Rheology Control of Ultra-high Performance Concrete (UHPC)

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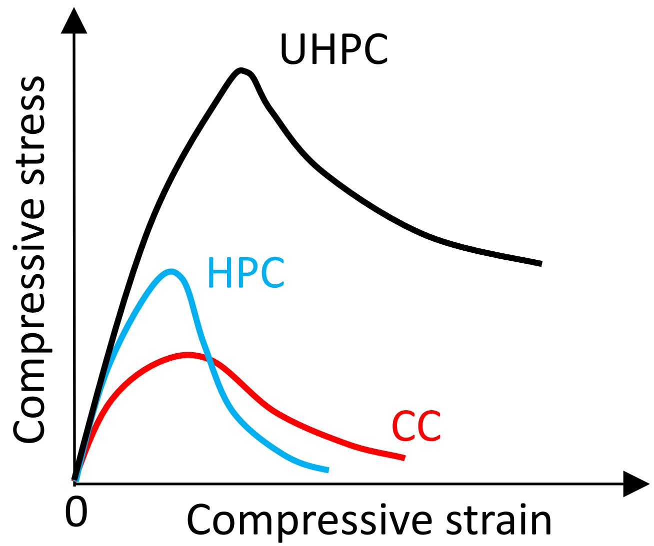
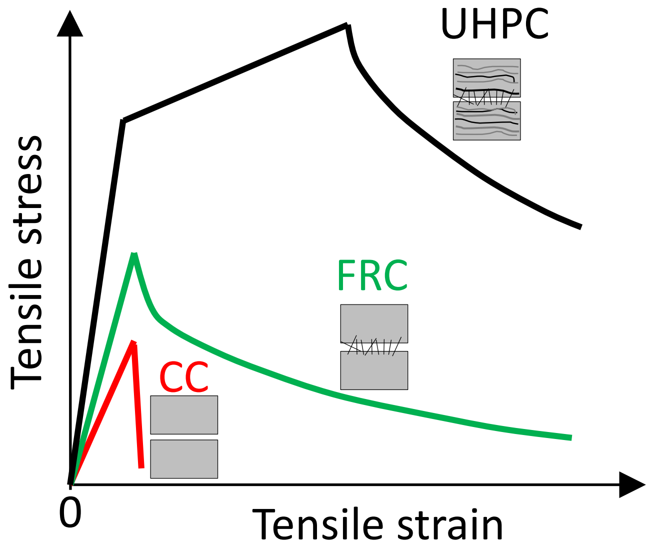
Outline

- ❑ Advantages of UHPC
- ❑ Improvement of Flexural Behavior of UHPC
- ❑ Method of Rheology Control for Better Fiber Distribution
- ❑ Performance of Optimized UHPC by Rheology Control
- ❑ Conclusions and Future Research

Advantages of UHPC

- High mechanical strengths
  - ➢ Compressive strength (28 days): ≥ 120 MPa
  - ➢ Tensile strength (28 days): ≥ 7 MPa
- Strain-hardening behavior



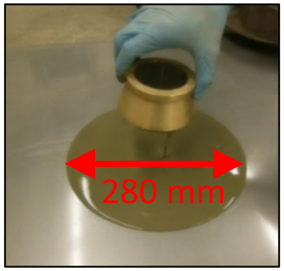


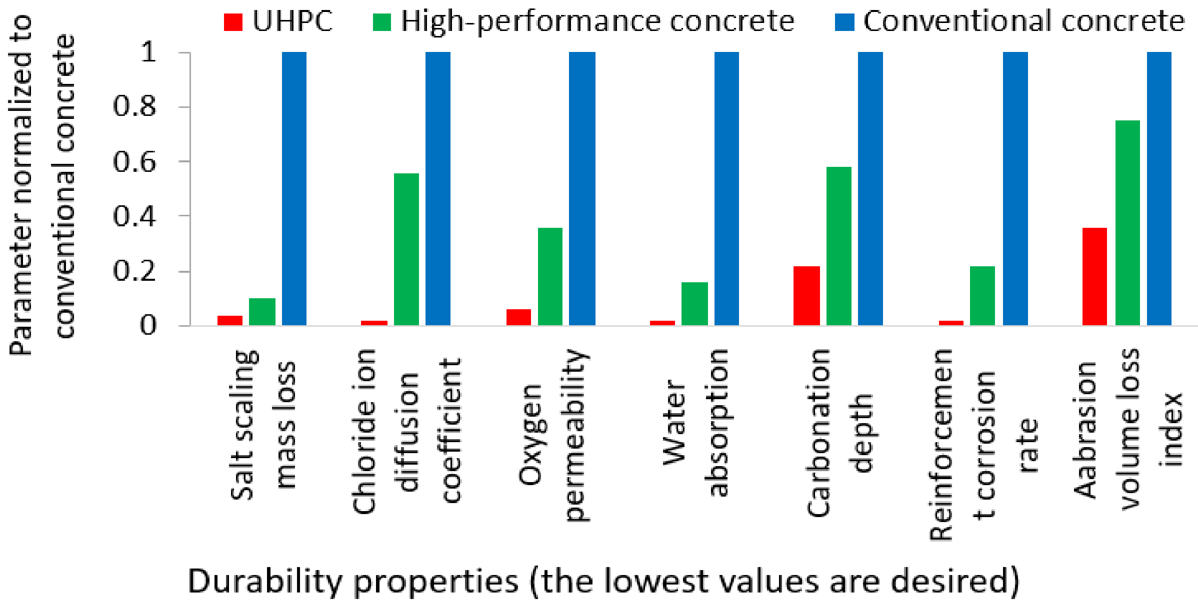
UHPC: ultra-high performance concrete
HPC: high-performance concrete

FRC: fiber-reinforced concrete
CC: conventional concrete

Advantages of UHPC

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



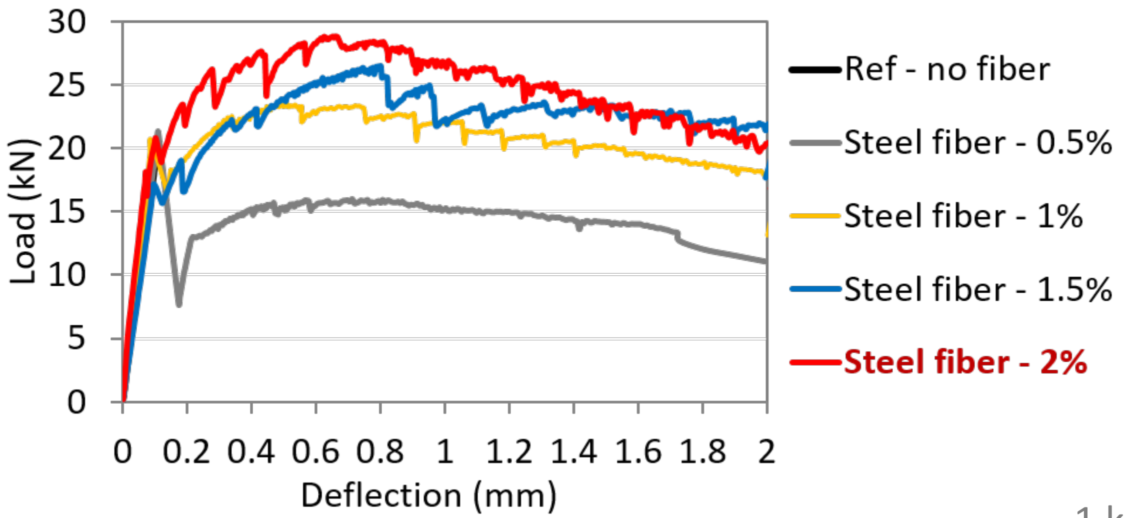


Existing Improvement Method for Flexural Behavior

Through four-point flexural test (ASTM C 1609)

- Beam specimen: 406 x 76 x 76 mm
- Hardening behavior (fiber content ≥ 1%)
- Flexural properties improve with increase of fiber content

- Can we improve flexural properties without increasing fiber content?



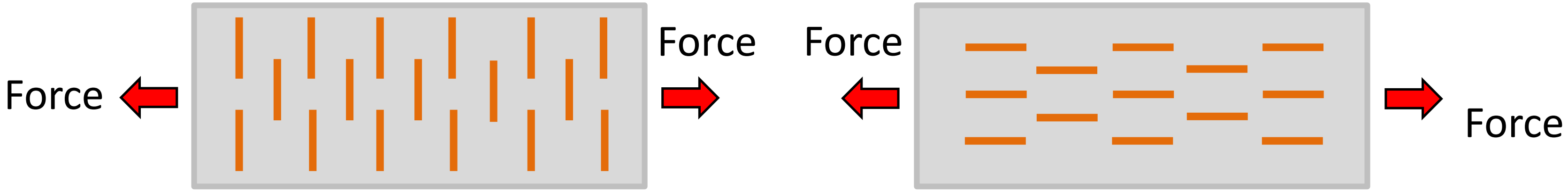
1 kN = 224 pounds 1 mm = 0.04 inch

Improve Flexural Behavior through Rheology Control

When fibers are fixed, tensile properties of UHPC are closely associated with:

- Fiber Dispersion
  - ✓ A uniform fiber dispersion is preferred for the quality of UHPC

- Fiber Orientation
  - ✓ Fibers along the loading direction can help resist tensile force

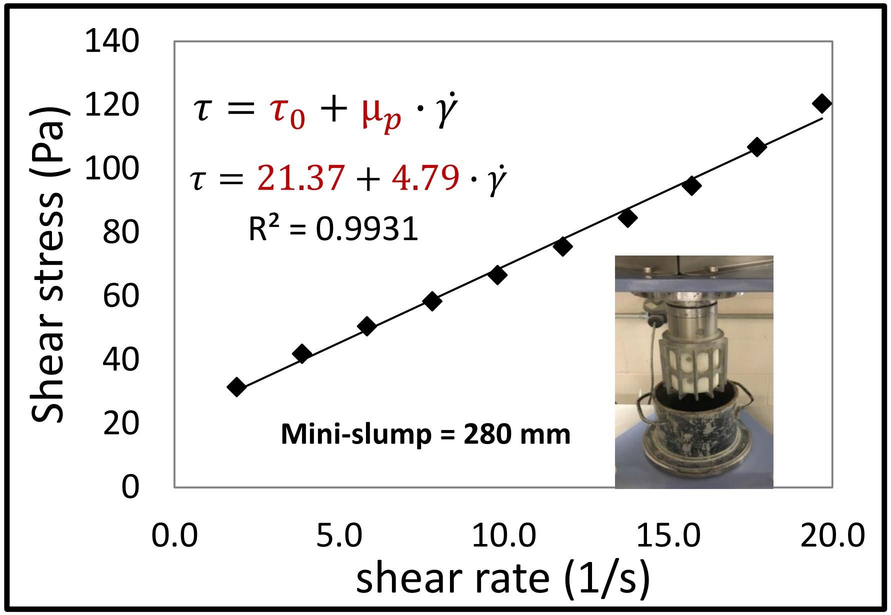


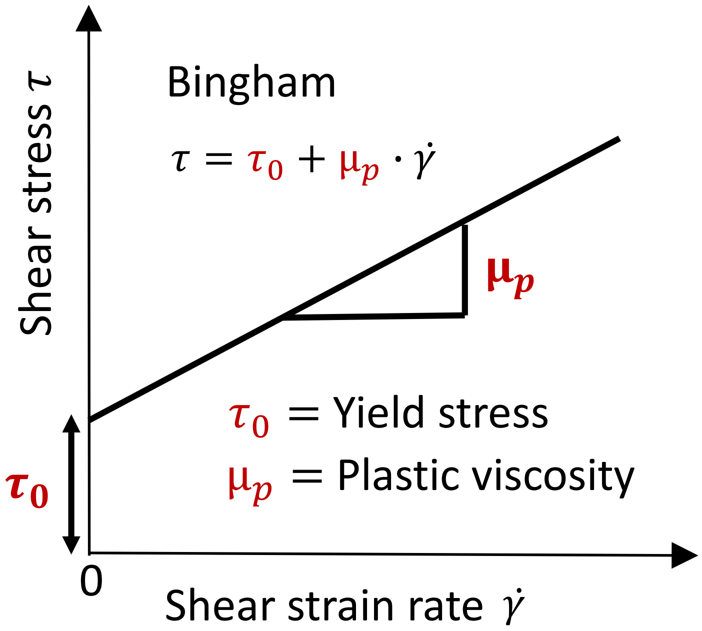
Perpendicular to loading

Along loading direction

> ➢ Both fiber dispersion and orientation are controlled by the rheological properties of UHPC suspending mortar/matrix

Use Bingham Model to determine plastic viscosity

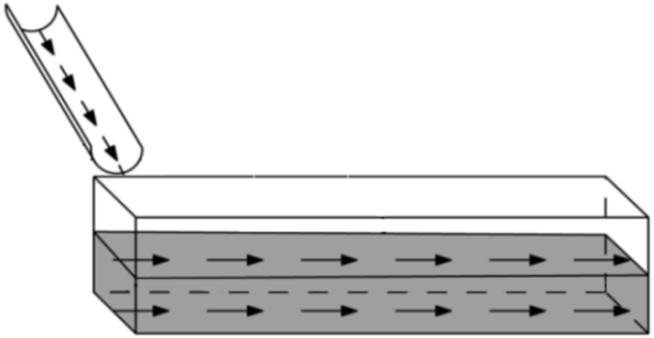




1 Pa=0.00015 psi

Cast method of UHPC beams

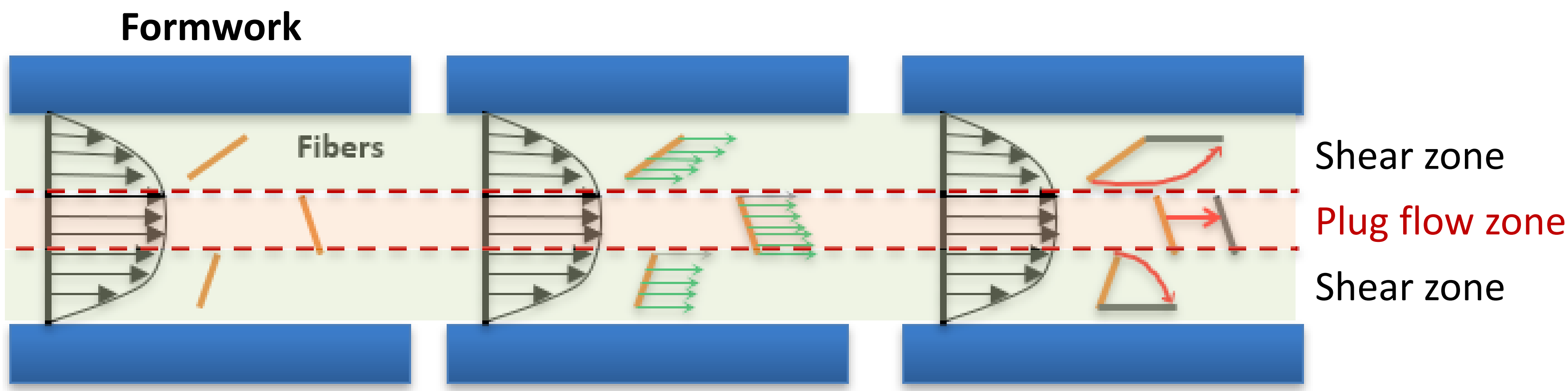
- Inclined chute with angle of around 30 degrees
- Concrete flows itself from one side of beam to the other



Cast method is important for rheology control !

Cast method of UHPC beams

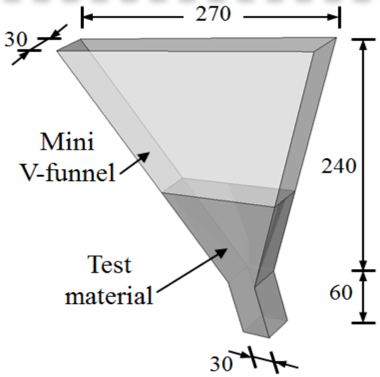
- Fibers are re-oriented during casting UHPC in a formwork, due to gradient of flow velocity



Flow-induced orientation of fibers

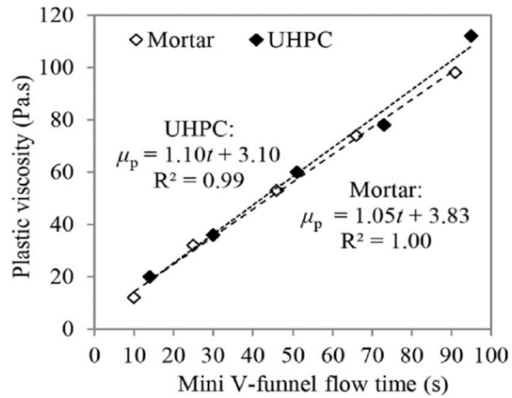
- Minimize thickness of plug flow zone by minimizing yield stress (high mini slump flow)
- Improve fiber orientation and dispersion by optimizing plastic viscosity

Establish relations of rheological properties



Flow time

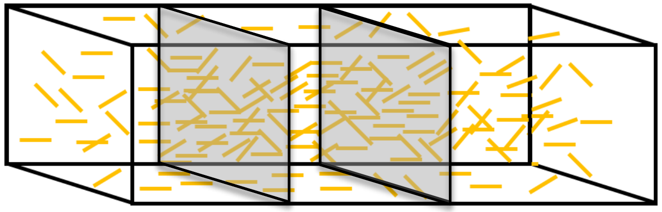
Flexural properties (with fibers)



Linear relationship

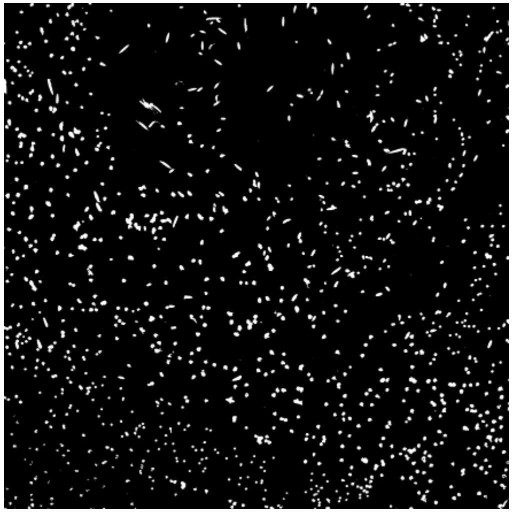
Plastic viscosity (μp)

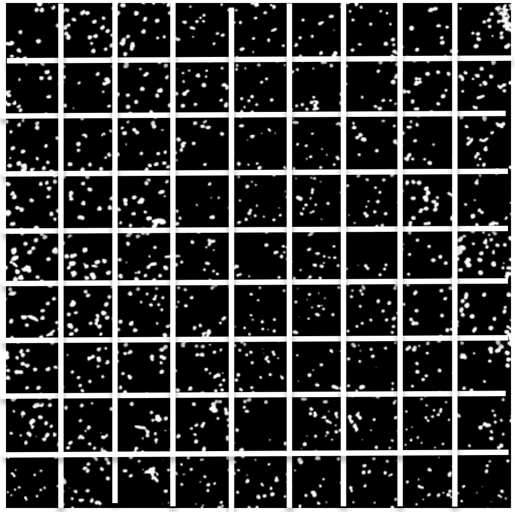
Fiber distribution (orientation and dispersion)

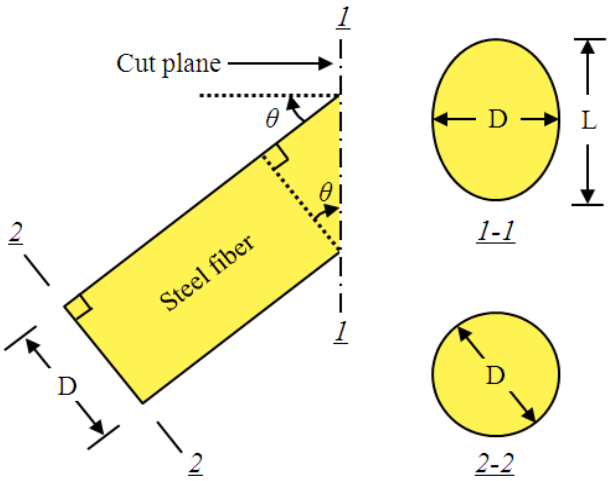


Cut sections

Image analysis for fiber dispersion and orientation







VMA-0 **VMA-1.0**

Binary images of the cross sections of beam specimens

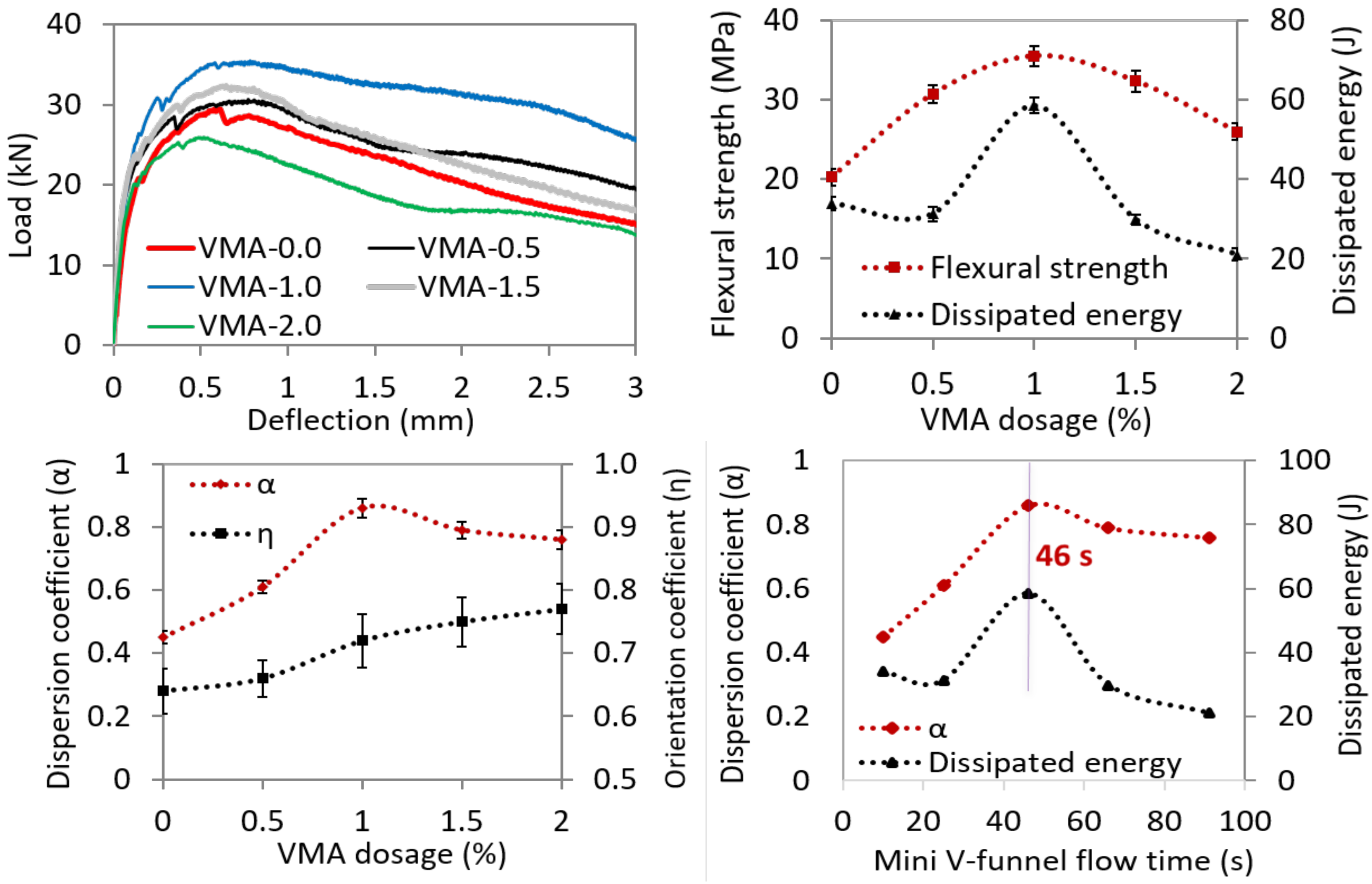
Fiber orientation coefficient (η):
η = 1, fibers aligned perpendicular to cross section

$$\eta = \int_{\theta_{min}}^{\theta_{max}} p(\theta)\cos^2\theta\, d\theta \qquad \left[\theta = \arccos\left(\frac{D}{L}\right)\right]$$

Fiber dispersion coefficient (α):
α = 1, fibers uniformly dispersed

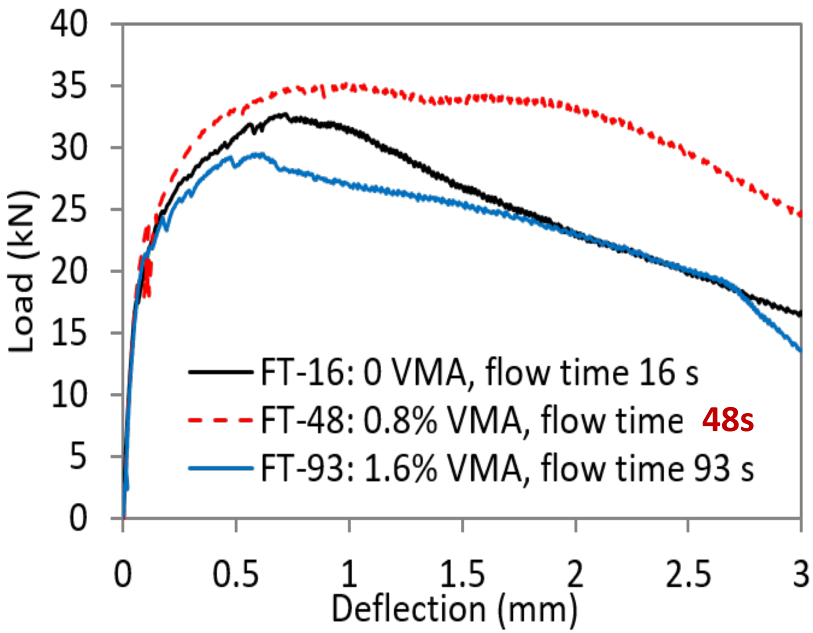
$$\alpha = \exp\left[-\frac{1}{x_0}\sqrt{\frac{\sum(x_i - x_0)^2}{n}}\right]$$

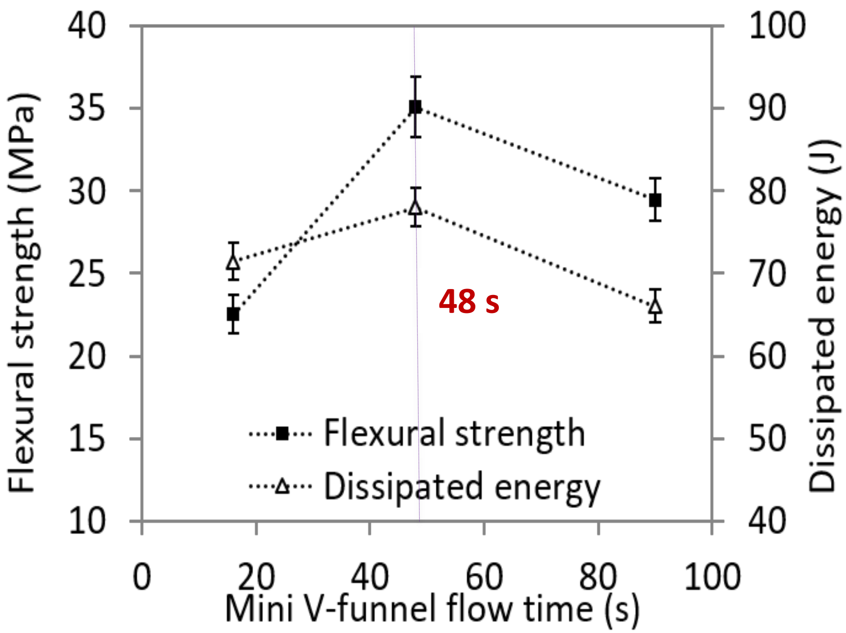
Effect of Rheology on Flexural Properties of UHPC



Validation of Rheology Control Concept

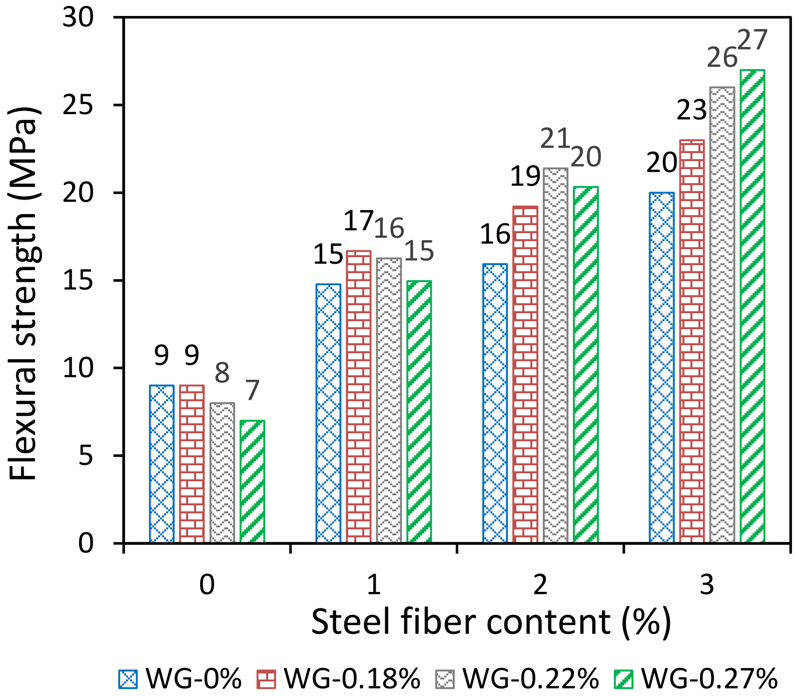
3 Different Mixtures:
The flow time of each mortar was controlled to: ①16s ②48s≈46s ③93s

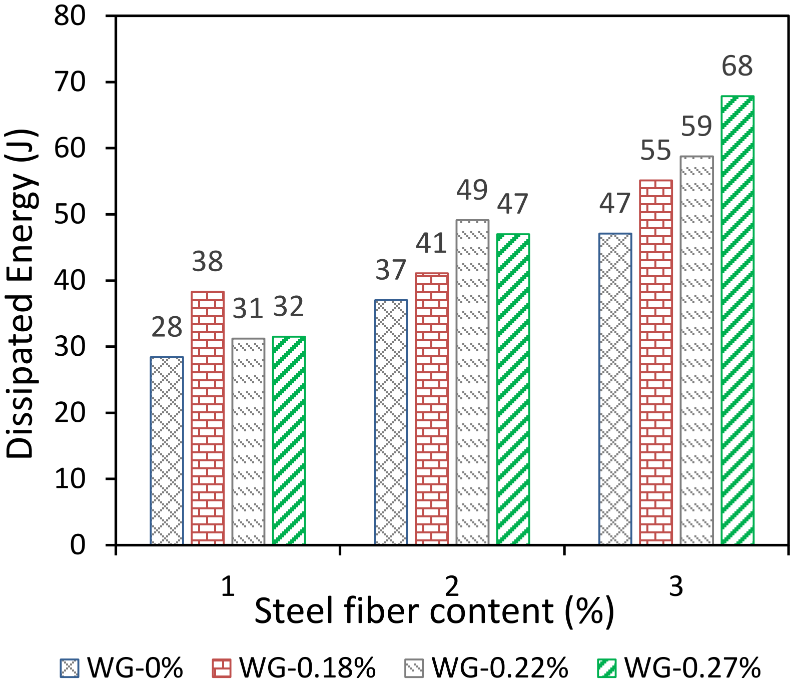




1 kN = 224 pounds 1 mm = 0.039 inch 1 MPa = 0.15 ksi

UHPC with Higher Fiber Content





- Welan gum (WG) powder and high-range water reducer (HRWR) were used to control the rheological properties of UHPC mortar.

1 kN = 224 pounds 1 mm = 0.039 inch 1 MPa = 0.15 ksi

Conclusions and Future Research

1. For UHPC containing 2% of micro steel fibers, the peak fiber dispersion coefficient was achieved at a plastic viscosity of 53 Pa·s.
2. The fiber orientation coefficient monotonically increased with plastic viscosity up to about 100 Pa·s.
3. The optimal mini V-funnel flow time of suspending mortar was determined to be 46s that ensures the greatest flexural performance of UHPC
4. Replacing the steel fibers with PE fibers while controlling the rheology properties.
5. Study on full-scale UHPC beams/slabs with rheology control.
6. Develop a self-cooling UHPC for better rheology using in filed applications.

Thanks!

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