Developing Engineered Polymeric Reinforced Cementitious Composite (EPRC) Using Mechanics of Materials Principles and Nature-Inspired Hollow Architectures

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Presented by: Amir Farnam, Associate Professor, yf338@drexel.edu

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College of Engineering

Drexel AIM Lab
Advanced Infrastructure Materials

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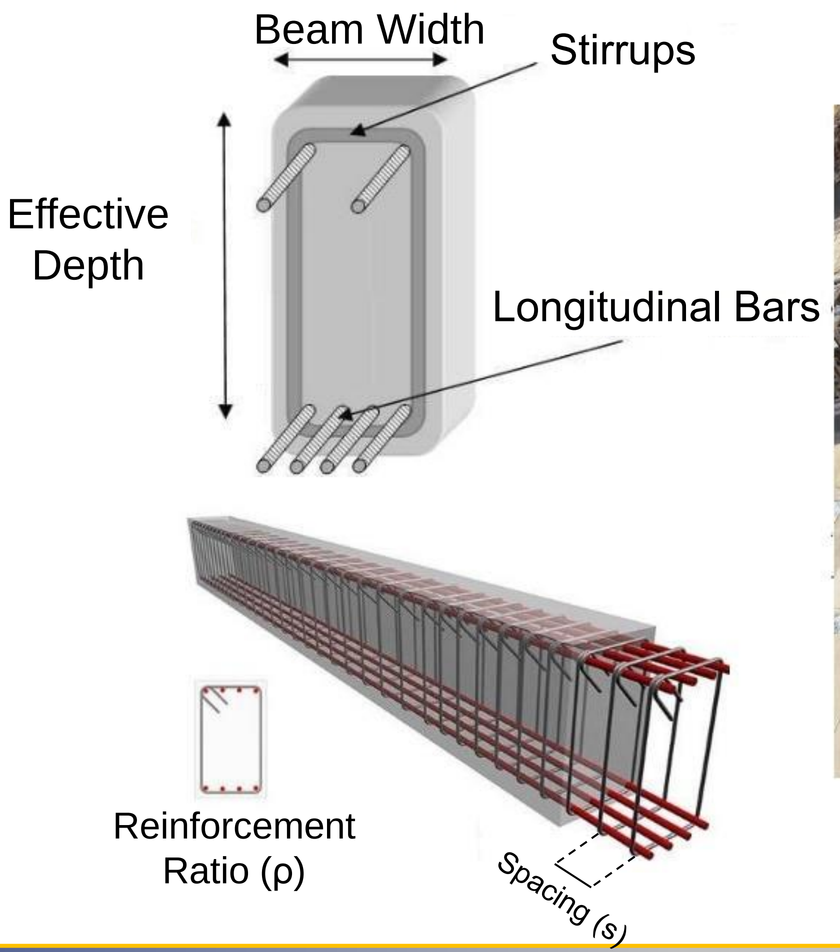
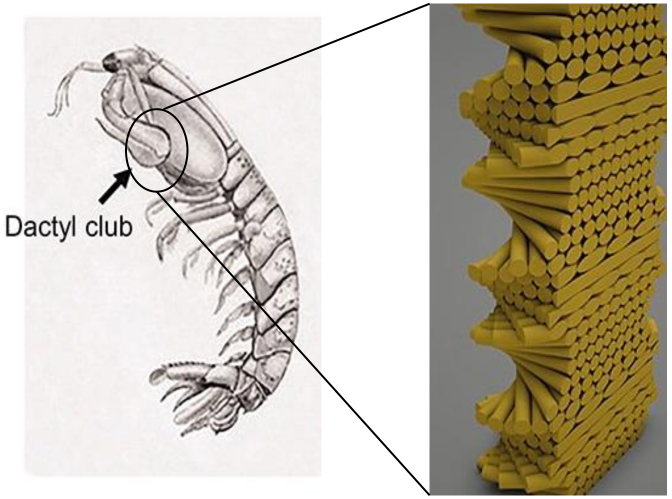
Conventional Reinforced Concrete

- Reinforcements are often used to improve tensile behavior.

- They help increase concrete toughness and prevent catastrophic tensile failure.

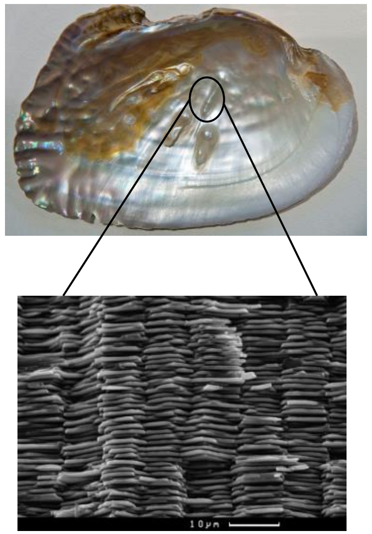


Nature-Inspired Architectures



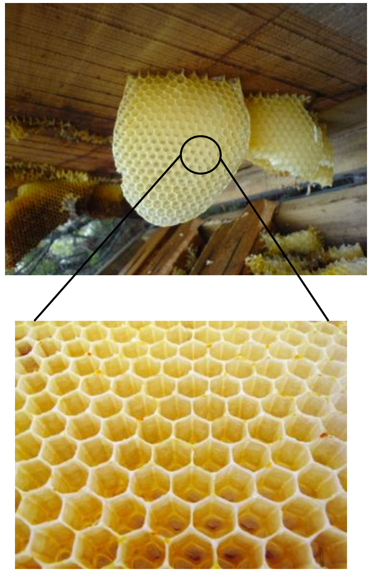
Bouligand: Improving fracture toughness

Pinto et al., (2016)



Alternating layers in Nacre: Improving fracture toughness

Rosewitz et al., (2019)



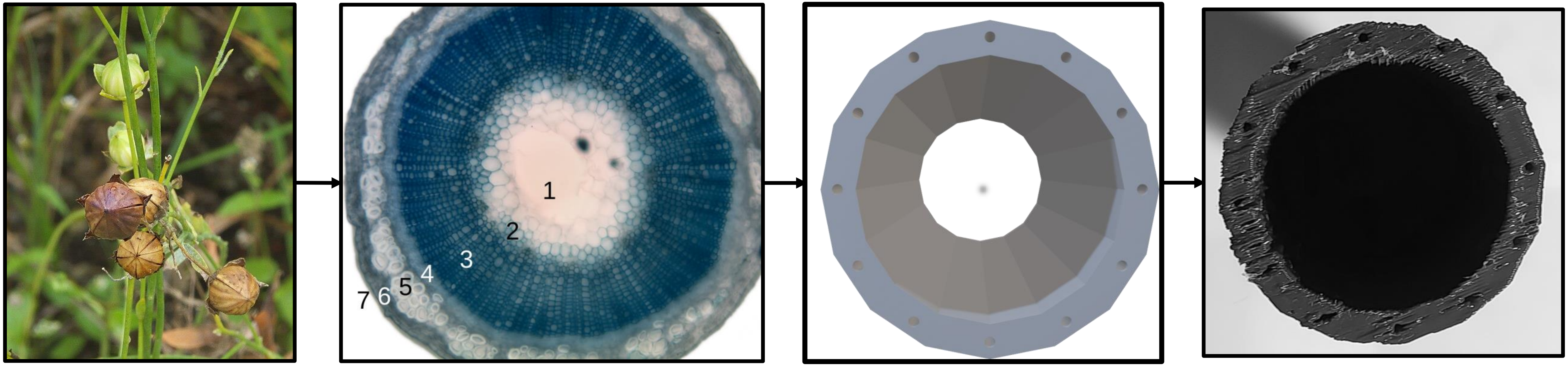
Honeycomb, sandwich effect: Improving compressive strength

Hector et al., (2019)

Plant Stem: Improving flexural behavior

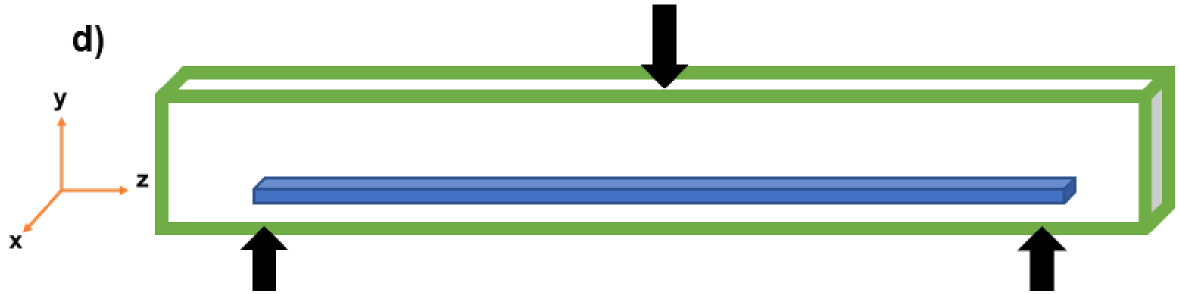
Speck et al, (2013)

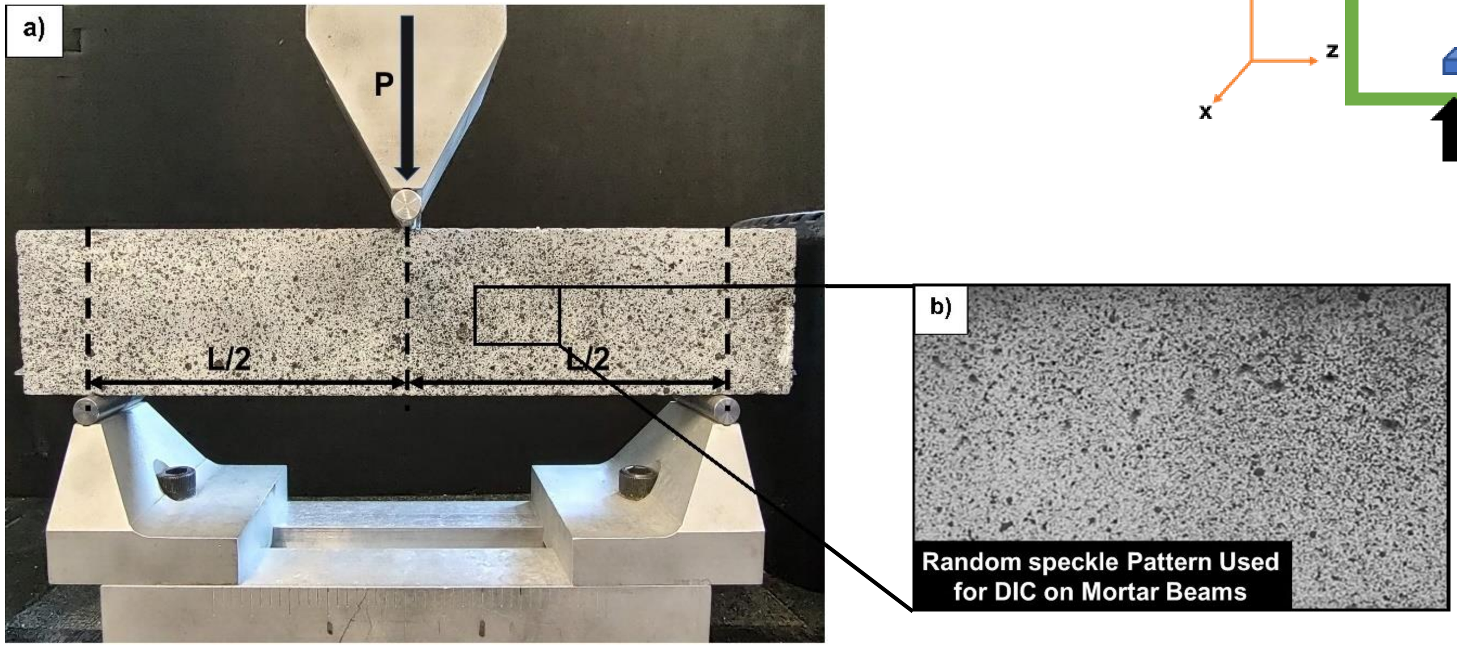
Plant Stem-Inspired Macro-Architectures:



Research Methodology

Experimental Analysis:





3-Point Bending **DIC**

- Mid-point deflection at rupture:
  - ➢ Random speckle pattern
  - ➢ GOM Correlate software

➢ Mortar, w/c=0.42 with polymeric reinforcement

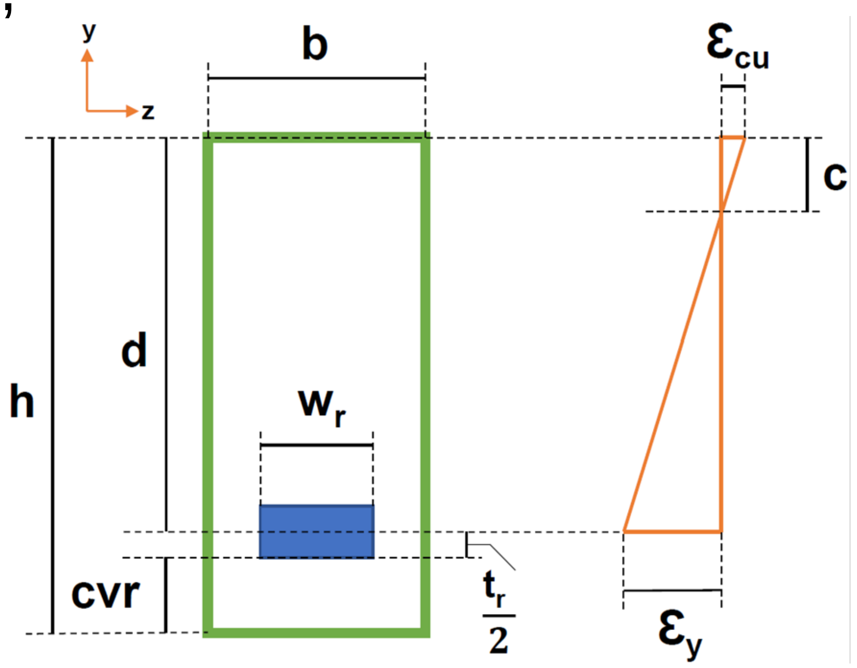
Research Methodology

Reinforcement Design

To find the balanced longitudinal reinforcement ratio, based on theories from mechanics of materials:

- **Depth of reinforcement:** $d = h - cvr - (\frac{t_r}{2})$
- **Depth of neutral axis:** $c = \left(\frac{\varepsilon_{cu}}{(\varepsilon_{cu} + \varepsilon_y)}\right) \times d$
- **Cross-section:** $A_r = \left(\frac{1}{f_y}\right) \times (0.85 \times f'_c \times b \times \beta_1 \times c)$
- **Reinforcement ratio:** $\rho_{bal} = \frac{A_r}{A}$

Namakiaraghi et al., (2023)



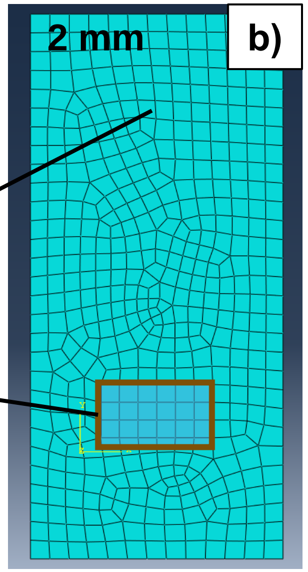
Research Methodology

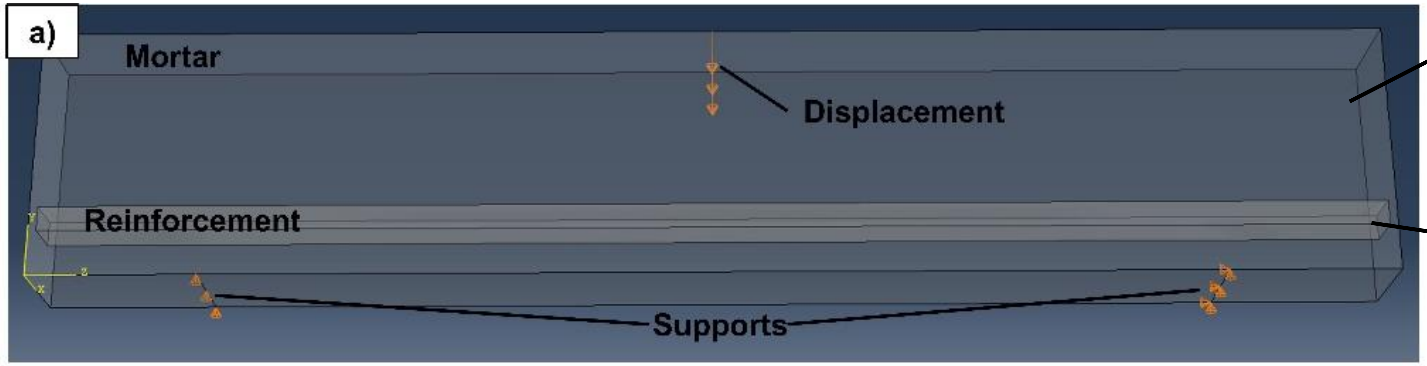
Numerical analysis:

- Mortar Matrix: Concrete Damaged Plasticity
- Reinforcement: Ductile Damage
- Interaction: Embedded Region

$$d_c = 1 - \frac{\sigma_c}{\sigma_{cu}}$$

$$d_t = 1 - \frac{\sigma_t}{\sigma_{t0}}$$

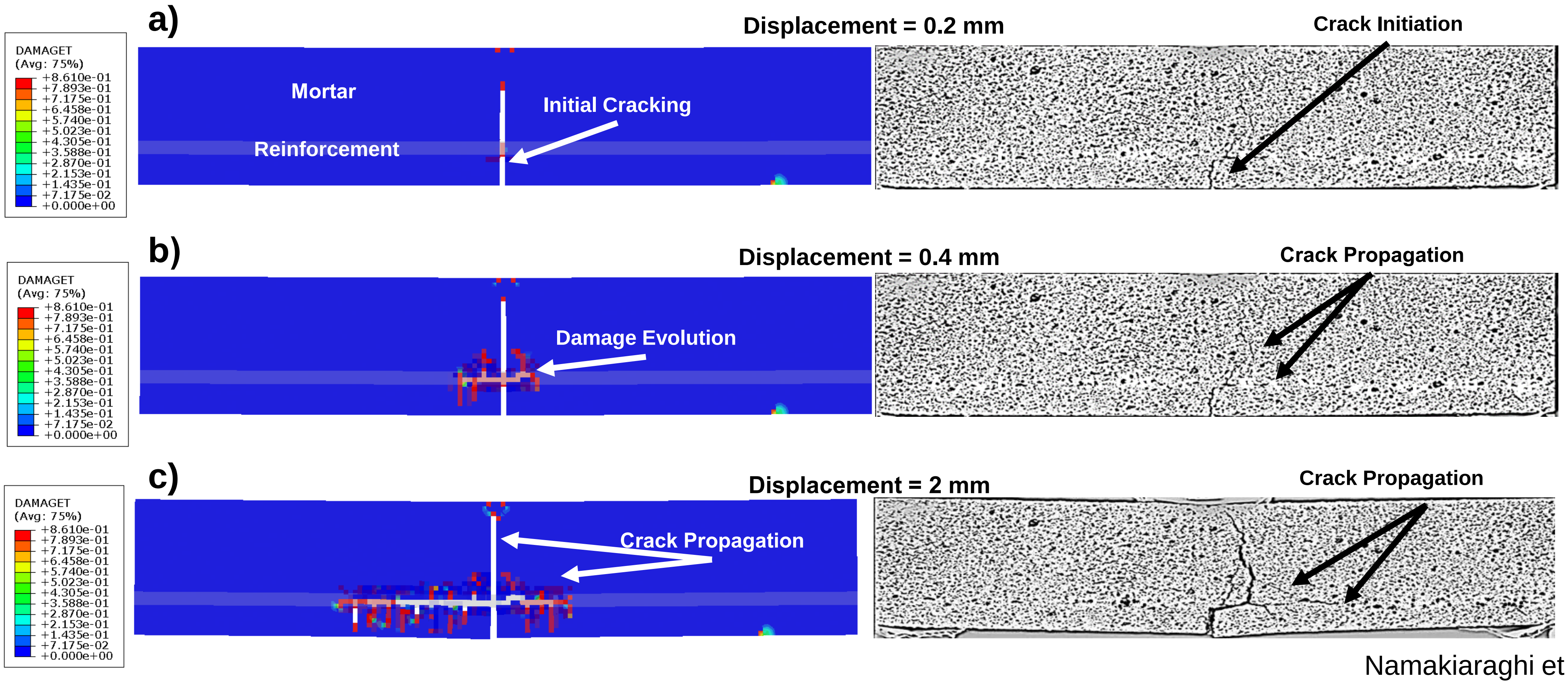




Namakiaraghi et al., (2024)

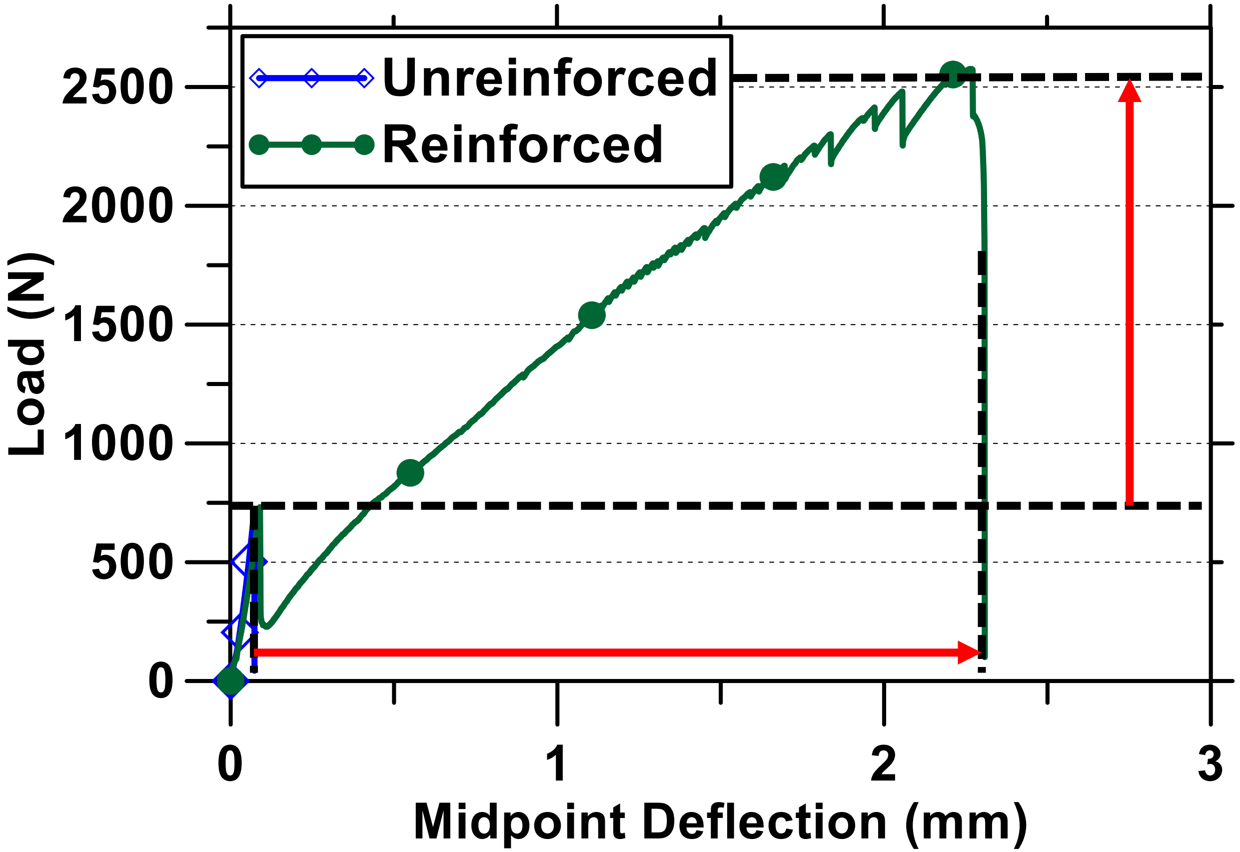
Calibration of FEM Model:

FEM Damage Evolution | **Crack Propagation in Experiment**



Namakiaraghi et al., (2024)

- Enhanced **flexural strength**
- Improved **ductility**
- Enhanced **bond strength**
- Reinforcement **ratio** was adjusted
- **Numerical** model was developed



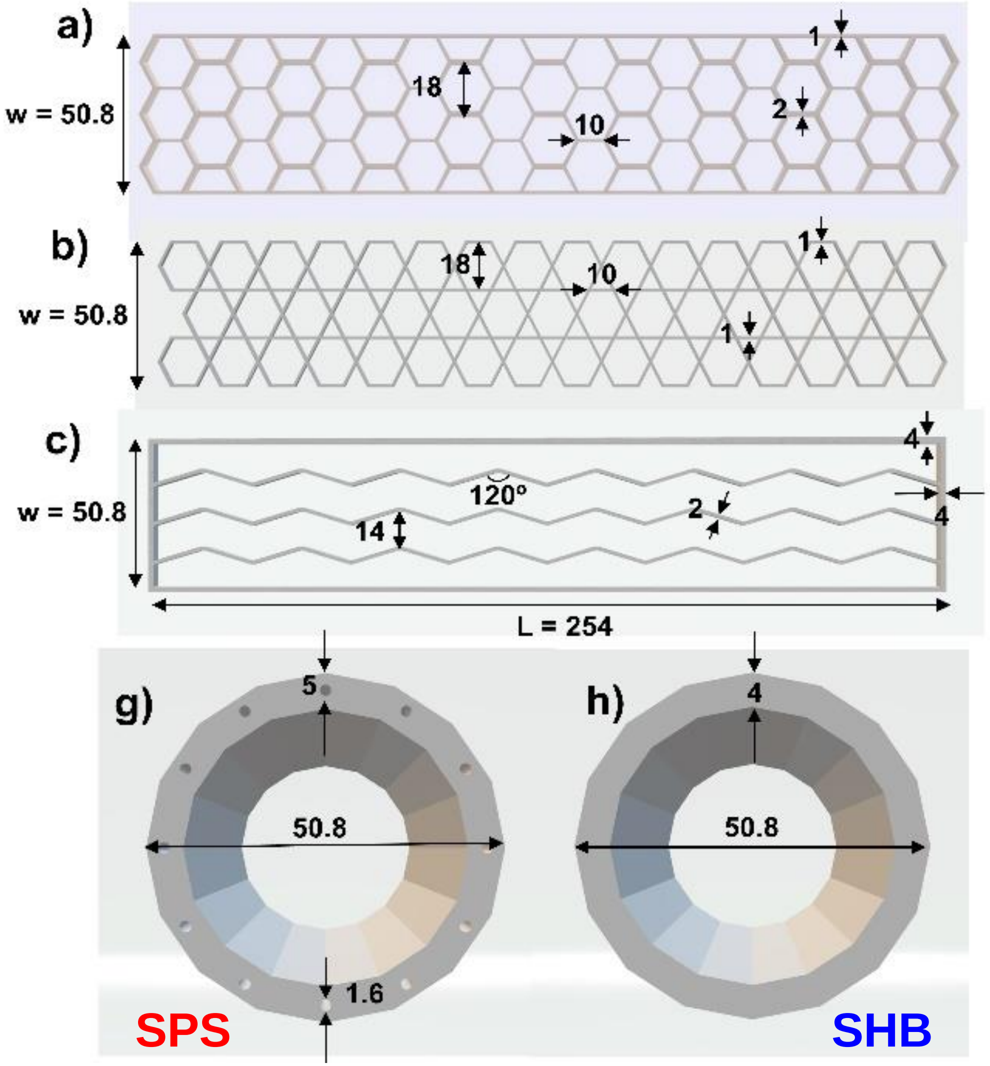
Macro-Architected Reinforcement Design:

- **Cellular**
  - ➢ **Hexagonal (HXN)**
  - ➢ **Kagome (KGM)**
  - ➢ **Sinusoidal (SNS)**

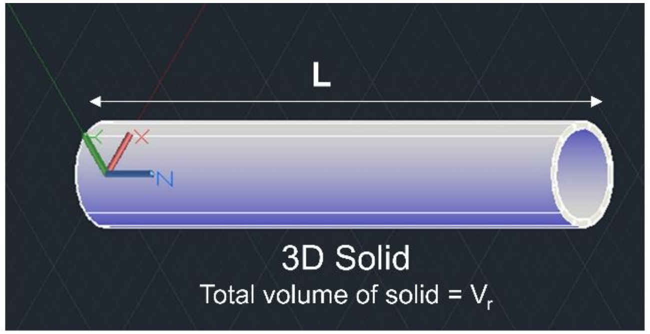
- **Hollow**
  - ➢ **Hollow bar (SHB)**
  - ➢ **Plant stem (SPS)**

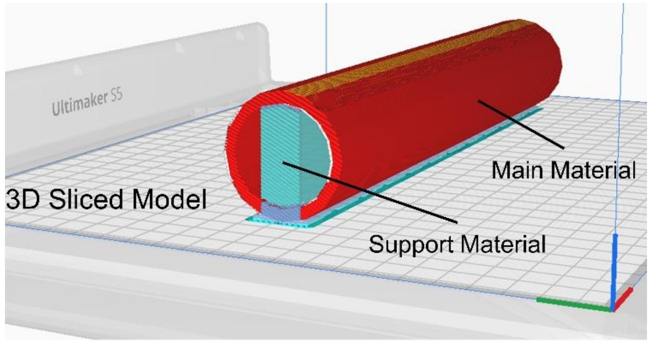
Design constraints

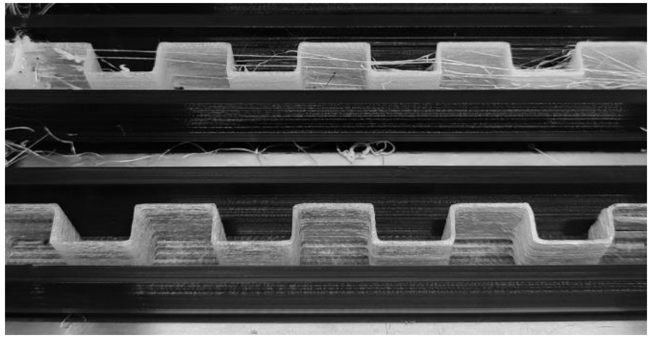
- ρ_{bal}
- Cover



Design, manufacturing and casting process:





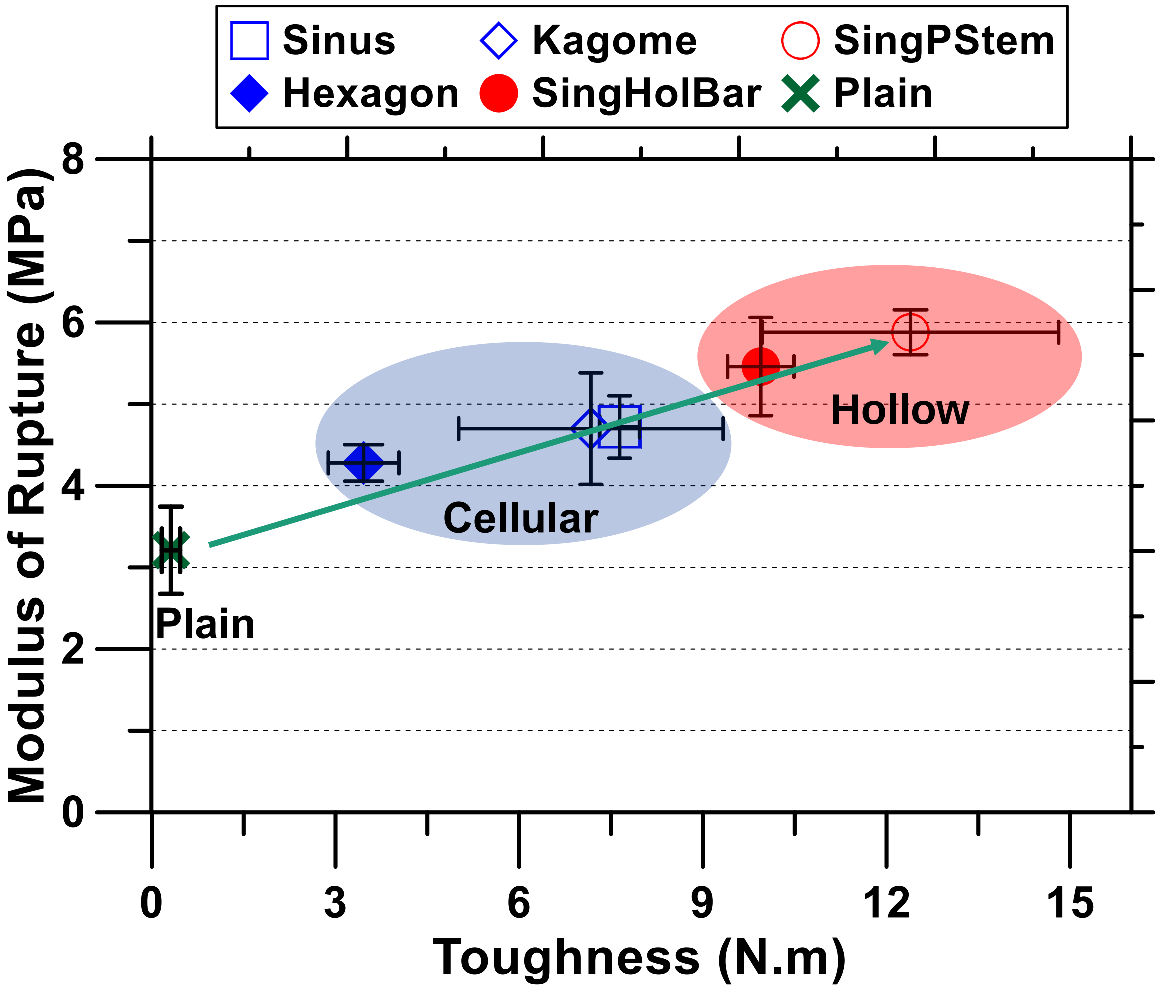


3D CAD → **Slicing** → **3D Printing** → **Casting**

3D CAD	Slicing	3D Printing	Casting
AutoCAD 3D Model	CURA 0.2 mm	Main: PLA Support: PVA	w/c = 0.42 Silica sand

Namakiaraghi et al., (2024)

Results: strength vs toughness



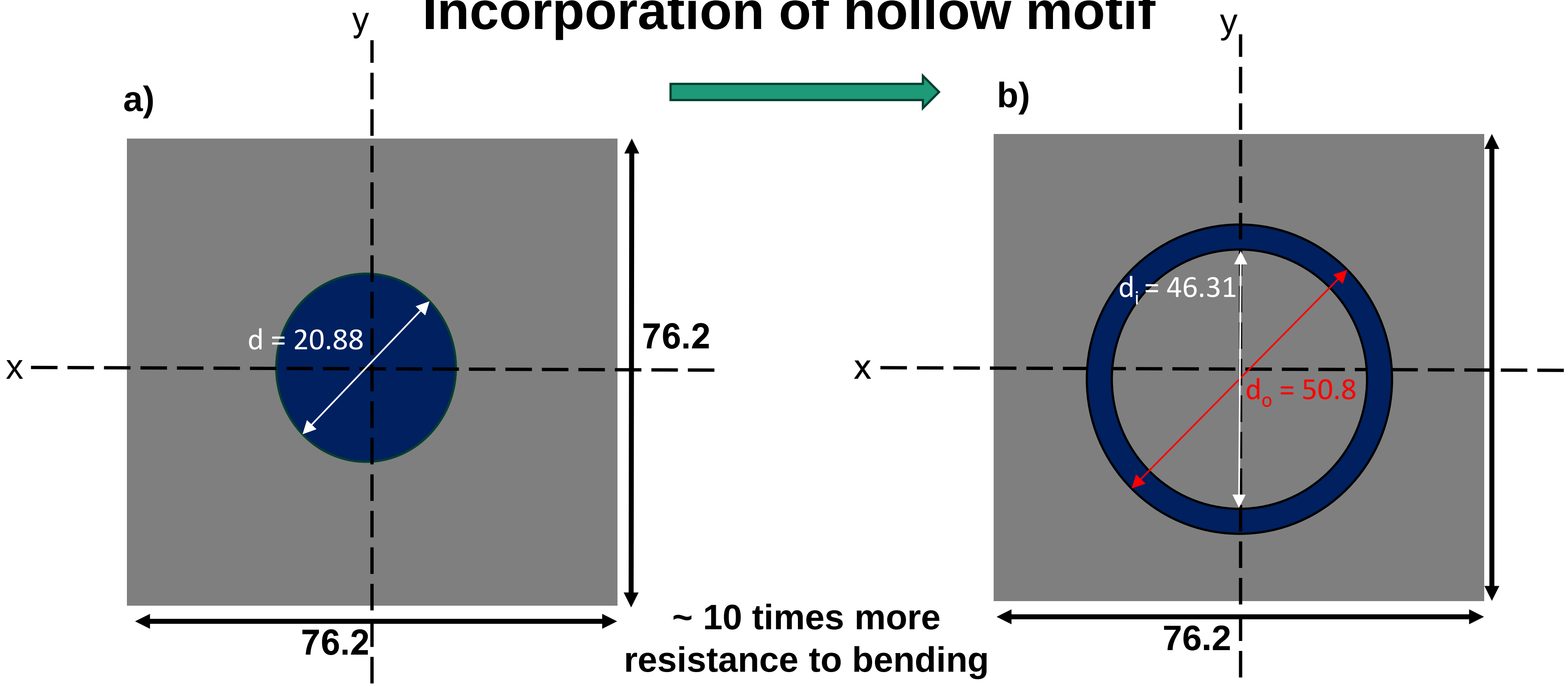
- From bottom left to top right, the flexural properties improve.
- Compared to plain, incorporating the polymeric reinforcements significantly enhances the flexural properties.
- Hollow reinforcements perform better than cellular.

Namakiaraghi et al., (unpublished data)

Concept of Area Moment of Inertia:

$$\sigma = \frac{Mc}{I}$$

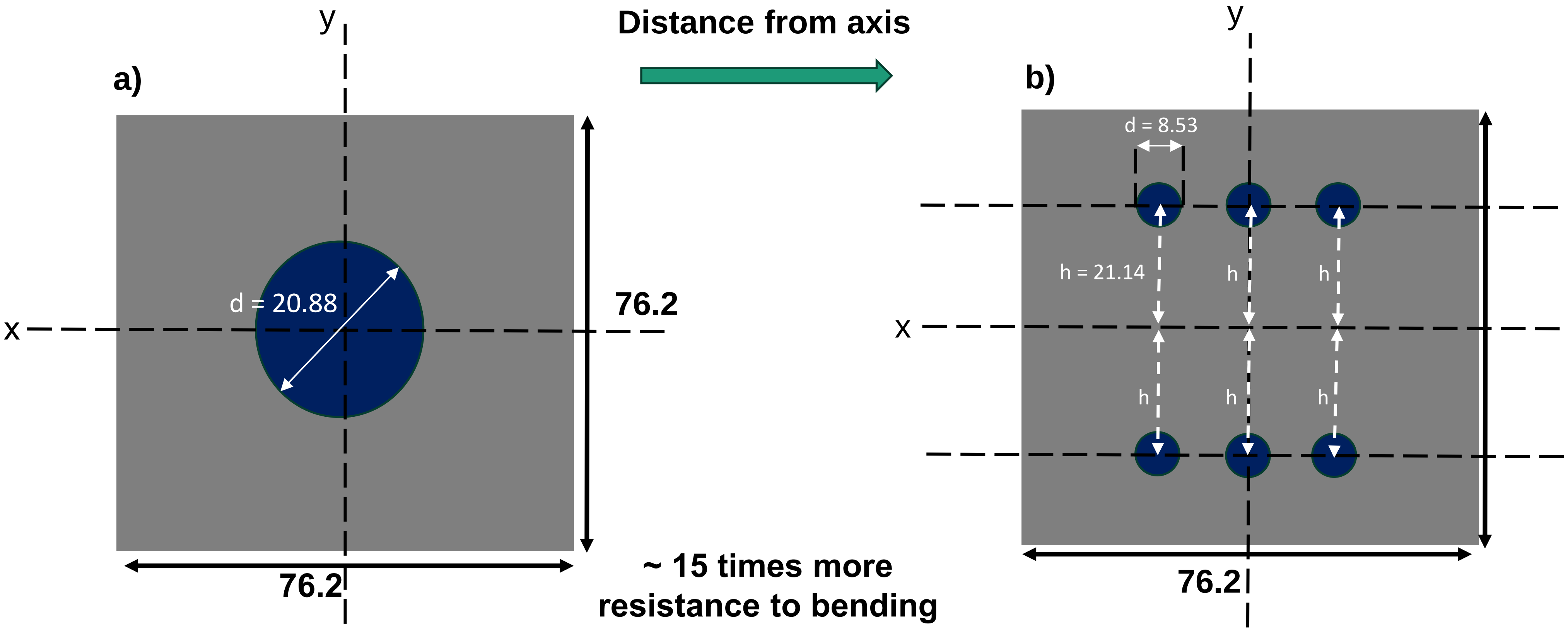
Incorporation of hollow motif



~ 10 times more resistance to bending

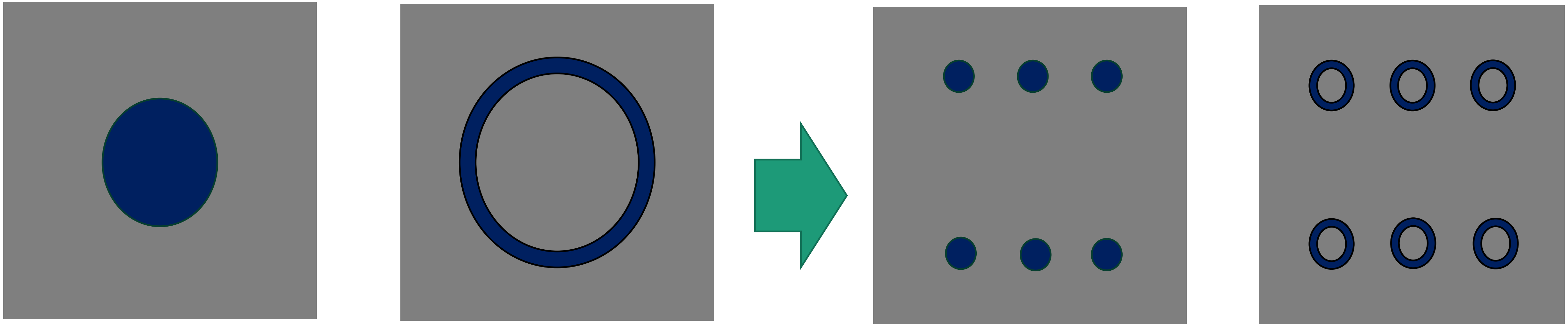
Mechanics of Materials (MoM)-based Design

$$\sigma = \frac{Mc}{I}$$



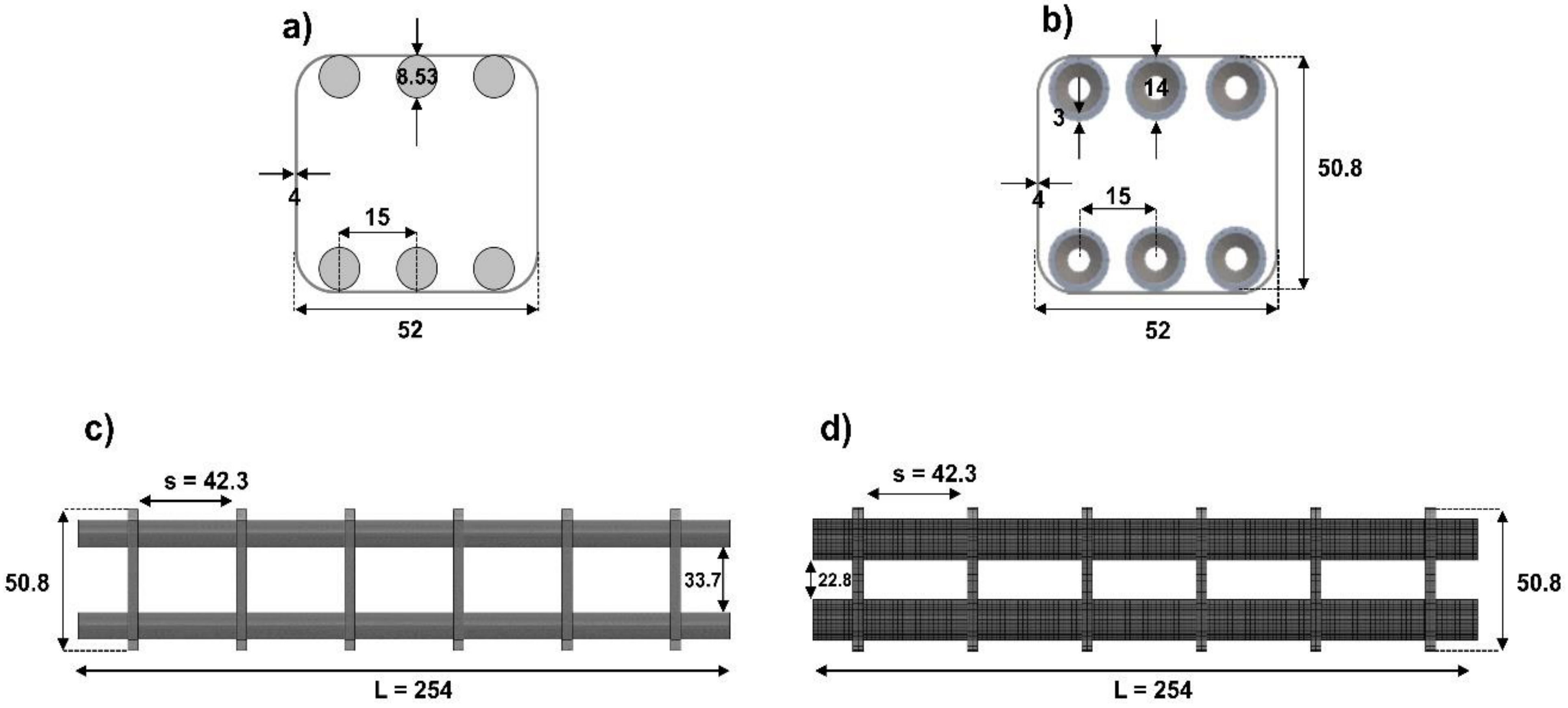
MoM + Hollow Design:

Singular rebar | **MoM-based**

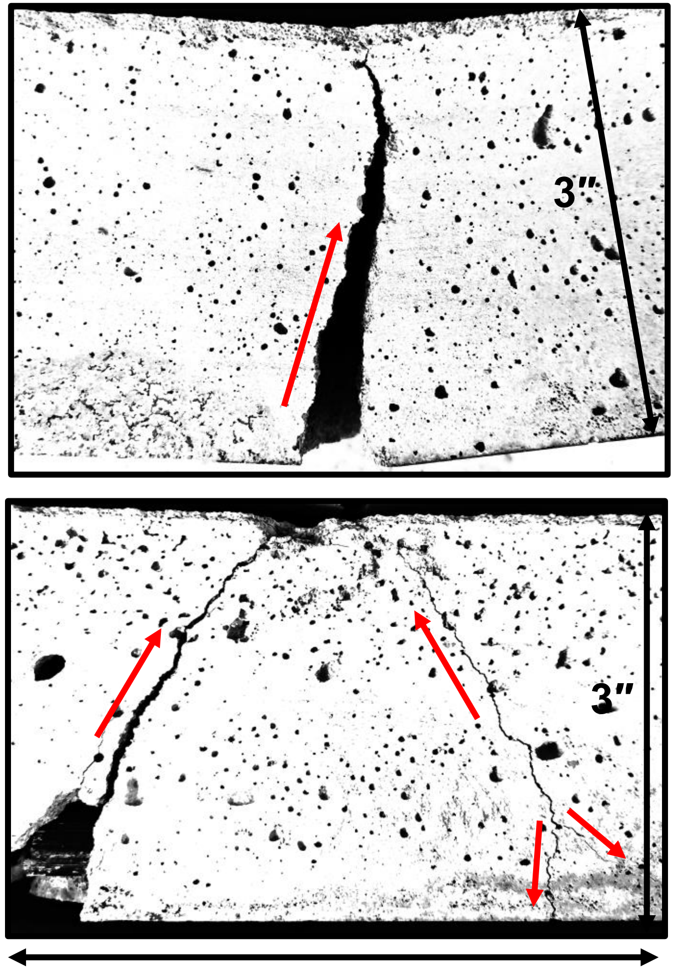


Solid	Hollow	Solid	Hollow
I_x	$\sim 10I_x$	$\sim 15I_x$	$\sim 12.5I_x$

Design Layout:

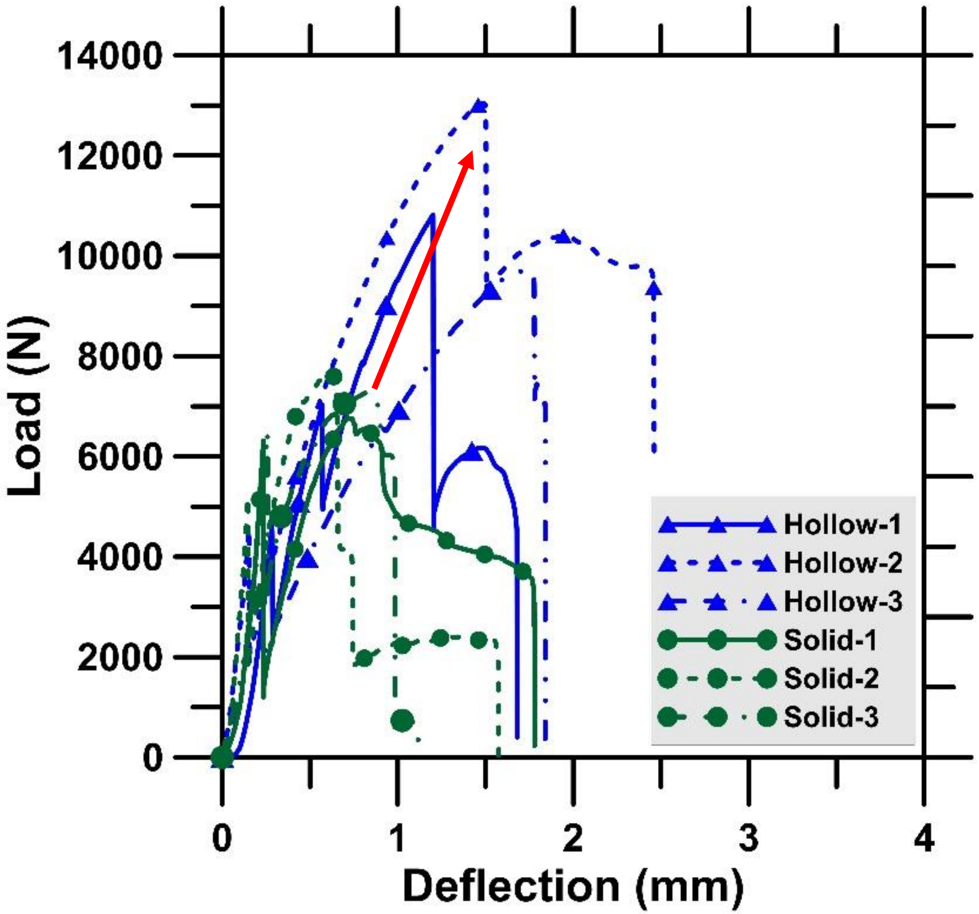


Results: 3-Point Bending



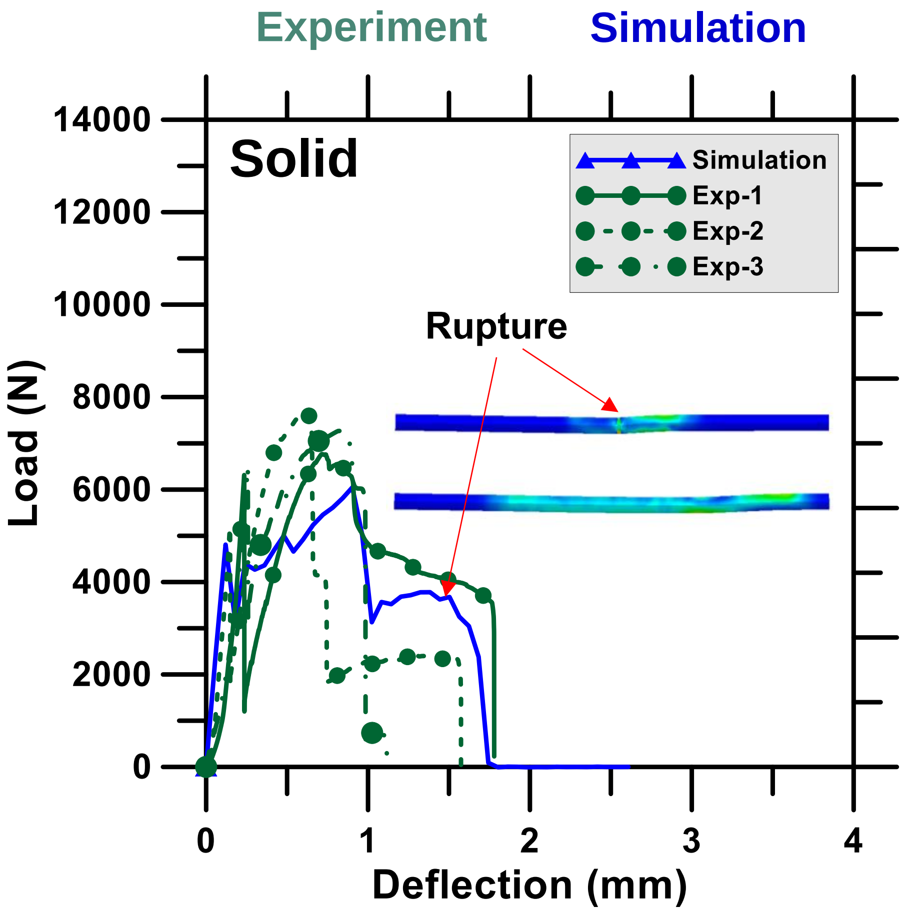
Solid

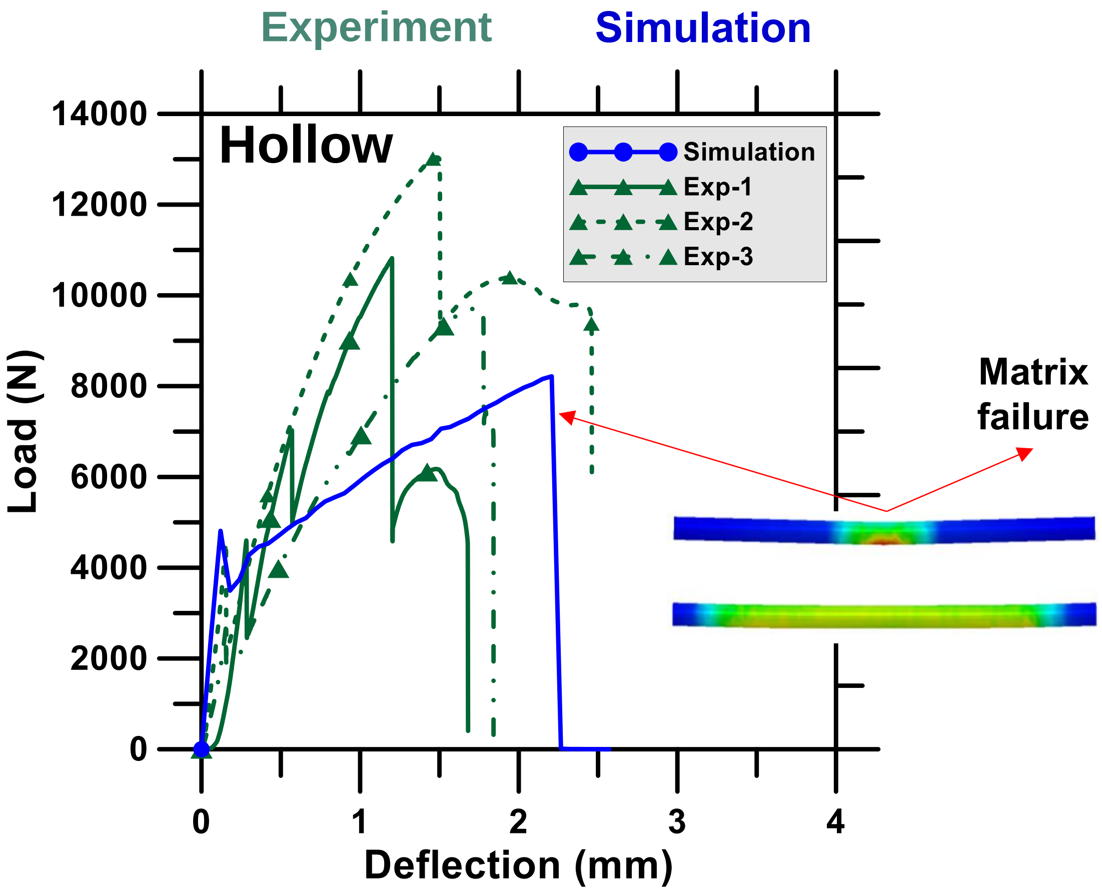
Hollow



Namakiaraghi et al., (2024)

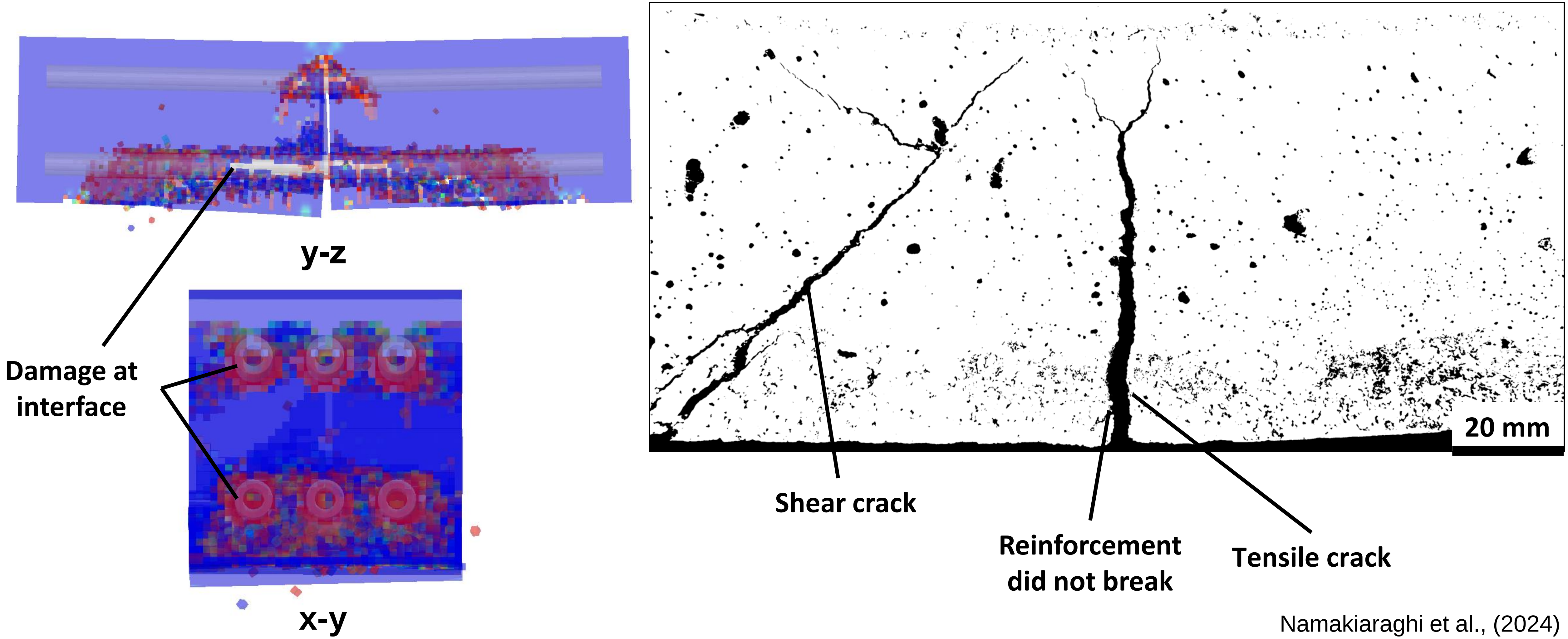
Results: 3-Point Bending, MoM





Namakiaraghi et al., (2024)

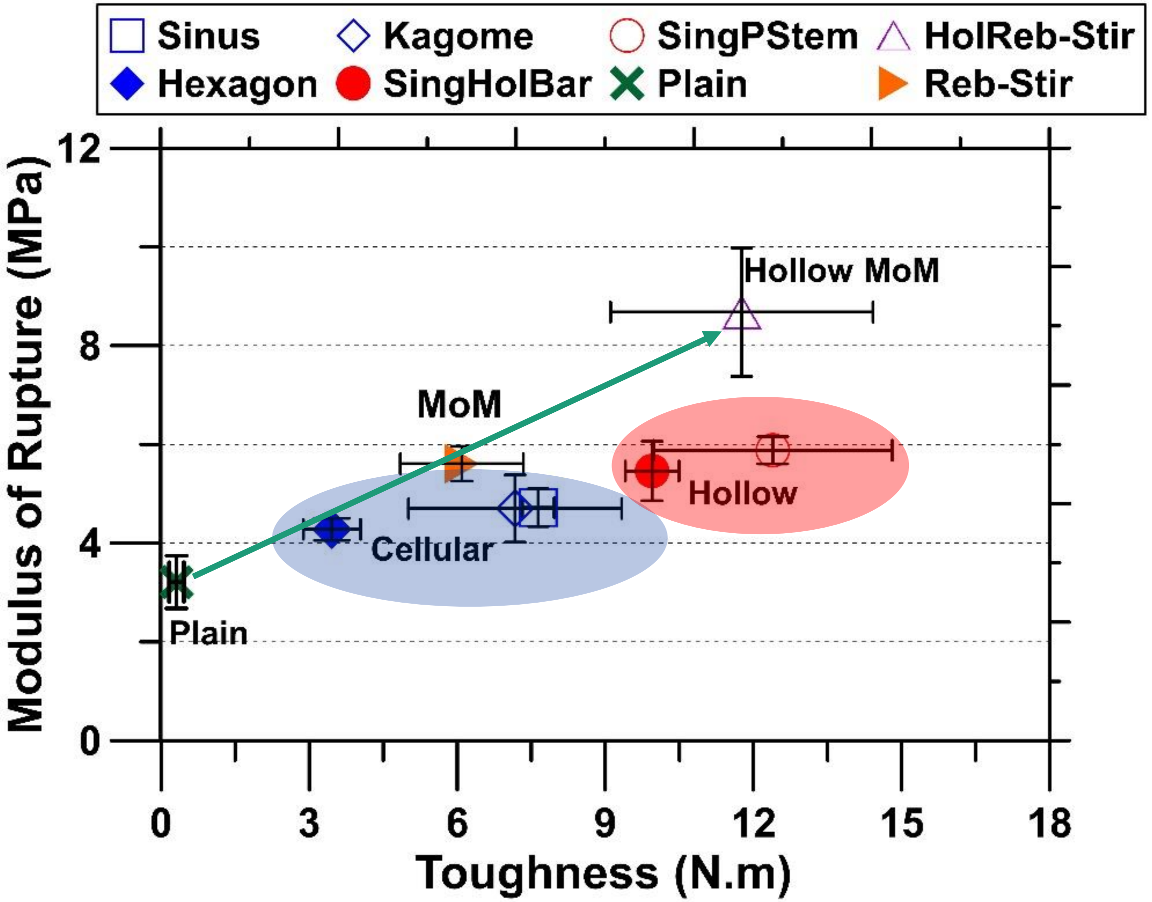
Results: failure mechanisms



Namakiaraghi et al., (2024)

Strength vs toughness:

- Higher area moment of inertia and bond strength work together to enhance the flexural properties in hollow architectures.
- Synergetic integration of nature-inspired motifs and MoM-based design provided the best flexural properties.

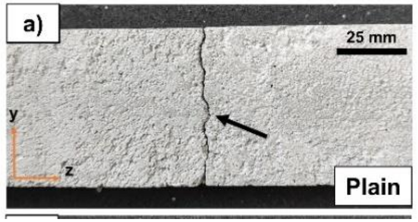


Namakiaraghi et al., (2024)

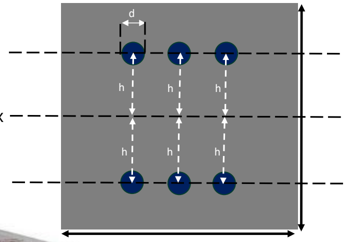
Summary: Development of Engineered Polymeric Reinforced Cementitious Composite (EPRC):

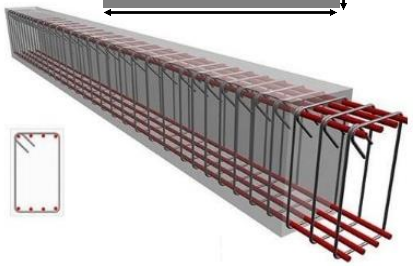
Flexural behavior enhancement

Plain concrete, a quasi-brittle material

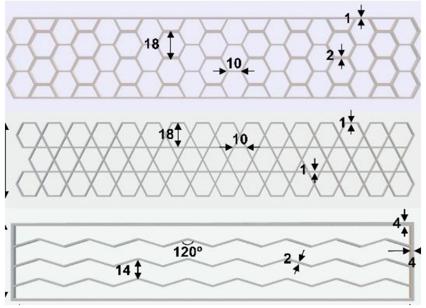


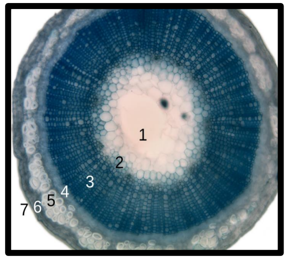
MoM-based reinforcement design

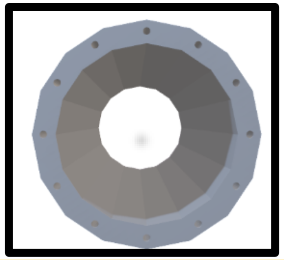




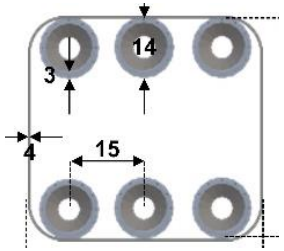
Nature-inspired macro-architected reinforcement design







Introduction of hollow motifs into the MoM-based design



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