Dual-Reinforcement Approach for Printable Cementitious Mixtures: Studying the Structural Properties of Printed Elements.

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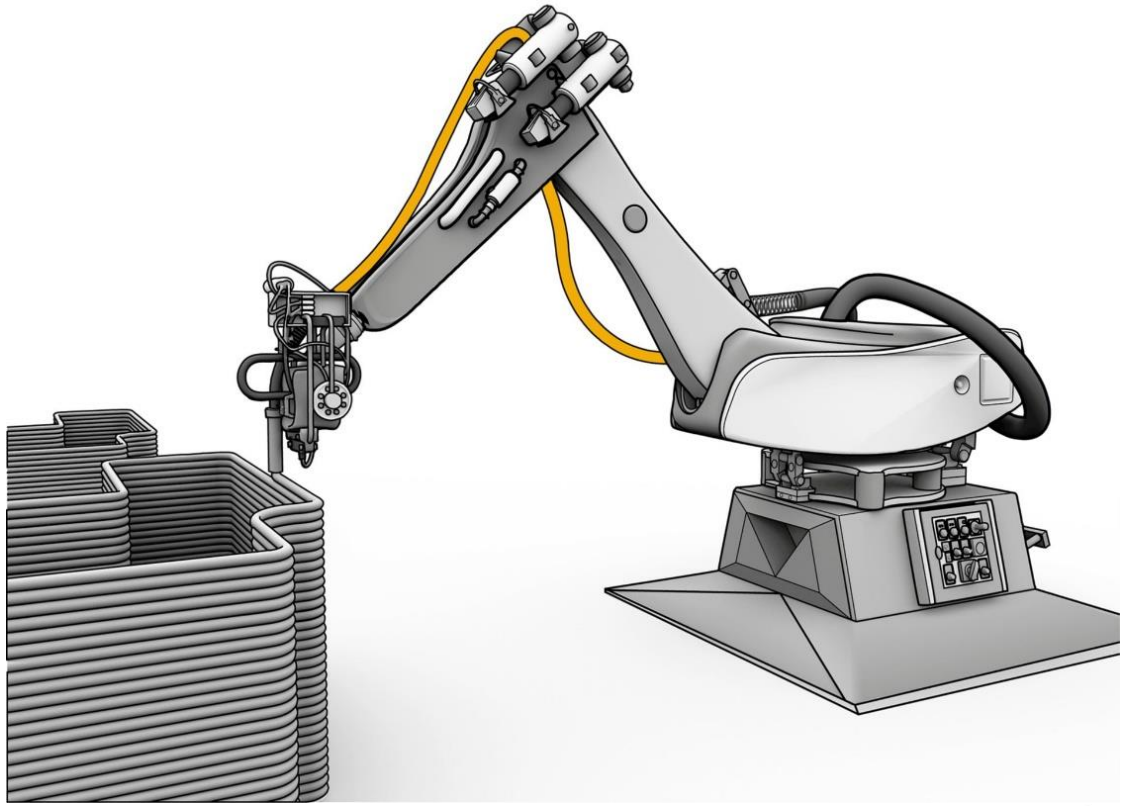
March 24, 2024

INTRODUCTION

- Concrete 3D Printing (C3DP)
  - Affordable and low-income housing
  - Infrastructural development
  - Emergency construction & disaster relief
  - Extraterrestrial construction
- Limitations
  - Building code compliance
  - Reliability and quality control
  - **Automated Reinforcement**
    - ✓Seamless integration process
    - ✓Maintain structural integrity
    - ✓Affirms other benefits of C3DP



Credit: Sika Group

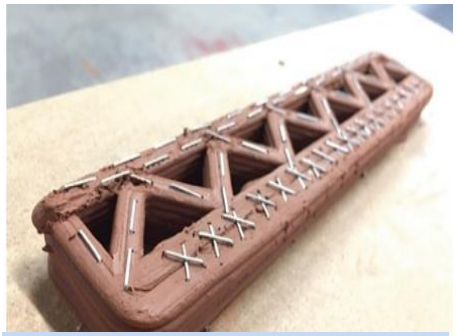
BACKGROUND: REINFORCEMENT INTEGRATION TECHNIQUES

PRE - C3DP

HuaShang Tengda Ltd.

DURING - C3DP

Bos et. al.



Geneidy et al.

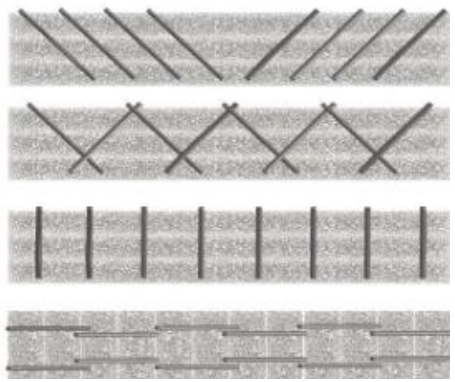
POST - C3DP

WinSun Ltd.

Vantyhem et al.

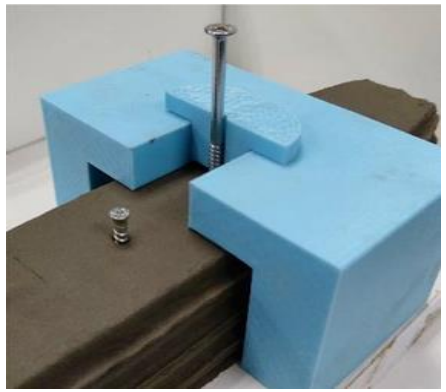
Bos et. al, Springer, 2019; Geneidy et al., Springer, 2020; Asprone et al., Construction and Building Materials, 2018; Vantyghem et al., Automation in Construction, 2020; Marchment & Sanjayan, Automation in Construction, 2020

BACKGROUND: PENETRATIVE TECHNIQUE



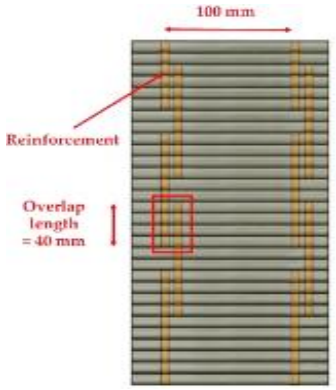
Perrot et al.: Nail insertion direction and reinforcement density have a significant effect on the bending performances

Up to 50% increase in flexural strength



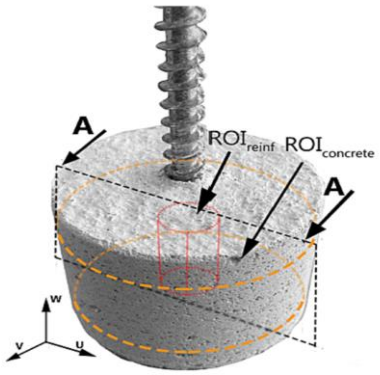
Cao et al.: Nail and thread type have a significant impact on pull-out and the split tensile properties

20 – 61% increase in split tensile strength



Park et al.: Short rebar type and overlap length influences the flexural strength

12.5 – 39.4% increase in flexural strength

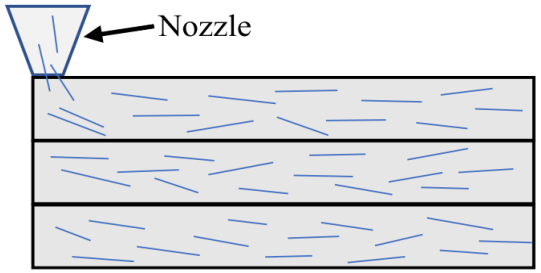


Hass et al.: Helical screw thread geometry/dia. and insertion duration (up to 200 mins from printing) do not significantly affect pull-out strength

Perrot et al., Materials, 2020; Cao et al. , Automation in Construction, 2022; Hass et al., Construction and Building Materials, 2022; Park et al., Materials, 2021;

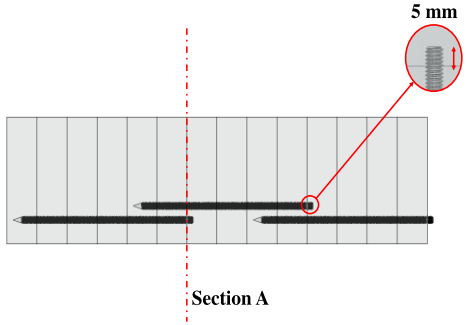
METHODOLOGY: DUAL REINFORCEMENT INTEGRATION APPROACH

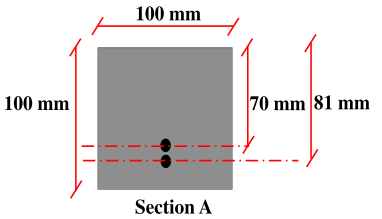
Fiber Reinforced Printing Material

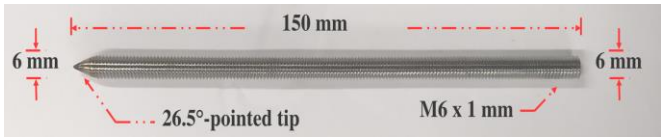


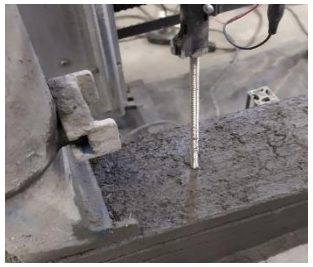
- Brass-coated steel fibers
- 13 mm fiber length
- High dosages of steel fiber (2.5% vol.)

In-line Reinforcement Penetration









- Short threaded vertical reinforcement
  - 304 Stainless steel
  - 500 MPa min. tensile stress
  - 1 mm threaded pitch
- Semi-automated insertion process

METHODOLOGY

Mixture Design Variables:

- Sand/Powder ratios: 1.4 (818 kg/m^3) and 1.8 (726 kg/m^3)
- Limestone powder (LS) as cement replacement - 0%. 5%, & 10%
- Fiber dosage: 0 - 2.5% vol.

Key Findings:

- High LS content negatively impact shape stability and printability window
- Higher cement content showed better mechanical properties
- With up to 2.5% vol. steel fiber, the flexural and tensile strengths increased by 129% and 148%, respectively

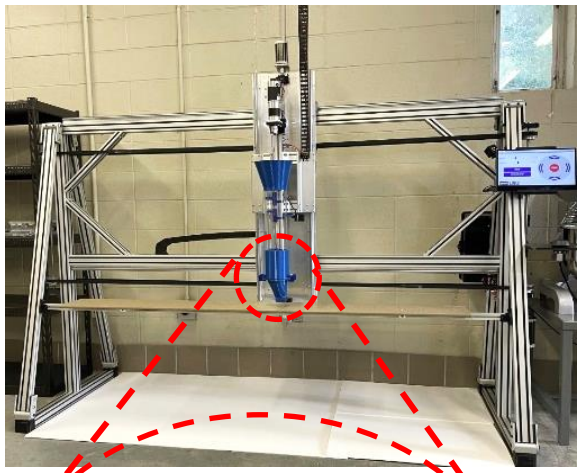
Best Performing Printing Material:

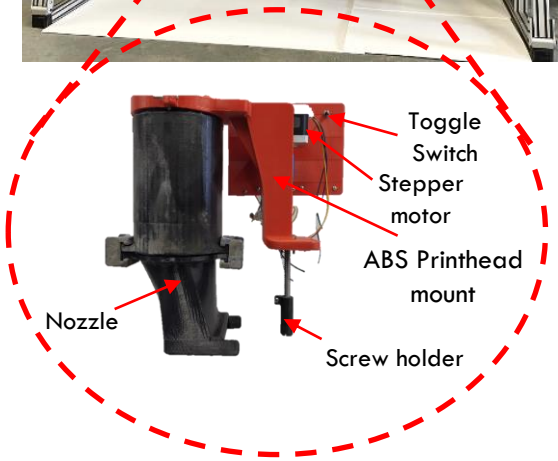
Flow diameter: 170-180 mm

Mixture ID	Portland Cement kg/m^3	W/C	Fiber kg/m^3 [vol.%]
F0	818	0.35	0 [0.0]
F2.5	**798**	**0.35**	**190 [2.5]**

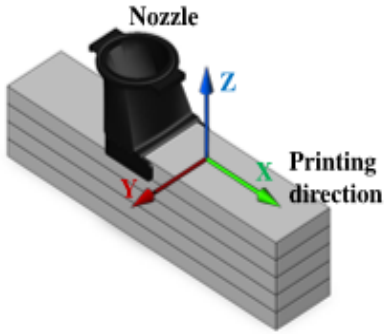
METHODOLOGY: SPECIMEN FABRICATION AND TESTING

100 mm (W) x 100 mm (H) x 350 mm (L) specimens





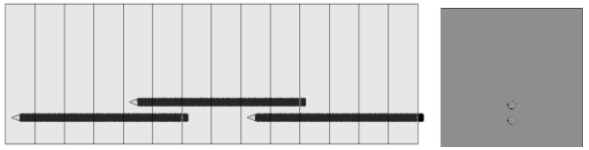
Reinforcement Insertion Module



Reinforcement integration process

4-layer specimen

14 -layer specimen



Specimen with threaded reinforcement

Four-point bending test ASTM C78/C1609

X-direction

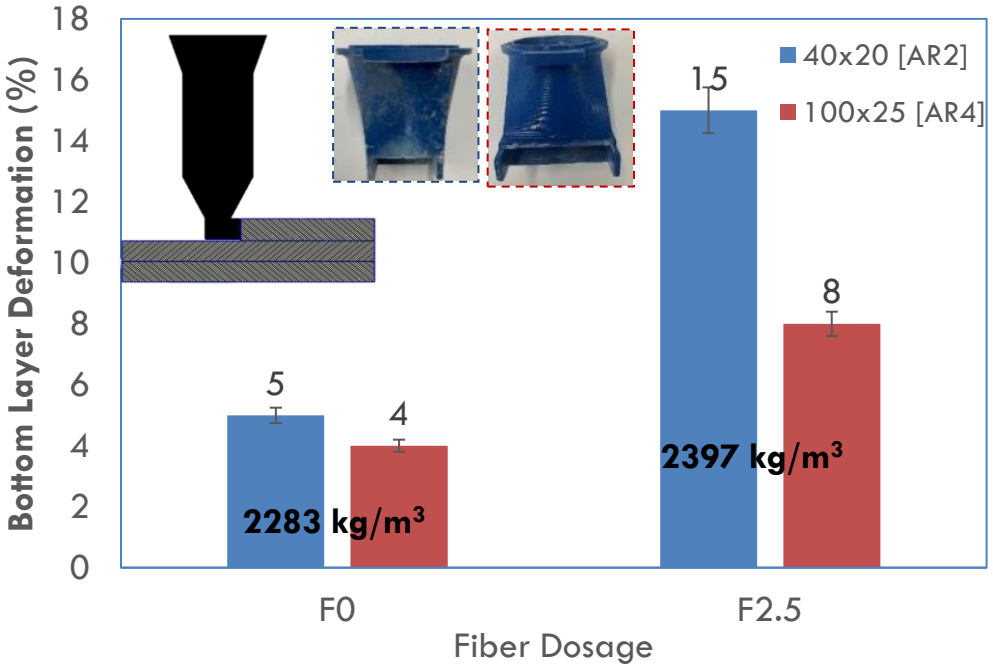
Y-direction

Z-direction

RESULT: SHAPE STABILITY

Main Findings:

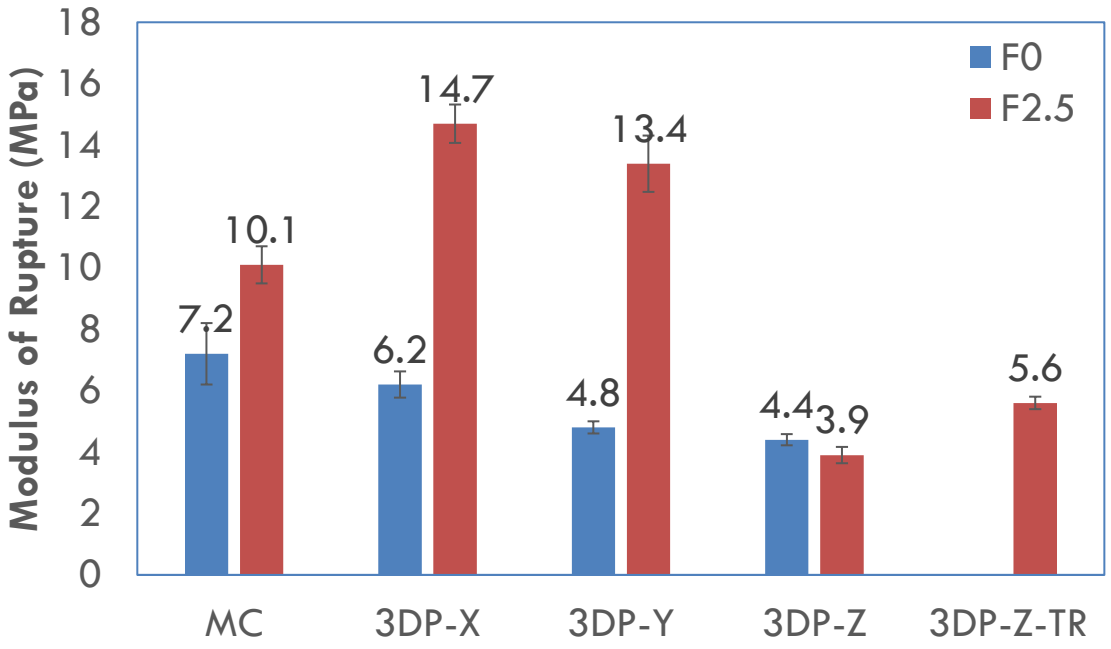
- Plastic deformation in the bottom layer increases with fiber dosage
  - Different flow properties
  - Increasing unit weight with an increase in fiber dosages
- The extent of layer deformation was lower in specimen with a larger nozzle aspect ratio (AR) - $AR_4 < AR_2$
  - Favorable load distribution on the substrate layer



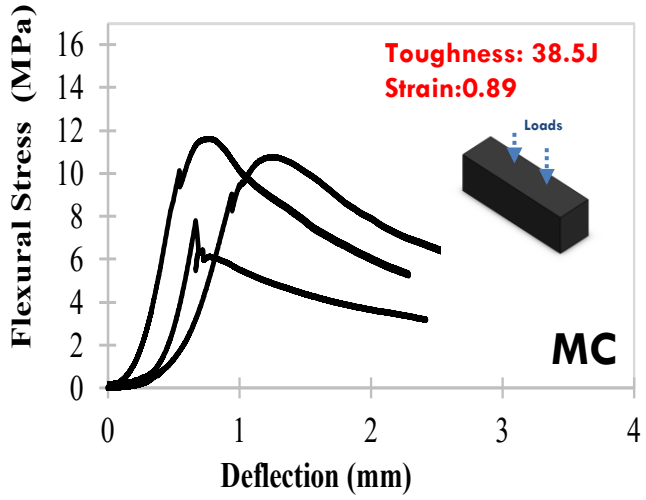
RESULT: FLEXURAL STRENGTH

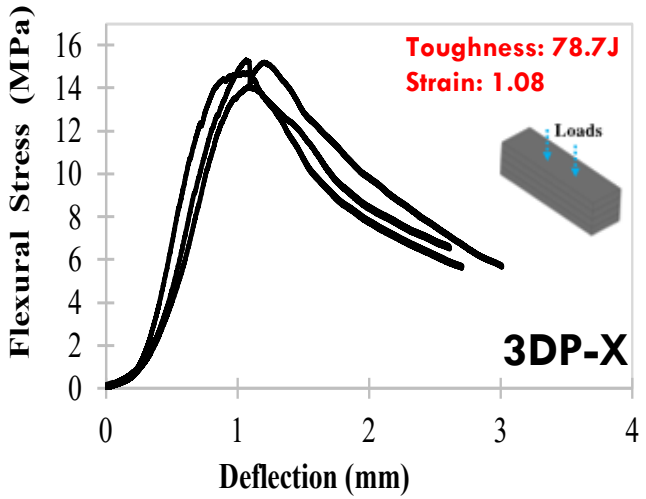
Main Findings:

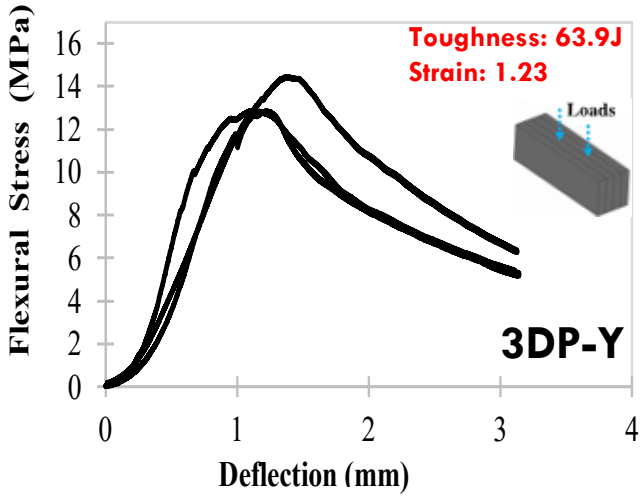
- The MoR of the plain MC beams surpasses the plain 3DP beams. However, an opposite result was observed in the case of the reinforced MC vs 3DP beams (except in the Z-direction)
- The MoR of the reinforced MC and 3DP beams was higher than the plain beams by up to 40% and 179%, respectively (except in the Z-direction)
- Anisotropic behavior in the 3DP beams
- Z-beams showed the least strength values, but introducing short threaded reinforcement improves the flexural strength by 44%

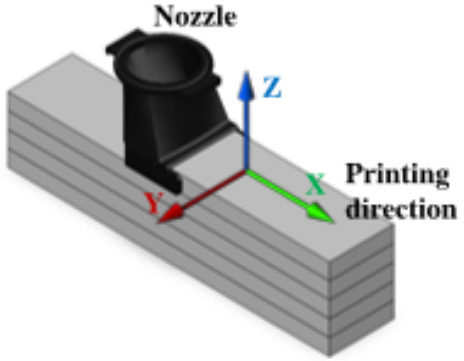


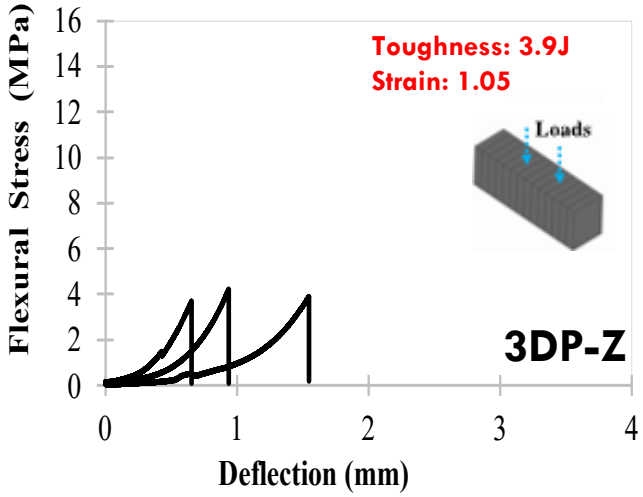
RESULT: LOAD-DEFLECTION CURVE

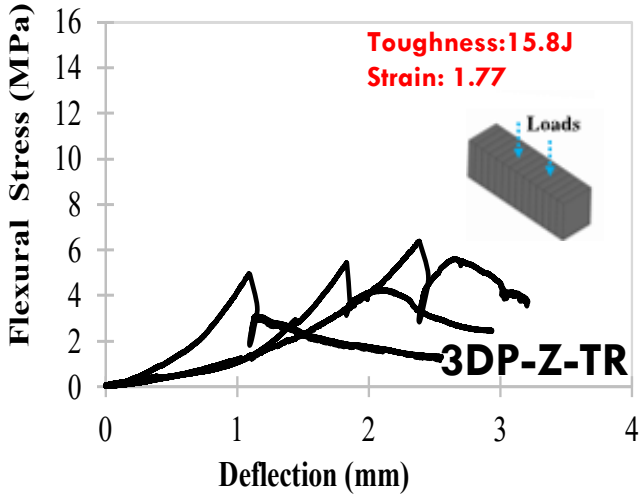








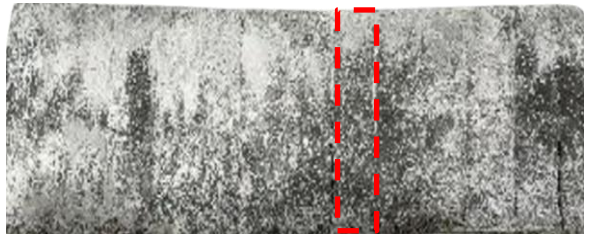




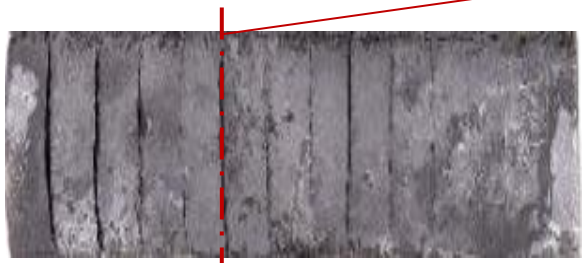
RESULT - CRACK PATTERNS

F2.5-MC

F2.5-3DP-X

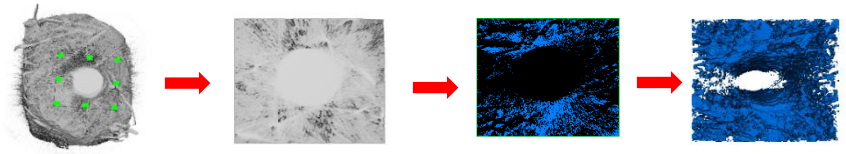


F2.5-3DP-Z

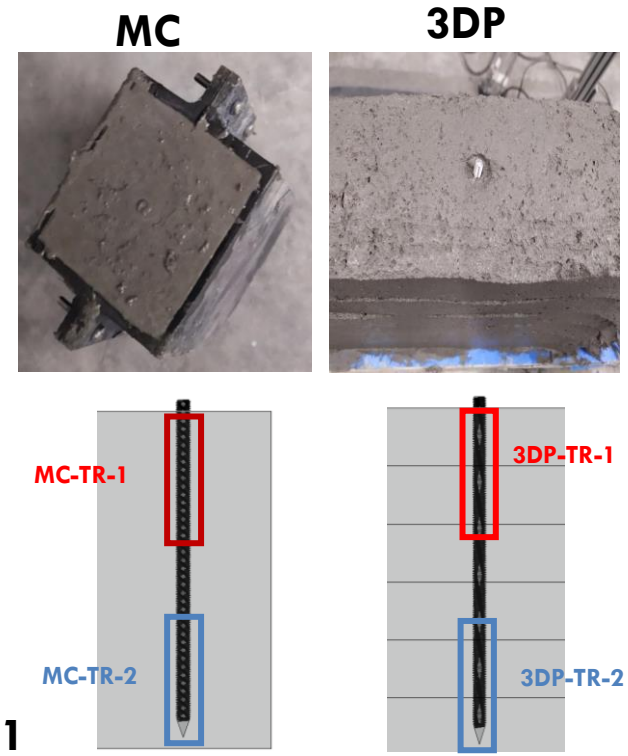


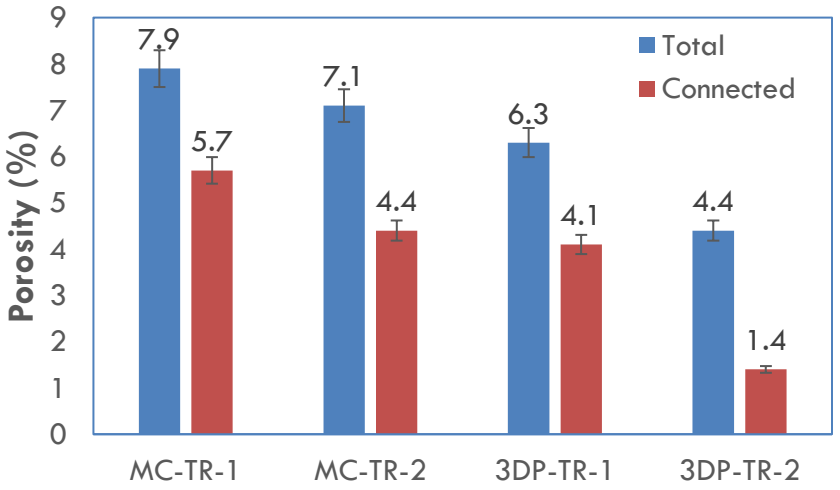
F2.5-3DP-Z-TR

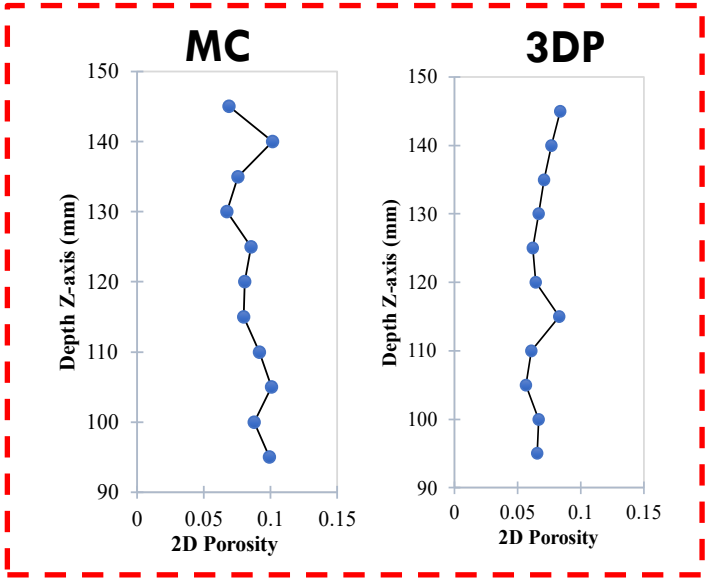
RESULT: POROSITY

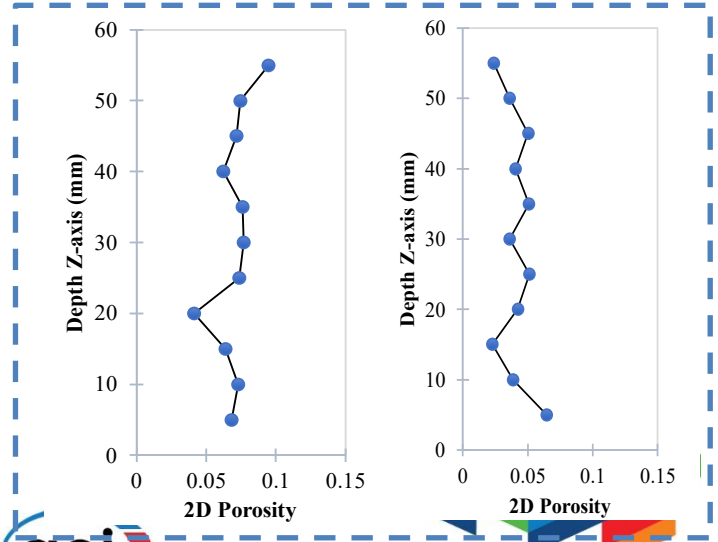


Scanned sample ROI (Top view) | 2D Image | Threshold Segmentation | 3D reconstruction of 2D image









CONCLUDING REMARK

- Material flow properties (influenced by the dosage of steel fiber) and nozzle design influences the extent of plastic deformation
- The reinforced MC and 3DP beams showed significantly higher flexural strength and post-crack properties compared to the plain beams.
- The 3DP beams exhibited anisotropic behavior
- No structural contribution of high fiber dosages to the Z-beams loaded along the interface. However, introducing a vertical reinforcement increases the flexural strength and post-crack properties.
- CT scan analysis shows that the proposed vertical reinforcement insertion technique led to lower porosity in the 3DP elements compared to the MC elements.

As future work, additional investigation into the effect of lapping length, lapping patterns, and reinforcement type on the structural performance of the 3DP beams is required.

ACKNOWLEDGEMENT

Tran-SET

Project Number: 21CLSU01

LOUISIANA TRANSPORTATION RESEARCH CENTER

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THANK YOU FOR YOUR ATTENTION!!!