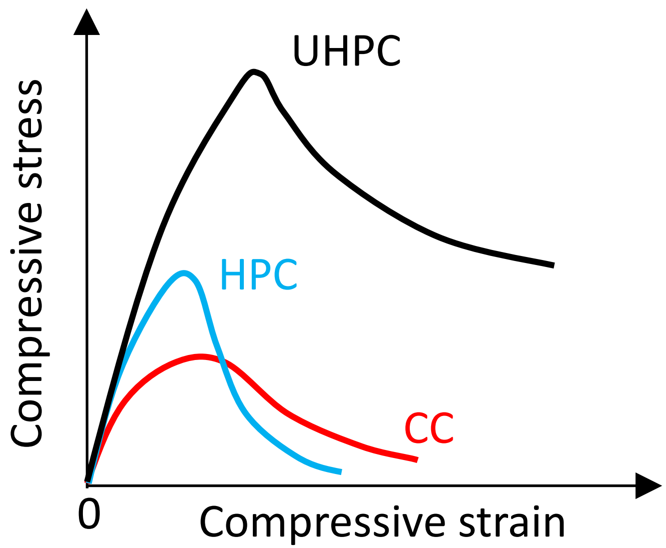
STEVENS INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY®

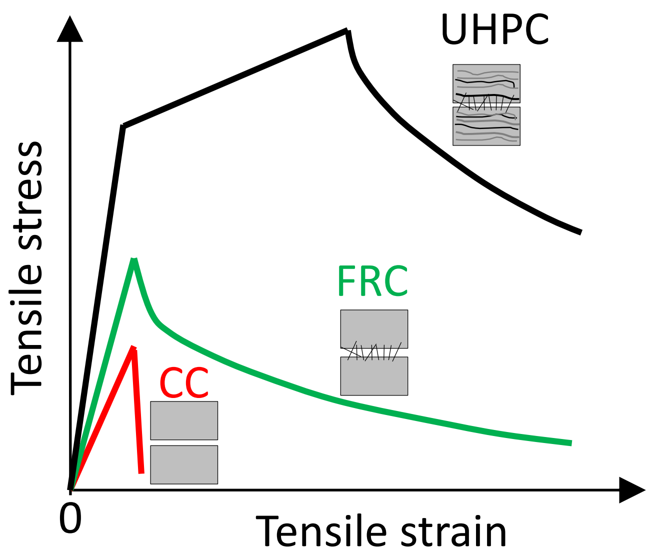
Design and Performance of Cost-Effective Ultra-High-Performance Concrete (UHPC) for Transportation Infrastructure

Weina Meng
Department of Civil, Environmental, and Ocean Engineering
Weina.Meng@stevens.edu

Advantages of UHPC

- Resilience
  - High mechanical strengths
    - ✓ Compressive strength (28 days): ≥ 125 Mpa (18 ksi)
    - ✓ Tensile strength (28 days): ≥ 8 Mpa (1.2 ksi)
  - Strain-hardening behavior

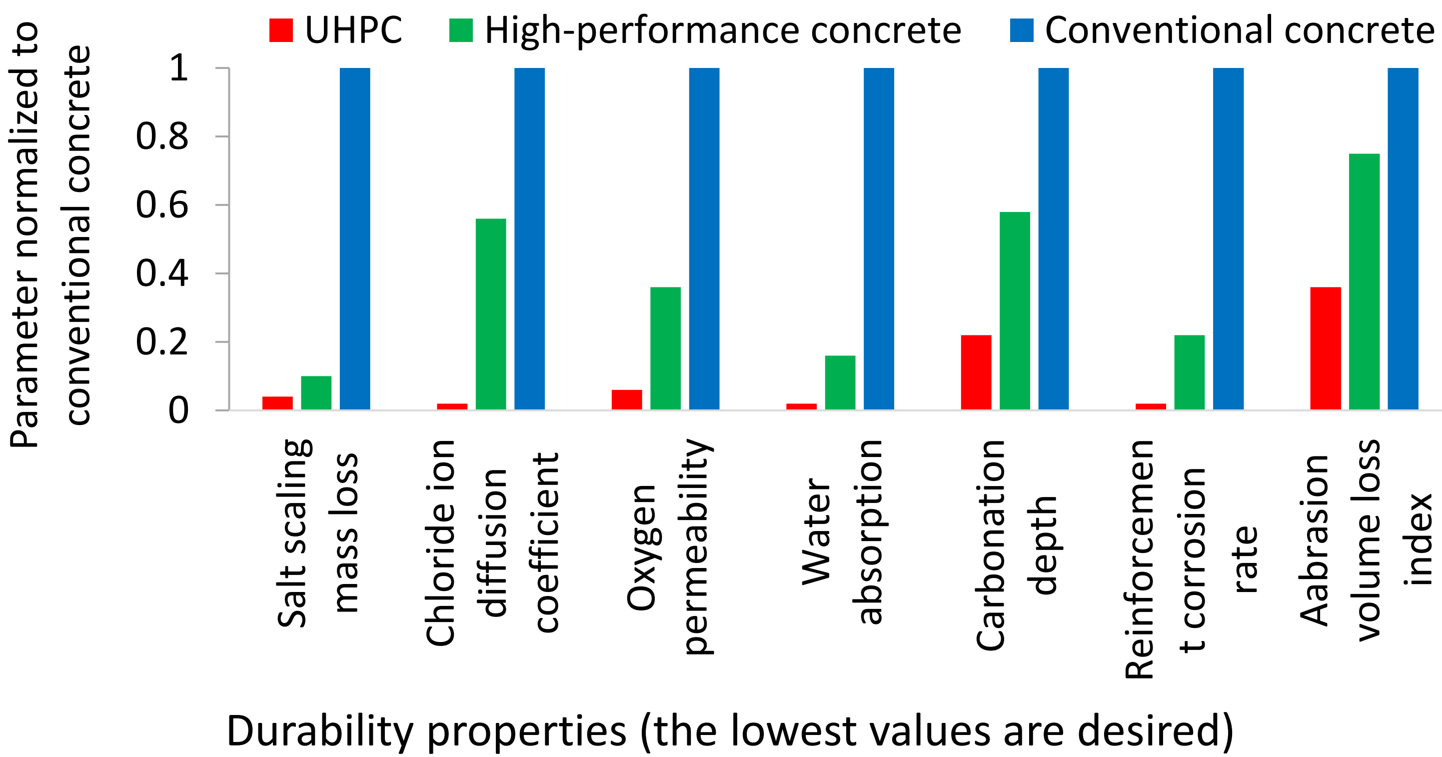




UHPC: ultra-high performance concrete
HPC: high-performance concrete
FRC: fiber-reinforced concrete
CC: conventional concrete

Advantages of UHPC

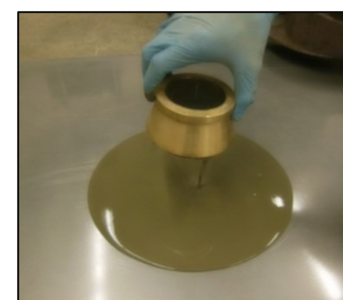
- Sustainability
  - ➢ Low life-cycle cost
  - ➢ Excellent durability



Ref: https://www.fhwa.dot.gov/hfl/partnerships/uhpc/hif13032/chap01.cfm

Advantages of UHPC

- Super workability (self-consolidating)
  - ➢ Low construction energy (no mechanical vibration for consolidation)
  - ➢ High construction quality

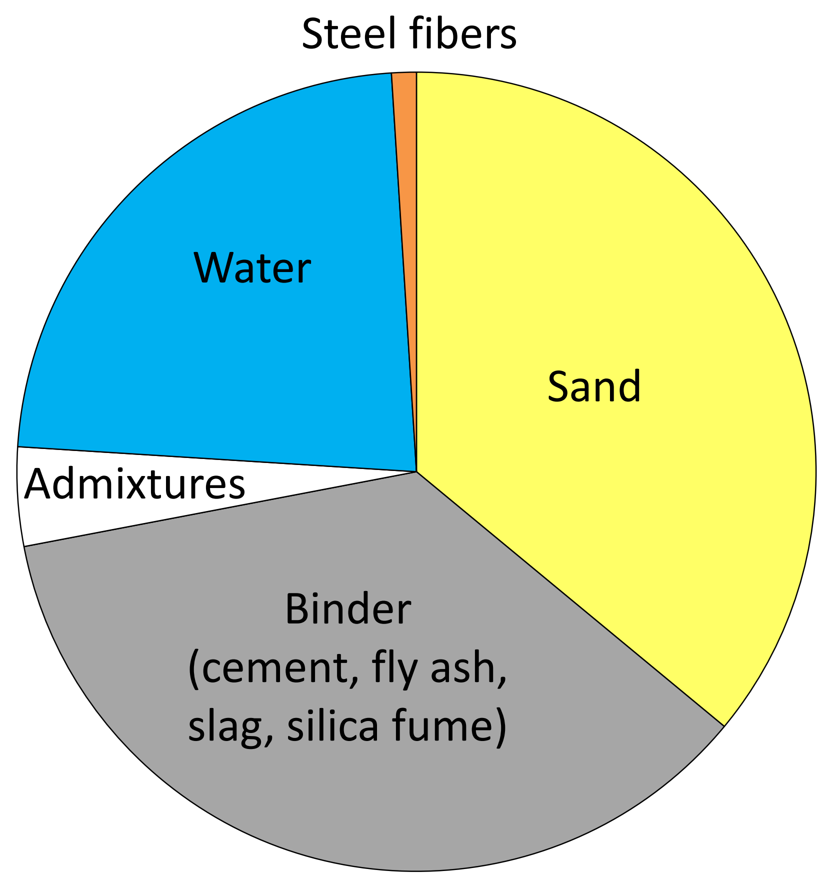


Current challenges

- Very high initial cost
  - Materials cost: 10-20 times of conventional concrete
- High autogenous shrinkage
  - Autogenous shrinkage (28 days): ≥ 1000 μm/m, risk of cracking
- Special curing conditions
  - Steam curing: ≥ 90˚C, high energy consumption
- Needs for higher tensile/flexural strength and ductility
  - Further improvement of resilience

Design of cost-effective UHPC

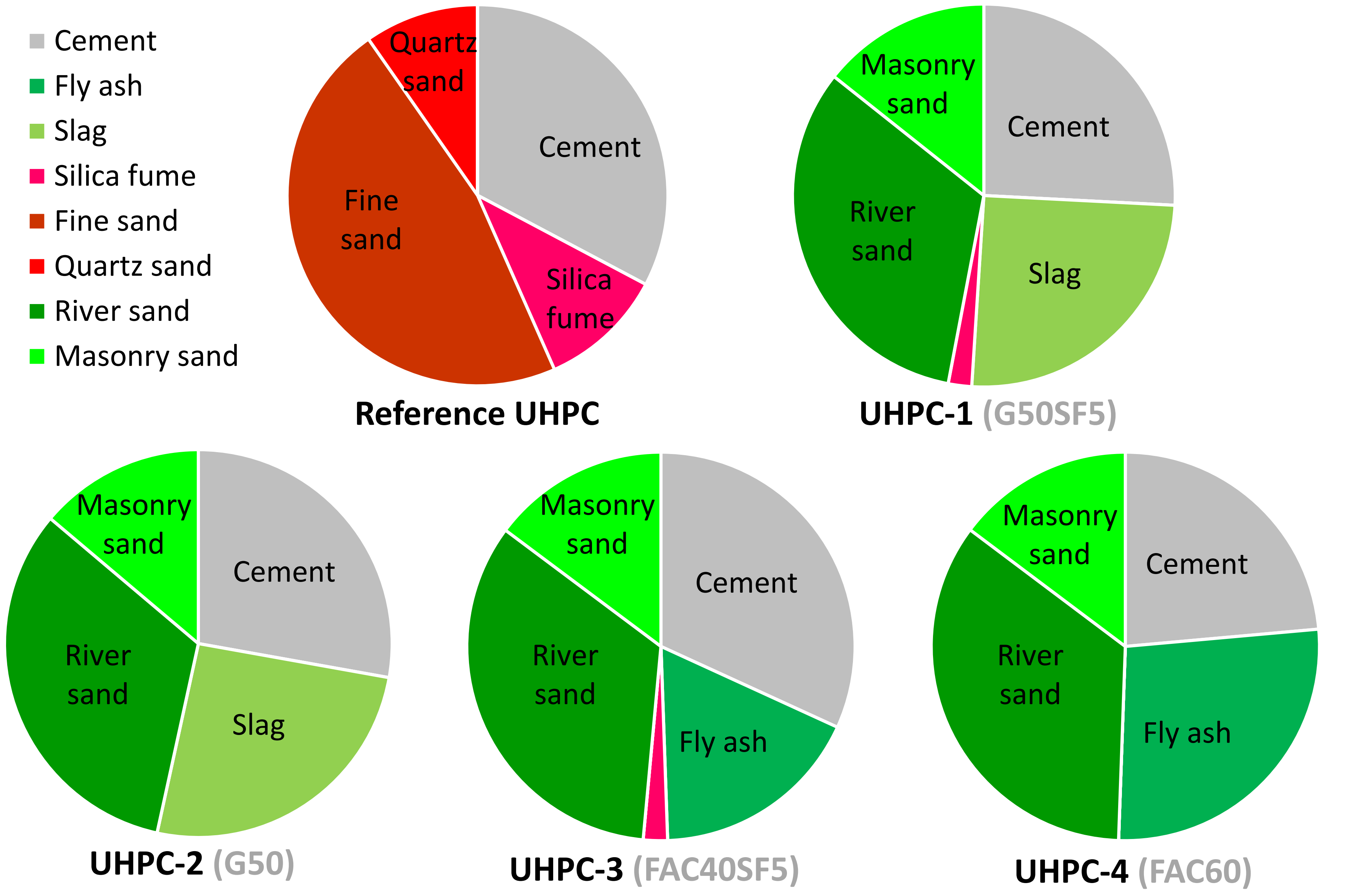
- Strategies
  - ➢ Use high-volume by-products (e.g. fly ash & slag) to partially replace cement
  - ➢ Use cost-effective sand to replace fine ground silica sand
  - ➢ Reduce fiber content
  - ➢ Reduce silica fume content
  - ➢ Reduce binder-to-sand ratio



Components of UHPC

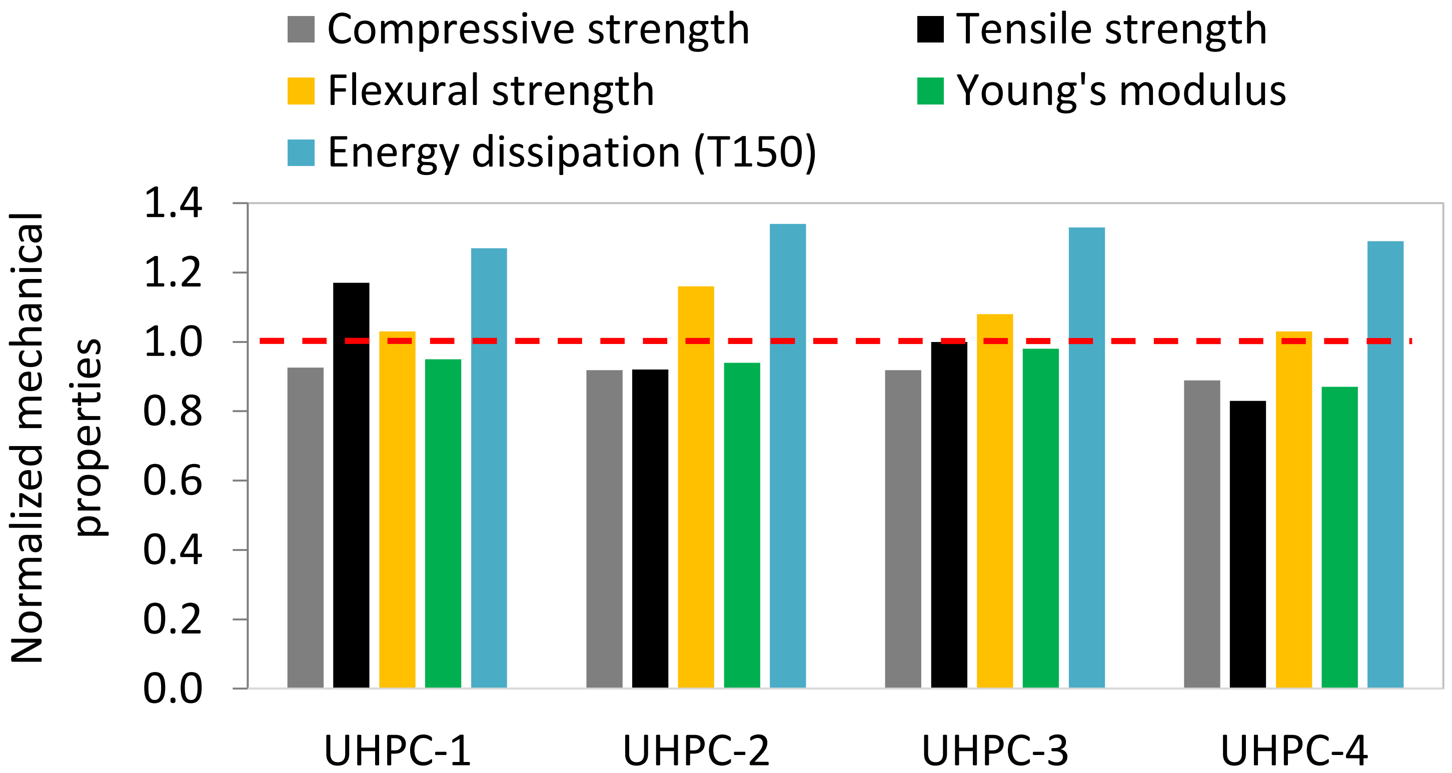
Meng W, Valipour M, and Khayat KH. Optimization and Performance of Cost-Effective Ultra-High Performance Concrete, *Materials and Structures 2016*, 50(1), 29.

Developed UHPC



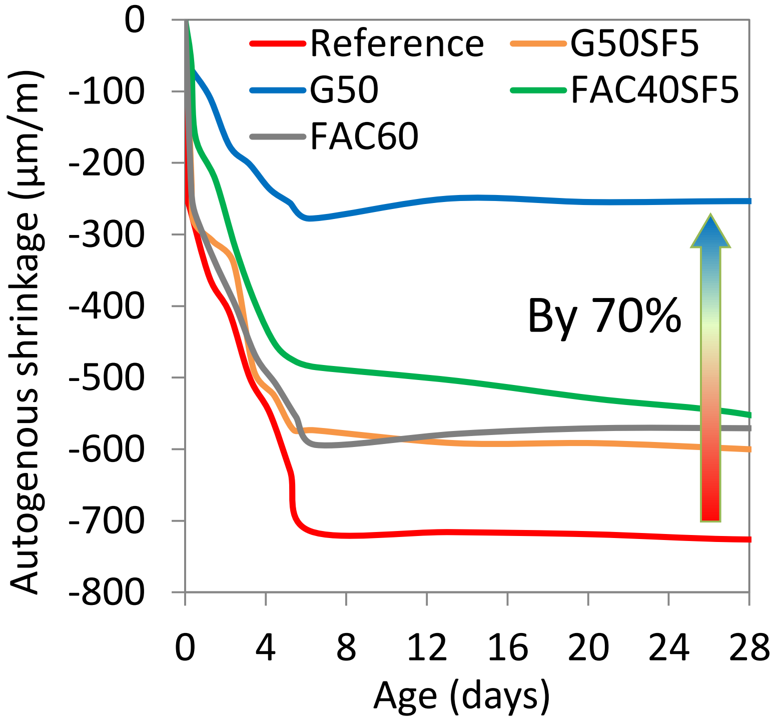
Mechanical properties of developed UHPC

- Normalized to the properties of the reference UHPC
- The optimized UHPC mixtures demonstrate comparable or better mechanical properties

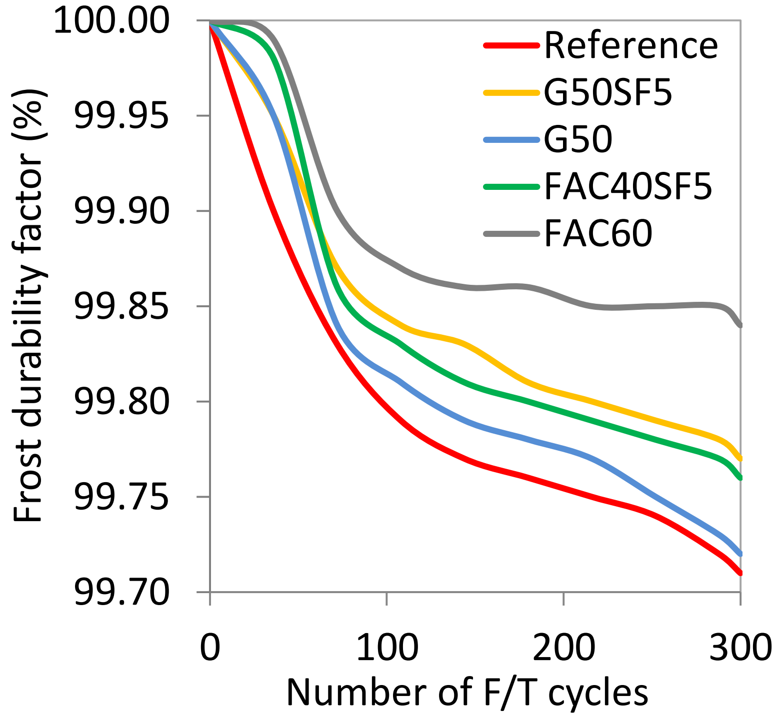


Shrinkage and durability of developed UHPC

- Compared with the reference UHPC, the optimized UHPC have:
  - ➢ Smaller autogenous shrinkage
  - ➢ Better freezing/thawing durability



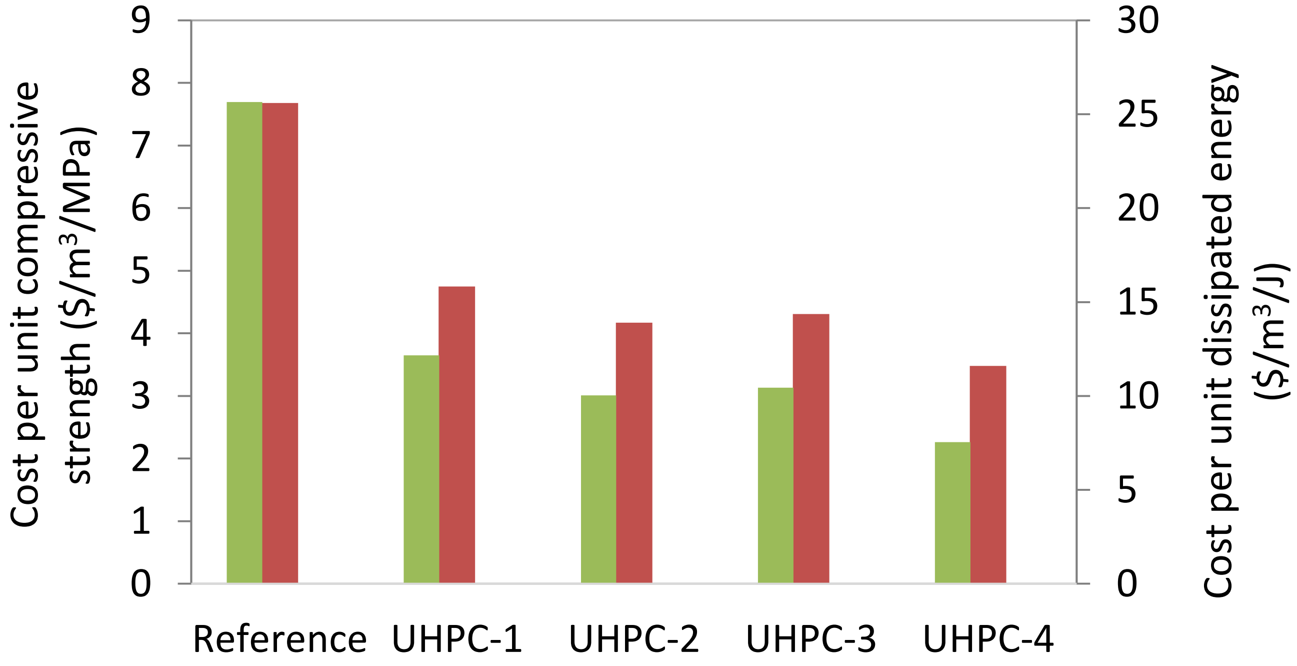
Autogenous shrinkage



Frost durability

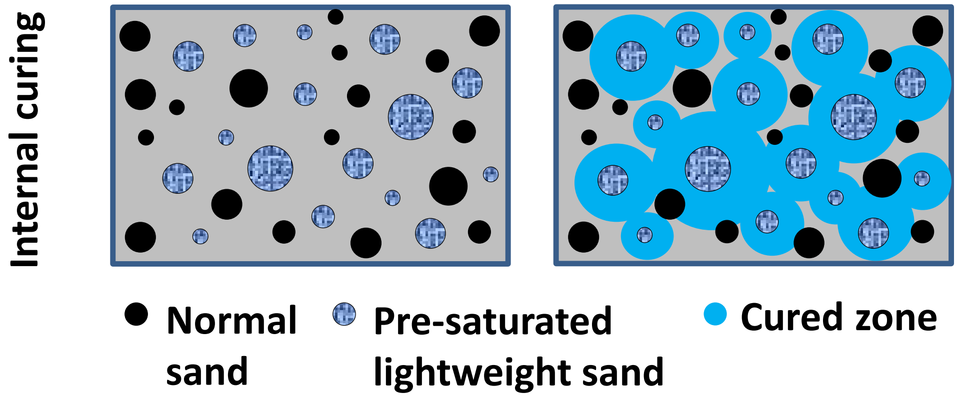
Cost of developed UHPC

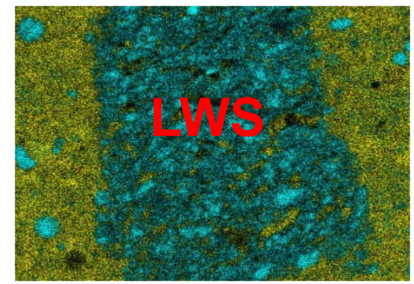
- Compared with the reference UHPC, the optimized UHPC have:
  - 40% to 50% lower cost per unit compressive strength
  - 45% to 65% lower cost per unit energy dissipation (T150)



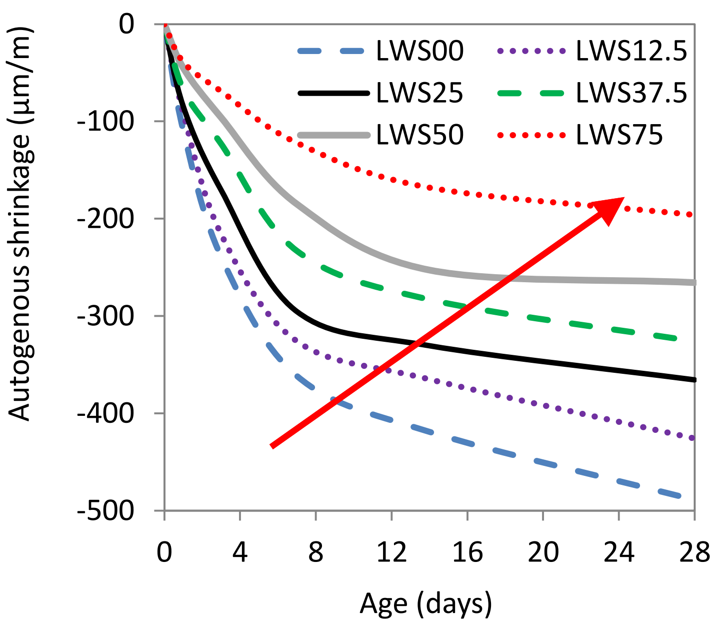
1. Improve UHPC by internal curing

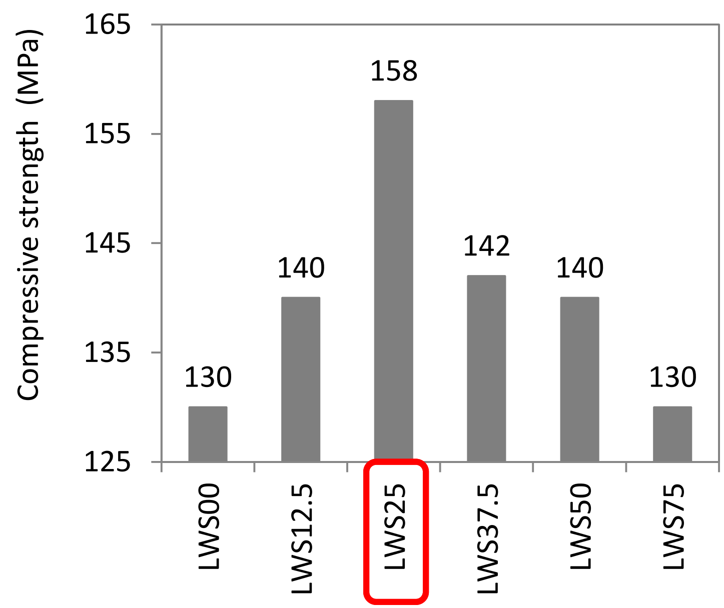
- Use of 25% lightweight sand (LWS) can effectively reduce shrinkage and increase compressive strength





Elementary mapping



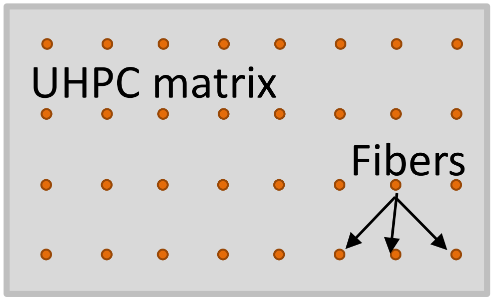


Meng W, Khayat KH. Effects of Saturated Lightweight Sand Content on Key Characteristics of Ultra-High-Performance Concrete, *Cement and Concrete Research*, 2017, 101, 46–54.

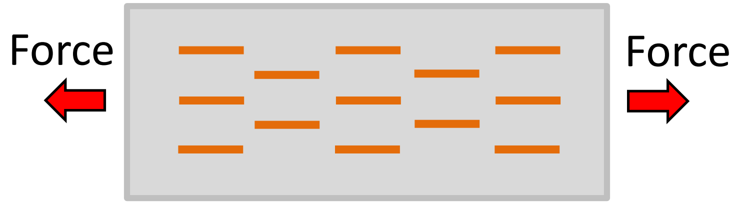
2. Improve UHPC by rheology control

- Fibers in UHPC can be controlled with:

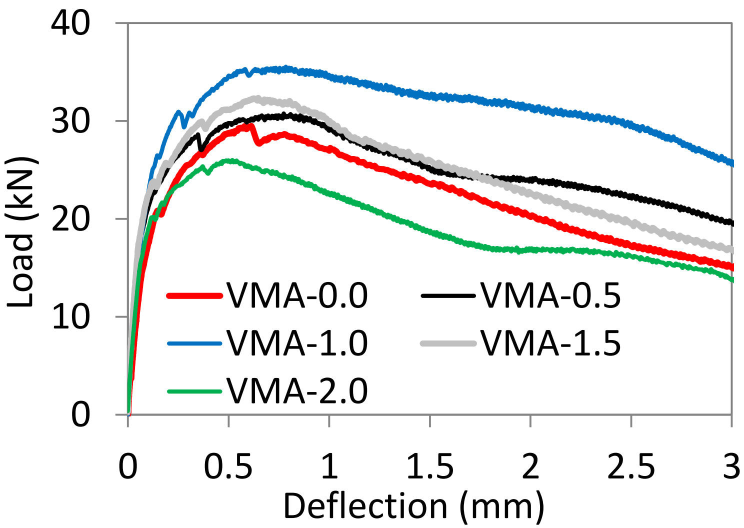
1) A uniform fiber dispersion

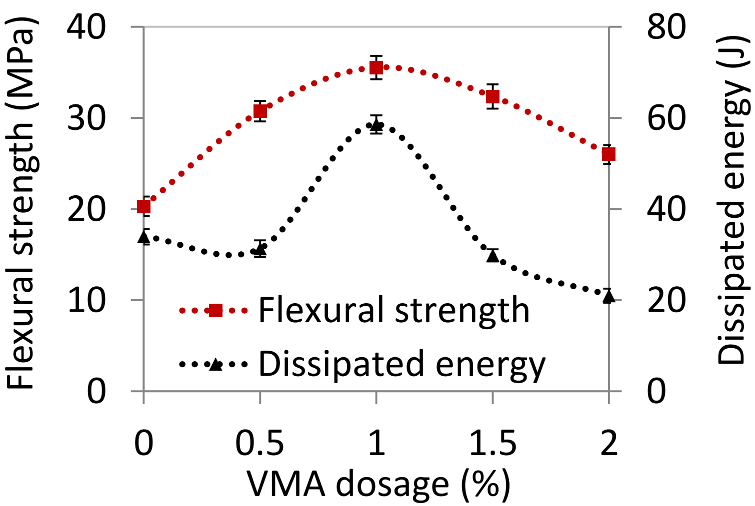


2) Tension direction fiber orientation



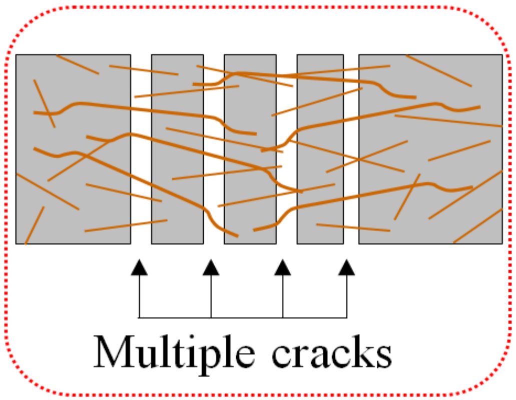
- The rheology of UHPC can be adjusted by adding **viscosity modified admixture (VMA)**. An optimum rheological property results in optimum fiber distribution, and thus, best flexural properties



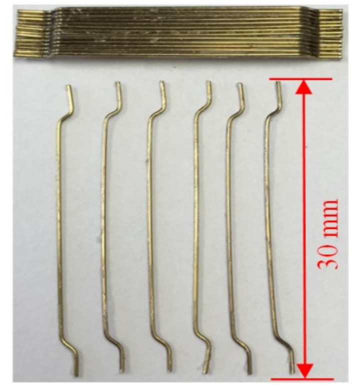


3. Improve UHPC using hybrid fibers

- Bridge cracks at different length scales

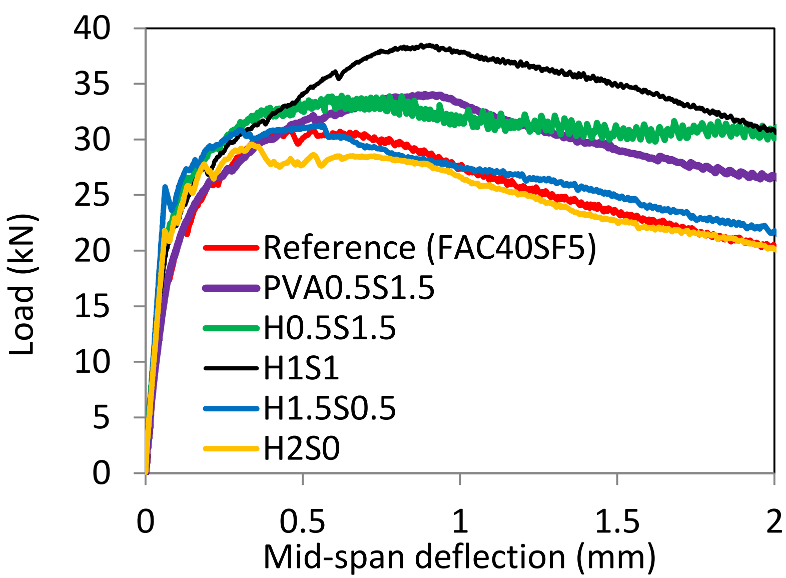


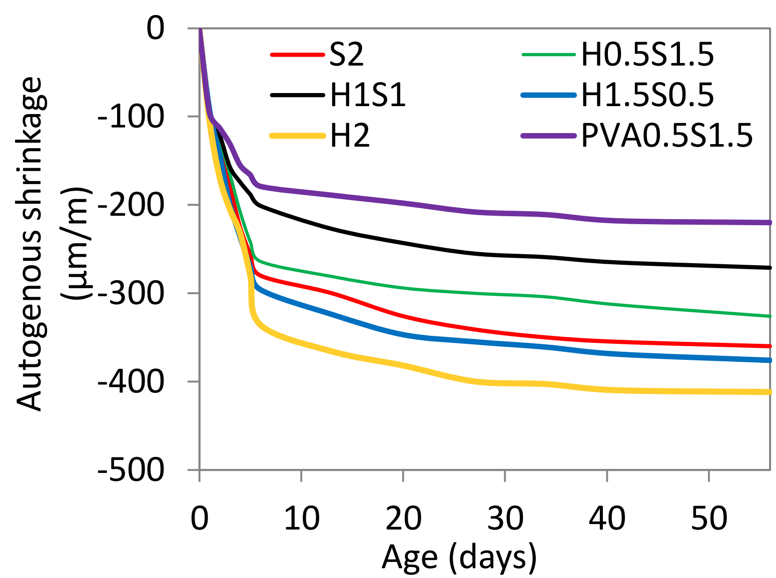
Straight (S)



Hooked-end (H)

PVA (8 mm)

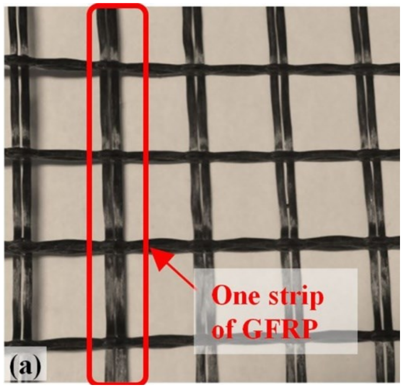




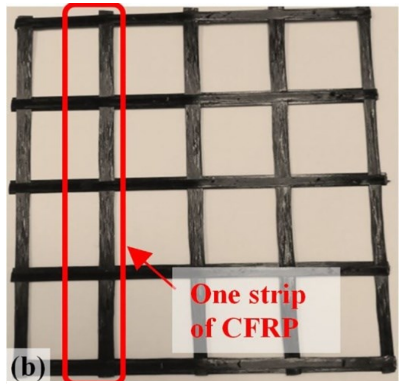
Meng W, Khayat KH. Effect of Hybrid Fibers and Fiber Content on Fresh and Hardened Properties of Ultra-High-Performance Concrete, *Journal of Materials in Civil Engineering*, 2018, DOI: 10.1061/(ASCE)MT.1943-5533.0002212.

4. Improve UHPC using fiber-reinforced polymer (FRP)

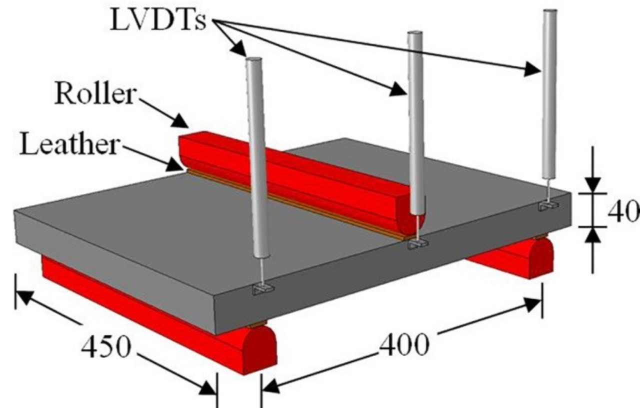
- Use glass FRP (GFRP) and carbon FRP (CFRP) grids (40×40 mm)



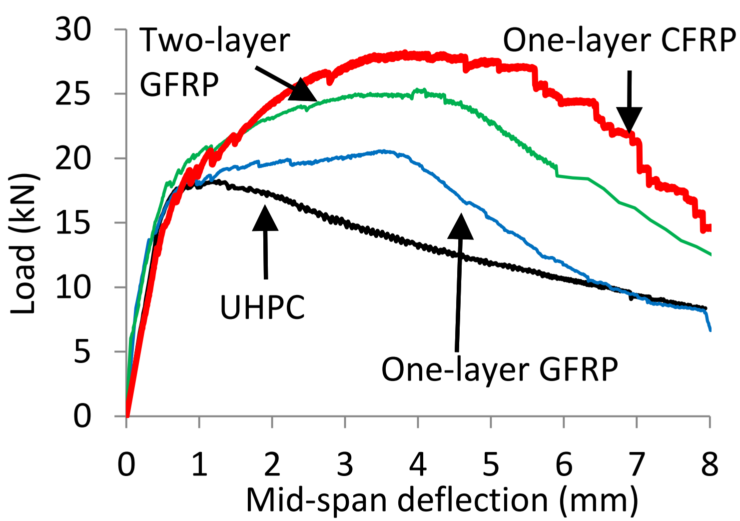
GFRP grid

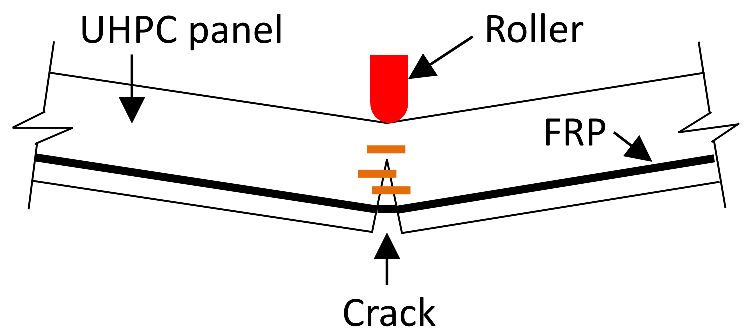


CFRP grid



Flexural test setup (unit: mm)

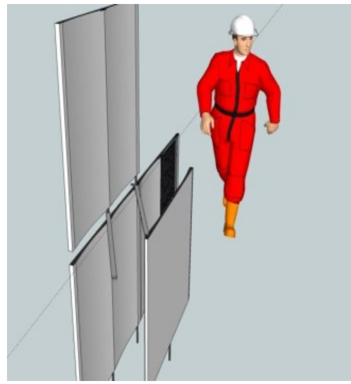


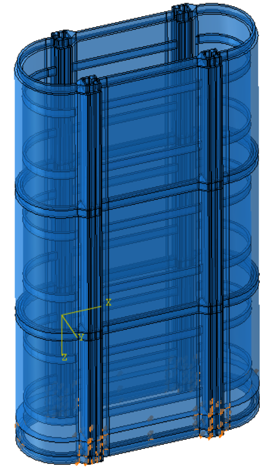


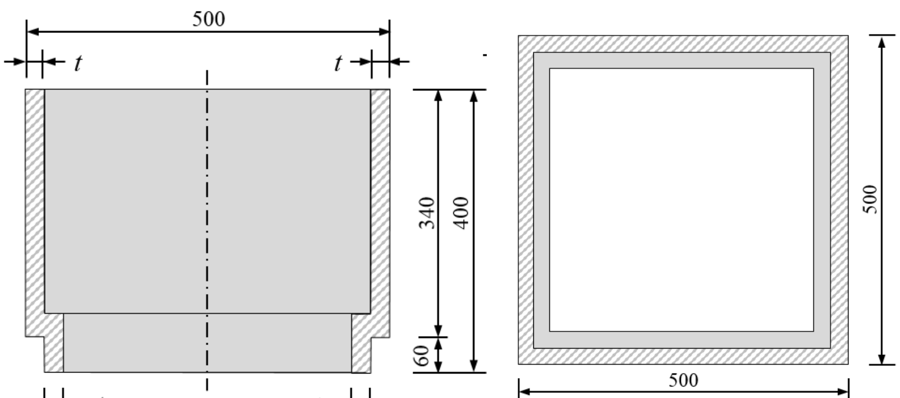
Meng W, Khayat KH, Bao Y. Flexural Behavior of Ultra-High-Performance Concrete Panels Reinforced with Embedded Fiber-Reinforced Polymer Grids, *Cement and Concrete Composites* 2018 (In press)

Application 1: Prefabricated stay-in-place formwork

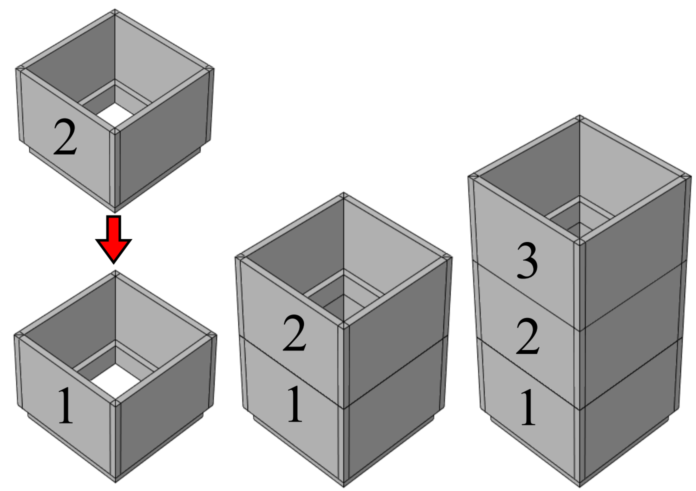
- Ultra-thin lightweight formwork for accelerated construction







Design of formwork (Unit: mm)



Meng W and Khayat KH, Development of Stay-in-Place Formwork Using GFRP Reinforced UHPC Elements, *Proc. 1st Int. Interactive Symposium on UHPC*, Des Moines, Iowa, 2016.

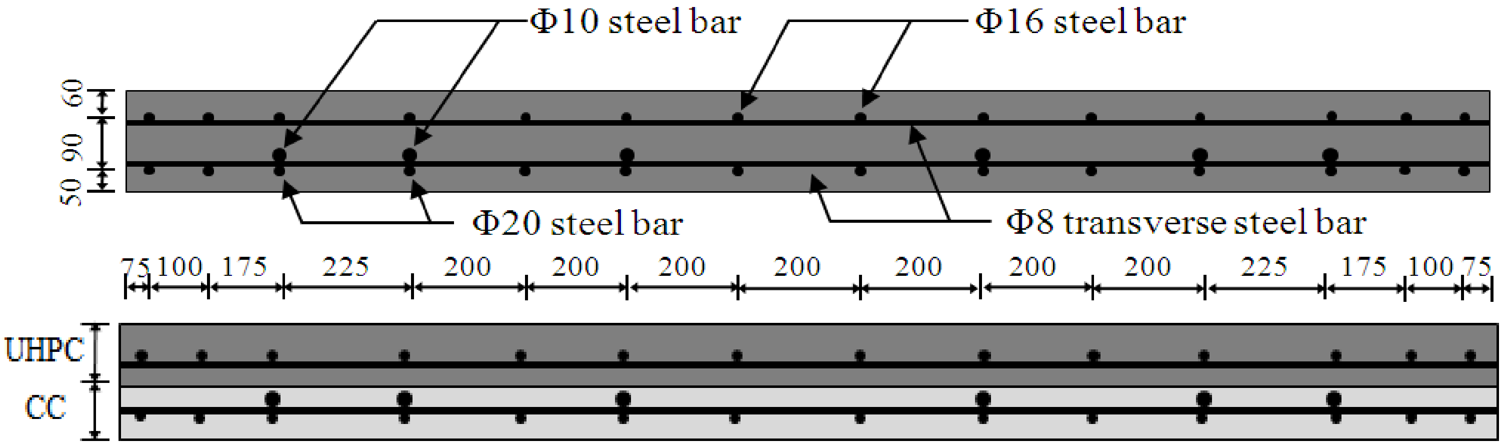
Application 2： UHPC bonded overlay

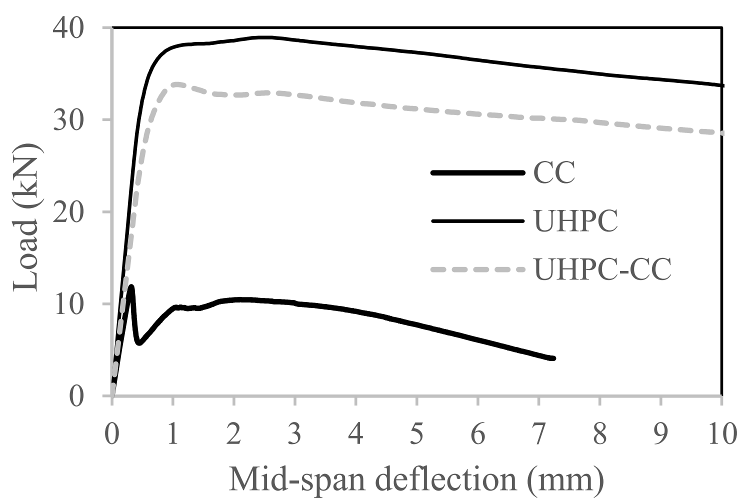
- Large-scale (3 m × 1.5 m × 0.1 m) panel specimens
  - ➢ Ultra-thin UHPC overlay (25 mm) on a concrete substrate (75 mm)

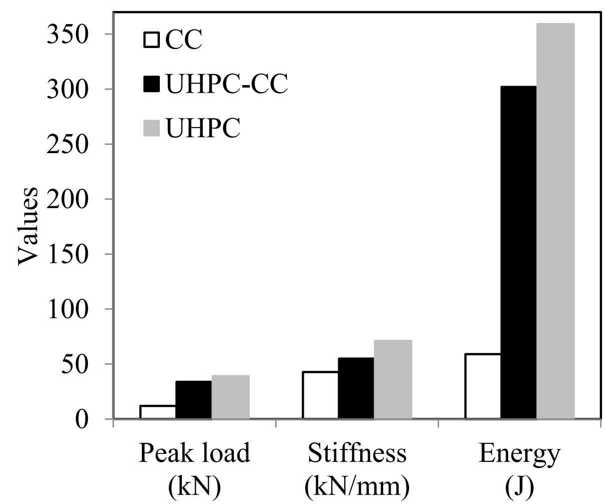
Bao Y, Valipour M, **Meng W**, Khayat KH, Chen G. Distributed Fiber Optic Sensor-Enhanced Detection and Prediction of Shrinkage-induced Delamination of Ultra-High-Performance Concrete Bonded over an Existing Concrete Substrate, *Smart Materials and Structures*, 2017, 26, p8.

Application 3: Functionally graded concrete slab

- Functionally-graded (UHPC-CC) vs. monolithic (CC, UHPC) slabs







Functionally-graded slab demonstrates less yet close flexural properties, compared with the monolithic UHPC slab.

Meng W and Khayat KH, Flexural Performance of Ultra-High Performance Concrete Ballastless Track Slab, *Proc. 2016 Joint Rail Conference,* Columbia, SC, 2016.

Weina Meng
Department of Civil, Environmental, and Ocean Engineering
Weina.Meng@stevens.edu

Thank You