freeze-thaw resistance, which are key requirements for bridges given they are usually exposed and vulnerable to changing weather conditions and other environmental factors—were compared to the properties of two proprietary mixtures, and all of the non-proprietary mixtures showed great promise in all key aspects for which they were tested.

- From the mixtures explored, it was found that those with straight steel and wire fibers worked best when the straight steel content was 1% or higher, while, for hooked fibers, the combination had better results with a straight steel dosage less than 1%.

- As far as efforts to explore less expensive synthetic fibers as partial or full replacement for steel fibers in UHPC mixtures, although the synthetic fibers resulted in some difficulty in mixing and workability, the results showed improved flexural strength and ductility.

Test setup used to capture flexural response of developed non-proprietary UHPC mixtures in the laboratory

- The workability of AR glass fibers was the best, followed by PVA and nylon fibers. Nylon fibers present particularly greater challenges because of their high absorption property. The results for flexural testing and toughness showed that the PVA fibers showed greater promise, even in lower steel dosages, followed by nylon fibers and PP fibers.

- Non-proprietary UHPC mixtures can be obtained by utilizing locally available materials. A sand-to-cement ratio in the range of 1.0–1.4, water-to-cement ratio in the range of 0.2–0.25, and silica fume-to-cement ratio of 0.7–0.14 can result in a cost-effective, non-proprietary UHPC mixture with the strength and durability comparable to those of proprietary mixtures.

Implementation Readiness and Benefits

The final report for this project provides details on a set of non-proprietary UHPC mixtures that can be prepared with locally available materials. The report also provides comprehensive insight into the strength and flexural response of non-proprietary mixtures.

The recommended mixtures can be prepared in the laboratory with pan mixers. The recommended combination for different ratios of types of steel fibers can be helpful depending on the type of application and availability of fibers. The recommended mixture for steel and synthetic fibers should be decided bearing in mind the two critical parameters: workability and flexural strength. A trade off may need to be made depending on the type of application.