Effect of Fiber Type and Content on Behavior of UHPFRC for Prestressed Girder Repair

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UHPC/UHPFRC Definition

FHWA Definition

- Compressive strength greater than 21.7 ksi
- Post-cracking flexural strength of 720 psi

ACI Definition

- Minimum compressive strength of 22,000 psi
- Tensile ductility in the form of elastic-plastic or strain-hardening behavior under uniaxial tension

General Definition

- Compressive strength of 18 – 30 ksi
- Post-cracking tensile strength of 700 – 900 psi

* UHPC is also referred as UHPFRC to emphasize on the importance of fibers.

UHPC Advantages

- High flowability
- Very low to negligible permeability
- Minimal freeze-thaw susceptibility
- Durability
- Impact resistance
- Specified toughness
- Fibers to achieve specified requirements

Research Objective

- Influence of fiber type on UHPC properties
- Influence of fiber content on UHPC properties (1%, 2%, 4%, 6% by volume)
- Prestressed girder end repair using UHPC

Fiber Types

	Fiber Type	Length (in)	Diameter (in)	Aspect Ratio	Tensile Strength (ksi)	Specific Gravity
Type 1	Straight	0.5	0.0079	63.3	313	7.85
Type 2	Straight	0.5	0.0079	63.3	413	7.8
Type 3	Hooked End	1.2	0.01	80	290	7.8

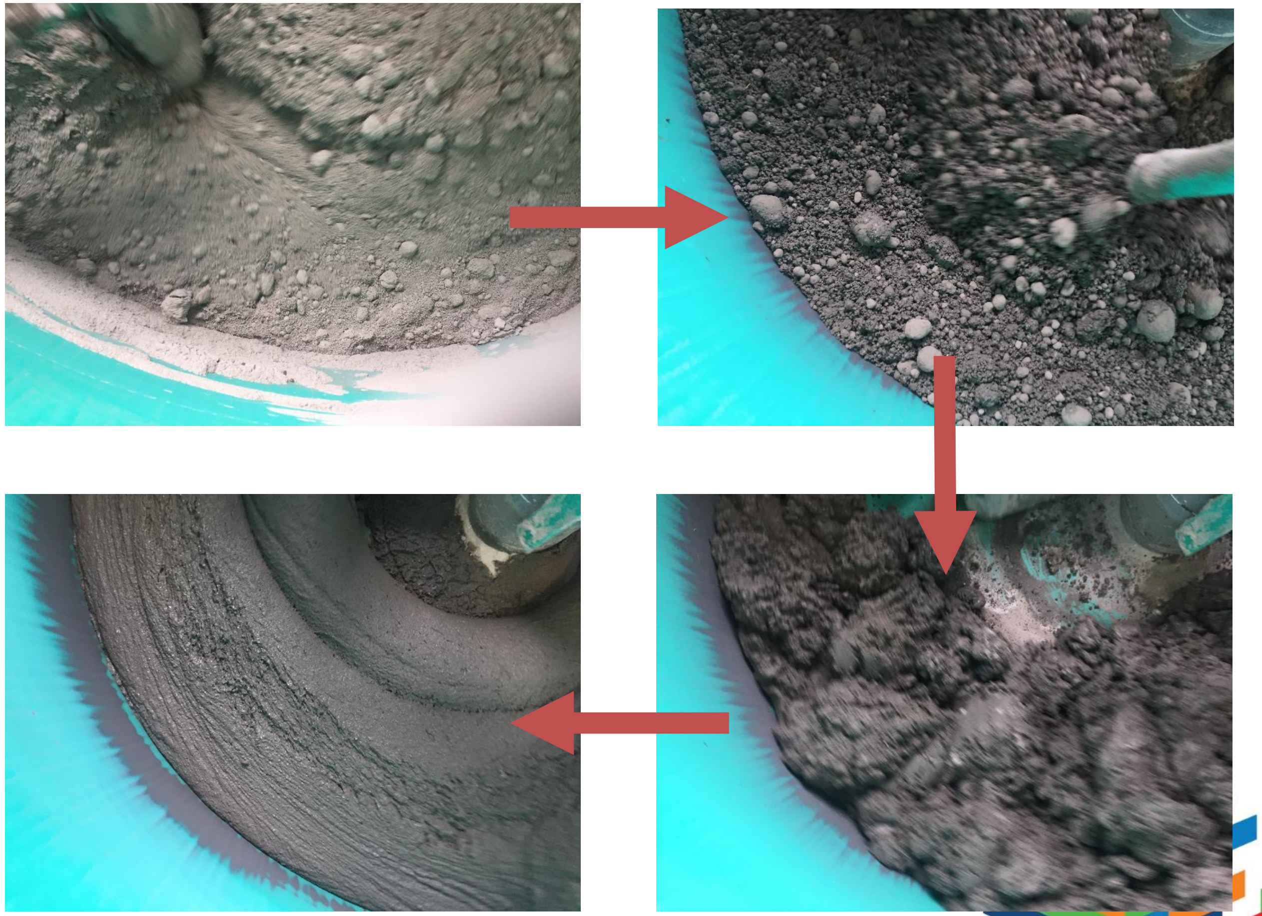
Baseline Mix Design Developed at OU

Constituent	Mix Proportion
Type I Cement	0.6
Silica Fume	0.1
Slag Cement	0.3
Masonry Sand (1:1 agg/cm)	1.0
w/cm	0.2
Steel Fibers	2% by Volume
HRWRA	18 oz/cwt

Weight ratios

UHPC Mixing Procedure

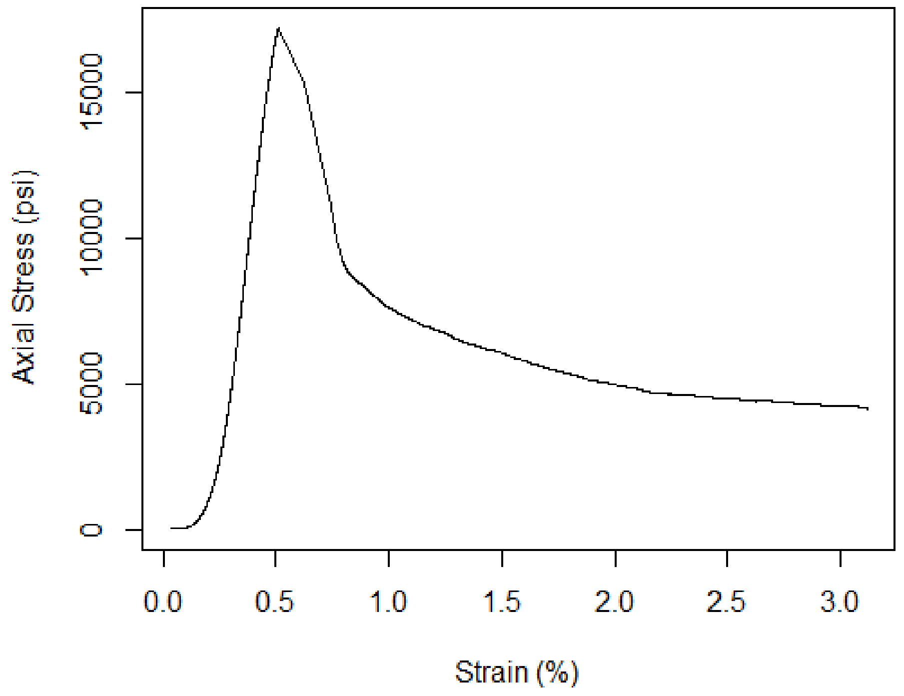
Process	Timeline (Minutes)
Mixing of dry materials	0 – 10
Mixing of water and half HRWR	10 – 12
Further Mix	12 – 13
Adding of remaining HRWR	13 – 14
Further Mix	14 – 24
Adding steel fibers	24
Final mix	24 – 26



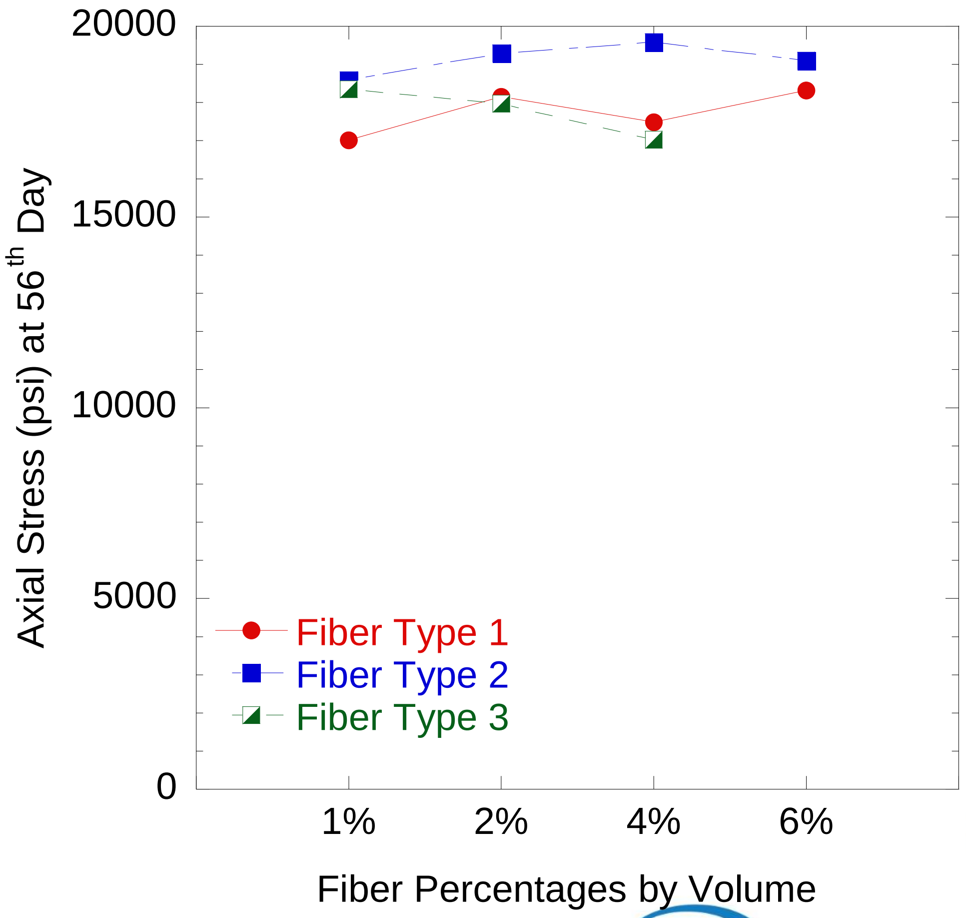
Compressive Strength

- Specimen: 3 in. by 6 in. cylinders
- According to ASTM C39/39M with modification using ASTM C1856
- Loading rate: 150 psi/s
- Specimens were tested at 3rd, 28th and 56th day

Compressive Strength Results



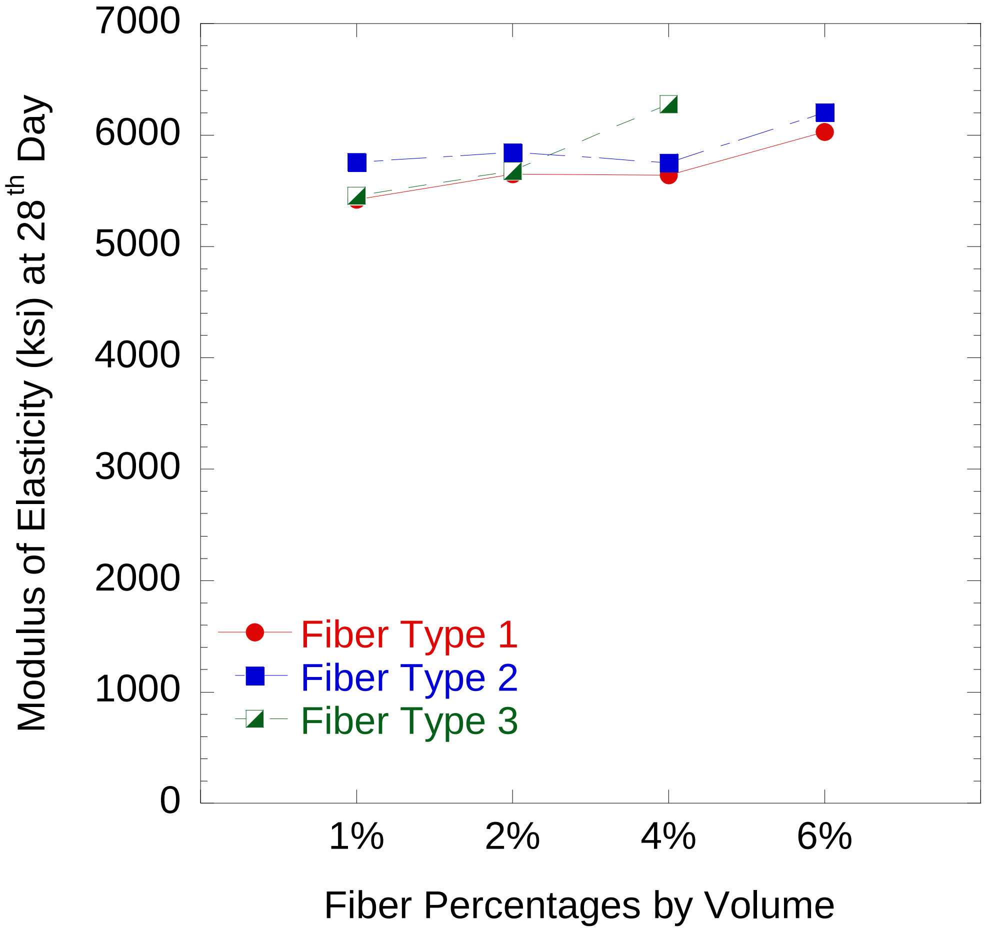
General compressive response



Modulus of Elasticity

- Specimen: 4 in. by 8 in. cylinder
- According to ASTM C469/469M with modification using ASTM C1856 (2017)
- Loading rate: 150 psi/s
- Each specimen was loaded to 40% of the compressive strength at 28^{th} day

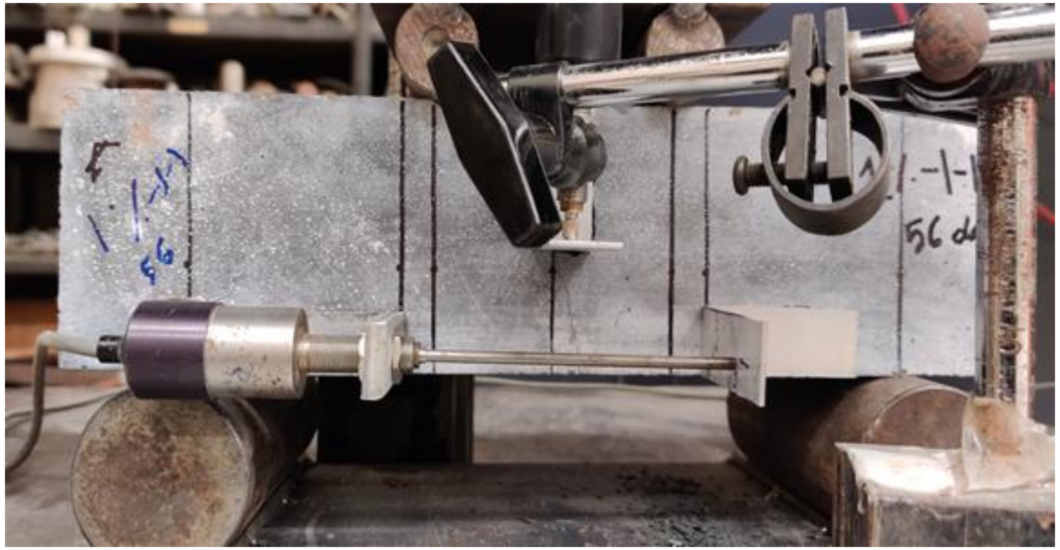
Modulus of Elasticity Results



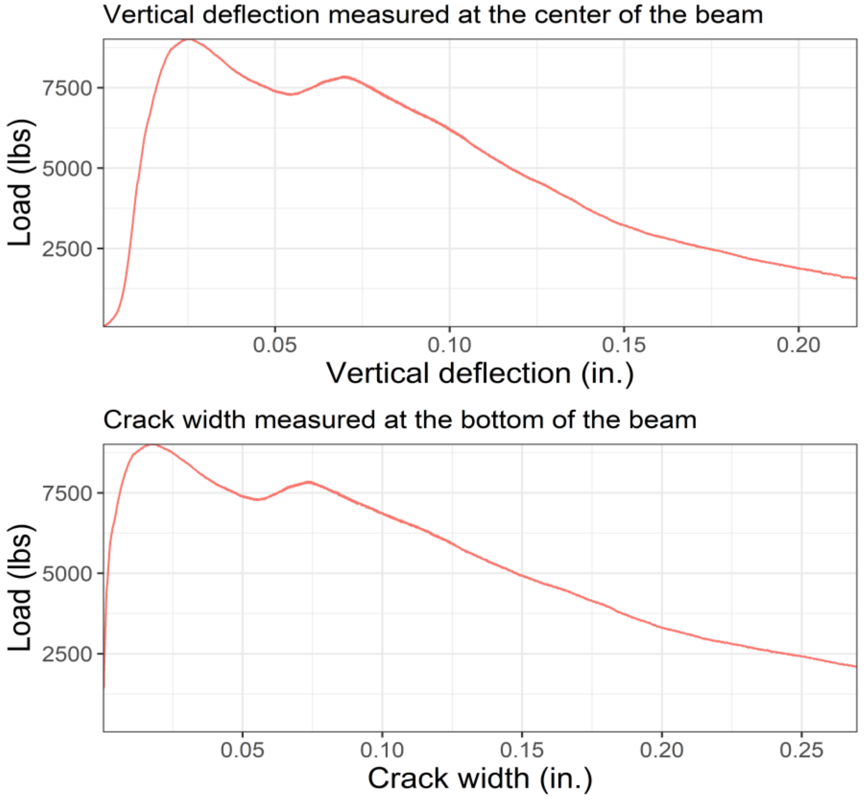
aci CONCRETE CONVENTION

Flexural Strength

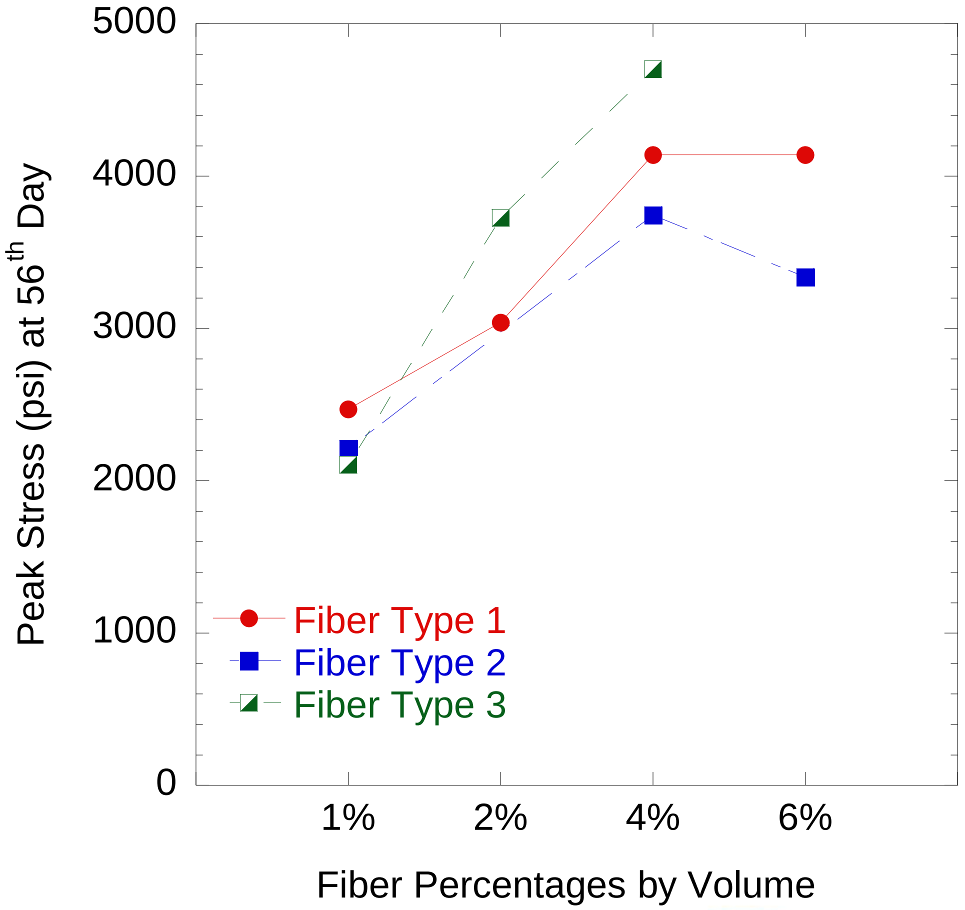
- Specimen: 3 in. by 3 in. by 12 in. prisms
- Utilizing ASTM C78 and ASTM C1609
- Loading rate: 17.5 psi/s
- Tested at 56th day



Flexural Strength Result

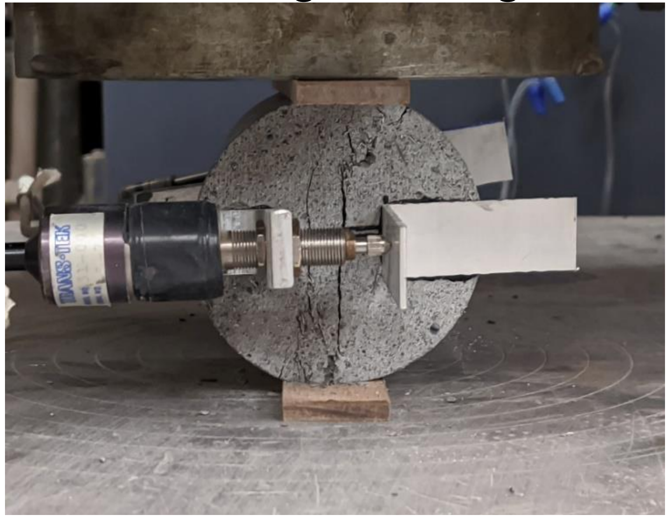


General flexural response

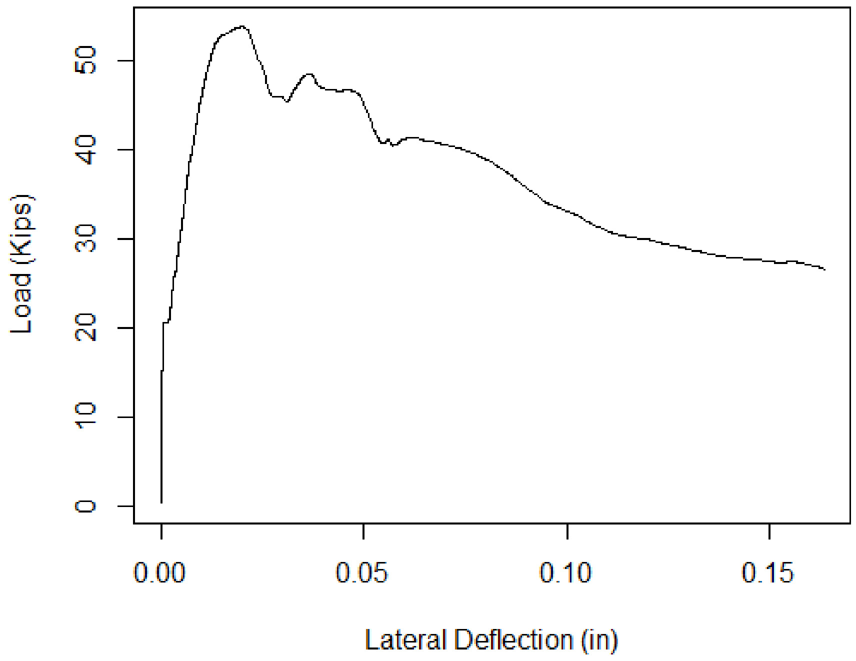


Splitting Tensile Strength

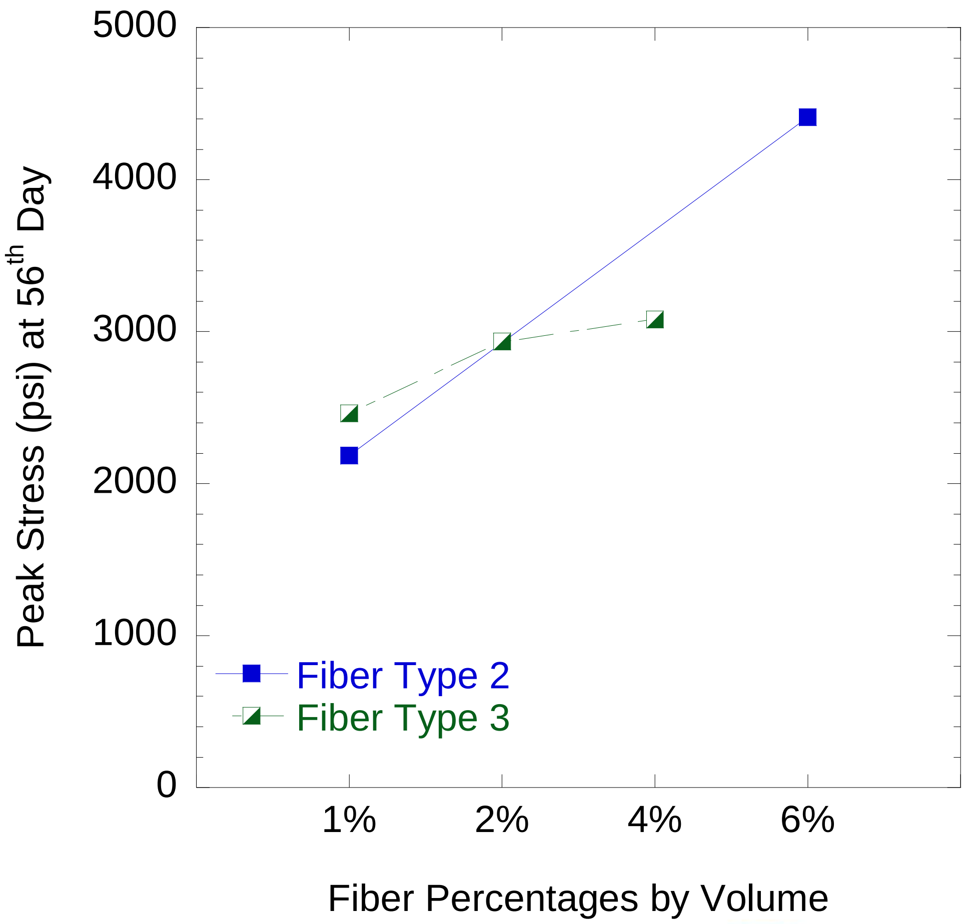
- Specimen: 3 in. by 6 in. cylinders
- According to ASTM C496/C496M
- Loading rate: 2.5 psi/s to failure at 56th day
- After reaching maximum load, the specimens crushed along the length



Splitting Tensile Results

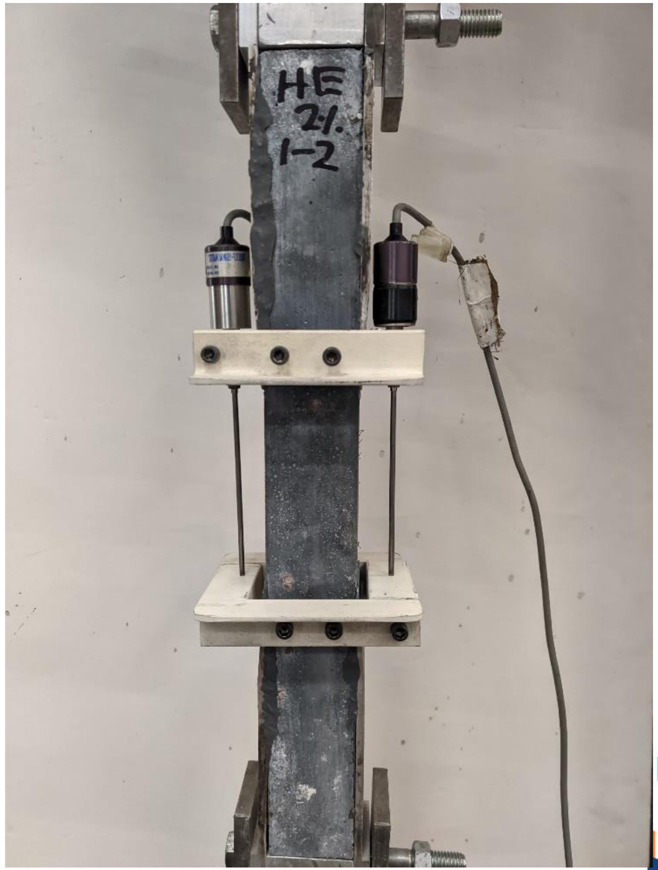


General Split Tensile response

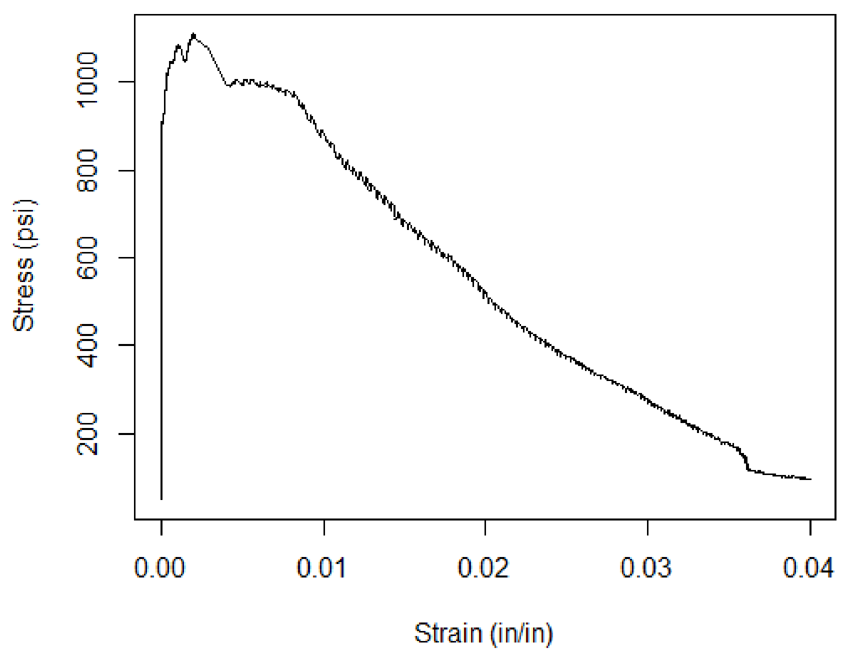


Direct Tensile Strength

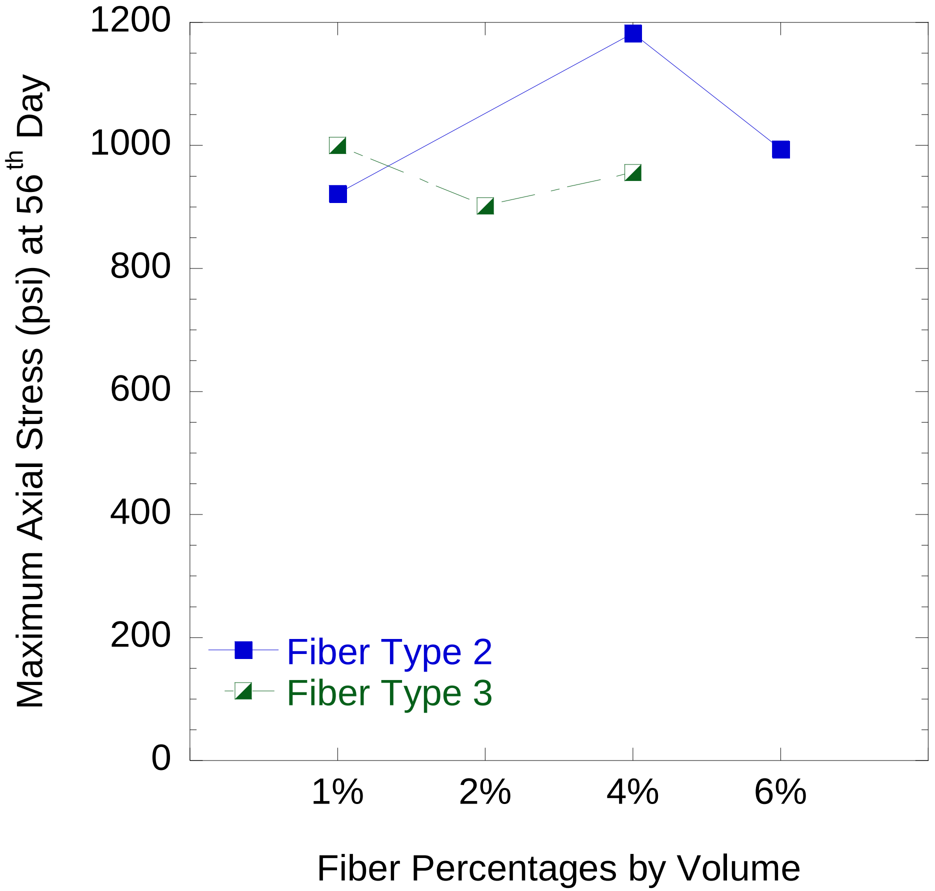
- Specimens: 2 in. by 2 in. by 17 in. prisms
- Based on the work of Graybeal and Baby (2013) with modifications for available equipment
- Loading rate: 100 lb/s to 150 lb/s
- Tested at 56^{th} day



Direct Tensile Strength Results



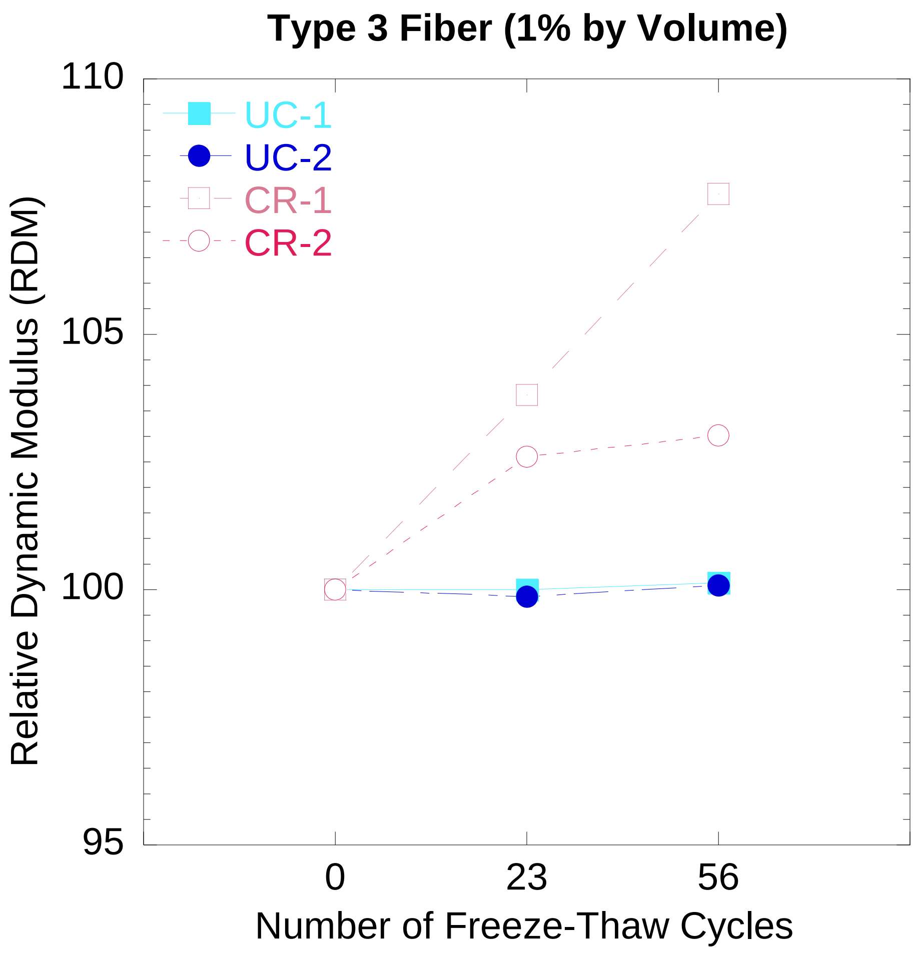
General direct tensile response

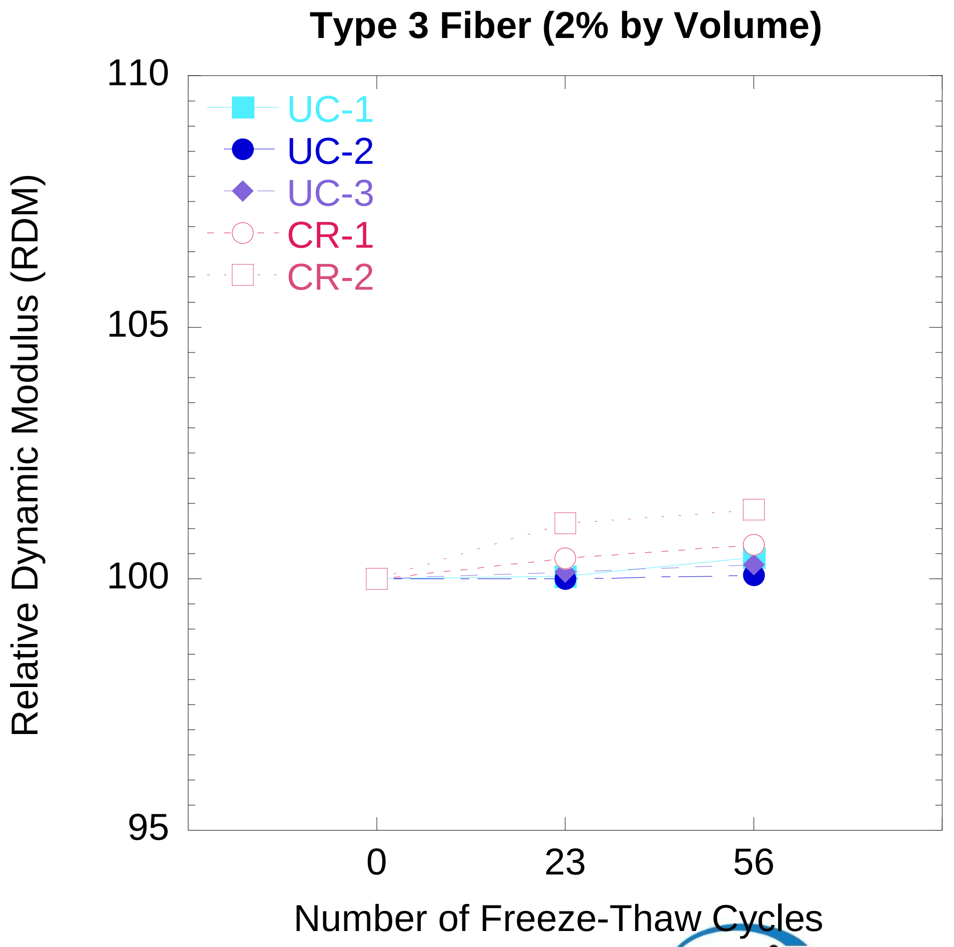


Freeze-Thaw Resistance

- Specimens: 3 in. by 3 in. by 12 in. prisms
- Specimens had 1% and 2% Type 3 fibers
- Two specimens from each fiber percentages were loaded till first crack using third point bending setup
- According to ASTM C666
- Resonant frequency was measured

Freeze-Thaw Resistance Results





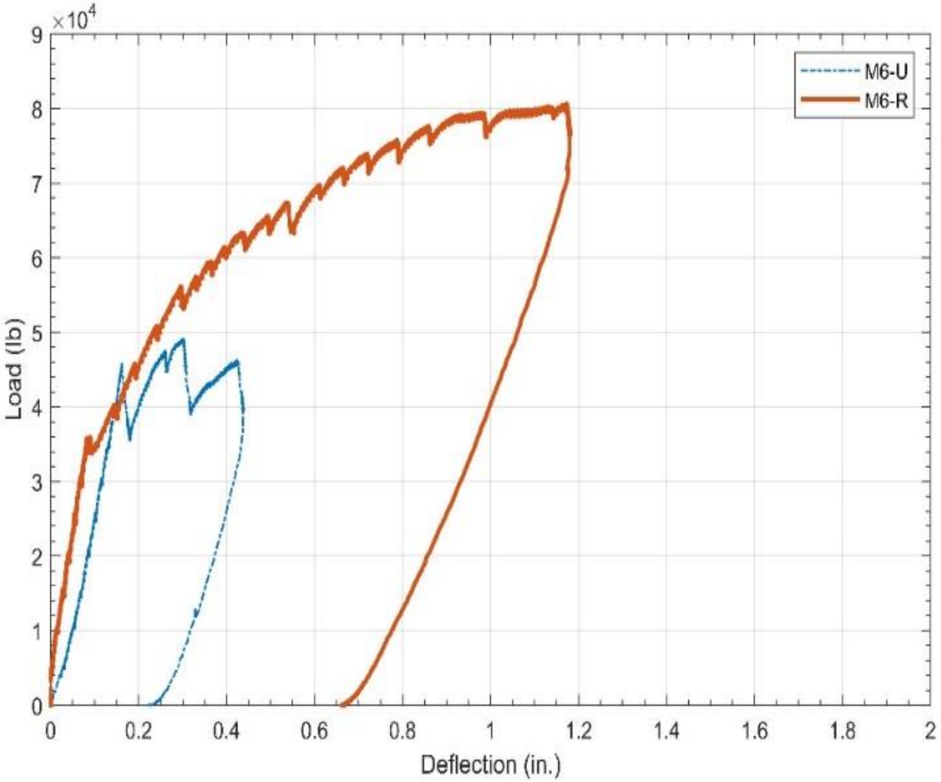
Damaged Prestressed Girder

- The prestressed beam was loaded until failure indicated by deck crushing
- Bond-shear was controlling failure mechanism
- First crack was at 45 kips
- Maximum load was 54 kips
- UHPC with 2% Type-2 fiber was used for repairing the beam end

Prestressed beam with bond-shear cracks

Prestressed Girder End Repair

Repaired Prestressed Girder Response



Preliminary Observations

- Fiber amount has little significance on UHPFRC compressive strength
- Tensile properties benefited due to increasing fiber amounts up to 4%
- Type-3 fiber can bridge cracks better than the smaller fibers if proper distribution is ensured
- UHPFRC may be able to heal cracks under suitable condition
- As UHPFRCC can ensure higher sectional properties than regular concrete, it can be a suitable product for structural repair

Ongoing Work

- Freeze-Thaw Resistance for Type-2 and Type-3 fibers for at least 350 cycles and residual flexural capacity of the specimens after exposure to freeze-thaw cycles
- Effect of synthetic fibers (Basalt, Alkali-resistant glass fibers) on UHPC properties
- Complete analysis of results

References

- Graybeal, B. A., & Baby, F., 2013. Development of Direct Tension Test Method for Ultra-High-Performance Fiber-Reinforced Concrete. ACI Materials Journal, 110(2). doi: 10.14359/51685532

Thank You

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