Fiber Distribution and Alignment in Structural UHPC Elements

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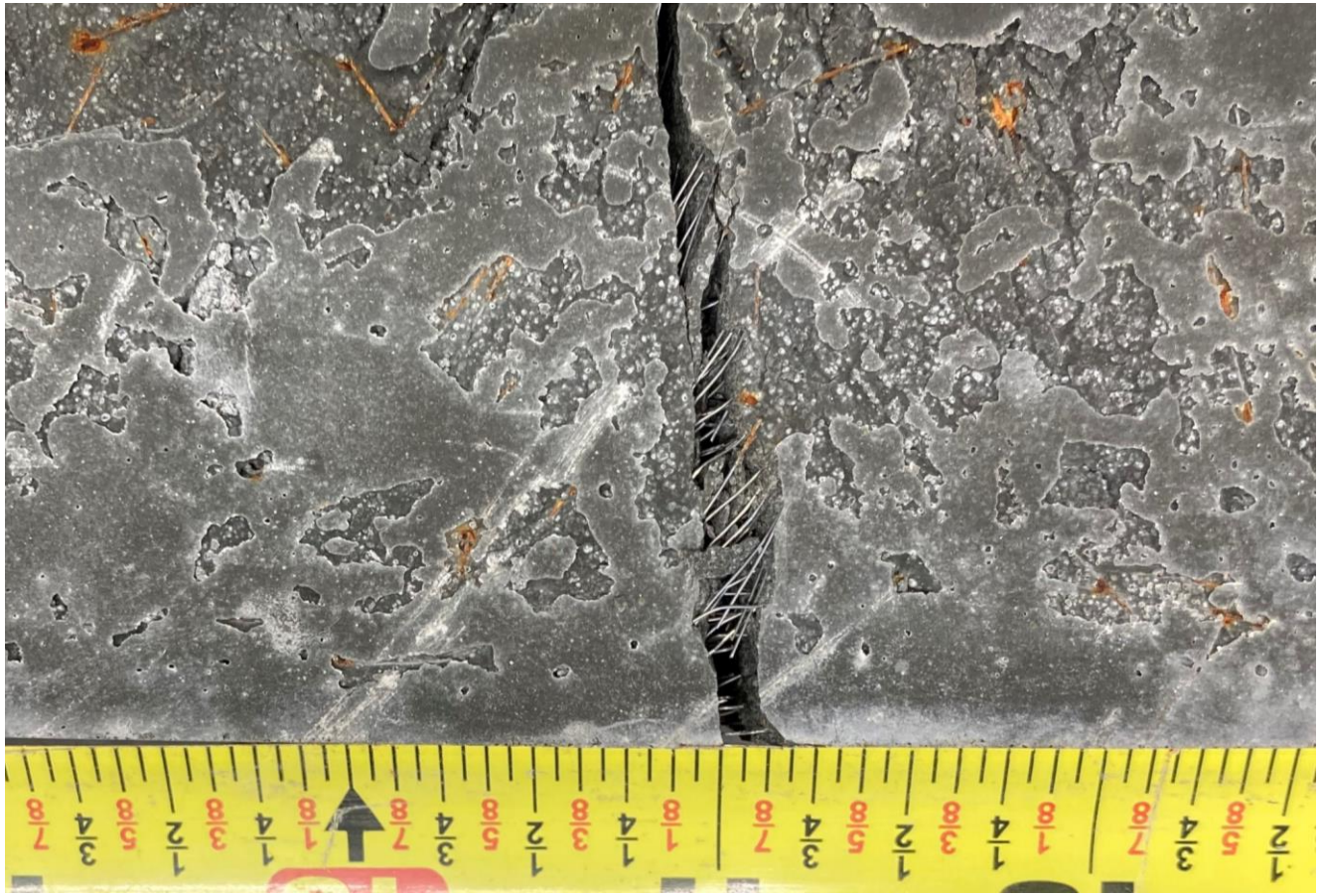

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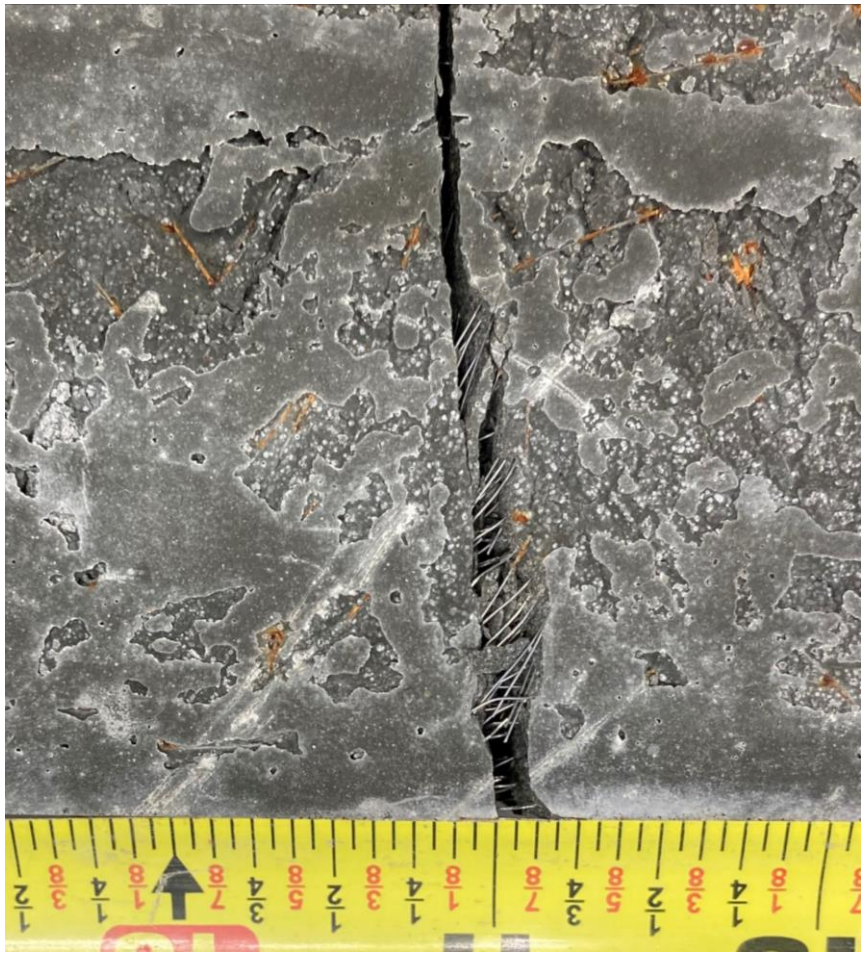
Outline

- Motivation
- Method
- Results
- Conclusions

Motivation

Motivation

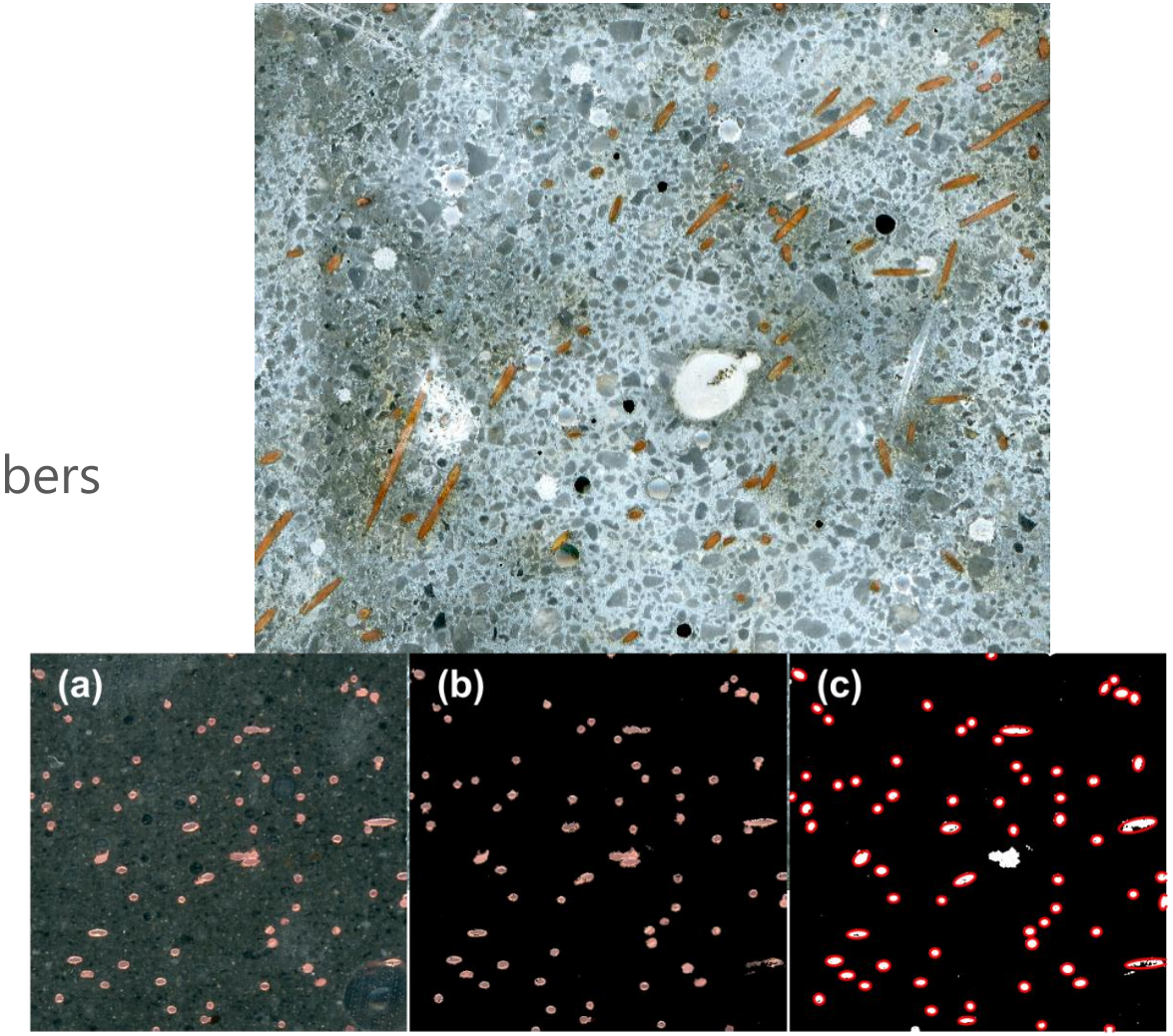
- Quantity and orientation of steel fibers can impact tensile capacity of UHPC structural elements
- Distribution and alignment will depend on:
  - Fresh UHPC characteristics (e.g., flow)
  - Mixing process
  - Geometry of structure
  - Placement process
- **Need a method to quantify effect of fiber distribution and fiber alignment**



Method

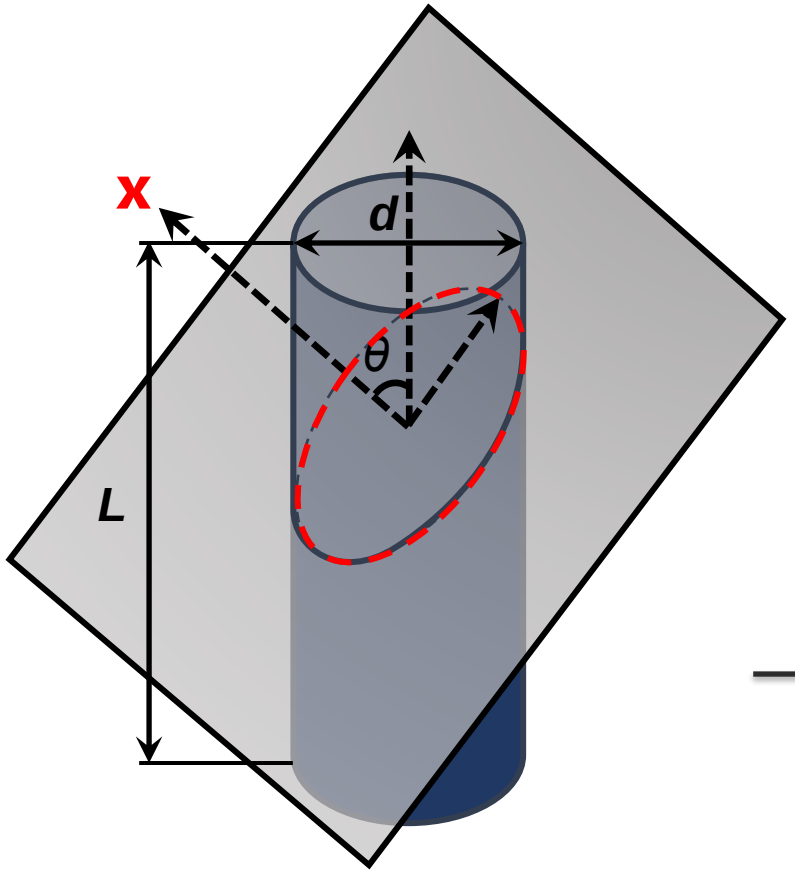
2D Image Analysis Process

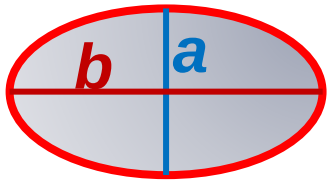
1. Sample Prep:
   a) Establish orientation, cut & polish surface
   b) Treat with copper sulfate solution
2. Scan at high resolution
3. Image Analysis:
   a) Use L*a*b* color thresholding to identify fibers
   b) Fit ellipse to each fiber
   c) Determine fiber count and alignment

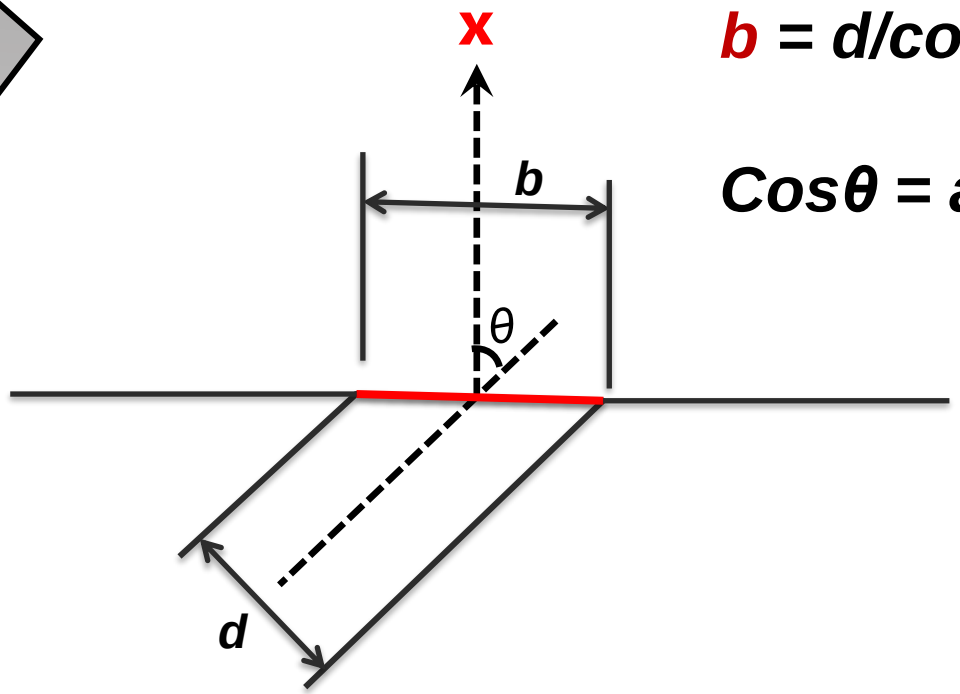


0.008 in. (0.2 mm) = 25 pixels at 3200 ppi

2D Image Analysis Process







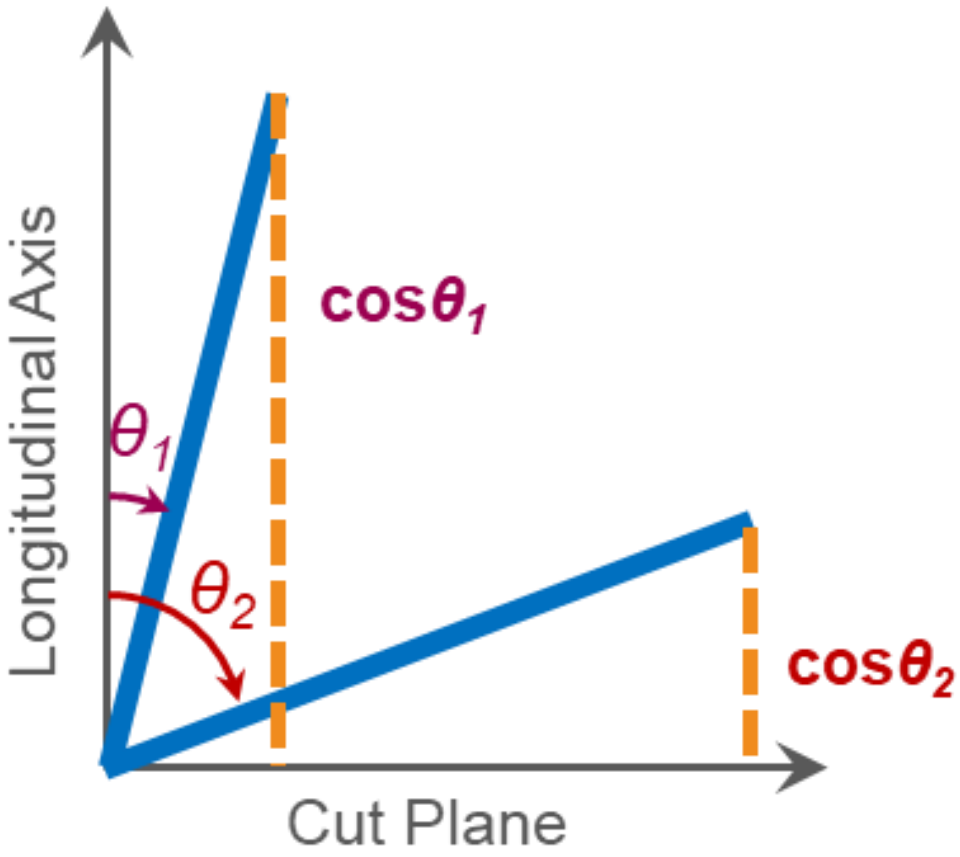
a vs b relationship indicates angle of fiber

a* = *d

***b* = *d*/cos(*θ*)**

Cos*θ* = *a*/*b*

2D Image Analysis Process



- **Axial alignment factor, k =** the average projection of all fibers in the orientation of interest

$$k = \sum_{i=1}^{N_f} \cos(\theta_i)/N_f$$

- **Fiber alignment factor, f**

$$f = k^{*}N_f/A$$

N_f = *number of fibers*
A = *area of concrete*

Results

Fiber Alignment vs Flexural Performance

Fiber Alignment vs Direct Tensile Test Performance

Fiber Alignment vs Shear Performance

Fiber Alignment: 2D vs 3D

Fiber Alignment vs Flexural Performance - Samples

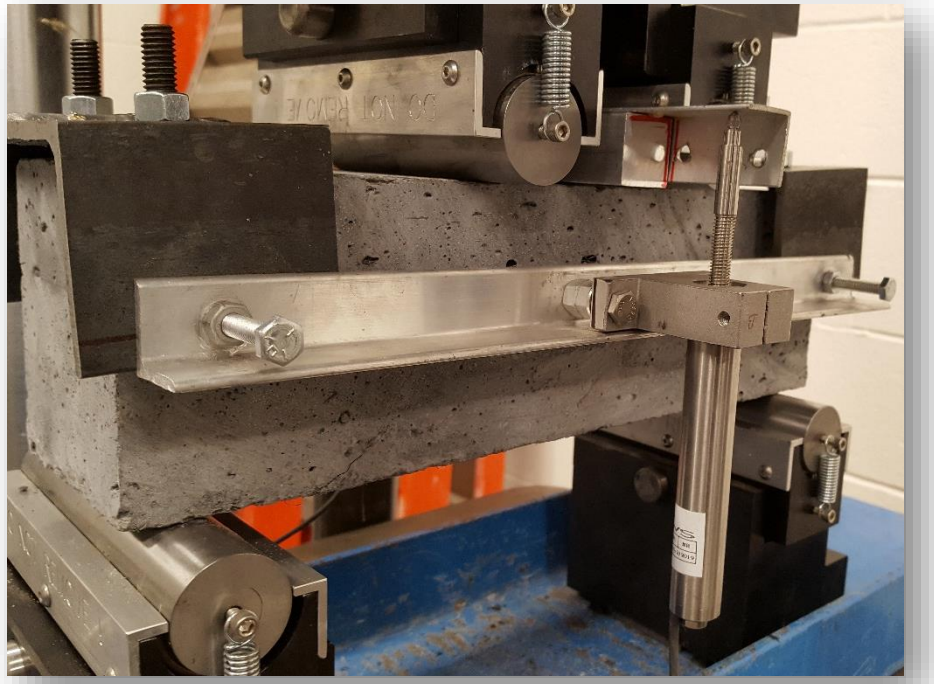
Beams cut from field-batched UHPC panels:

- A-C: parallel to flow
- D-F: perpendicular to flow

Goal: Evaluate impact of placement method on fiber alignment and flexural performance.

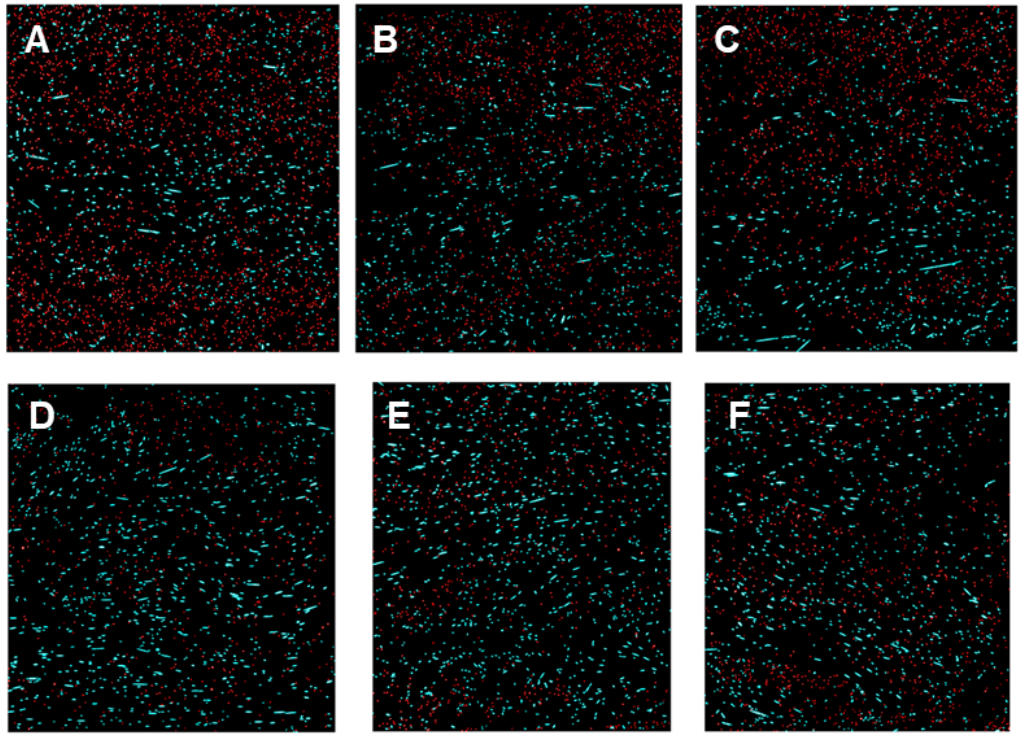
Flexural Test Results – C1609

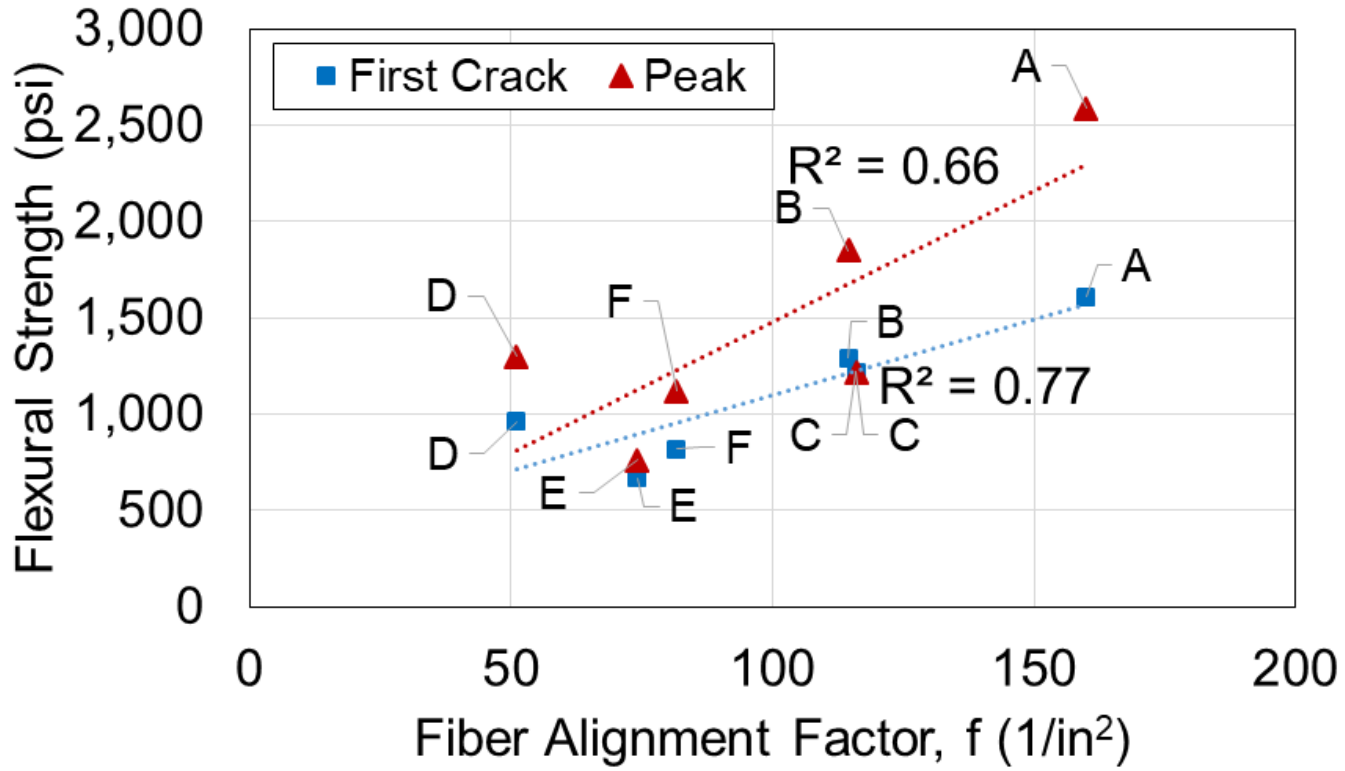
Sample	First Crack Strength (psi)	Peak Strength (psi)
A	1,610	2,590
B	1,290	1,850
C	1,220	1,220
D	960	1,300
E	670	760
F	820	1,120
A-C avg.	***1,370***	***1,890***
D-F avg.	***820***	***1,060***



Fiber Alignment vs Flexural Performance

- Axial alignment factor, k = $\sum_{i=1}^{N_f} \cos(\theta_i) / N_f$
- Fiber alignment factor, f = kN_f/A





Results

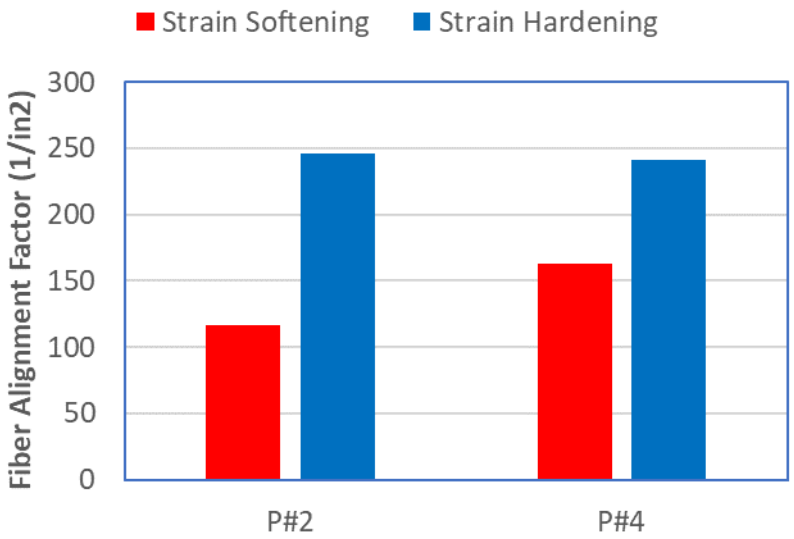
Fiber Alignment vs Flexural Performance

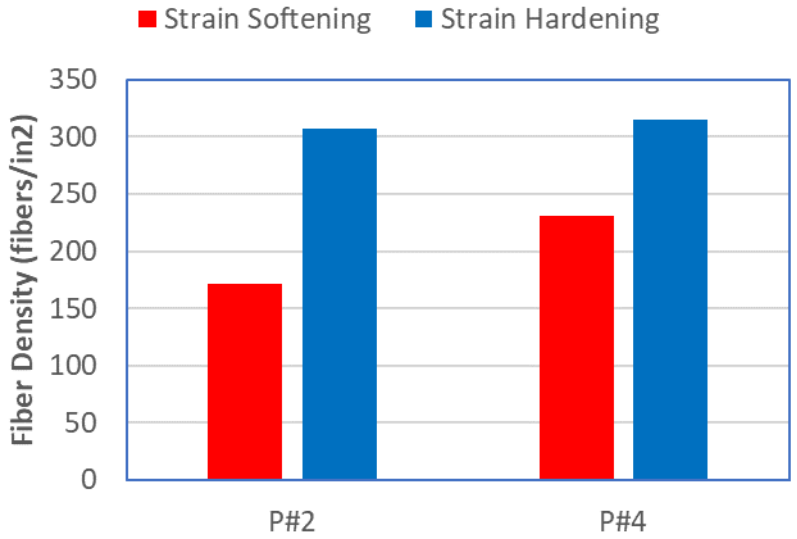
Fiber Alignment vs Direct Tensile Test Performance

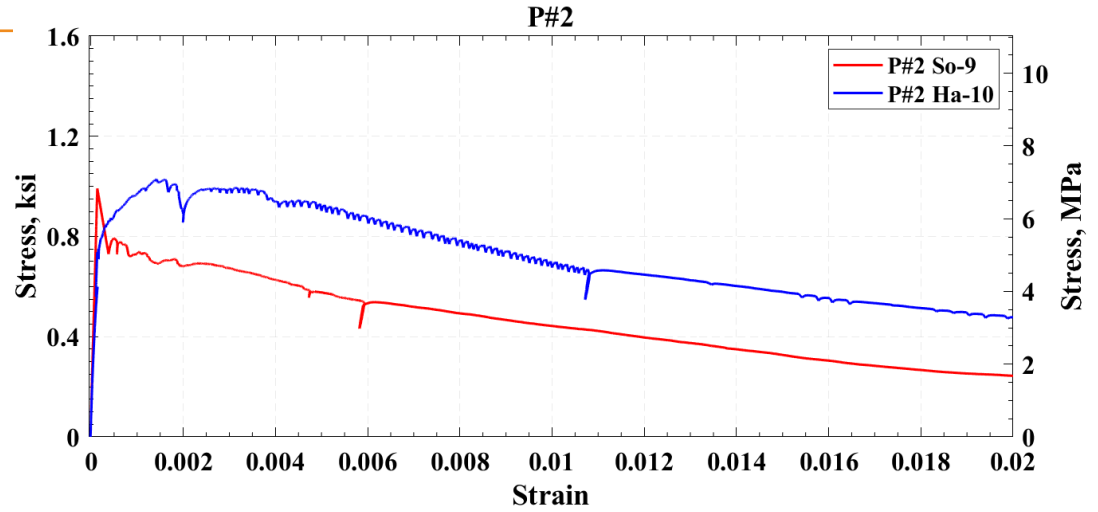
Fiber Alignment vs Shear Performance

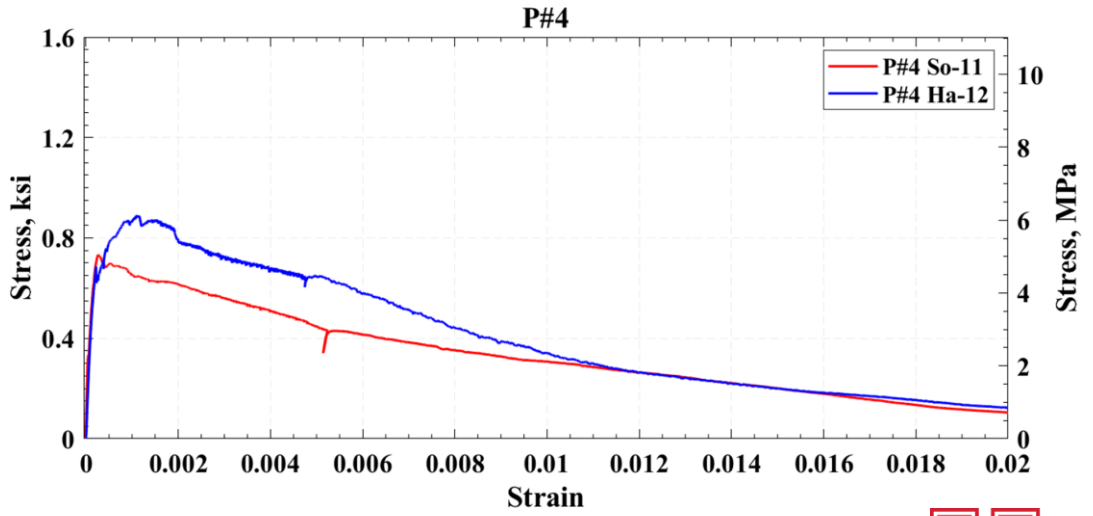
Fiber Alignment: 2D vs 3D

Fiber Alignment vs Direct Tension Test Performance









Kalliontzis, D., A. Salah. (2024) "Material Characterization of Ultra-High-Performance Concrete (UHPC)", in *Database for Material Characterization of Ultra-High-Performance Concrete (UHPC)*. DesignSafe-CI. https://doi.org/10.17603/ds2-7gar-ps40 v1

Results

Fiber Alignment vs Flexural Performance

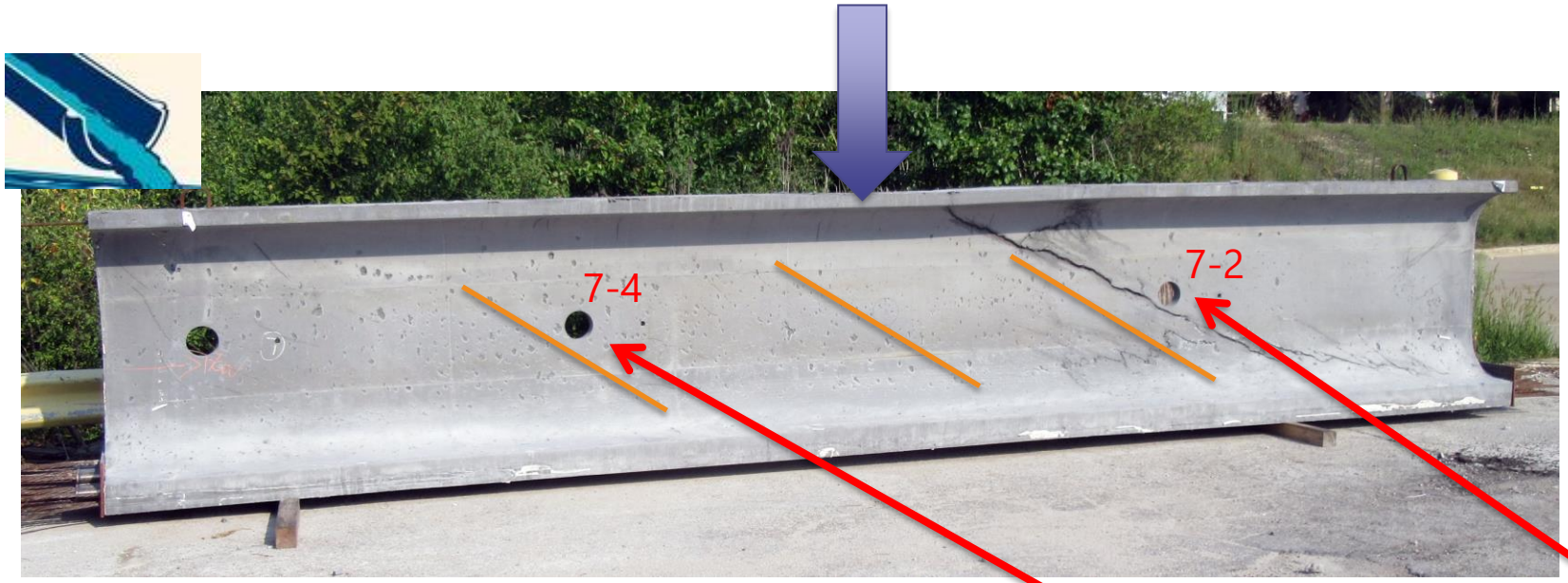
Fiber Alignment vs Direct Tensile Test Performance

Fiber Alignment vs Shear Performance

Fiber Alignment: 2D vs 3D

Fiber Alignment vs Shear Performance

4′-8″ Deep UHPC Beam Shear Failure



Cut plane parallel to crack

Sample ID	7-4	7-2
Fiber Alignment Factor, f (1/in^{-2})	128	81
Fiber Density (fibers/in^{-2})	186	132

Beam 7

Results

Fiber Alignment vs Flexural Performance

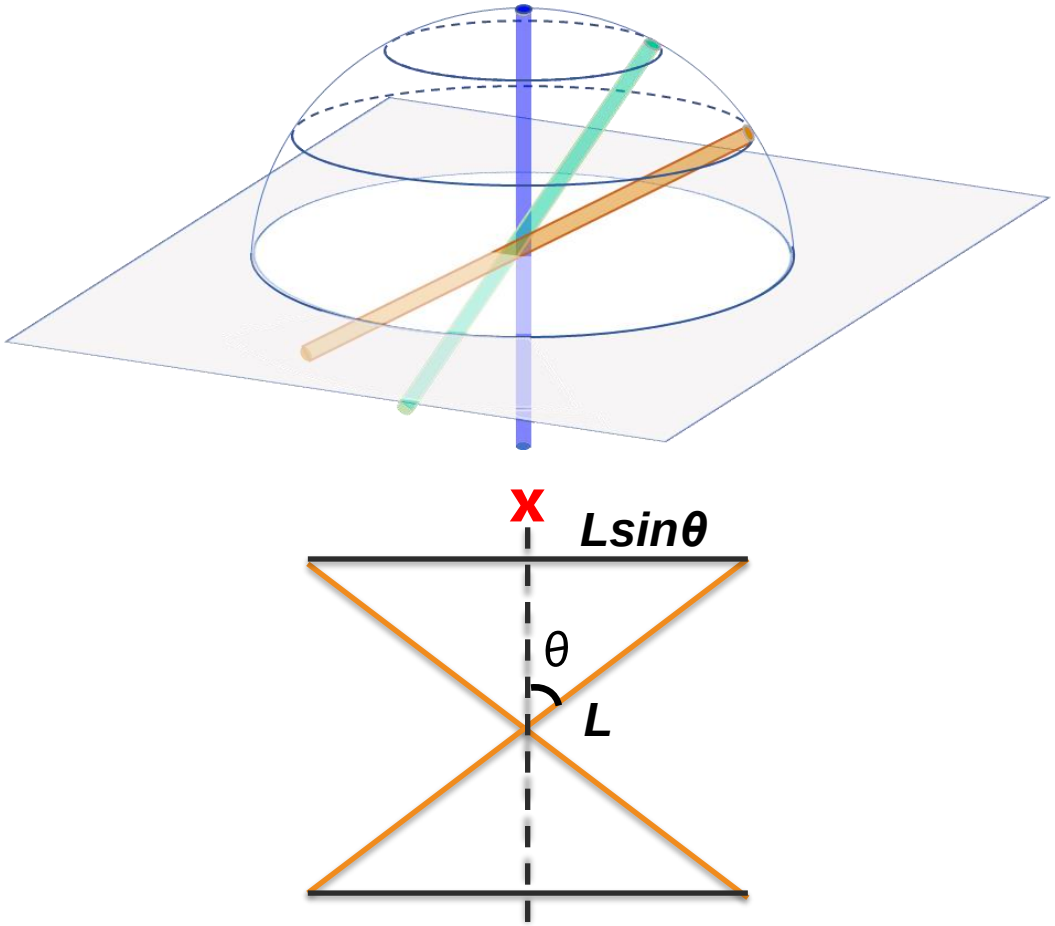
Fiber Alignment vs Direct Tensile Test Performance

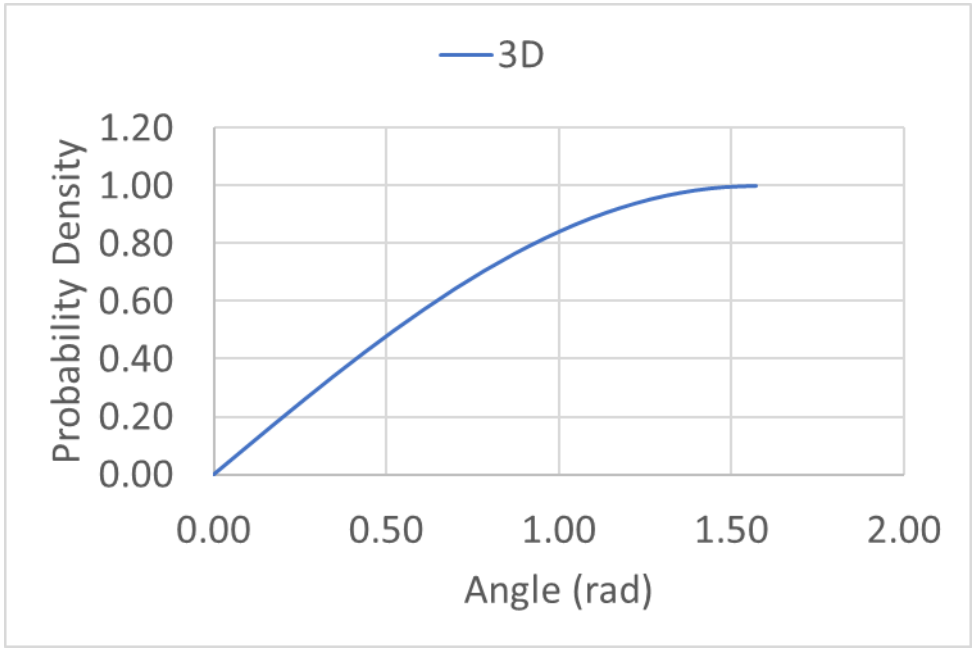
Fiber Alignment vs Shear Performance

Fiber Alignment: 2D vs 3D

3D – Randomly Distributed Fibers

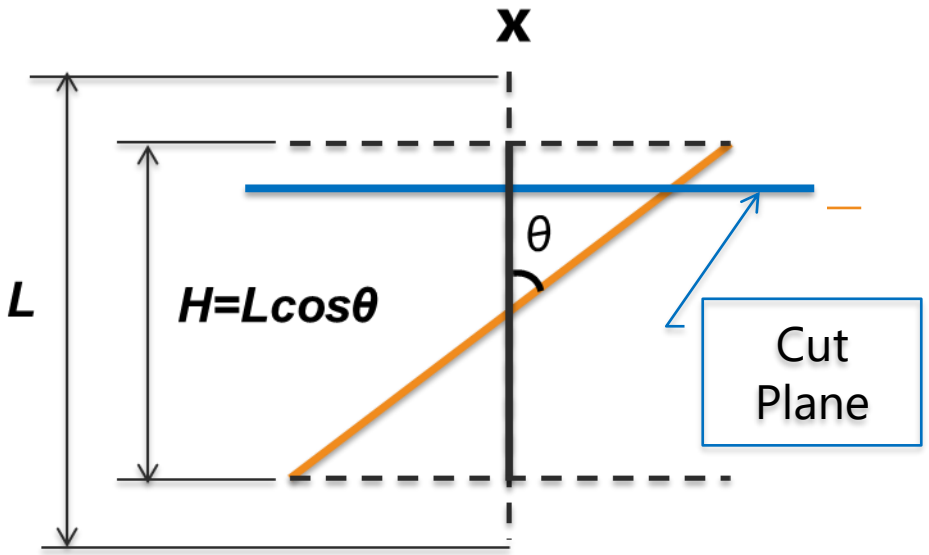
- Relative likelihood of a fiber oriented at an angle θ is sin(θ)





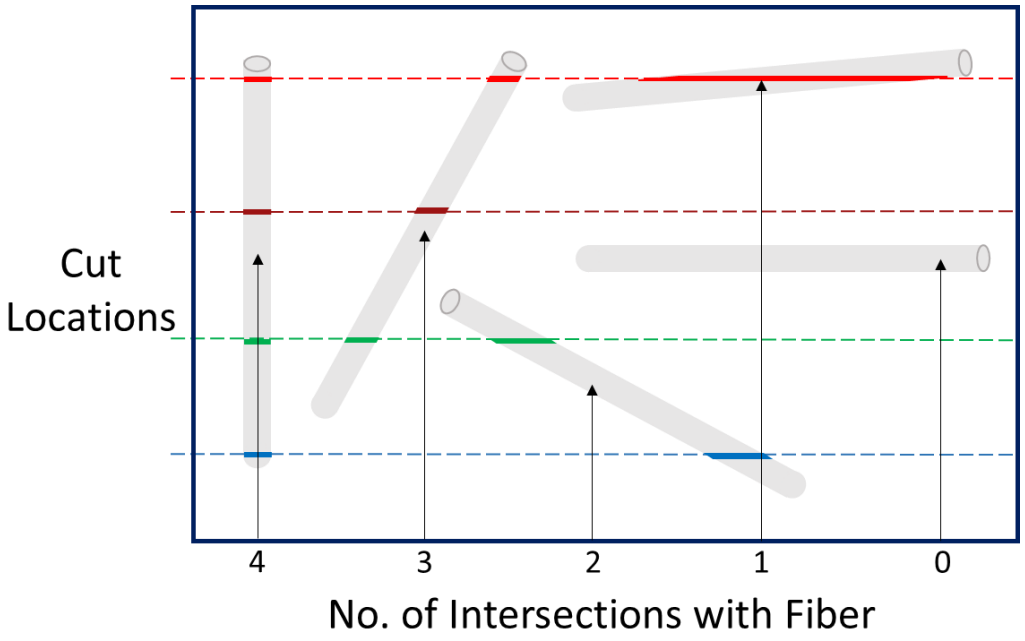
2D Geometry Effects

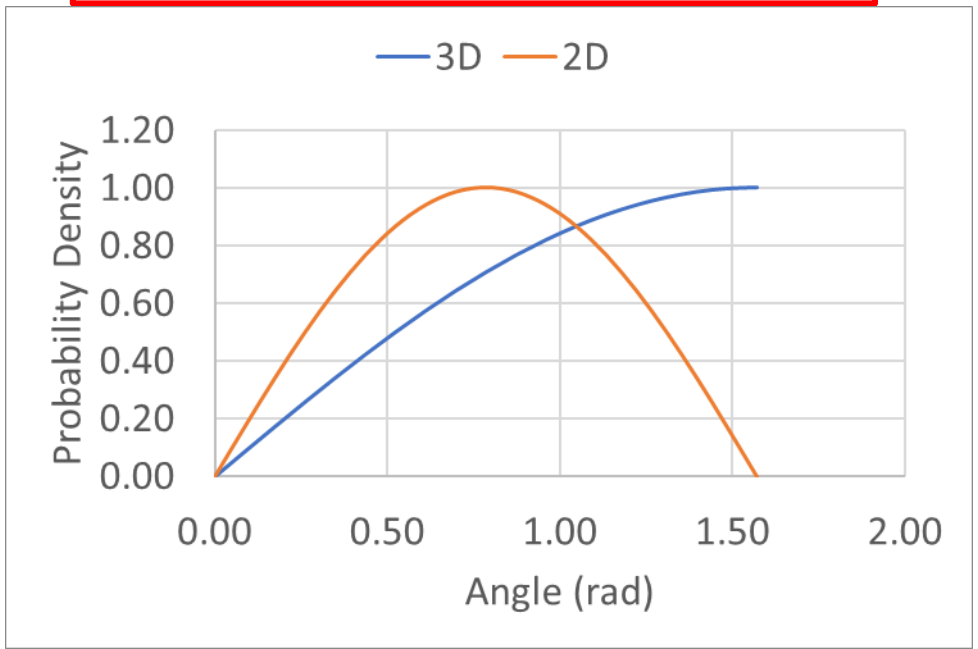
- The probability a fiber is cut through in 2D process reduces as fiber deviates from the reference direction:



$P(\theta) = H/L = \cos\theta$

$P_c(\theta) \sim \cos(\theta)\sin(\theta)$





2D Geometry Effects

Hypothetical Scenarios	k_{2D}	k_{3D}
All fibers in direction of reference orientation	1	1
Perfectly random	0.67	0.50
All fibers perpendicular to the reference direction	0	0

- Normalized 2D Alignment factor, k'_{2D} (To allow comparison to 3D):

$$k'_{2D} = 0.75{k_{2D}}^2 + 0.25k_{2D}$$

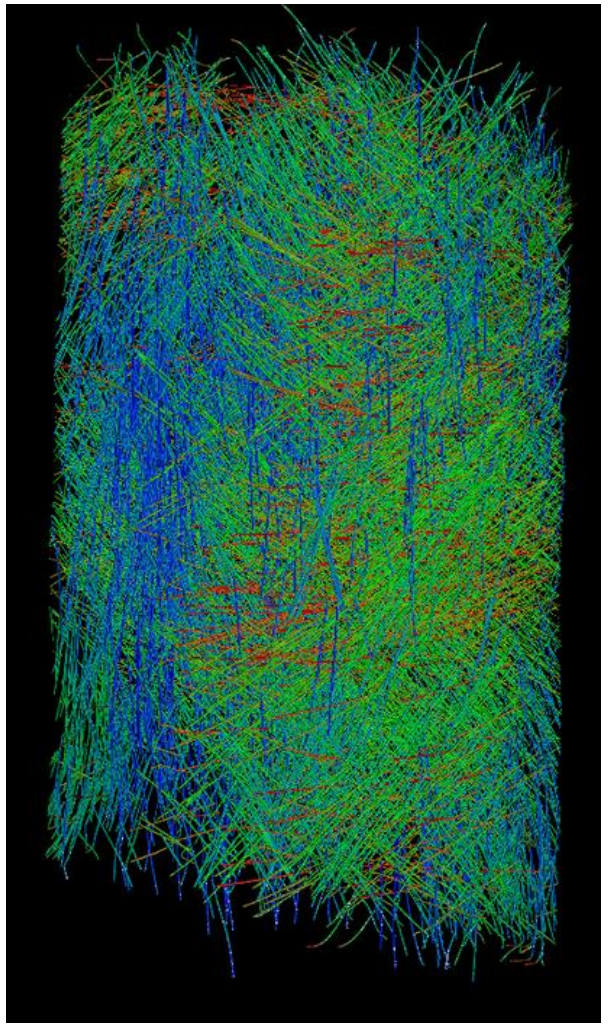
- Normalized Fiber Alignment factor:

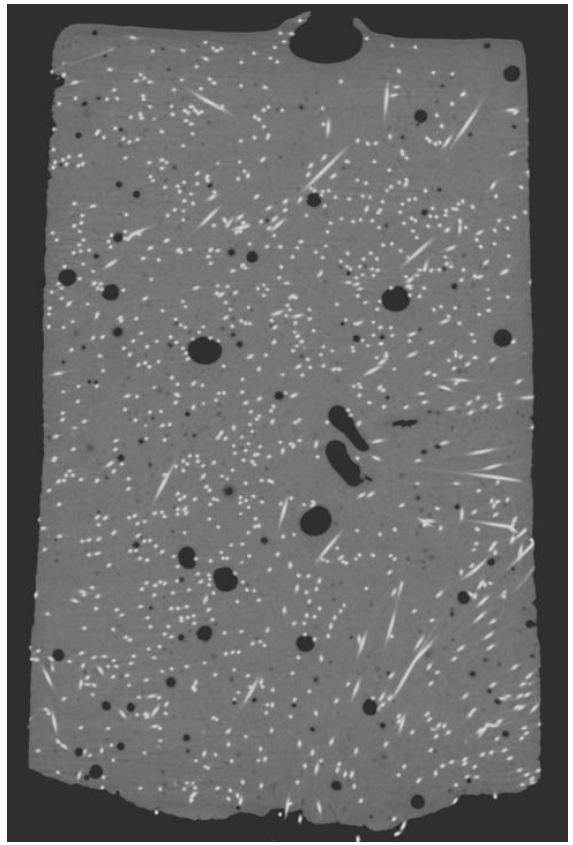
$$f' = k'_{2D} N_f / A$$

Samples

- 10 cores were taken from different full-scale UHPC members
  - H-Pile
  - Slabs
  - Box Beam
  - I Beam

3D Imaging Using CT Scan





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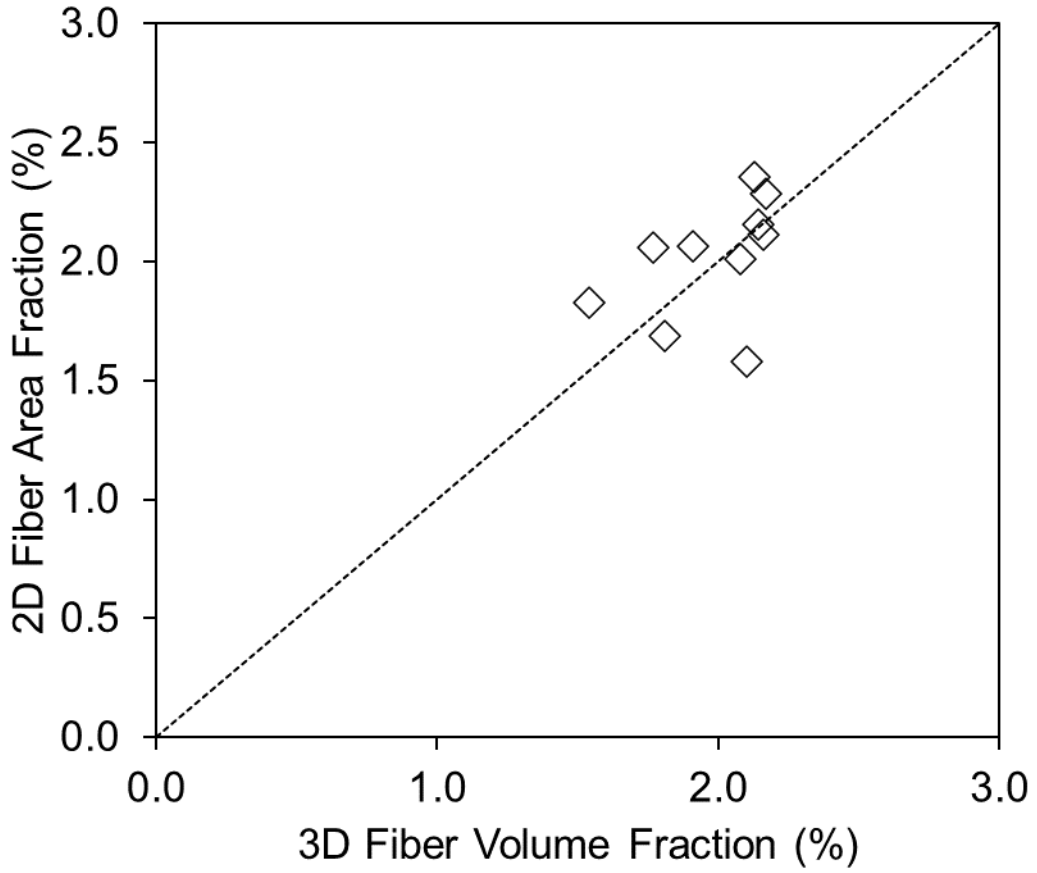
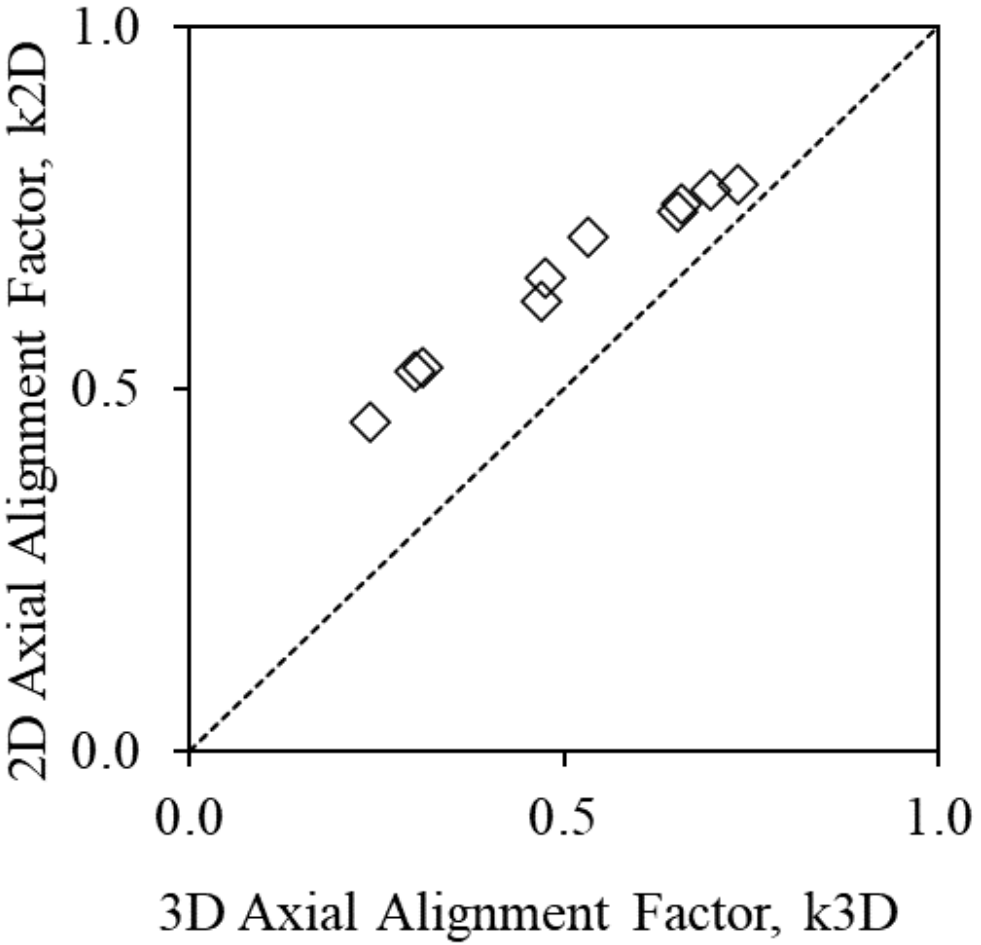
2D vs 3D: Comparison of Fiber Content (Multiple Cores)

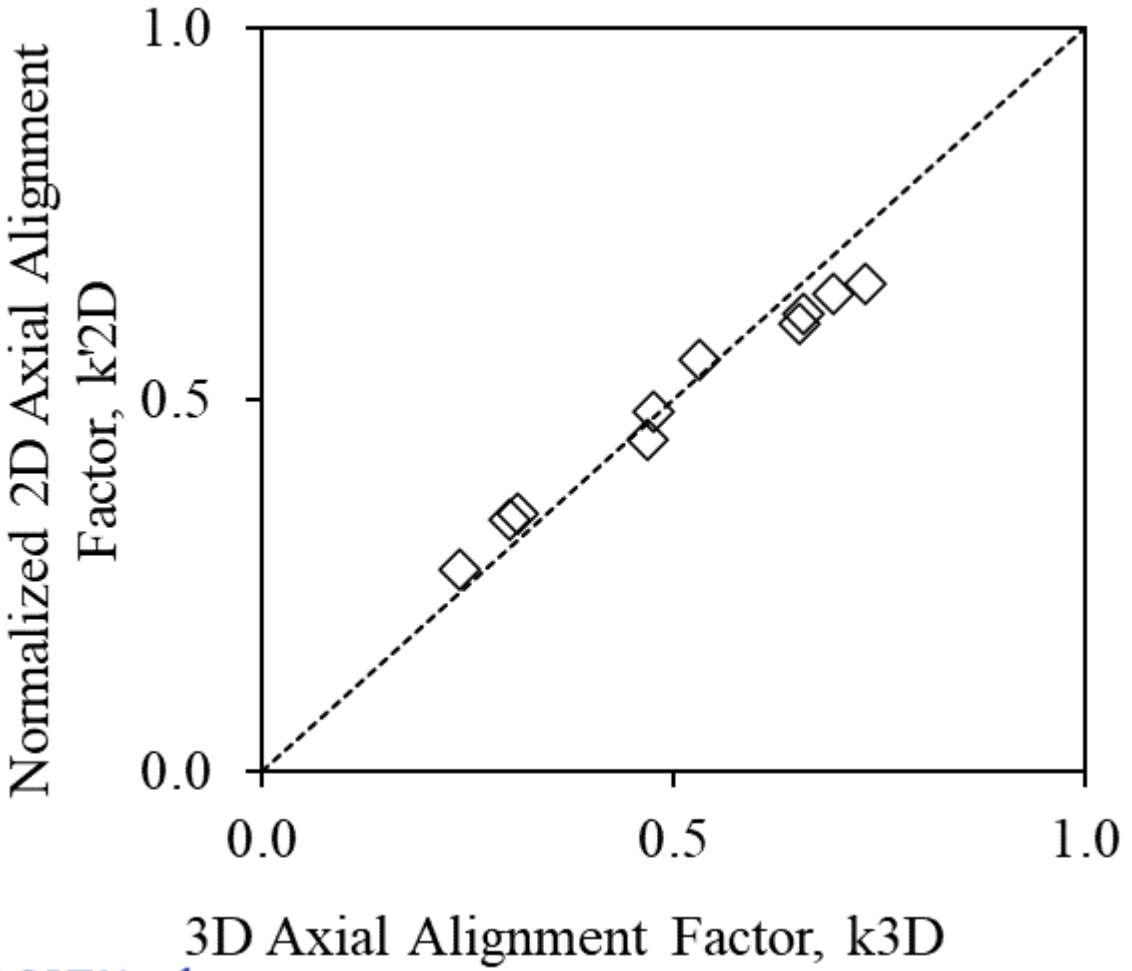


2D vs 3D: Comparison of Axial Alignment Factors (Multiple Cores)

NOT Normalized



Normalized



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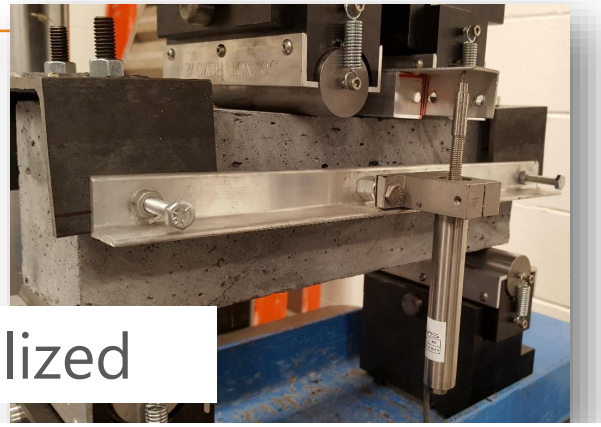
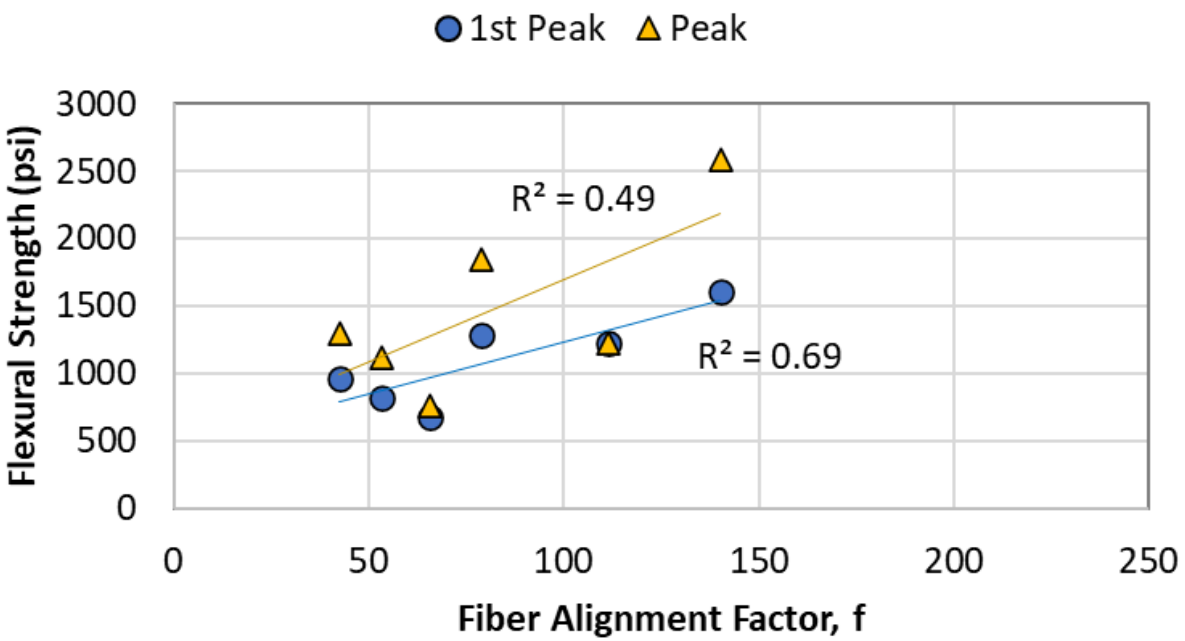
Normalized Fiber Alignment Factor vs Flexural Performance

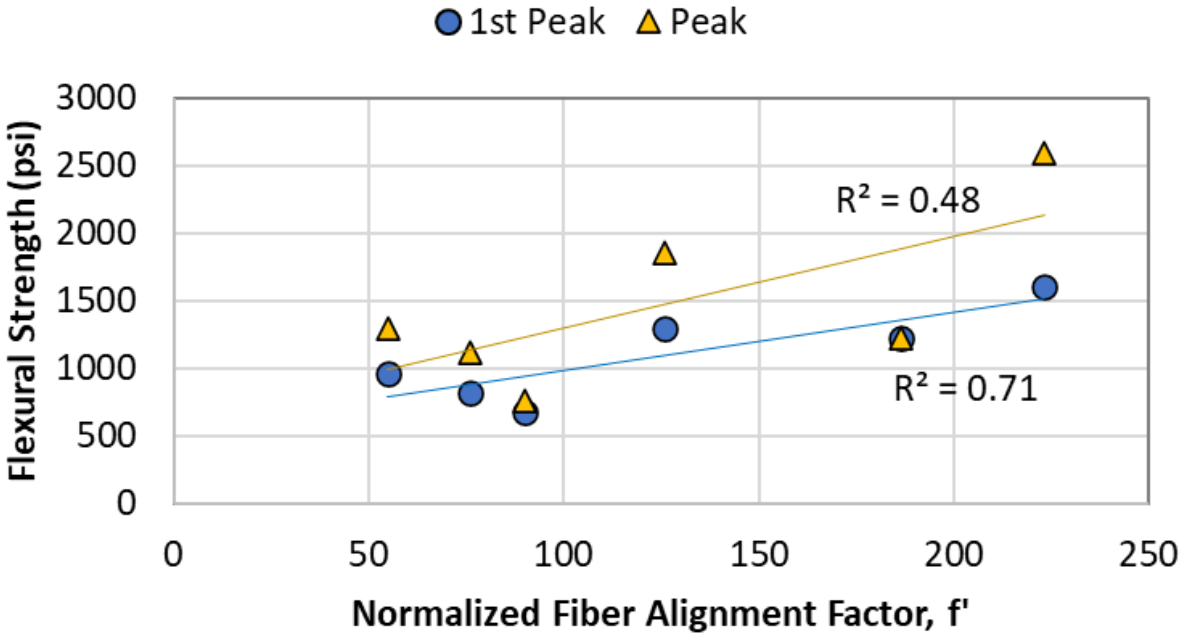
- Re-analyzed flexural beams with normalized fiber alignment (Results shown for bottom half of beams)



NOT Normalized



Normalized



Conclusions

Conclusions

- Fiber alignment and distribution are both important for the performance of UHPC elements
- 2D Image Analysis is a practical method for characterization of fiber alignment
- Fiber alignment factor correlates with flexural, tensile, and shear performance
- Axial alignment factors k_{2D} and k_{3D} correlate well, provided that k_{2D} is appropriately normalized
- Applications:
  - Evaluate effect of UHPC placement method and UHPC flow characteristics on fiber alignment
  - Investigation and trouble-shooting of low strength results

Acknowledgement

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Questions?

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