2021 RESEARCH PROJECT STATEMENT

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

Research Budget and Timeline:

- $160,000-$200,000
- 21-27 months (of which final 3 months are for review)

Problem Statement and Objectives
Ultra-high performance concrete (UHPC) is a cementitious composite material composed of an optimized gradation of granular constituents, a low water-to-cementitious materials ratio, and a high percentage of discontinuous internal fiber reinforcement. Due to the excellent mechanical properties, ease of placement and volume stability, UHPC is often used in transportation infrastructures including roads, underground structures, and bridges. While research efforts have been invested and generated valuable results regarding concrete mixture design, utilization of chemical admixtures, incorporation of reactive additives (e.g. fly ash, slag, silica fume, etc.) and fillers (e.g. nano-silica, limestone powders), fibers, which are the primary constituent to guarantee concrete ductility, are much less investigated. After decades of development, the reinforcement employed for UHPC is still focused primarily on steel fibers. It's more important to note that, although the composition of the concrete matrix (i.e. incorporation of chemical and mineral admixtures) can result in superior performance, the hybridization of fibers, which has a great potential to offer solutions to some critical materials design problems, has not been fully understood. In particular, there exist critical significant gaps in understanding the efficiency of multi-scale hybrid fibers (MSHFs) on concrete properties, especially the durability-related properties.

MassDOT is seeking to improve the quality and durability of fiber-reinforced concrete (FRC) for longevity and constructability of new structures and repair of structural elements such as columns, bent caps, closure caps, girders, decks and overlays. A better understanding of the role of MSHF will provide knowledge advancements including: (i) innovative concrete property control through nanoengineering and performance-orientated means; (ii) transformative guideline based on physical-chemical-mechanical laws of infrastructural materials with unprecedented properties, and (iii) development of high-quality concrete to stratify the performance expectation of future infrastructures.

The overall research objective of this project is to develop a UHPC reinforced with MSHFs, to identify and maximize the roles of these fibers and additive in enhancing

durability-related properties of UHPC, and to promote the widespread use of MSHF reinforced UHPC in transportation infrastructures. Towards this end, the research team will work with MassDOT to pursue five research tasks:

(i) Establish an experimentation-based database for qualified fibers' selection and screening based on open source and literature, related projects, and new laboratory testing;
(ii) Engineer a novel UHPC based on elaborate fiber hybridizations and additive substitutions;
(iii) Investigate cement hydration (i.e. kinetics analysis, hydration products, microstructure characterization, etc.) in the presence of nano-/micro-fiber and additives, and identify the correlations between cement chemistry and property development of UHPC;
(iv) Evaluate both fresh and hardened mechanical properties of UHPC under various curing conditions;
(v) Characterize and optimize durability-related properties of the developed UHPC in the presence of MSHF including interfacial bonding, permeability, shrinkage, cracking, water absorption, chloride penetration and carbonation, which are directly related to various concrete deterioration issues such as rebar corrosion, freezing/thawing damage, and sulfate attacks.

Anticipated Outcomes and Deliverables

• A solid literature review, experimentation-database and fundamental understanding of the current state of knowledge and existing knowledge gaps with respect to FRC, especially the utilization of multiscale fibers in UHPC.

• Development of a novel UHPC reinforced with MSHF and nano-scale additives with enhancement in both early-age properties and long-term performance, such as high early-age strength, low volume change, low permeability and extended service life in the presence of environmental threats in Massachusetts including cyclic freezing and thawing, deicing salt damage, scaling and corrosion.

• A comprehensive understanding of the roles of MSHF, additives and cement chemistry in improving durability-related properties of UHPC, which will be fed into ultra-high durable and resilient concrete infrastructure design.

• Guidelines or best practices recommendations for the design of UHPC, the use of multi-scale fibers and hybrid fibers in both UHPC and normal FRC, and their use in transportation infrastructures.

• Development of standard specification for UHPC and the constituent materials incorporated.

• Development of Qualified Construction Materials List (QCML) for the constituent fibers incorporated (i.e, manufacturers, types, etc.).

• Recommended applications for UHPC.

Deliverables:

1. Standard Specification
2. Qualified Construction Materials List (QCML) of constituent fibers incorporated
3. Final Report
4. Final Presentation