Project Summary Report: 8237-001

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Development of Non-Proprietary Ultra-High Performance Concrete

http://www.mdt.mt.gov/research/projects/mat/high_performance_concrete.shtml

Introduction

Ultra-high performance concrete (UHPC) has mechanical and durability properties that far exceed those of conventional concrete. Thus, elements made with UHPC can be thinner/lighter than elements made with conventional concrete. The enhanced durability properties of UHPC also allow for longer service lives and decreased maintenance costs. However, using UHPC in conventional concrete applications is extremely expensive, with commercially available/proprietary mixes exceeding $2,000 per cubic yard, which is approximately 20 times the cost of conventional concrete.

The overall objective of this project was to develop and characterize economical non-proprietary UHPC mix designs made with materials readily available in Montana. Such mixes would be significantly less expensive than commercially available UHPC mixes, thus allowing for the use of UHPC in construction projects in Montana. In particular, the Montana Department of Transportation (MDT) Bridge Bureau is interested in using UHPC as a field-cast jointing material between precast concrete deck panels (Figure 1).

What We Did

In this research, suitable materials for production of UHPC that are readily available in Montana were obtained and characterized. Initial trial UHPC mixes were then prepared and tested to determine concrete behavior across a range of potential mix proportions (e.g., water to cement ratios, paste contents, admixture dosage rates).

Figure 1: Field-cast joint being filled with proprietary UHPC on a previous MDT Project

A statistical experimental design procedure (Response Surface Methodology: RSM) was then used to characterize the effects of these various parameters on the behavior/performance of the UHPC. Ultimately, RSM was used to determine optimized mixes that met specified performance criteria (e.g., 8-11-in flow (Figure 2), 20 ksi compressive strength (Figure 3)). The effect of batch size and mixing/curing procedure was then investigated with these optimized mixes (Figure 4).

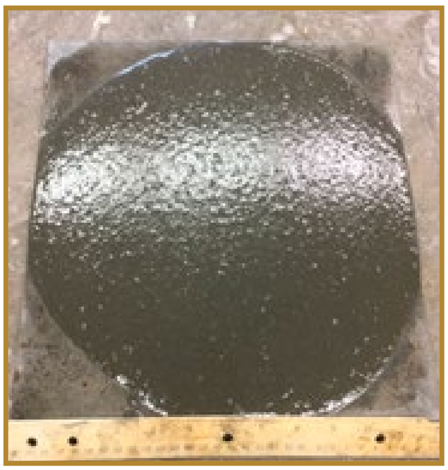

Figure 2: Flow Test

Figure 3: Brittle Failure of Cylinder after Compression Test

Figure 4: UHPC After Mixing

Based on this investigation, a mix protocol was established, and a modified mix design was selected for further evaluation. The mechanical properties and durability of this selected UHPC mix was then evaluated through a suite of ASTM tests. Specifically, the mechanical properties tested in this research were compressive and tensile strength, elastic modulus, and shrinkage. Durability tests included alkali-silica reactivity, absorption, abrasion, chloride permeability, freeze-thaw resistance, and scaling.

What We Found

Based on this investigation, the following conclusions can be made.

1. Suitable materials for use in UHPC can be easily obtained in the state of Montana. Specifically, this project used (a) Type I/II portland cement from the CRH plant in Trident, MT, (b) a Montana-sourced fine sand that met standard masonry sand specifications, (c) a class F fly ash from the Coal Creek Station near Underwood, ND, (d) silica fume sourced through BASF, (e) a high range water reducer (HRWR) sourced from CHRYSO, Inc., and (f) steel fibers from Nycon.
2. Response Surface Methodology proved to be an efficient tool for characterizing the effect of the various constituents on the performance of UHPC, and for optimization. Using this methodology, four mixes were identified that met the desired performance criteria: $300-$350 cost (without fibers), 8-11 inch flow, and 20-21 ksi strength at 56 days. The measured responses from these mixes were all within 12 percent of the predicted responses, and all easily within the 95% confidence interval (Figure 5).
3. Batch size and mixing method were observed to have a significant effect on resultant plastic and hardened concrete properties. It was determined that a conventional fixed-vane rotating drum concrete mixer was not able to mix these UHPC mixes (at least not at the batch sizes used in this research); however, a conventional fixed-drum rotating-fin mortar mixer was found to provide adequate mixing action/energy. In addition to the observed variability with batch size, a significant amount of variability was observed between repetitions of identical batches. It was determined that much of this variability could be reduced by including steel fibers, and modifying the curing procedure and the manner in which the test specimens used to characterize the concrete performance were prepared (e.g., sealing

top of freshly cast test specimens with plastic wrap to prevent surface moisture loss).

4. The mechanical and durability tests performed on the selected UHPC mix demonstrated the exceptional mechanical properties and durability of this material.
5. Overall this research demonstrated that non-proprietary UHPC mixes can be made economically (less than $1,000/yd^3) with materials readily available in the state of Montana.

What the Researchers Recommend

While this research demonstrated the feasibility of producing lower cost non-proprietary UHPC, further research is required before this material can be used in real-world applications, and more specifically before it can be used in field-cast joints between adjacent precast deck panels. In the research discussed herein, the concrete batches were 0.2- to 1.5-cubic feet in size, and were mixed using equipment available in the Montana State University concrete lab (i.e., an industrial cake mixer, and a conventional horizontal mortar mixer). This research and previous research on UHPC has shown that batch size, mixing equipment, mixing method, and mixing energy can have a significant effect on the performance of the resulting UHPC mix. Therefore, further research should be conducted on the proposed UHPC mix using the equipment that will be used in the field (most likely a high-shear pan mixer), under various mixing conditions (e.g., various temperatures and aggregate moisture conditions), and in larger batch sizes. Further, previous research on UHPC field cast joints has shown that UHPC can reduce development lengths of the reinforcing in the inter-element connection zone, and thus reduce spacing between decks. However, this research was conducted using only proprietary UHPC mixes. Further research should be conducted on field-cast joints using the newly developed non-proprietary mix to ensure that this mix behaves as expected in this application (e.g., increased bond strength, decreased deck joint width).

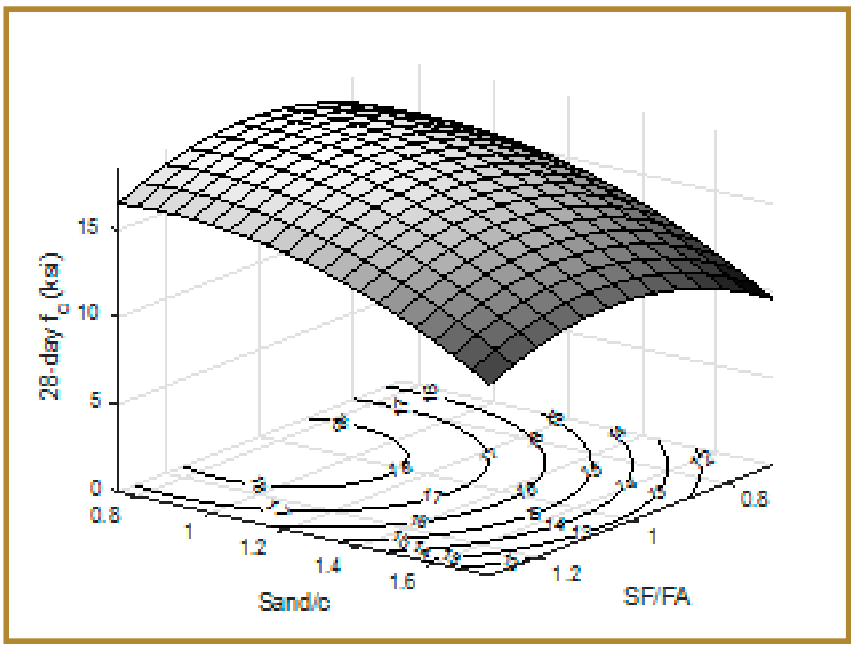

Figure 5: Typical Response Surface

For More Details . . .

The research is documented in Report FHWA/MT-17-010/8237-001, http://www.mdt.mt.gov/research/projects/mat/high_performance_concrete.shtml.

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To obtain copies of this report, contact MDT Research Programs, 2701 Prospect Avenue, PO Box 201001, Helena MT 59620-1001, mdtresearch@mt.gov, 406.444.6338.

MDT Implementation Status: December 2017

The Montana Department of Transportation has initiated a Phase 2 research project to answer the remaining questions. More information can be found at the above URL. It is expected there will be implementable results from this follow-on project.