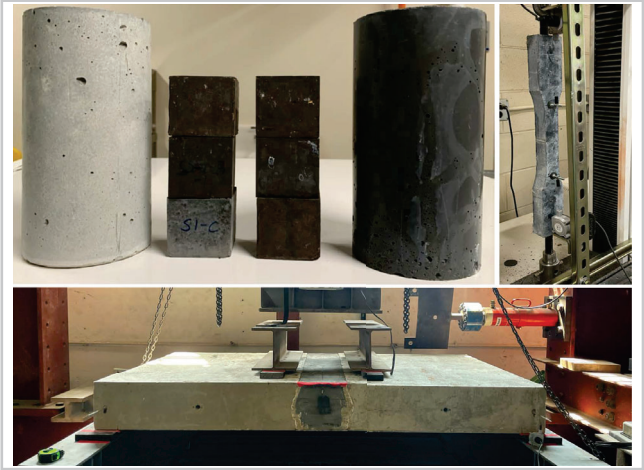
Research Summary

Ultra-High Performance Concrete Reinforced with Multi-Scale Hybrid Fibers and Its Durability-Related Properties

Research Need

Featured with high flowability and strength, ultra-high performance concrete (UHPC) is considered one of the most promising fiber-reinforced cementitious composites for future structures. The mixture design of UHPC and its correlation with the performance under different curing conditions remain unclear, and there exist critical gaps in understanding the efficiency of fibers and mixture design on the mechanical, physical, and durability-related properties.



Goals/Objectives

This project aims to develop UHPC mix design formulations with locally sourced and attainable materials that can be implemented at ready-mix batching plants or precast/prestressed concrete fabrication facilities. The key objectives of this project include:

- A fundamental understanding of the current state and existing knowledge gaps in UHPC.
- Establish an experimentation-based database for qualified fibers selection FRC and UHPC.
- Develop non-proprietary UHPC mix design formulations that can be modified for implementation at ready-mix batching plants or precast/prestressed concrete fabrication facilities.
- Obtain a comprehensive understanding of fresh and hardened properties of FRC and UHPC under different curing conditions.
- Laboratory mock-up tests to investigate merits and barriers in the implementation of UHPC in transportation infrastructure.

Methodology

(1) Conduct a comprehensive review of mixture design, fiber reinforcement, and applications of UHPC in transportation infrastructure projects.
(2) Characterize the microstructure, dimension, surfaces, and strength of different micro- and macro-fibers via microstructure analysis and single-fiber tension test.
(3) Develop mix design formulations of UHPC based on a novel two-step particle-packing density optimization method.
(4) Study the hydration of cementitious binders by monitoring hydration kinetics and evolution of hydration products.
(5) Investigate the permeability, shrinkage, compressive, flexural, tensile strength, and sulfate attack of UHPC with different fibers.
(6) Conduct large-scale lab tests on closure gap connections to simulate the connection between two bridge deck panels.

Key Findings

Seven mix design formulations of UHPC were developed, which reached a 3-day compressive strength of over 20,000 psi, a 28-day flexural strength of over 4,500 psi, a significant decrease in autogenous shrinkage, improved sulfate resistance, and permeability in the "very-low" range. Micro-steel fiber yields superior performance to other investigated non-metallic fibers. The UHPC connections can provide adequate transfer of forces between the structural components.

Use of Findings

Four FRC mixes and seven UHPC mixes based on two types of Portland cement (Type I/II and Type III), five supplementary cementitious materials (silica fume, ultra-fine fly ash, Class C fly ash, Class F fly ash, and metakaolin) were developed and evaluated. The influence of different fibers (micro-steel fiber, polyvinyl alcohol fiber, basalt fiber, and glass fiber) and curing conditions (regular lime water curing and steam curing)on the development of mechanical properties of UHPC provided practices recommendations for the design and curing of UHPC based on its applications.

The findings in early-age shrinkage behavior, permeability, and the development of compressive strength, flexural strength, direct tensile strength, and resistance against sulfate attack revealed the promising performance of the developed UHPC. Based on the availability of materials, the ease of mixture design and properties, a UHPC mixture for large-scale batching and commercial field applications was recommended.

The findings from lab mock-up tests confirmed the development of the required strength in the UHPC for closure gaps and validated the viable applications of the developed UHPC mixture in transportation infrastructure.

Project Information

This project was completed as part of the Massachusetts Department of Transportation (MassDOT) Research Program with funding from Federal Highway Administration (FHWA) State Planning and Research (SPR) funds.

Principal Investigators:

Jianqiang Wei, Sergio Breña

Performing Organization:

Univ. of Massachusetts, Lowell and Amherst

Project Champion:

Richard Mulcahy

Project Start Date:

September 2021

Project Completion Date:

December 2023

MassDOT Research Project Number:

23-048

Key Words:

UHPC, Fiber, Strength, Durability, Closure gap

Research and Technology Transfer Section
MassDOT Office of Transportation Planning
Planning.Research@dot.state.ma.us

massDOT
Massachusetts Department of Transportation