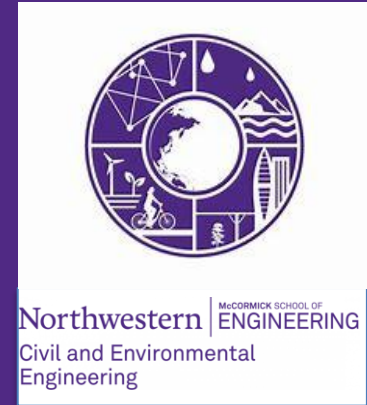


Mechanical Characterization of 3D Printed Ultra High-Performance Concrete

ACI Fall 2024 Convention



Shady Gomaa



November 3rd, 2024

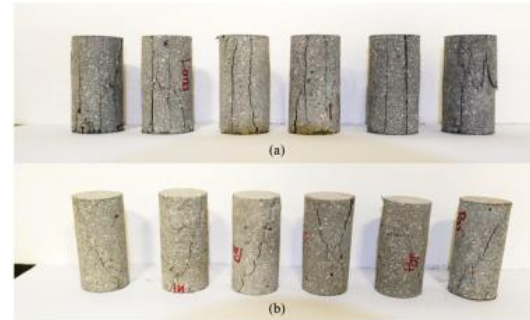
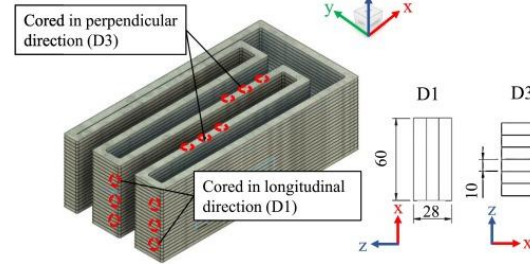
Background

Background

Full-Scale Structural Tests



(Han et al., 2022)



(Van Den Heever et al., 2022)

Cored and Polished Specimen

Problem Statement

Full-Scale Structural Tests

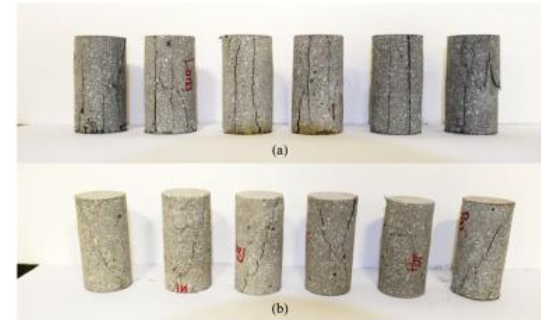
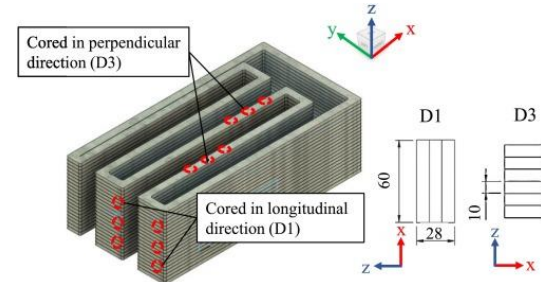


(Han et al., 2022)

Capturing
Printing
Features
Effects of
3D-Printed
Material

Providing
Appropriate
Loading
Surfaces

Small Scale



(Van Den Heever et al., 2022)

Cored and Polished Specimen

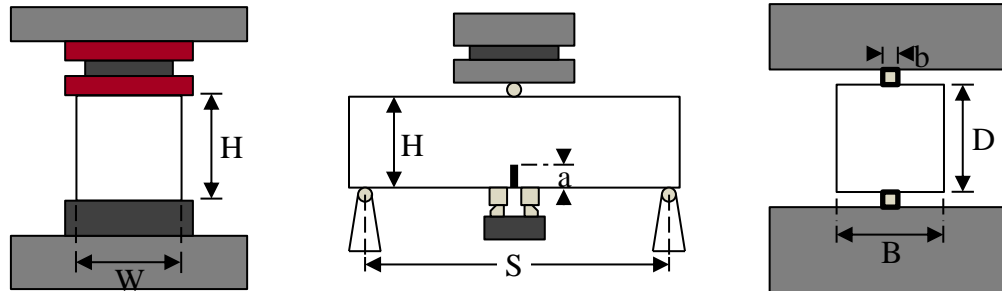
Problem Statement

Deeper understanding of the failure mechanisms of 3D-printed structures to develop better printing methods and systems.

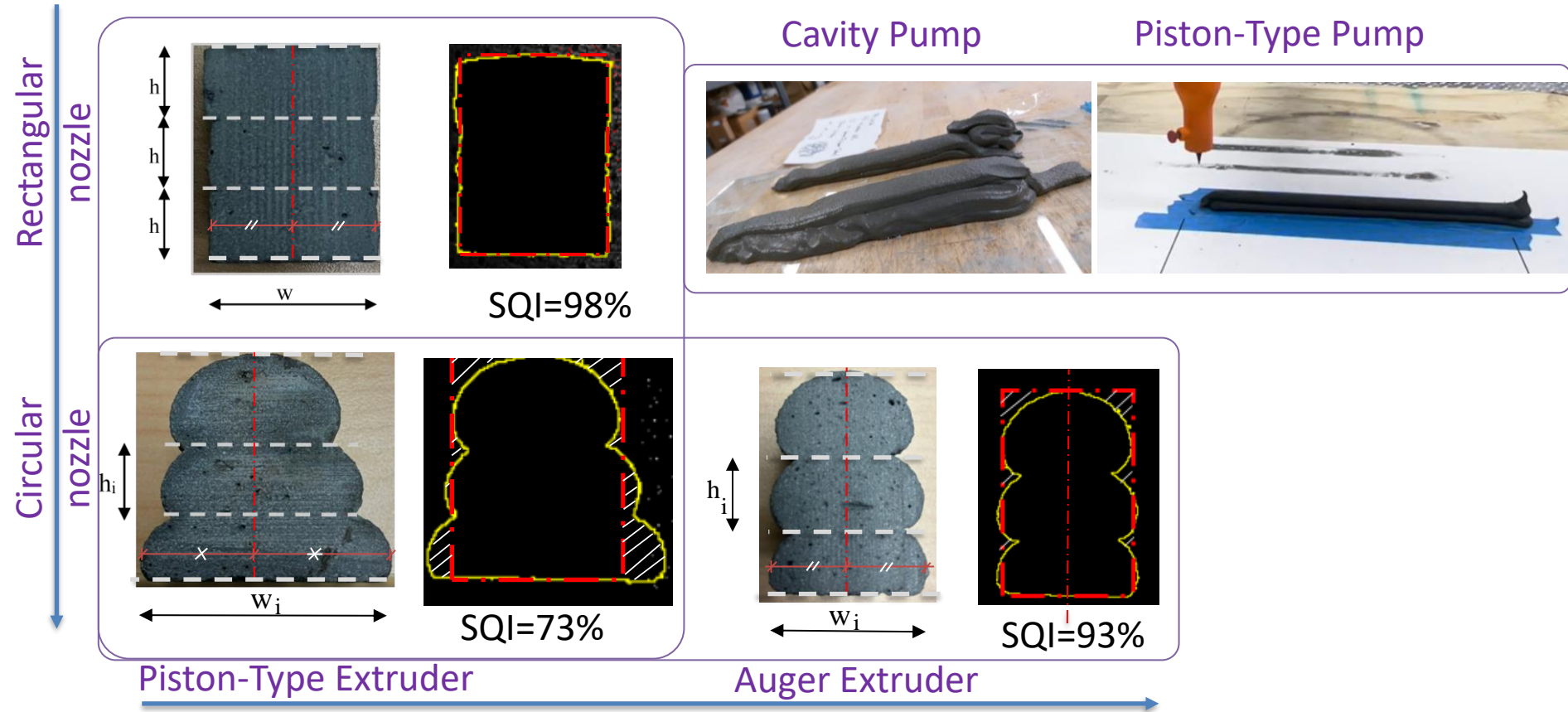
Calibrating and validating computational models, greatly reducing the “trial and error” phase of concrete 3DP.

Experimental Campaign

1. Development of a **printable*** UHPC concrete mix and printing system using rheological modifiers and fiber reinforcement.
2. Characterization of mechanical properties of 3d-printed specimen.

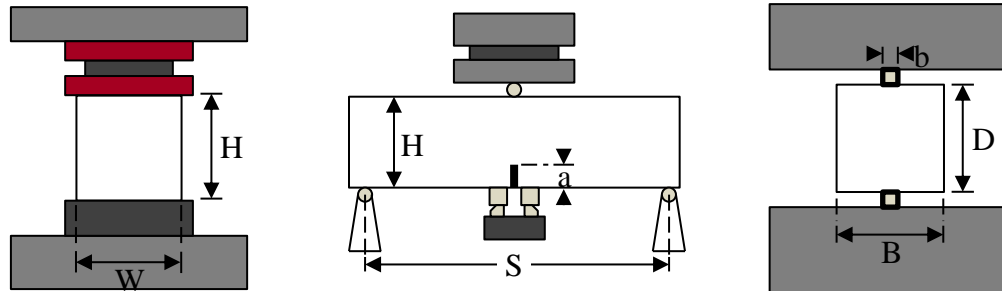


Remember: Shape Stability for Different Printing Systems



Experimental Campaign

1. Development of a **printable*** UHPC concrete mix and printing system using rheological modifiers and fiber reinforcement.
2. Characterization of mechanical properties of 3d-printed specimen.



Materials and Methods

The Material

Base Mix: ERDC UHPC

Ingredient	Type	Proportion
Cement	LaFarge Type H	1.0000
Silica Sand	F-50	0.9674
Silica Flour	Sil-co-sil 75	0.2768
Silica Fume	Elkem 940U	0.3890
Superplasticizer	ADVA-190	0.0180
Water	Tap	0.2082

Rheological Modifier



ActiGel® 208 (Nano-Clay)

Added as % weight
of binder

Fiber Reinforcement

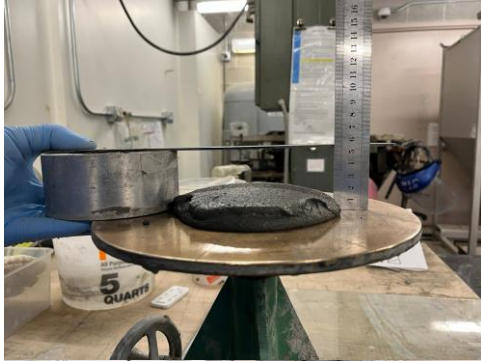


HiPer Fiber® 6mm Steel Fiber

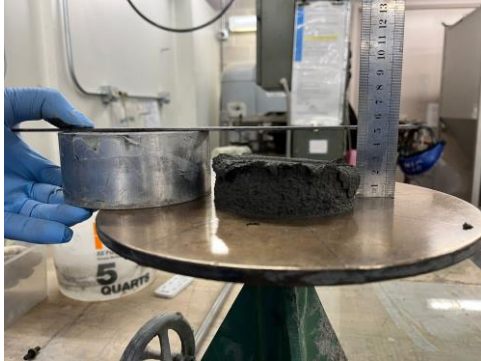
Added as % of total
volume

The Material

Base Mix



NC Added



Rheological Modifier



ActiGel® 208
(Nano-Clay)

Added as % weight
of binder

Fiber Reinforcement



HiPer Fiber®
6mm Steel Fiber

Added as % of total
volume



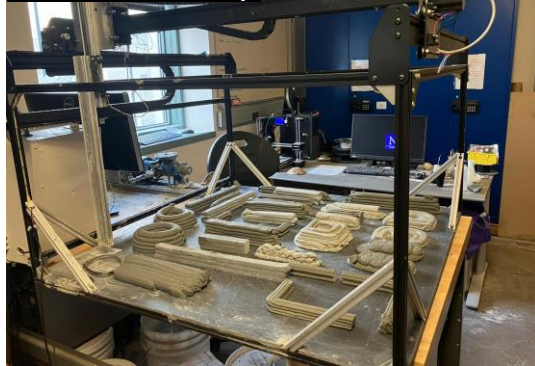
Printing Systems

Automated Machines

ABB Robotic Arm



Medium Scale Gantry



Extrusion Systems

Auger system

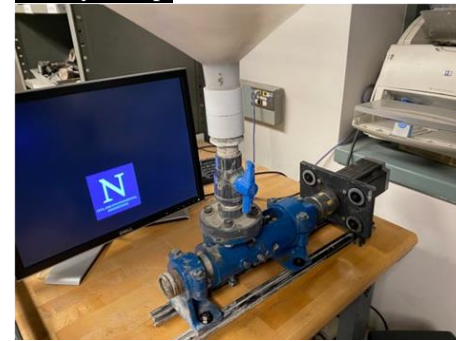


Piston type system



Pump Systems

Cavity Pump



TK 7 Pump



Nozzle Shapes

Circular Nozzle



Corrugated smooth

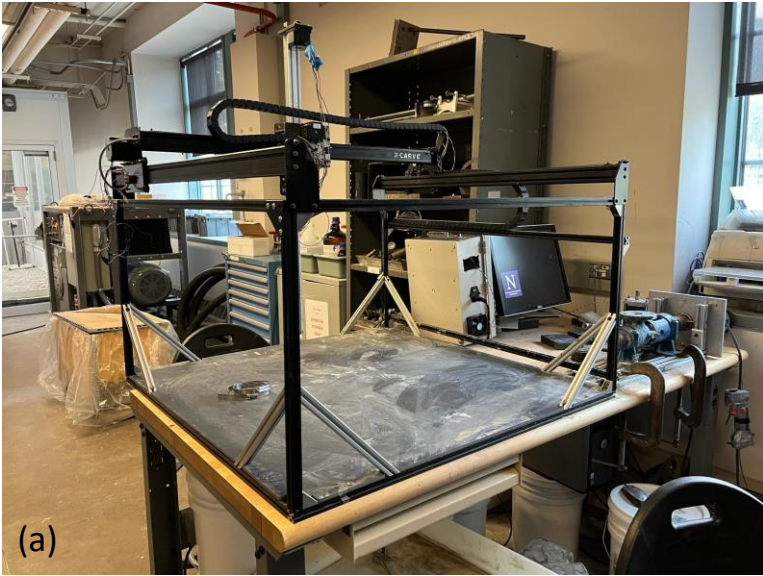
Vertical Outlet

Rectangular Nozzle

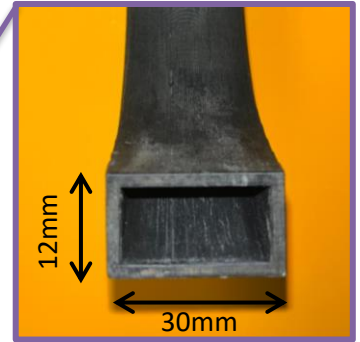


Horizontal Outlet

Printing System



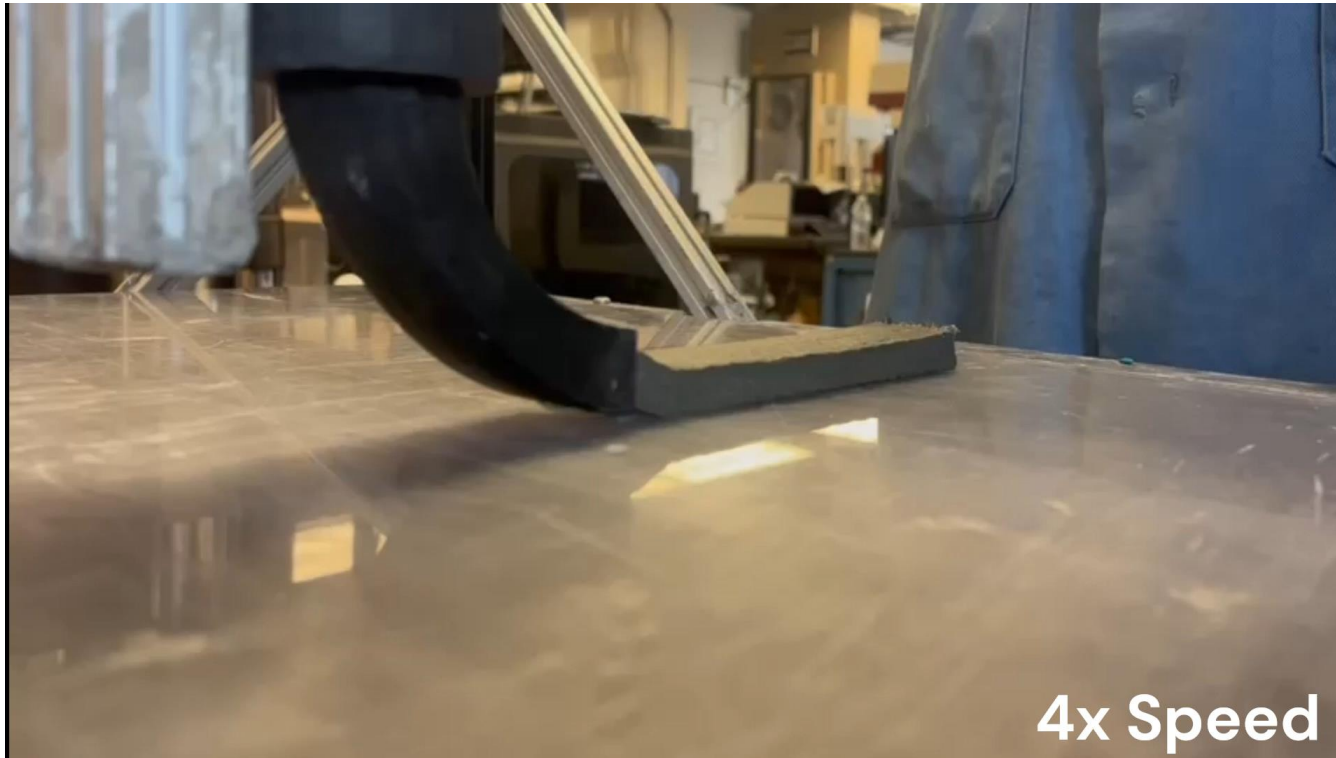
(a) 3-axis gantry robot



(b) Piston extruder (Milwaukee® M18)

(c) 12x30mm rectangular nozzle with 90° bend

Printing Procedure



Speed:

6.5mm/s

Extrusion Rate:

0.027cc/s

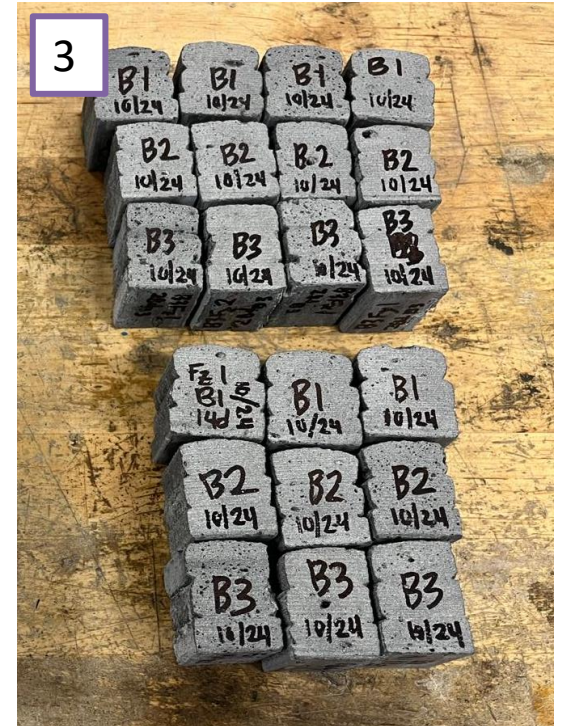
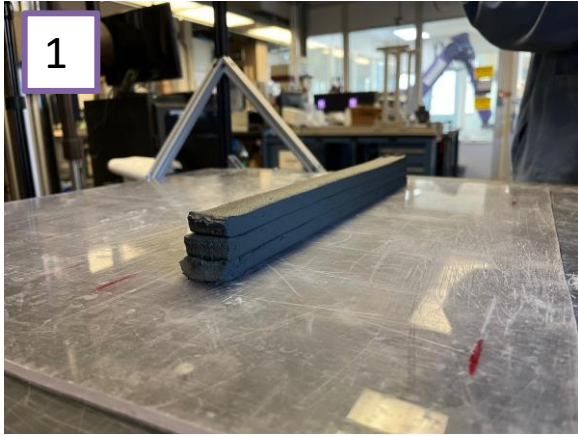
Wait time:

3min

Num. of Layers:

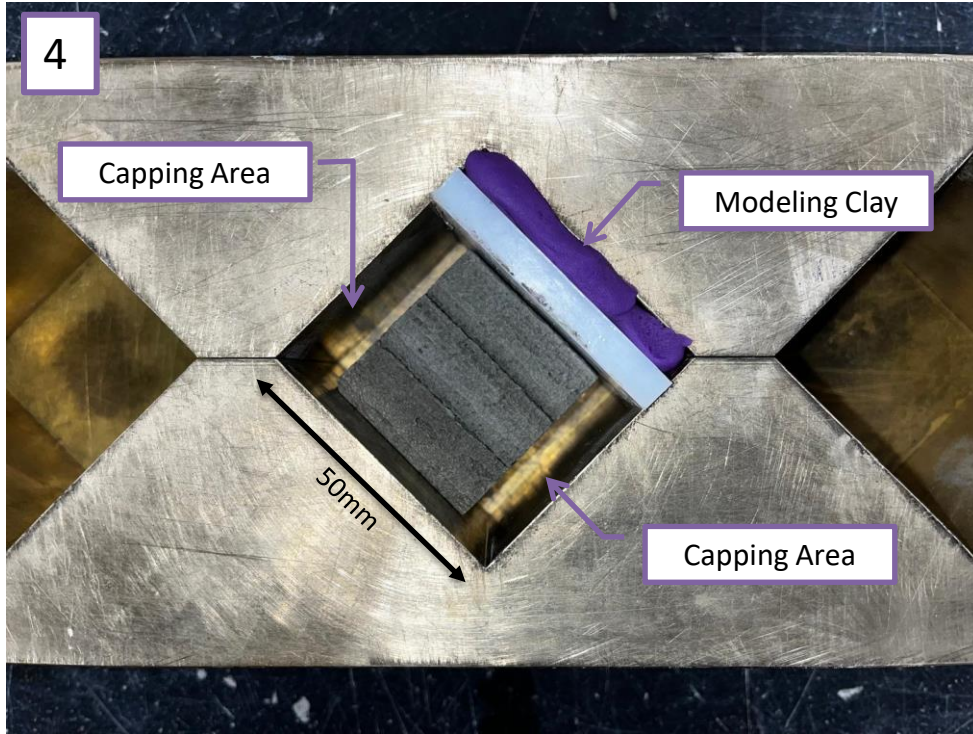
3

Specimen Preparation



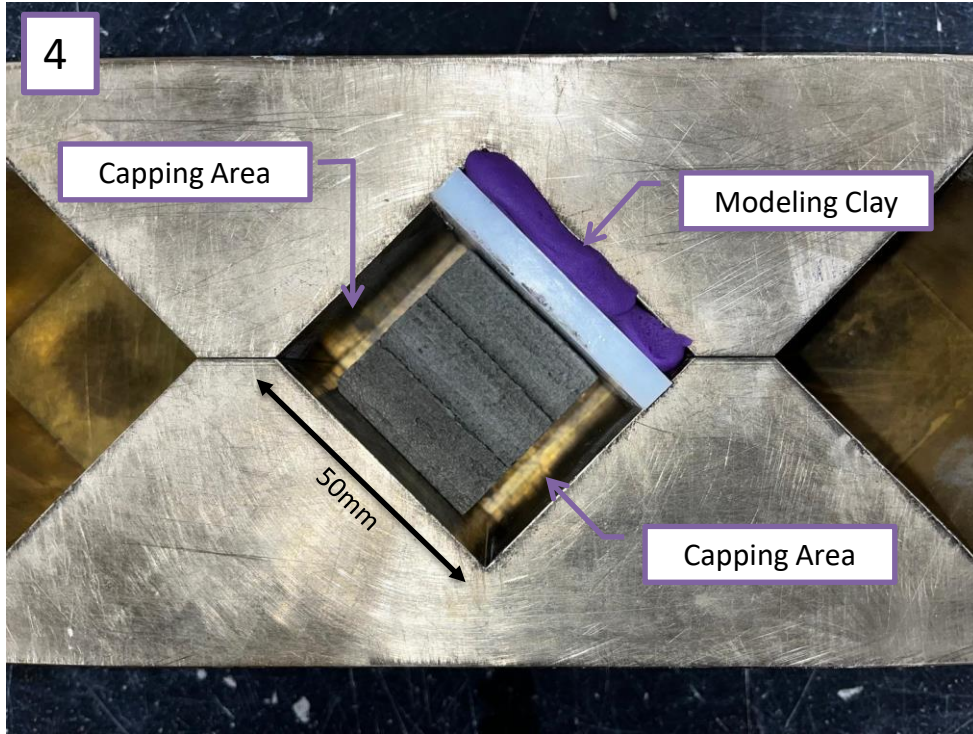
1. Specimen is printed
2. Transferred to humidity-controlled curing room (48hr)
3. Cut to desired shape using diamond-coated band saw

Specimen Preparation



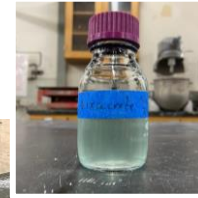
4. Specimen is capped using flowable variant of UHPC mix

Specimen Preparation



4. Specimen is capped using flowable variant of UHPC mix

Highly Flowable UHPC



Sika Viscocrete 2100

Capping Material

ERDC UHPC (Control)

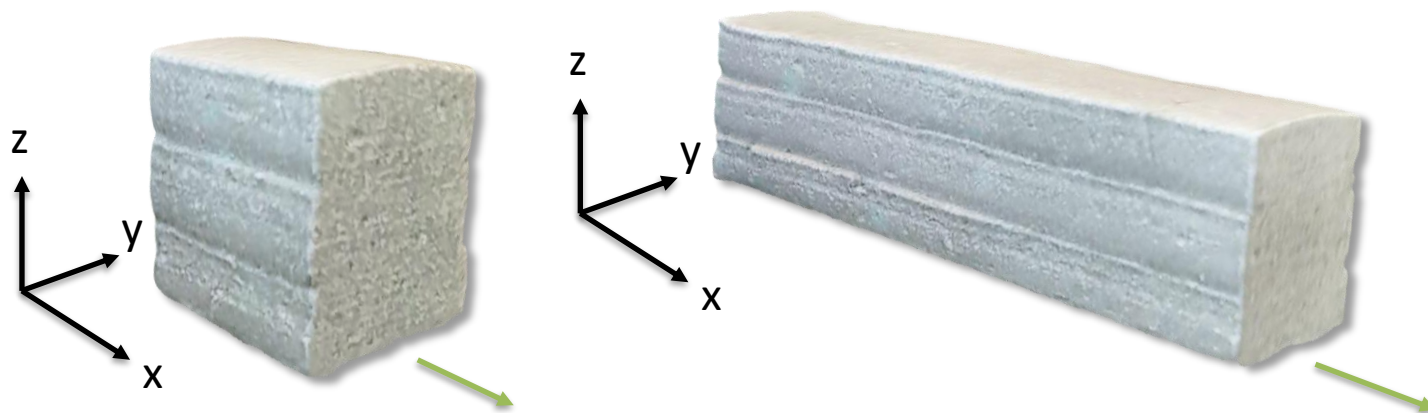


ADVA 190

Specimen Orientation

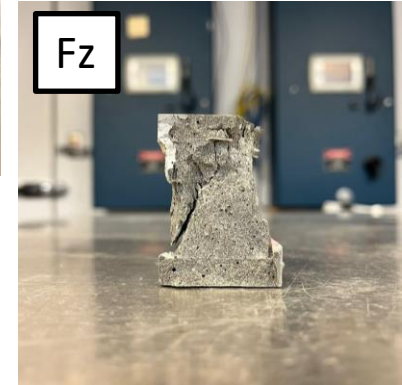
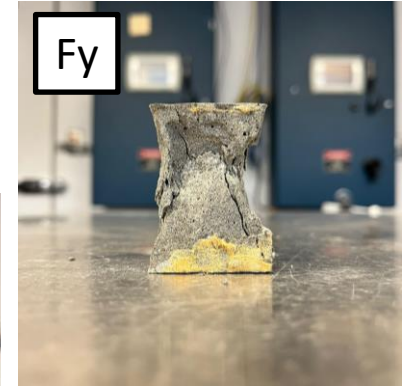
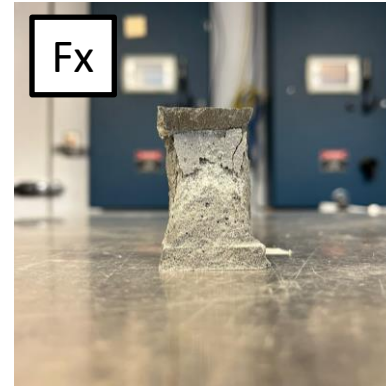
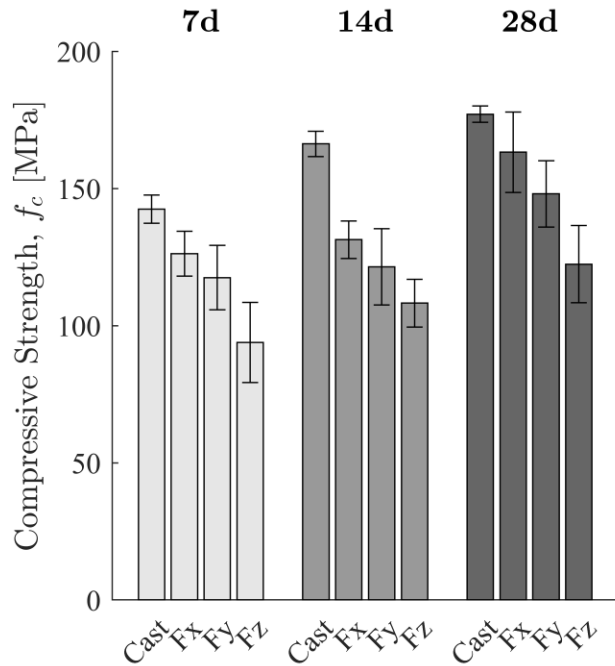
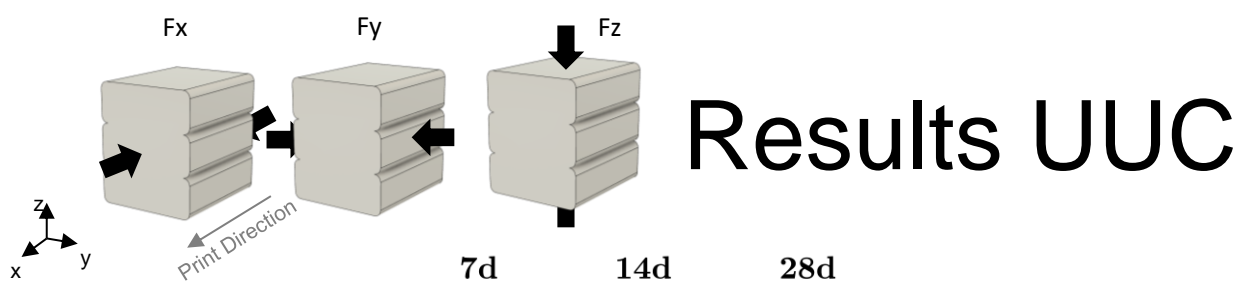


Specimen Orientation

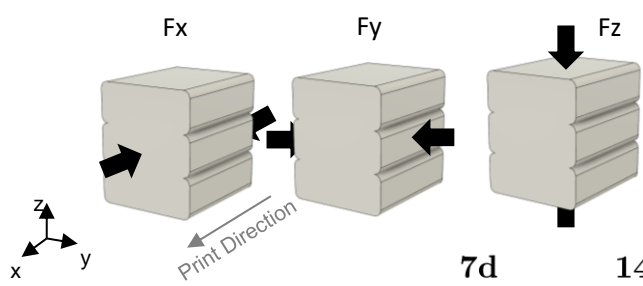


x → longitudinal direction (print direction)
y → transverse direction
z → normal direction

Results

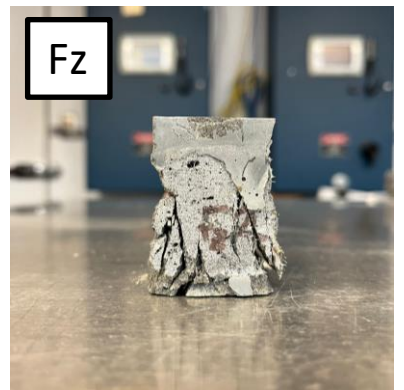
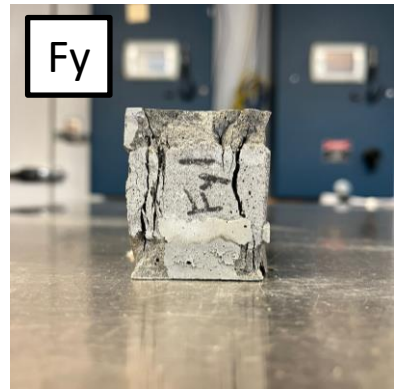
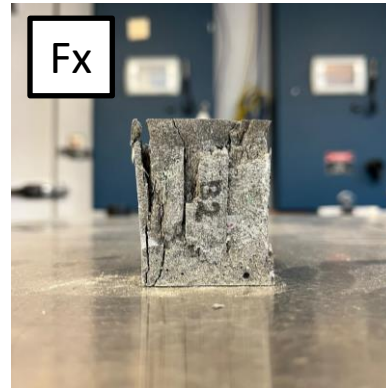
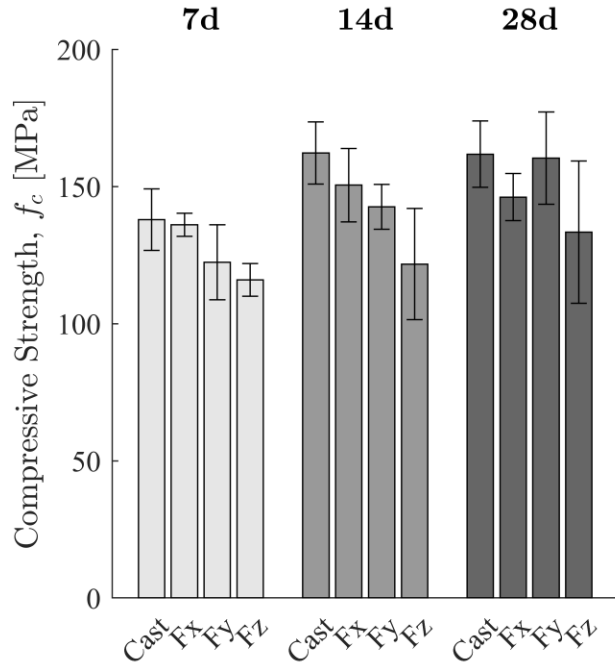


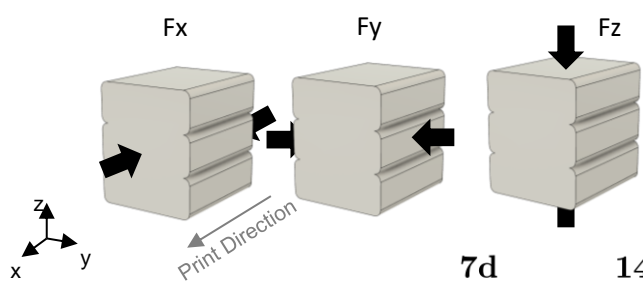
$$\sigma = P/A$$



Results UUC

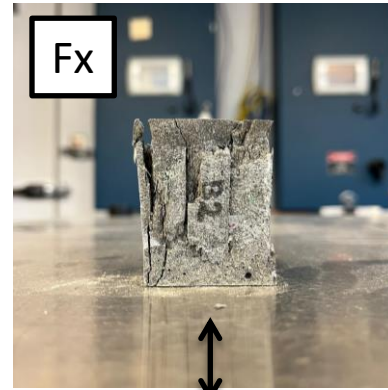
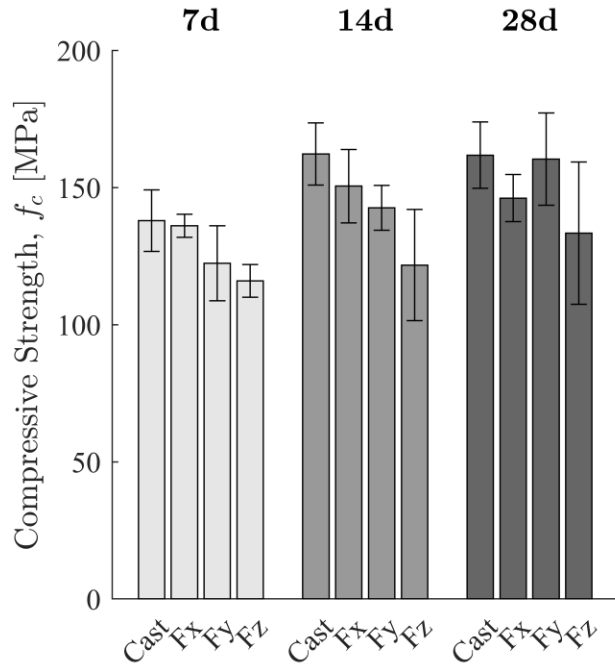
$$\sigma = P/A$$



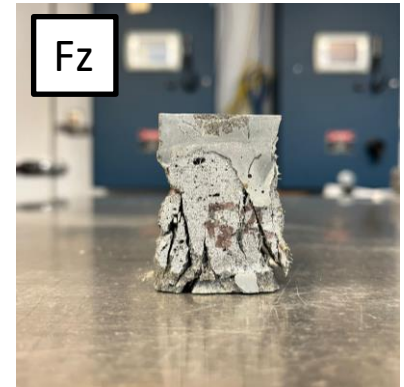
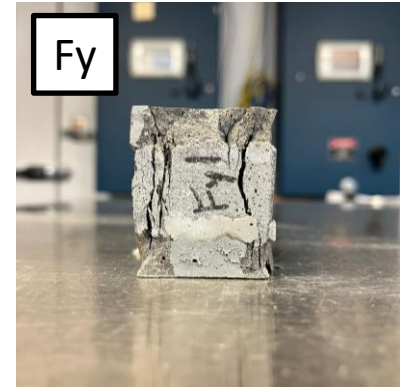


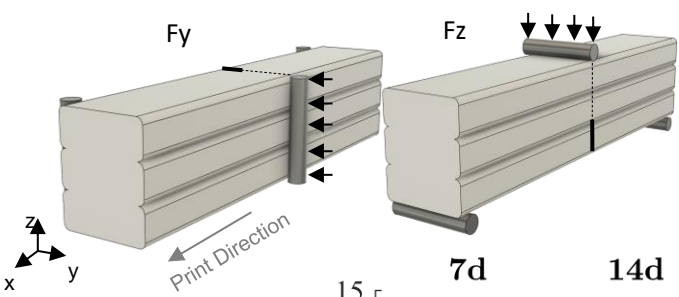
Results UUC

$$\sigma = P/A$$



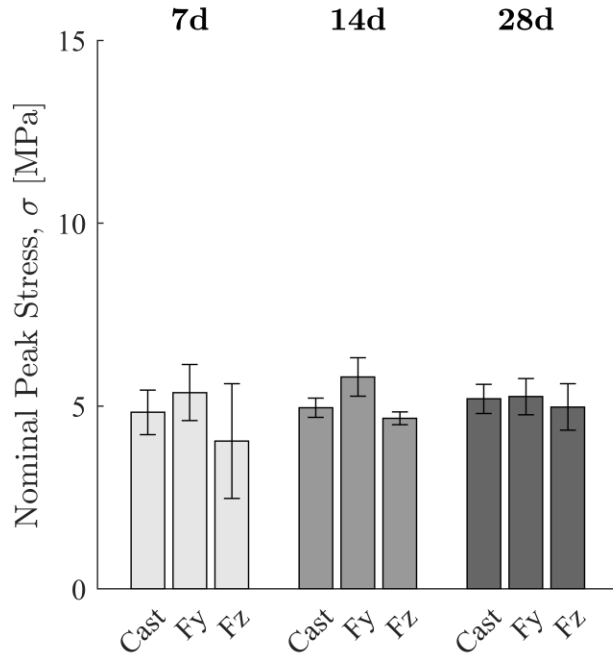
Un-reinforced →

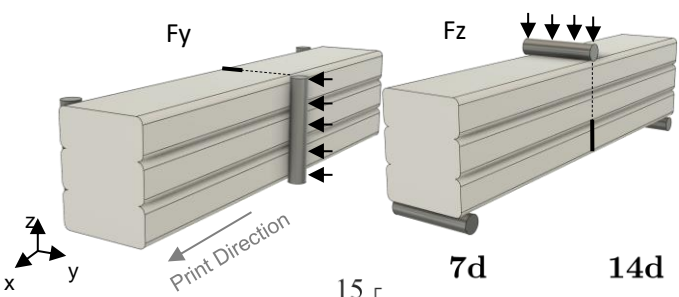




Results TBP

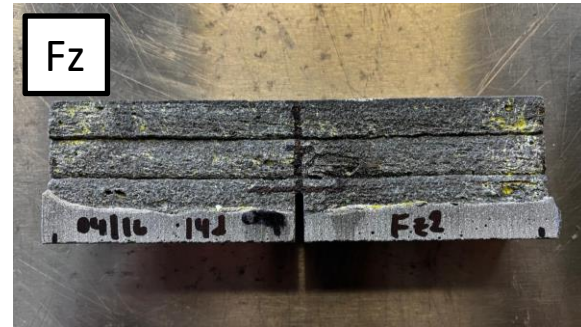
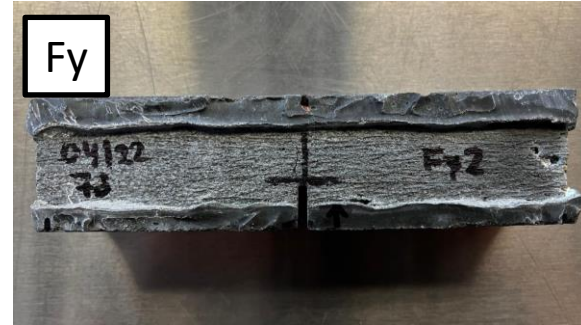
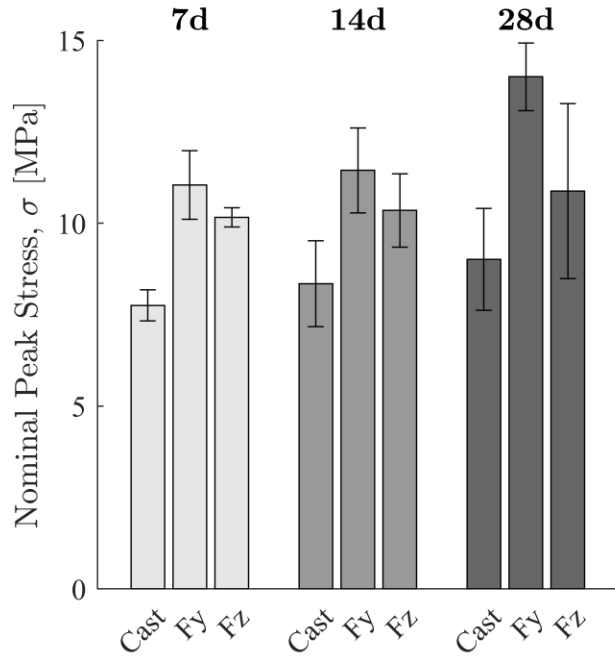
$$\sigma = 3PS / 2BH^2$$

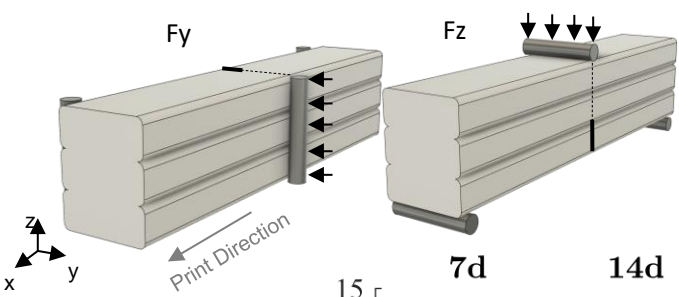




Results TBP

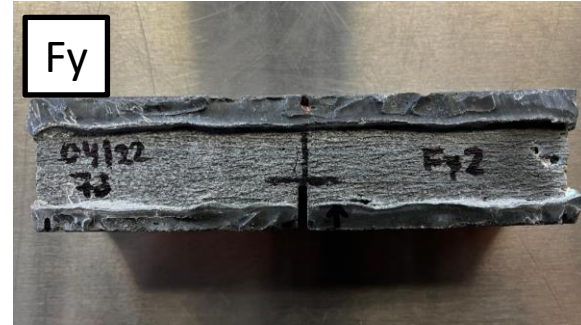
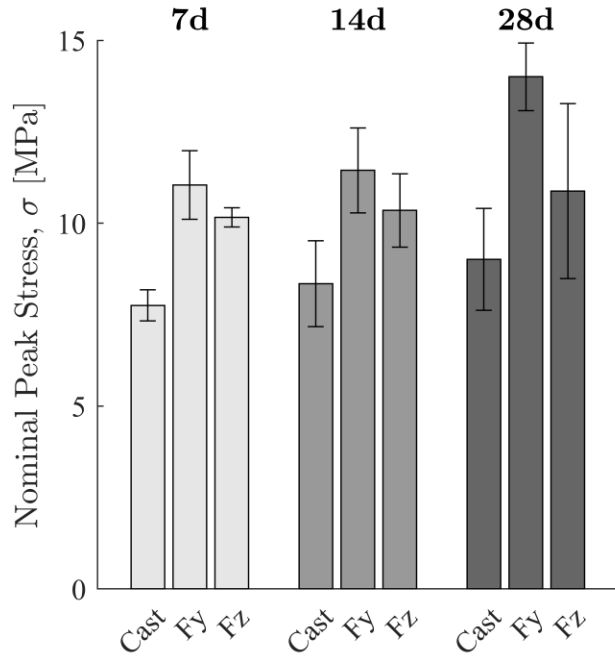
$$\sigma = 3PS / 2BH^2$$

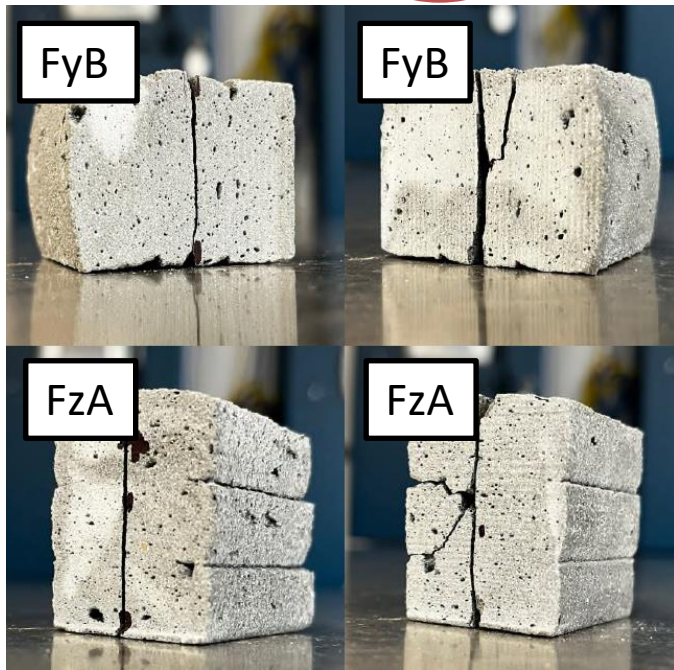
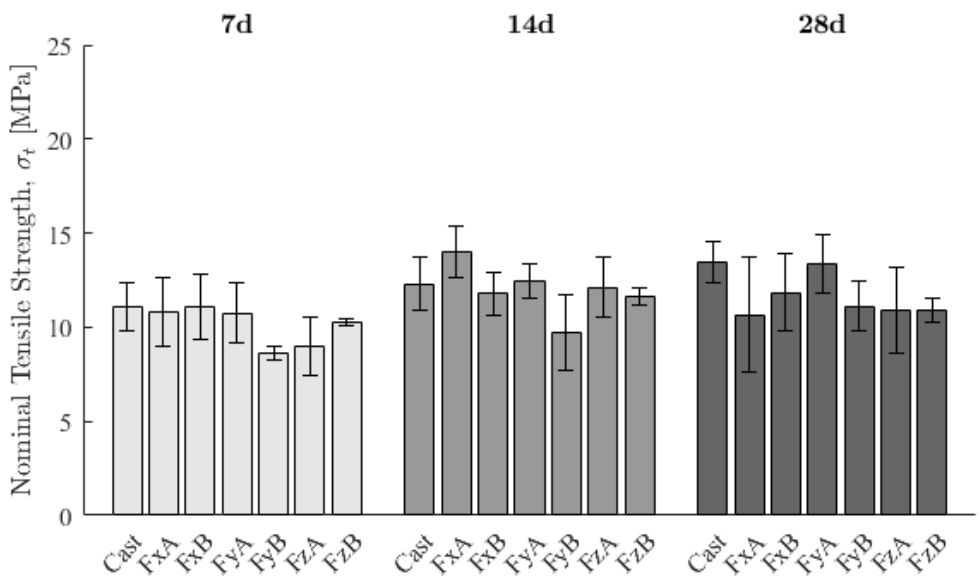




Results TBP

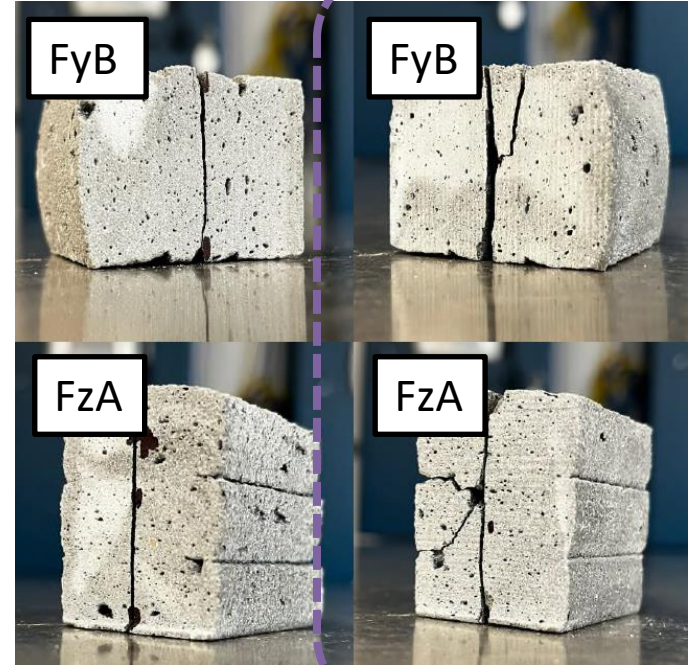
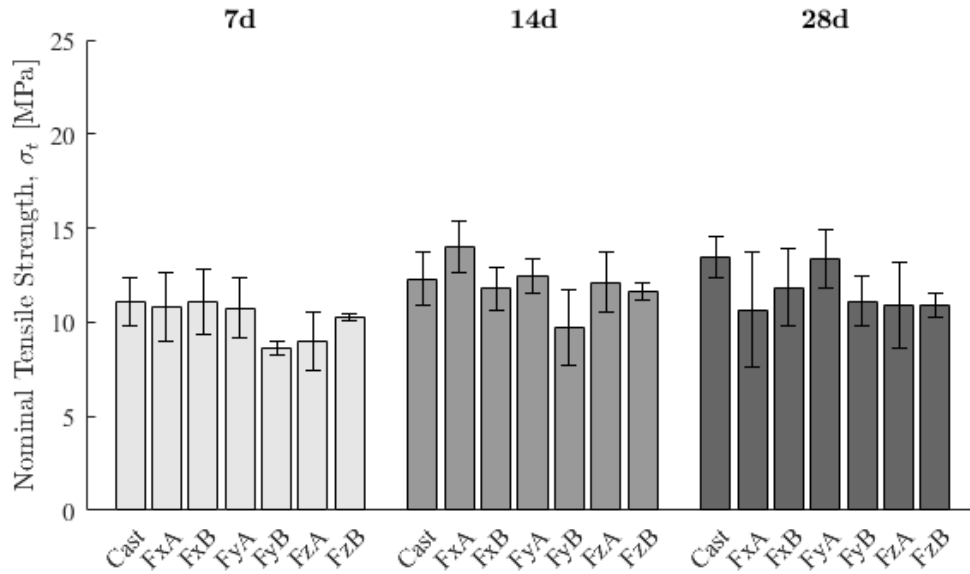
$$\sigma = 3PS / 2BH^2$$

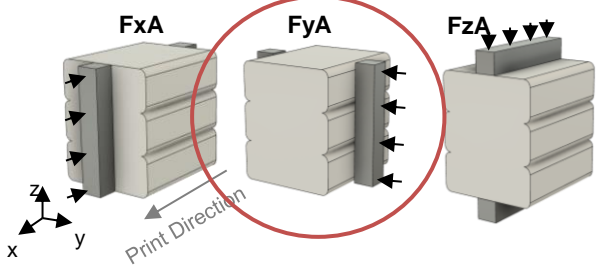




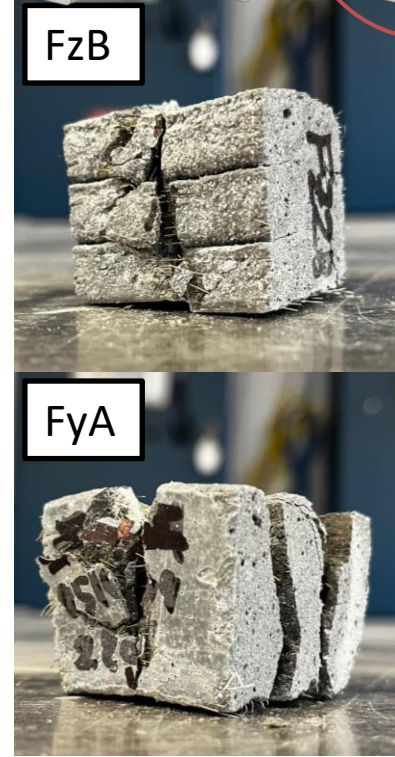
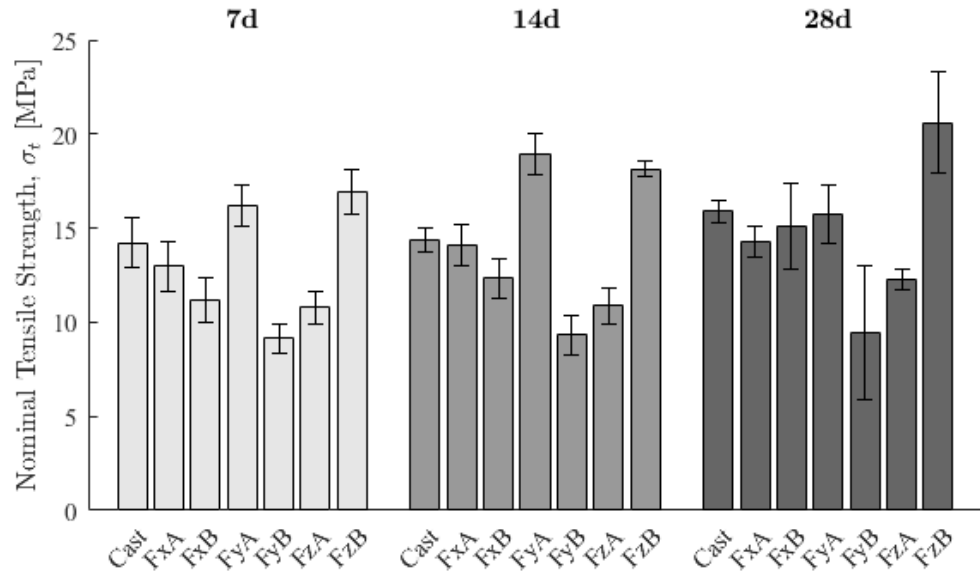
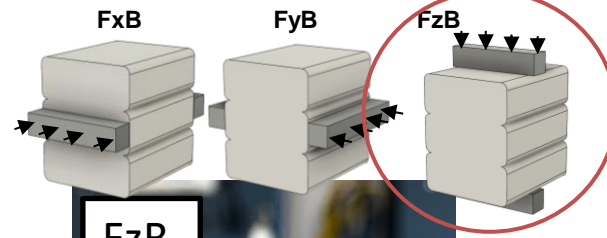
Results Splitting

Qualitative
Geometric
Effects





Results Splitting



Conclusions

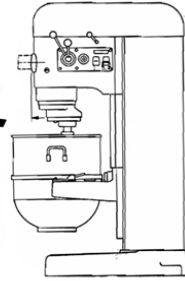
Conclusions

1. Clear anisotropic behavior observed in uniaxial compression with respect to loading direction in 3d-printed UHPC specimen.
2. Notched three-point bending and tensile splitting tests show no significant effects from inter-layer bond strengths for un-reinforced specimen.
3. Addition of fibers produces weak zones in the inter-layer boundary, altering the failure modes and the anisotropic behavior compared to un-reinforced specimen.

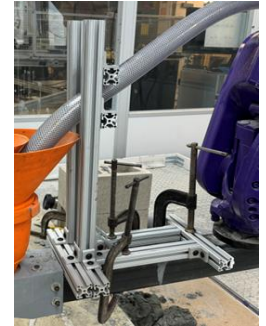
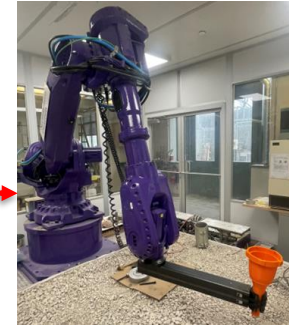
Future Work

Large Scale Printing

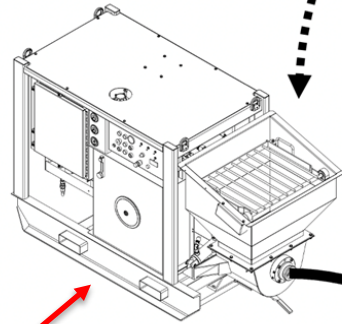
(1) Hobart V1401 Mixer



Robotic Arm



Hose Support

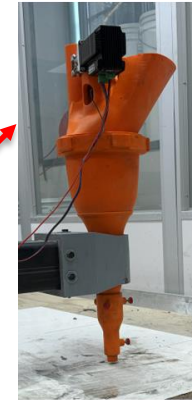


(2) TK7 Pump
30 hp (22kw)

(3) Rigid Hose
(10 ft length and
2" inner diameter)

(4) Flexible Hose
(12 ft length and
2" inner diameter)

(5) Auger
System



Auger System

Nozzle



rectangular



circular

Large Scale Printing



Acknowledgements

People



Prof. Gianluca Cusatis



Dr. Raul Marrero Rosa



Elmer Irizarry



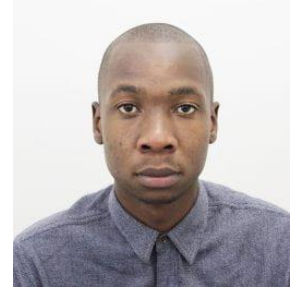
Ayesha Ahmed



Samuel Feldman



Chyim Bowen



Tapiwanashe Bhibho



ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER

Funding

Questions?

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