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Fiber Alignment in UHPC Tensile Tests

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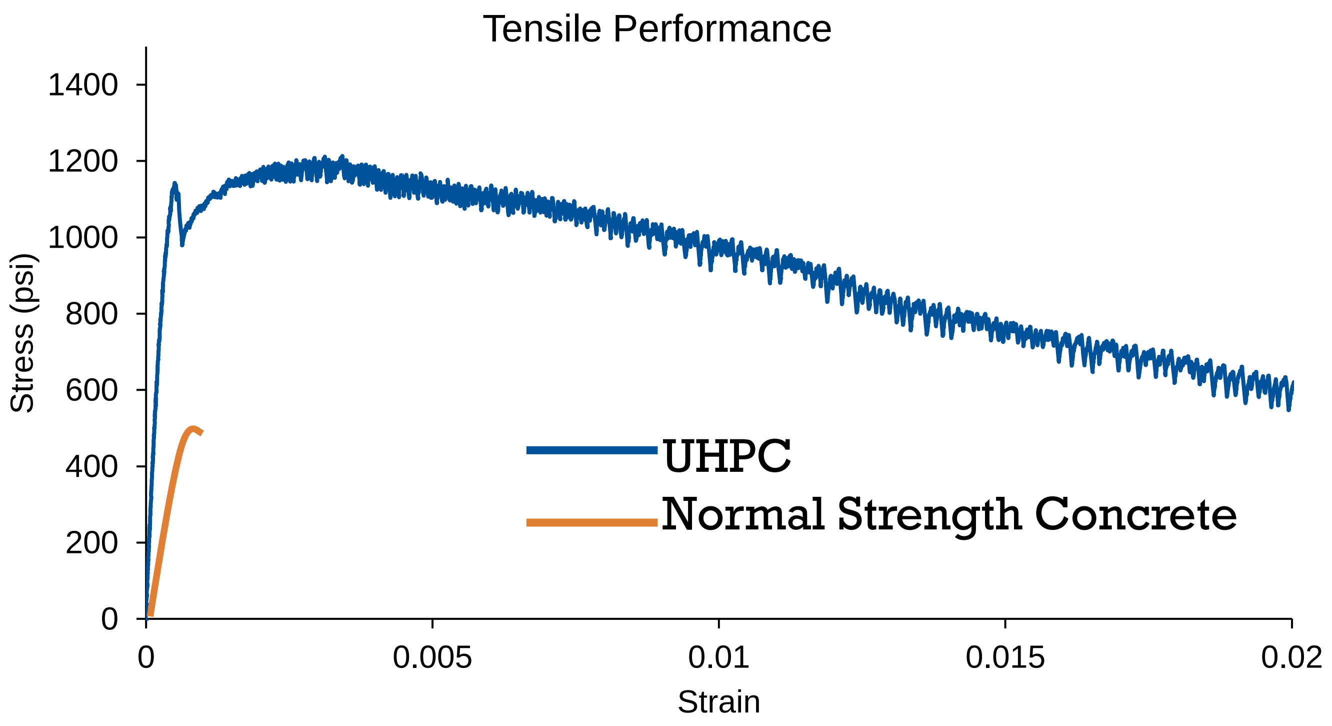
POWERING THE NEW ENGINEER TO TRANSFORM THE FUTURE

Properties of UHPC

- High-strength steel fibers in UHPC give it high strength and ductility in tension

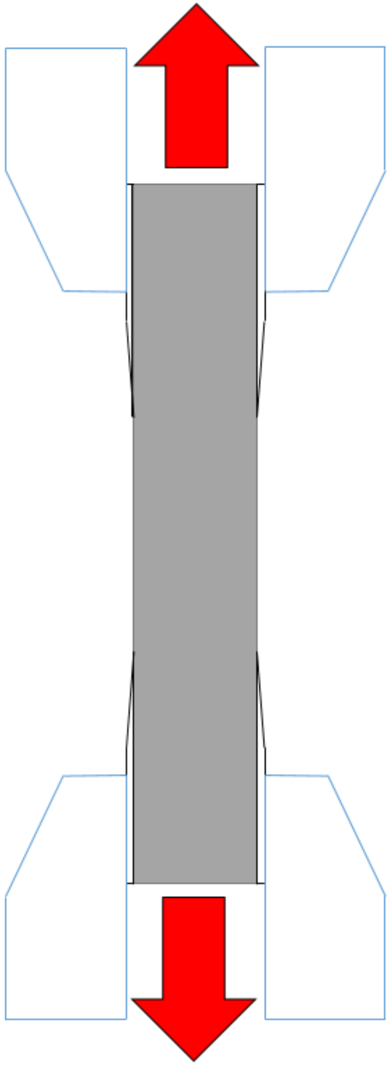


What Objectives Should I Have for Tensile Testing?

- What are we trying to demonstrate?
- Ideal QC test would:
  - Accurately characterize tensile strength
  - Provide a measure of ductility or toughness
  - Can be performed with equipment commonly available
  - Simple to perform, easy for technicians to learn
  - Repeatable

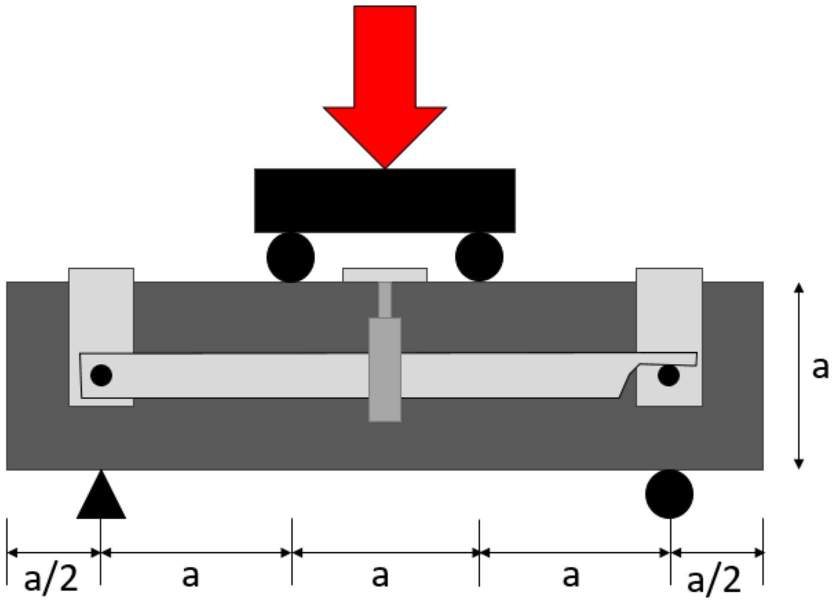
1: Direct Tension

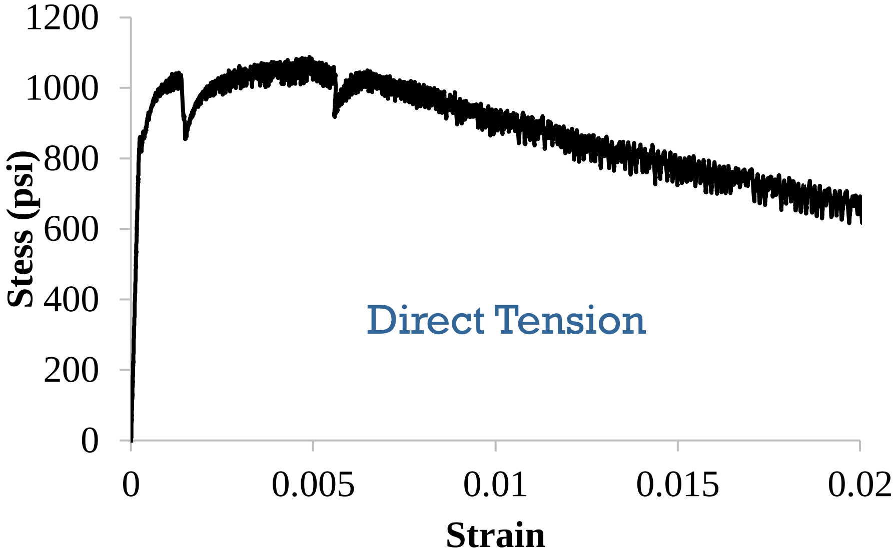
- Produces excellent stress vs. strain results
- Does not require inverse analysis
- Very specialized equipment
- High proportion of failed tests
- Preferentially-oriented fibers

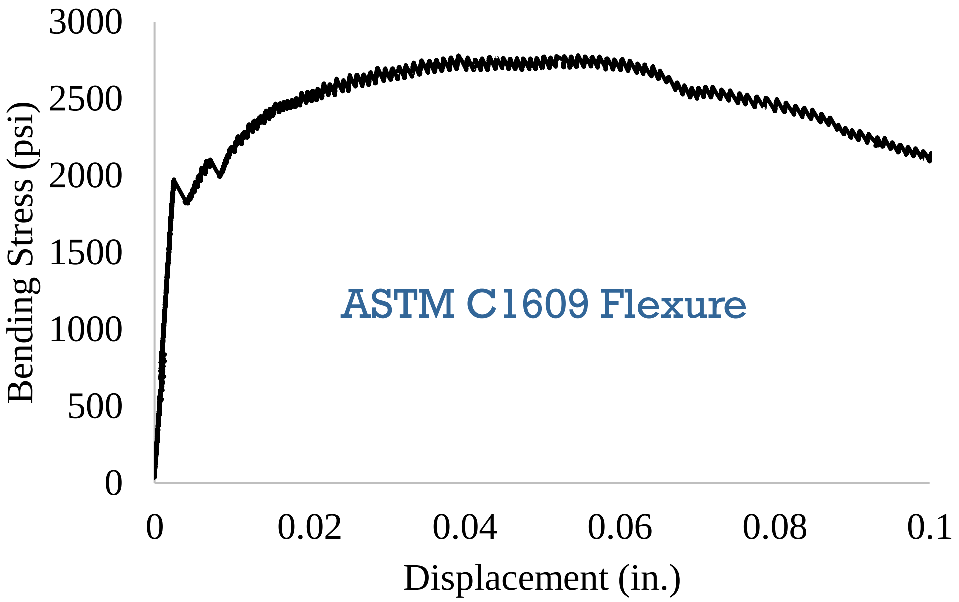


2. Flexure Test

- Gives post-cracking data
- More widely-accessible equipment
- Multiple ASTMs for flexure (ASTM C1609 is recommended for UHPC)
- inverse analysis needed
  - Inverse analysis involves assumptions
  - No standard inverse analysis

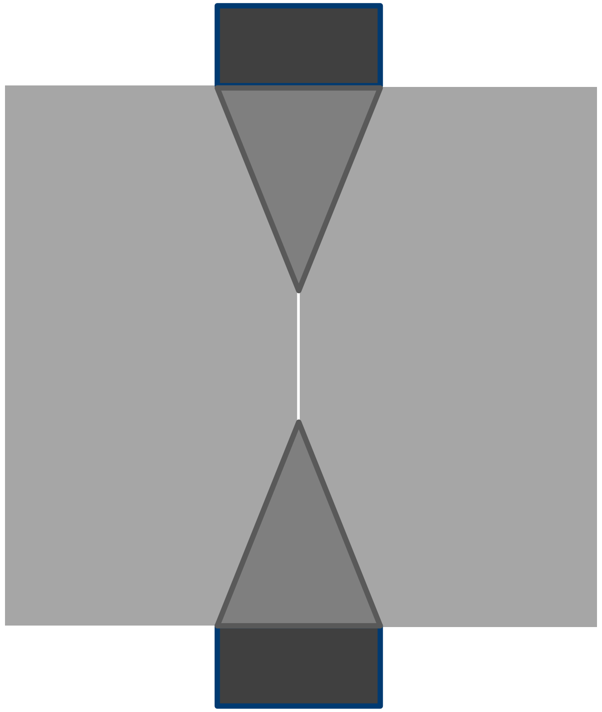


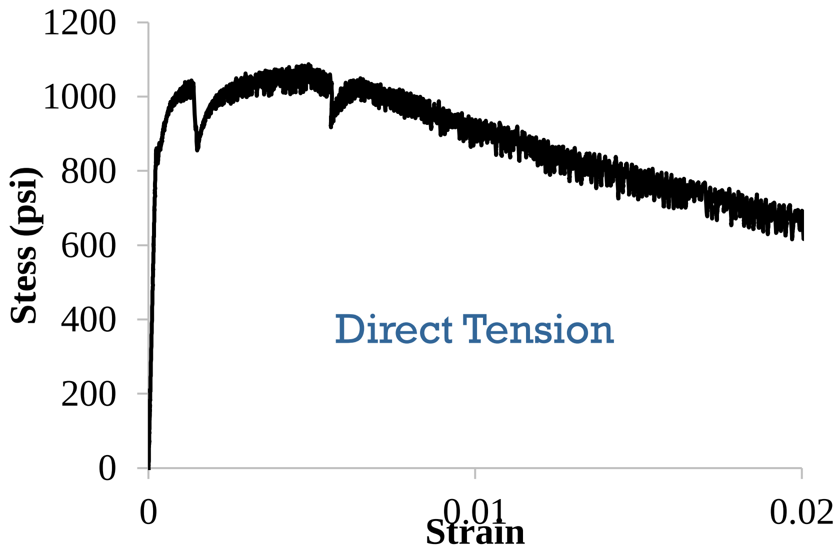


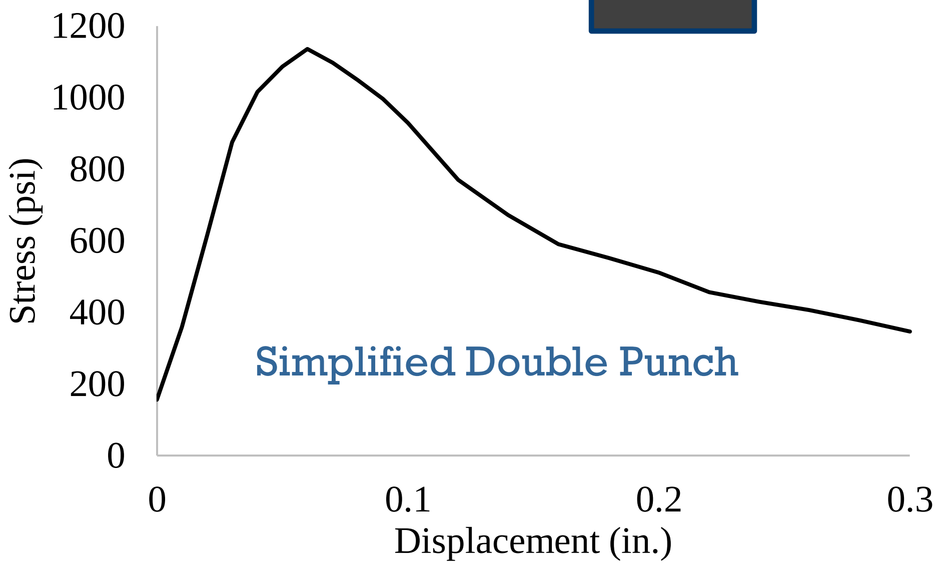


3. Simplified Double-Punch

- Does not require expensive equipment
- Gives post-cracking data
- Does not give strain data
- Not widely standardized in U.S.

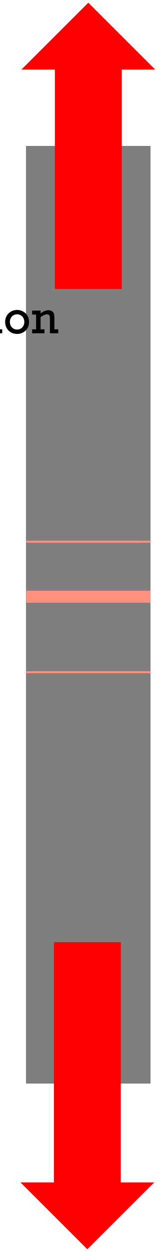




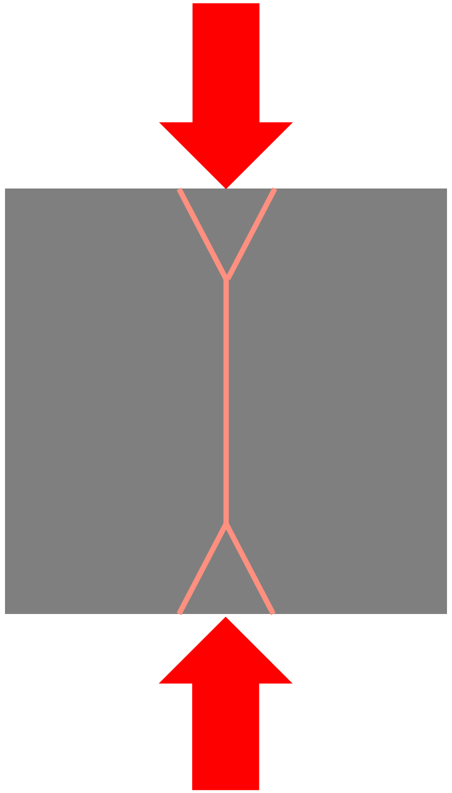


Tensile Tests Methods

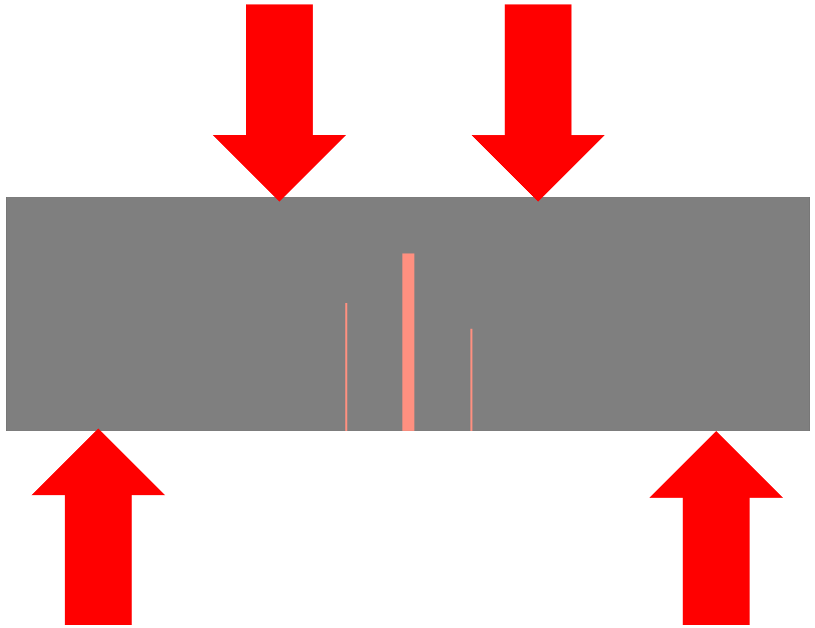
Direct Tension



Simplified Double-punch



ASTM C1609 Flexure



Placement Effects

- A funnel was used to place the concrete in the tensile molds.
- Tensile specimens were created with UHPC placed at the center or at the edge of the specimens.
- No significant strength difference was observed when comparing edge vs. center funnel placement.

Broken samples that were filled from the edge

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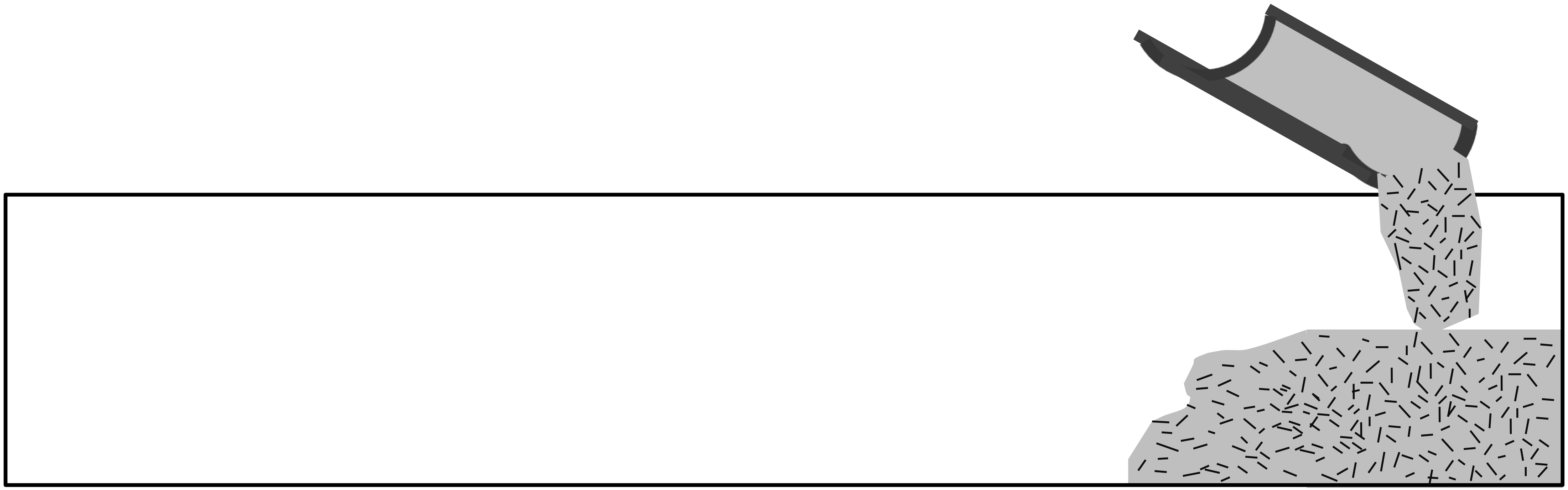
What Can Happen During Placement?



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What Can Happen During Placement?

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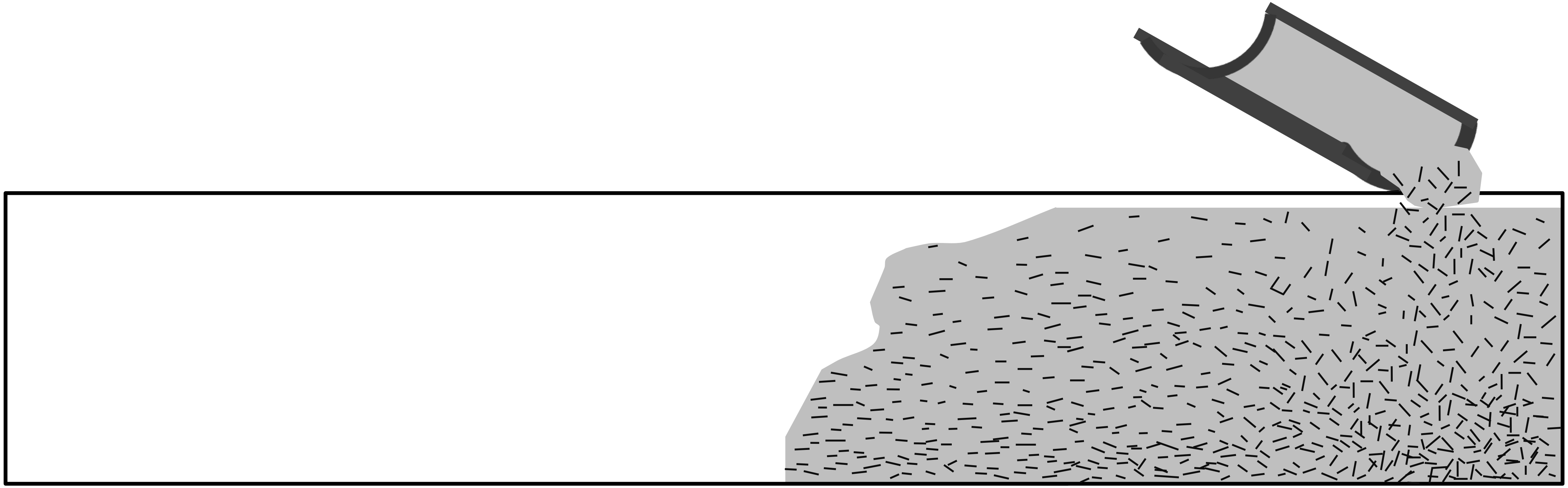
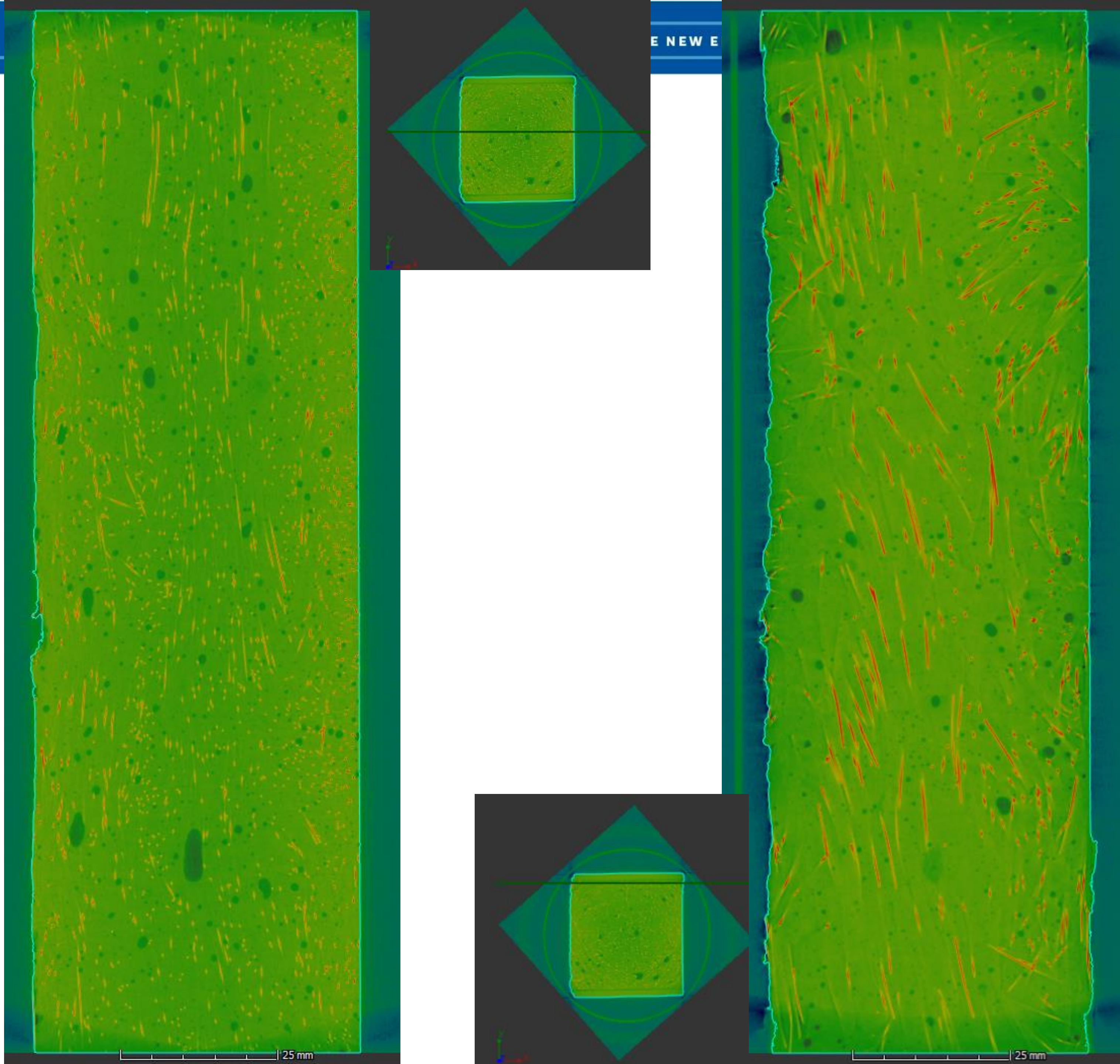
What Can Happen During Placement?



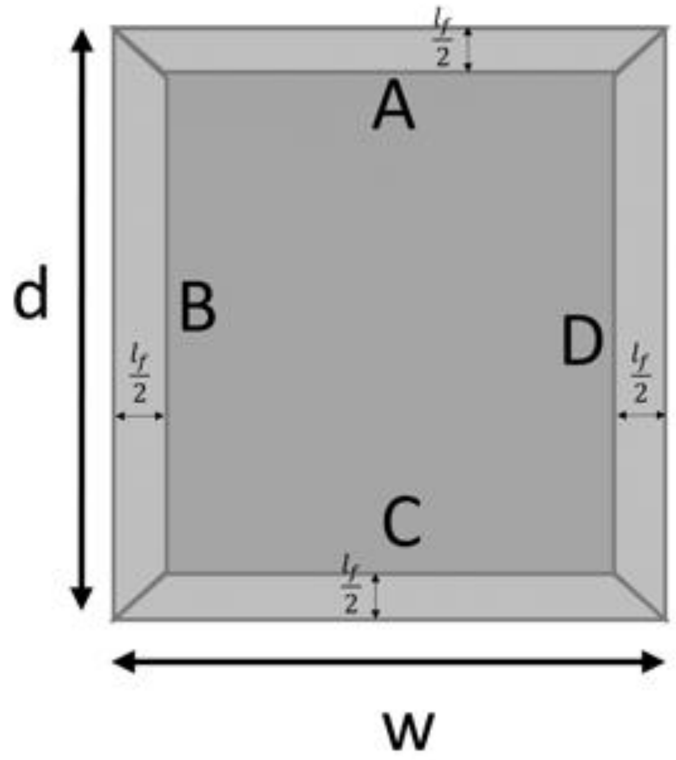
Accounting for fiber edge effects

- CT scanning was performed on tensile specimens to see how orientation differs at sample edges
- Fibers are shown in red
- Scan at center of beam (left) shows more perpendicular fibers (dots), and scan at edge of beam (right) shows more parallel fibers (lines)



Accounting for Fiber Edge Effects

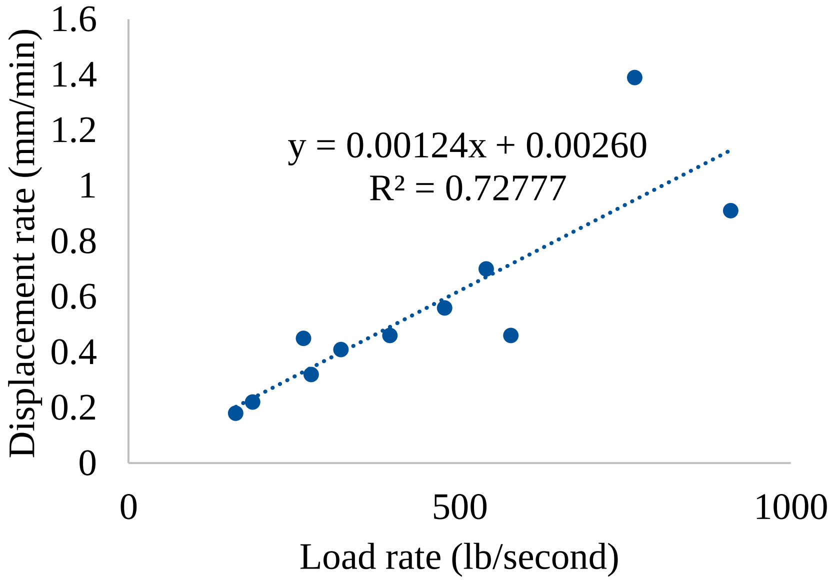
- Method to account for edge effects on fiber orientation – taken from French method for accounting for edge effects in flexural tests
- This method uses a correction factor to adjust the effective area of sections that are half of the fiber distance from the edge.

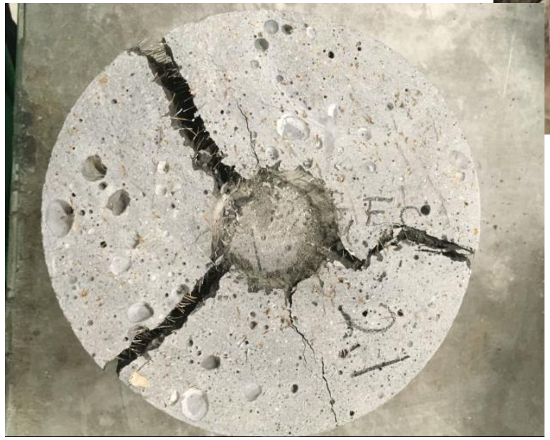


Location	Correction Factor, C_f
Formed edges	1.2
Sawn edges	0.5
Edges not formed or sawn, and any portion of the cross-section farther than l_f from the edge	1

FM 5-626: Modified double-punch test

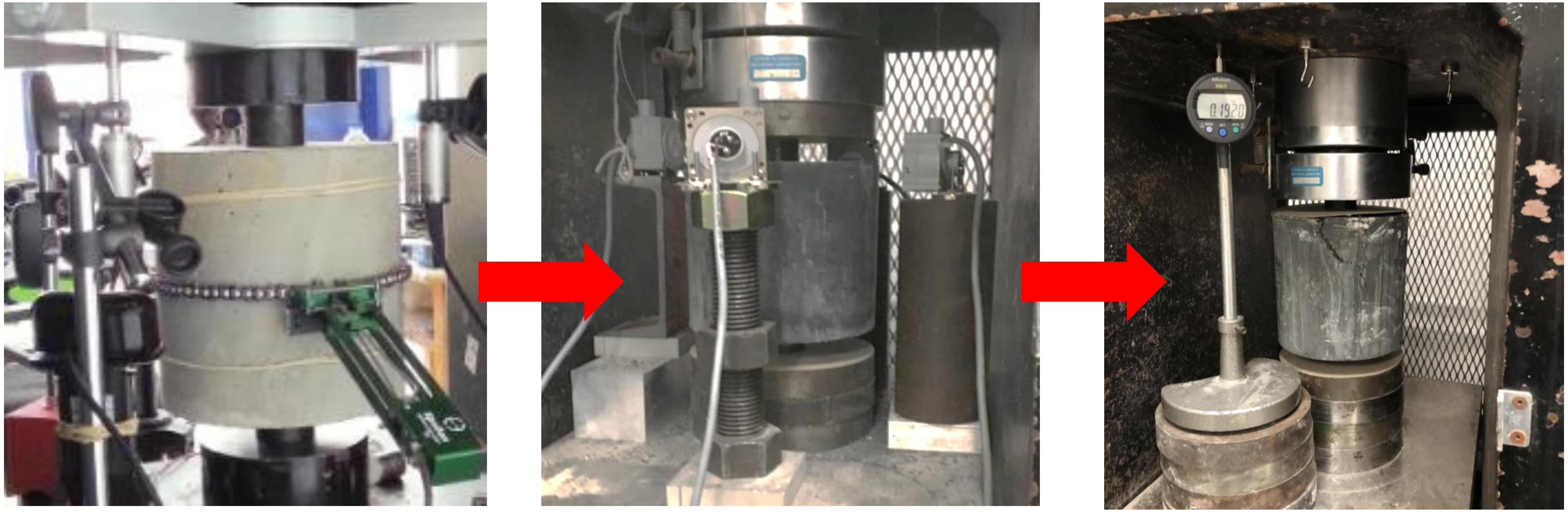
- Based off Spanish test UNE 83515-2010
- Open loop displacement control
- Displacement-load pairs recorded manually





Simplifications to Double-Punch Test

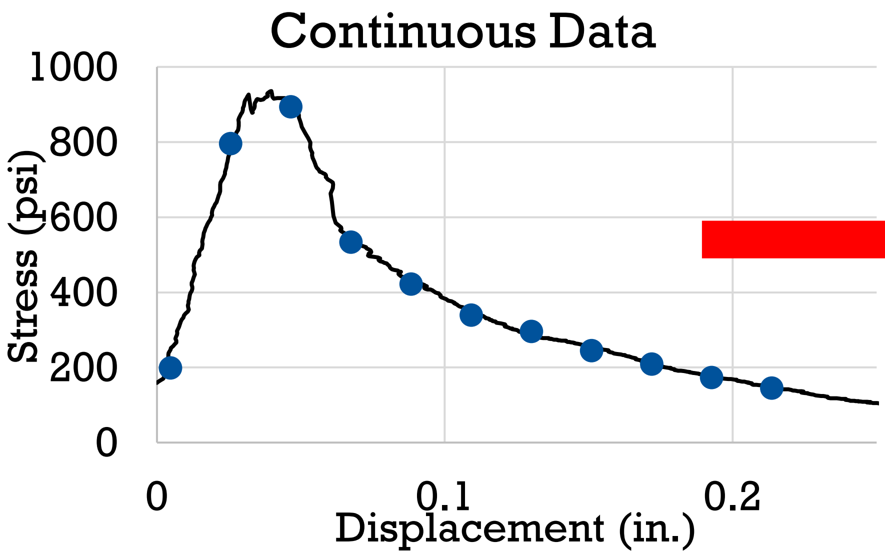
- Displacement measured as vertical displacement instead of circumferential expansion

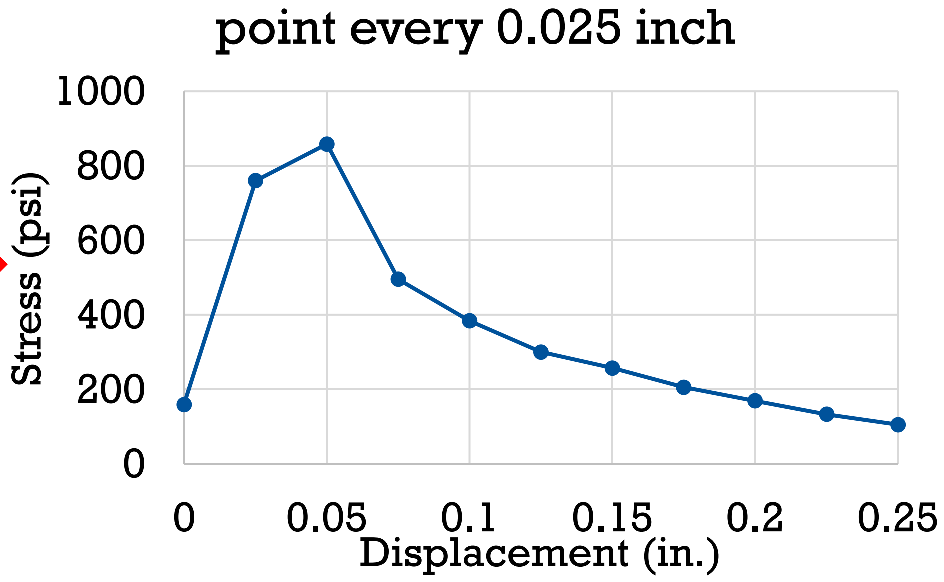


Choumanidis, D., E. Badogiannis, P. Nomikos, and A. Sofianos. (2017). Barcelona test for the evaluation of the mechanical properties of single sand hybrid FRC, exposed to elevated temperature. *Construction and Building Materials, 138*. 296-305.

Results - Simplifying for Dial Gauge

- Continuous axial displacement data was taken with string potentiometers
- Discrete data points at different displacement intervals were selected from continuous measurements to simulated manual recording of strength at these displacement values





Ruggedness Study & Machine Comparison

- Ruggedness study found that grinding samples, 5mm punch offset, and loading rate were not significant, but filling samples by scoop or in one placement with a bucket were statistically significant
- Tested 18 samples, 6 in 3 different testing machines

Peak Strength

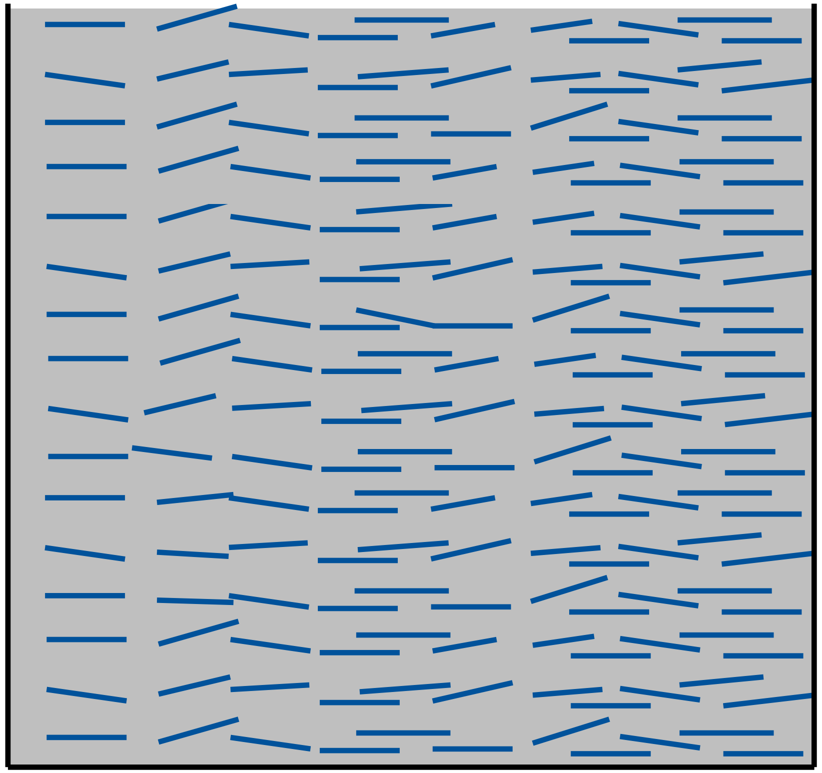
Average	1143 psi
Standard Deviation	94 psi
Coefficient of Variation	8.2%

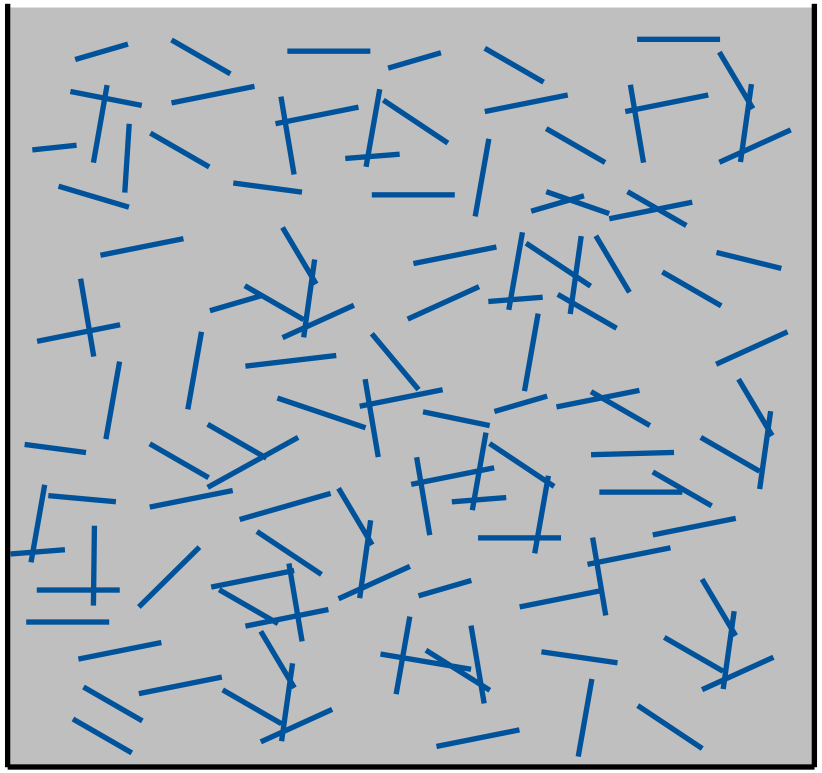
Toughness

Average	161.8 psi-in.
Standard Deviation	94 psi-in.
Coefficient of Variation	15.8%

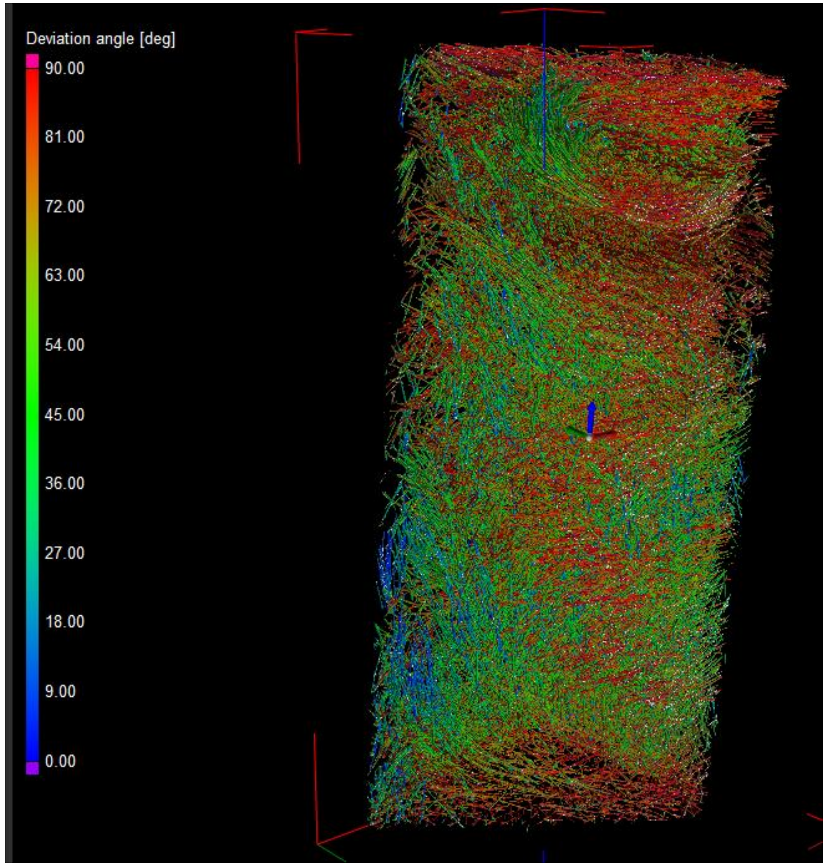
Machine used was not found to be statistically significant using student T-test

Specimen Fabrication Method

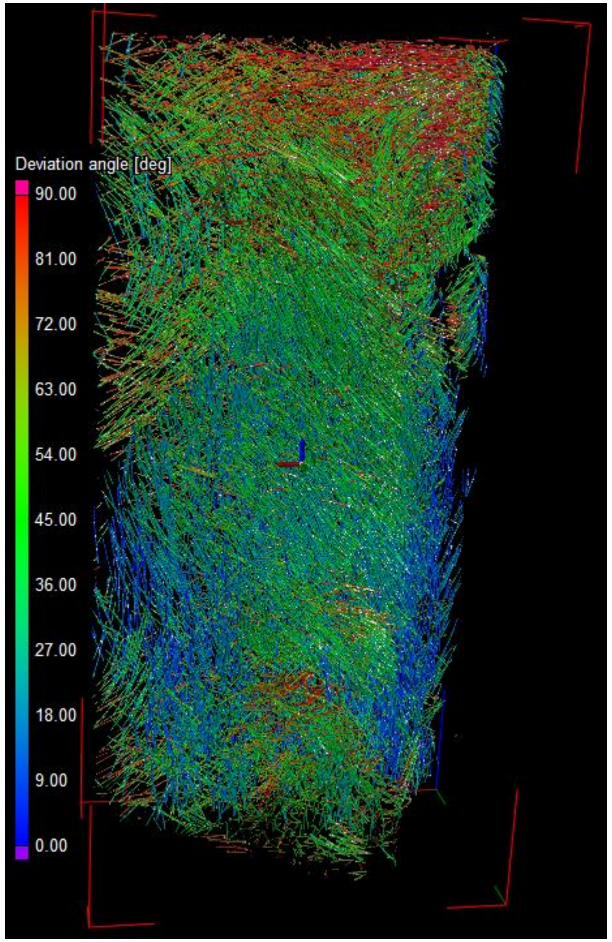




Specimen Fabrication Method



Scoop-Filled Specimen



Bucket-Filled Specimen

Modified Double Punch Round Robin Study

- 3 Different UHPC mixtures used

Mix	Concrete Mix (w/cm)	Fiber Content (% volume)	Batch Size (ft^3)	56-day Compressive Strength (psi)
Practice Samples	0.1625	1.5	3.5	-
Material A	0.1625	1.5	3.5	19,600
Material B	0.1625	2.5	3.5	18,300
Material C	0.20	3.0	4.0	18,400

Material A & Material B

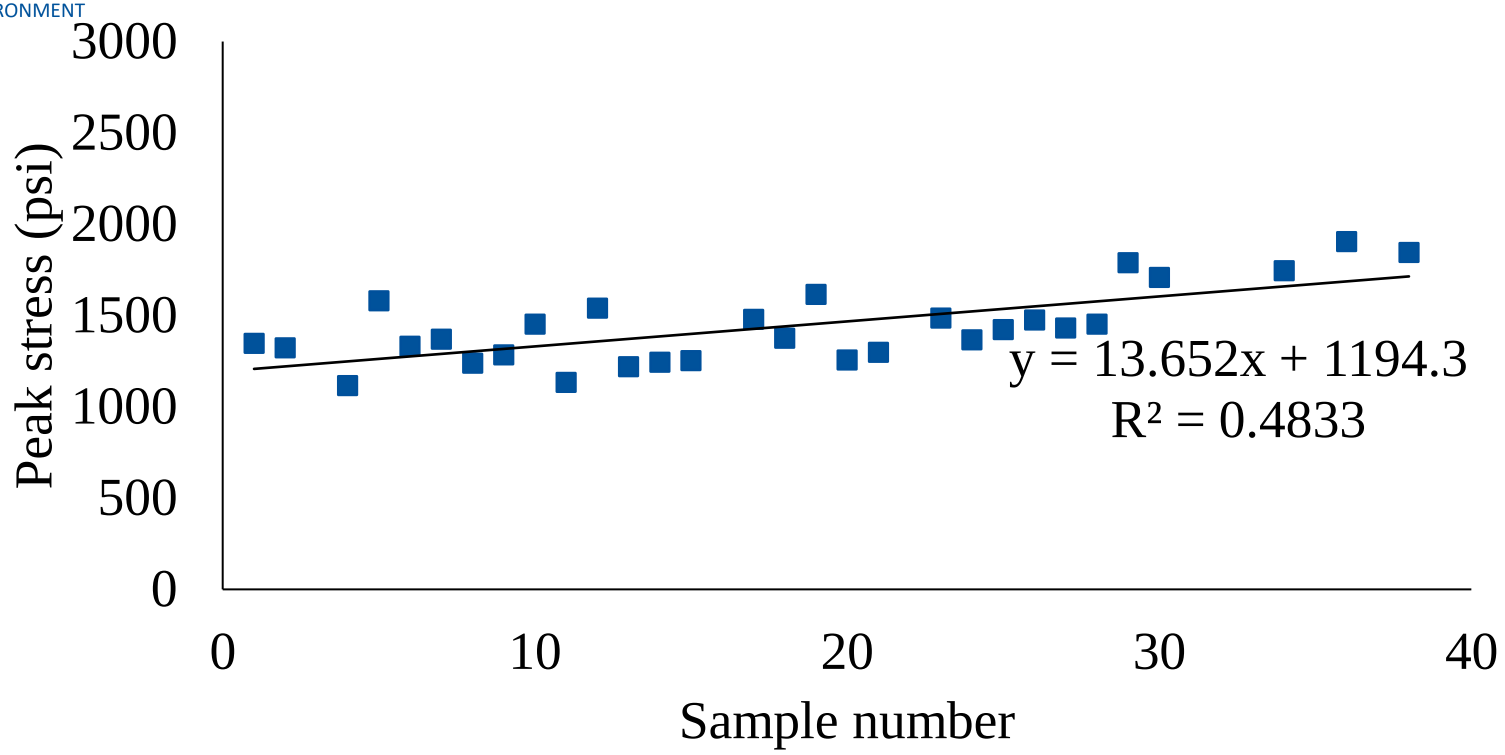
Material A

1.50% Fiber	All tests		Lab averages	
	Peak Stress (30) psi	Toughness (29) psi*in	Peak Stress (10) psi	Toughness (9) psi*in
average	1196.9	152.9	1196.9	151.9
st.dev	133.6	27.4	73.7	16.3
CV (%)	11.2	17.9	6.2	10.7
variance	17,848	750	5425	265

Material B

2.50% Fiber	All tests		Lab averages	
	Peak Stress (30) psi	Toughness (26) psi*in	Peak Stress (10) psi	Toughness (8) psi*in
average	1416.7	186.8	1416.7	187.5
st.dev	141.9	31.3	66.1	16.6
CV (%)	10.0	16.8	4.7	8.9
variance	20,137	981	4370	277

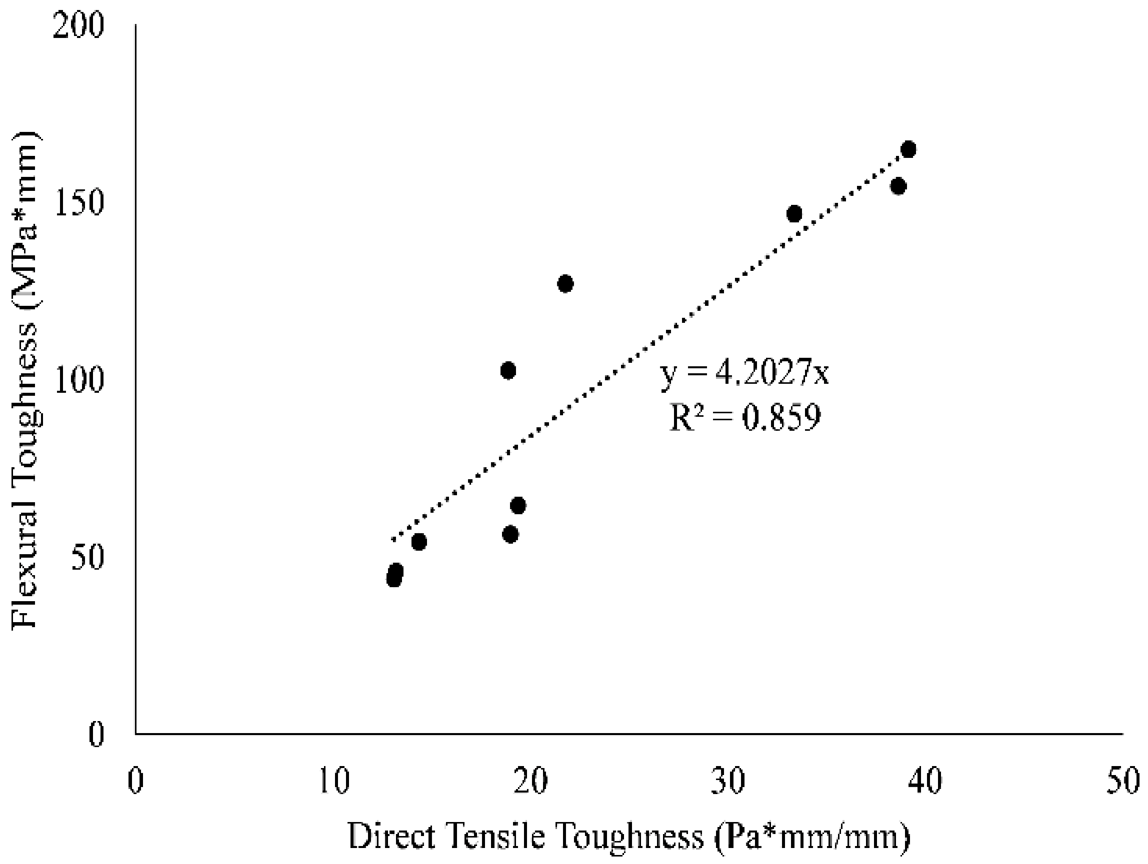
Material C

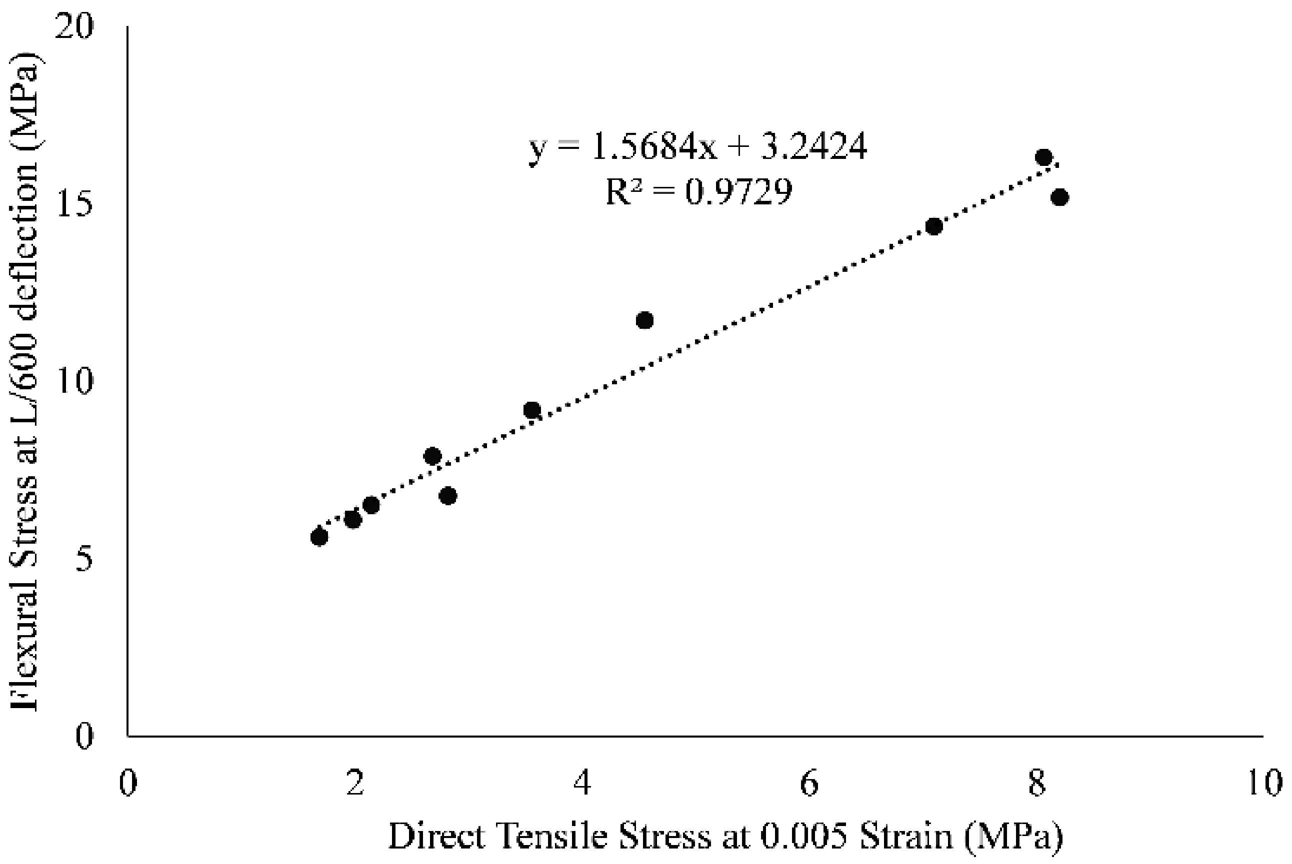


	All tests		Lab averages	
	Peak Stress (30) psi	Toughness (25) psi*in	Peak Stress (10) psi	Toughness (8) psi*in
average	1436.4	211.9	1436.4	205.9
st.dev	205.2	63.5	87.5	25.5
CV (%)	14.3	29.9	6.1	12.4
variance	42,125	4,026	7,661	648

Results from both simplified test methods correlate to direct tension test results

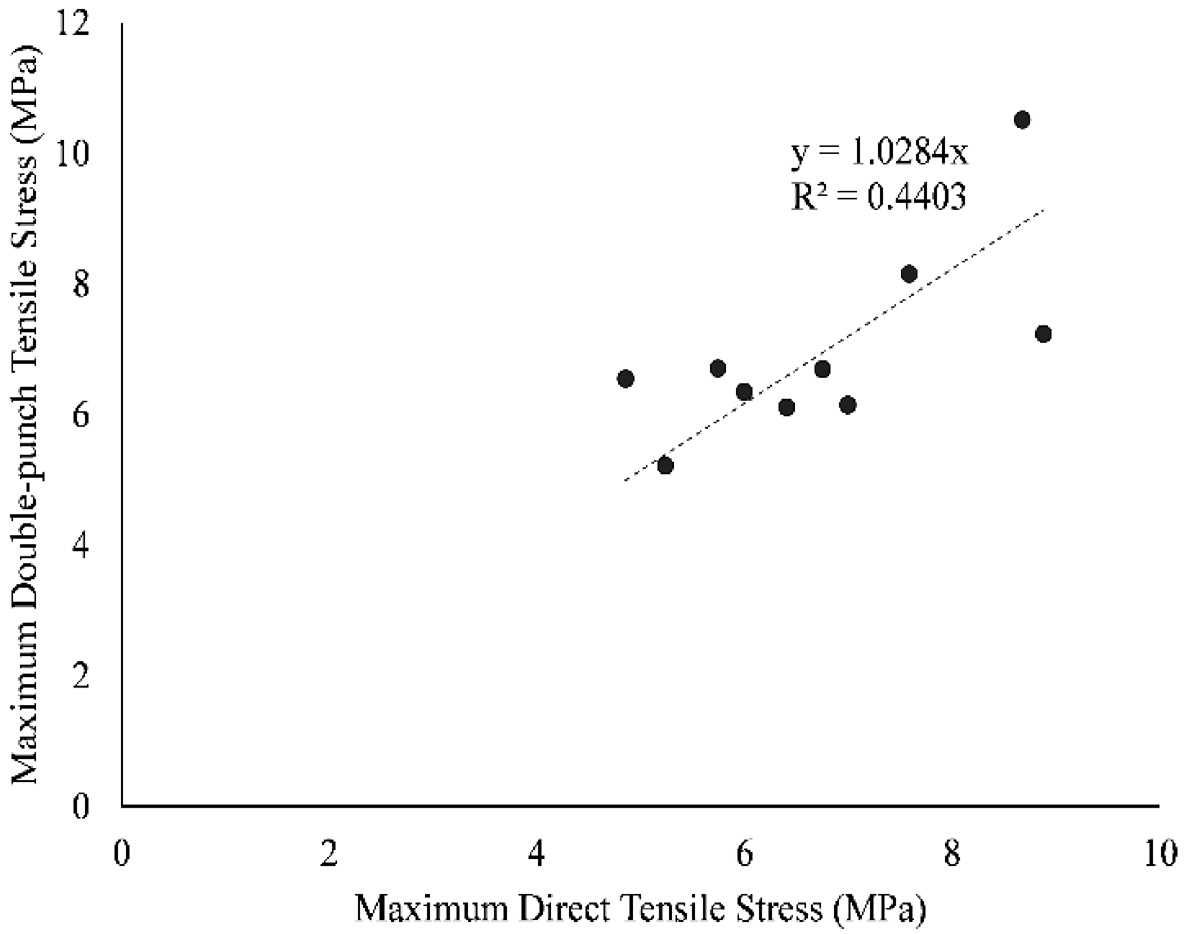
- A) Flexure test:





Results from both simplified test methods correlate to direct tension test results

- B) Double-Punch test:



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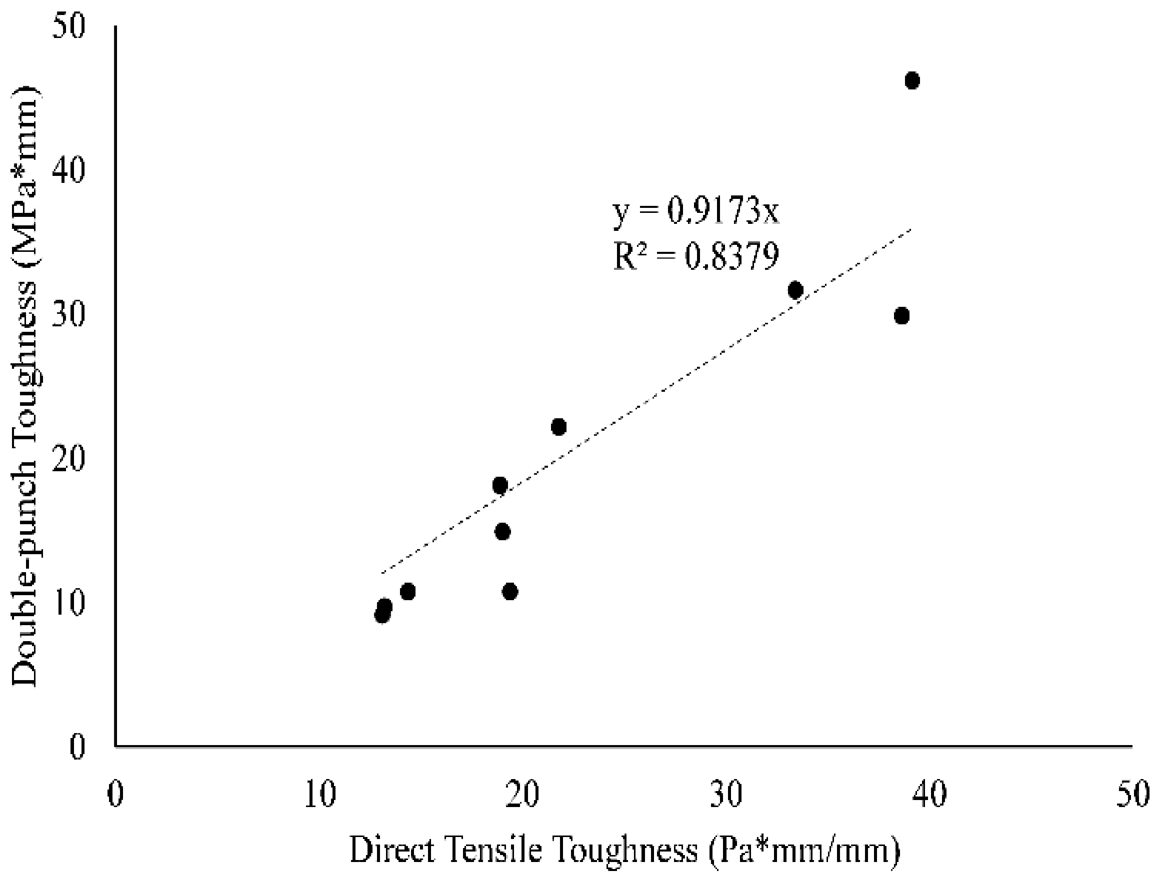
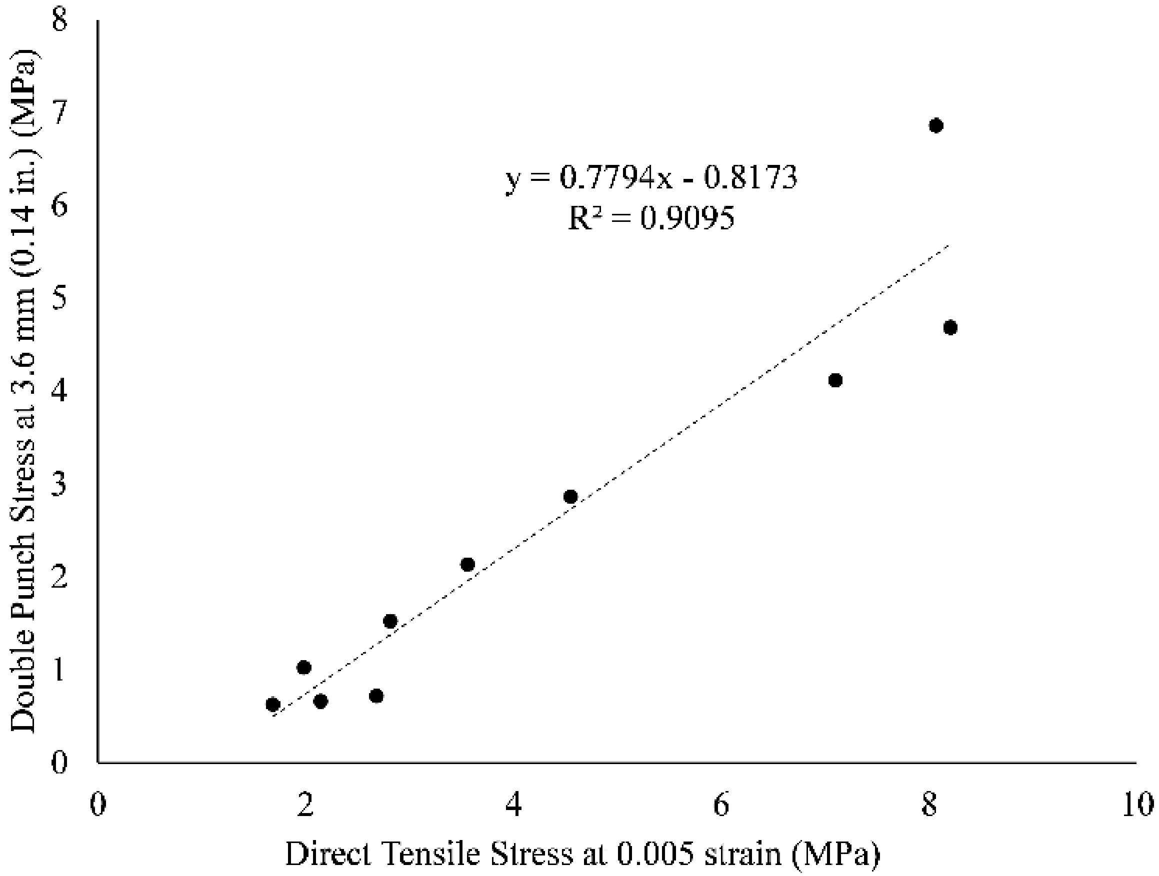
- B) Double-Punch test:





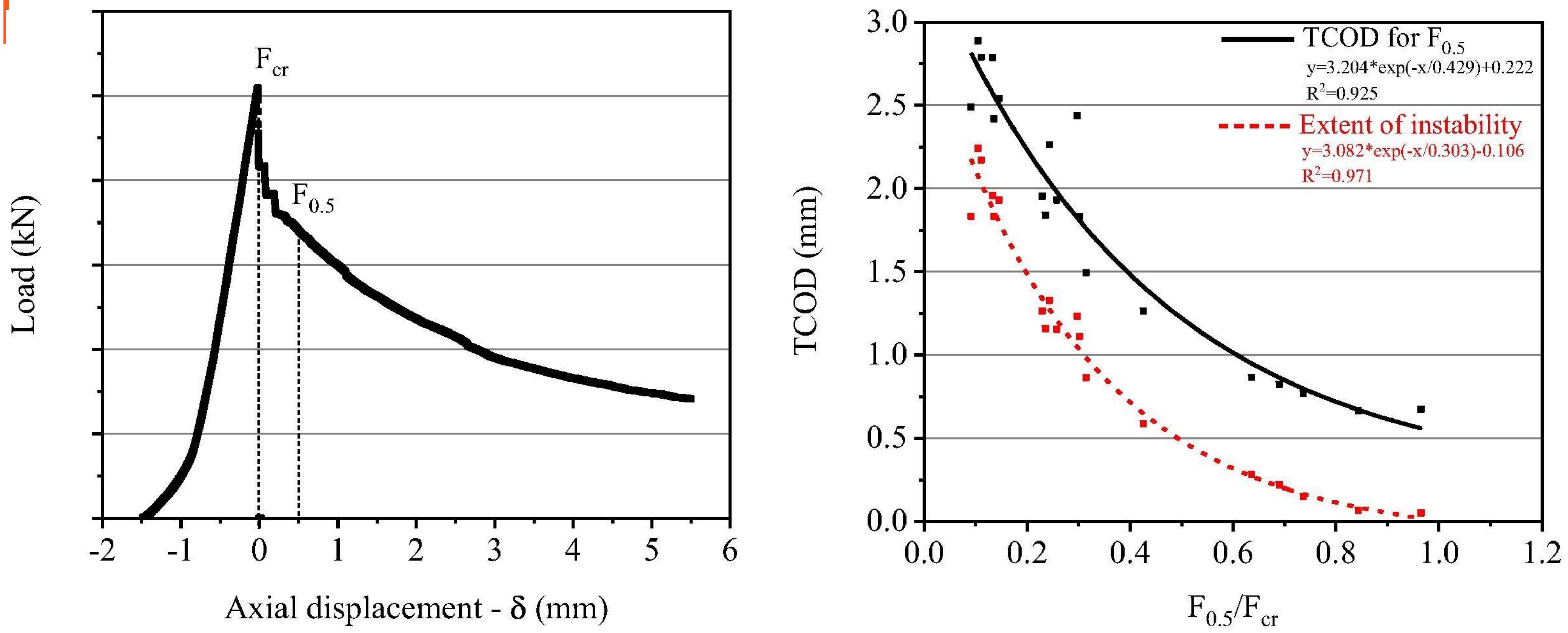
Conclusions

- Get preferential orientation at edges of direct tension samples
- Double punch test has acceptable repeatability, potential for QC testing
- Correlation testing done during qualification testing could provide path for using simpler tests for QC

Acknowledgements

- FDOT for funding this research
- The advice of Steve Nolan and Dale DeFord from FDOT are acknowledged

Instability in Open Loop System



Luana de Carvalho Ribeiro Simão, André Baltazar Nogueira, Renata Monte, Renan P. Salvador, Antônio Domingues de Figueiredo, "Influence of the instability of the double punch test on the post-crack response of fiber-reinforced concrete," Construction and Building Materials, Volume 217, 2019, Pages 185-192, ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2019.05.062.