Combined effects of fiber reinforcement and layer orientation on properties of 3D printed concrete

Avinaya Tripathi

Graduate Student, School of Sustainable Engineering and the Built Environment
Arizona State University

Sooraj Nair

Senior Researcher, Gypsum Panel Laboratory

USG corporation

Harshitsinh Chauhan

Project Engineer

Coreslab Structures

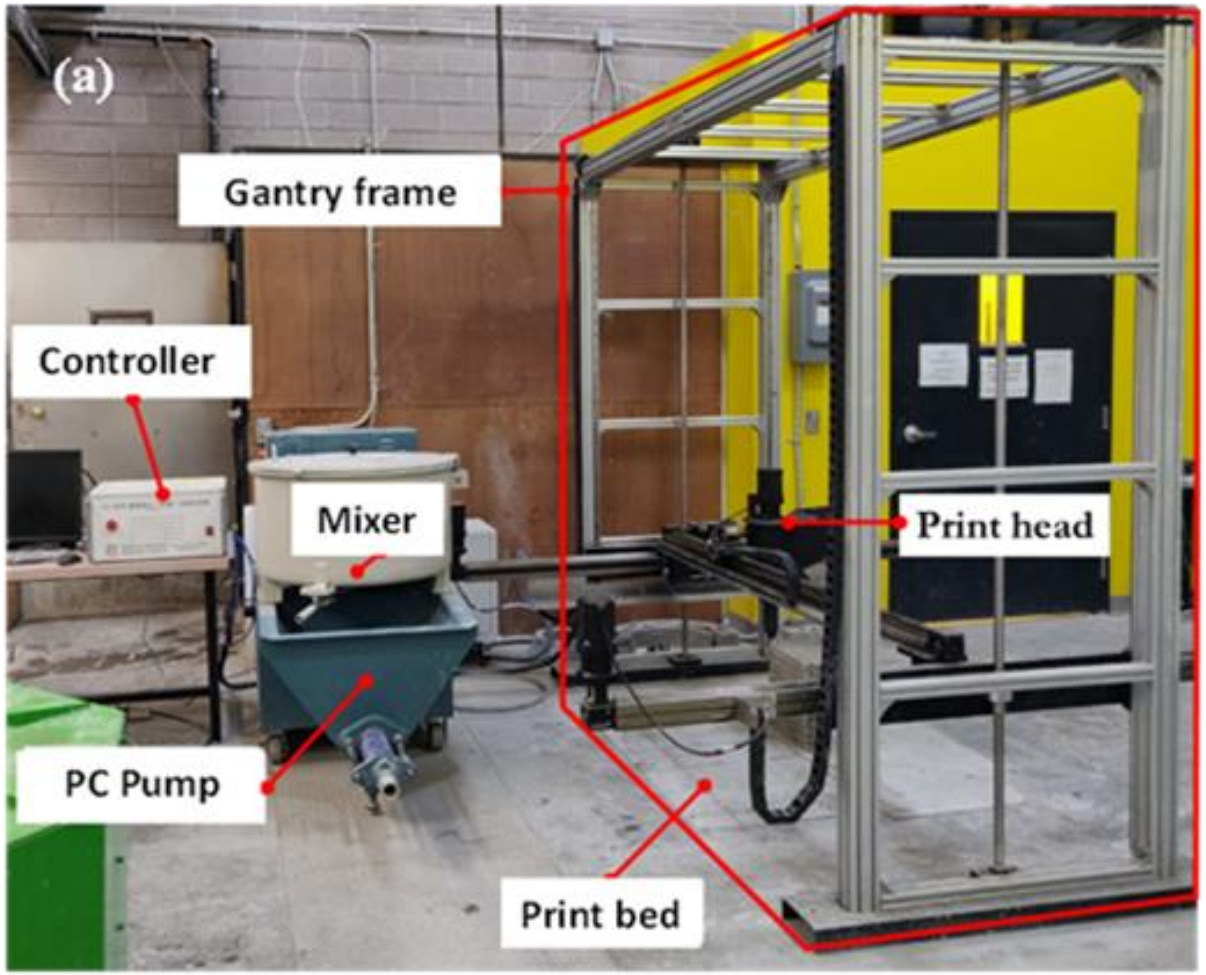
Barzin Mobasher, Narayanan Neithalath

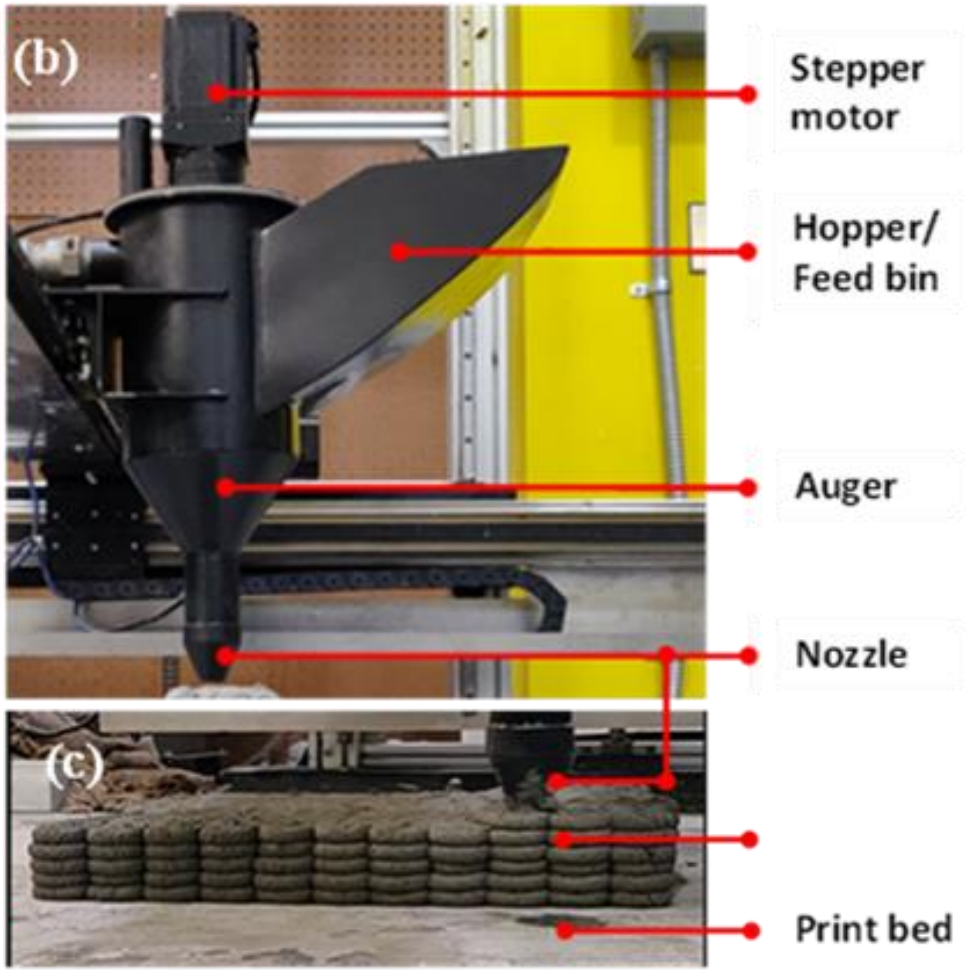
School of Sustainable Engineering and the Built Environment
Arizona State University
Narayanan.Neithalath@asu.edu
http://neithalath.engineering.asu.edu; http://3dconcrete.asu.edu

Presented at The Spring ACI convention, San Francisco, April 2023

Concrete 3D Printing

Concrete printer

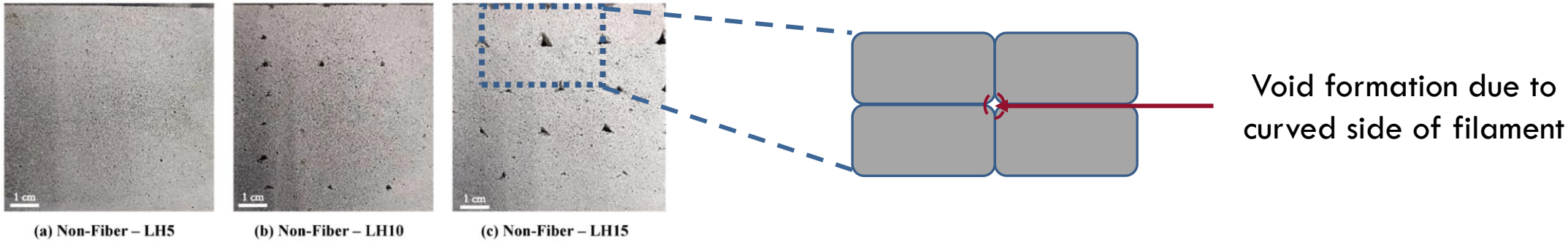




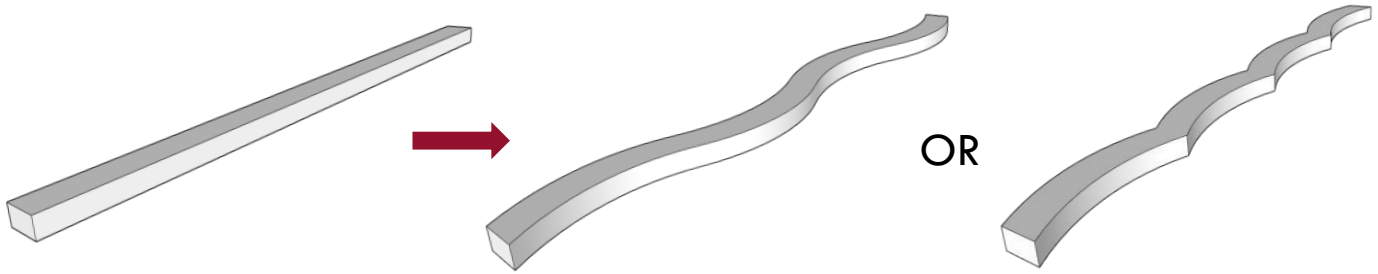
Presented at The Spring ACI convention, San Francisco, April 2023

Conventional Printing

- Lack of compaction results in weak bonding, sometimes formation of gap/voids mainly when using larger layer height

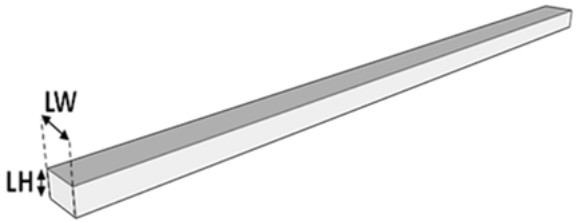


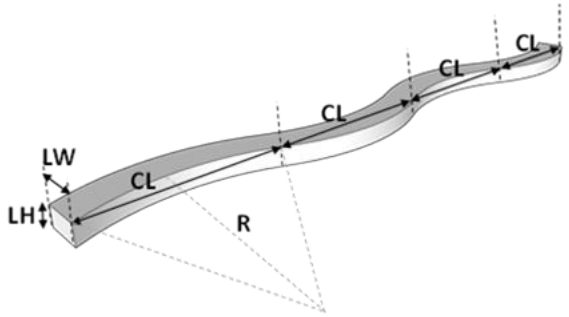
- Usually linear extrudate printed in practice, why not curve them?

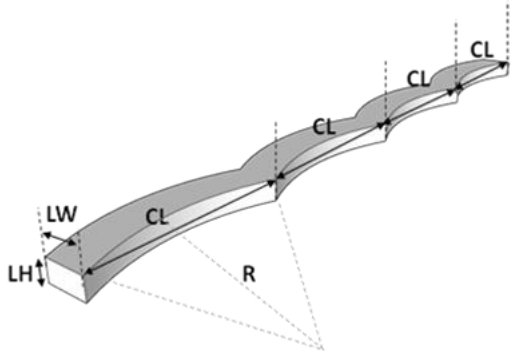


- Staggering layer could help reduce chances of void formation
- Use of fiber can help bridge crack once they initiate

Filament dimensions







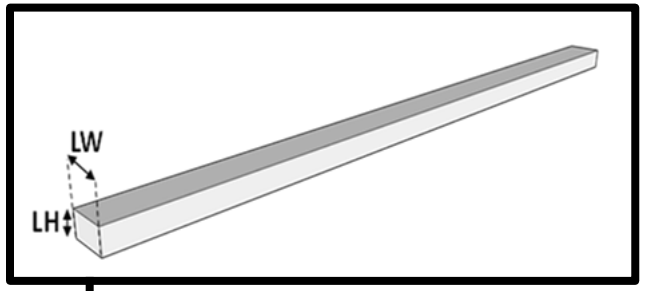
Layer Height (LH) = 10 mm;

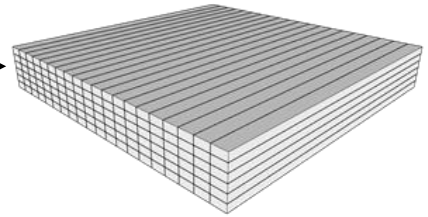
Layer Width (LW) = 20 mm

Chord Length (CL) = 100 mm

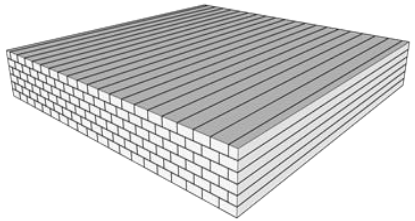
Radius (R) = 120 mm

Layering type

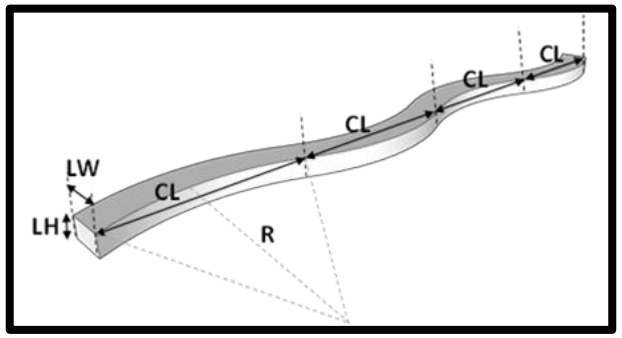


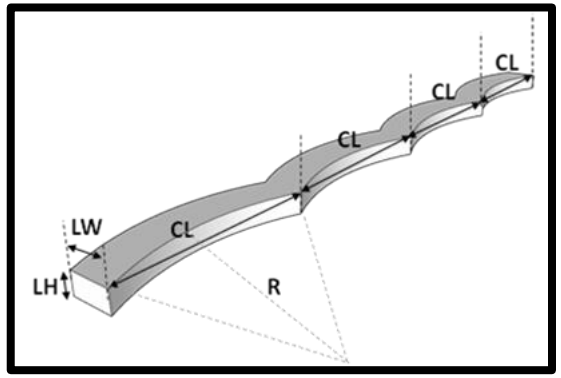


Linear Conventional (L-C)

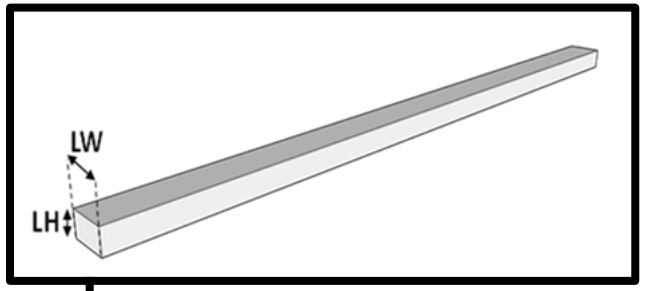


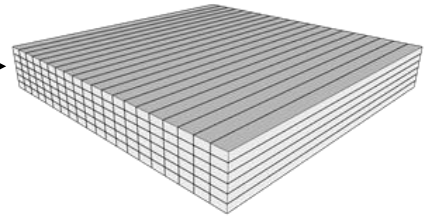
Linear Staggered (L-S)



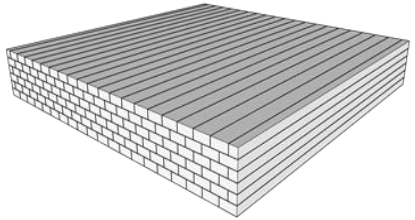


Layering type

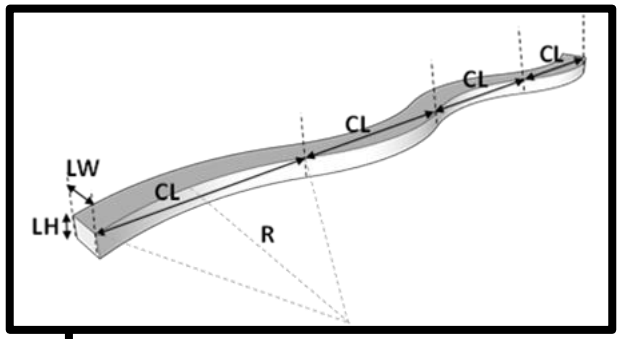


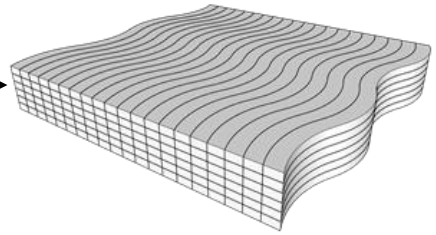


Linear Conventional (L-C)

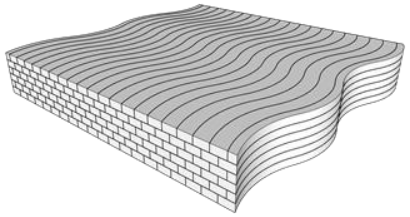


Linear Staggered (L-S)

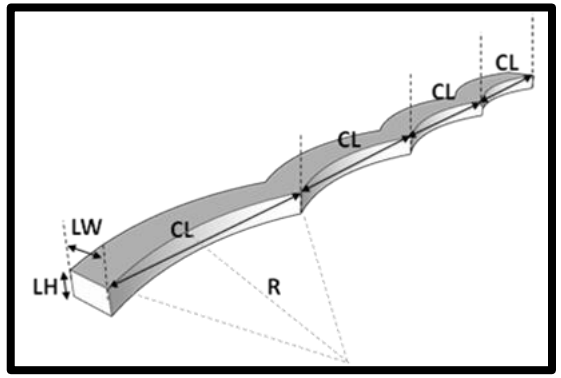




S-shaped Conventional (S-C)

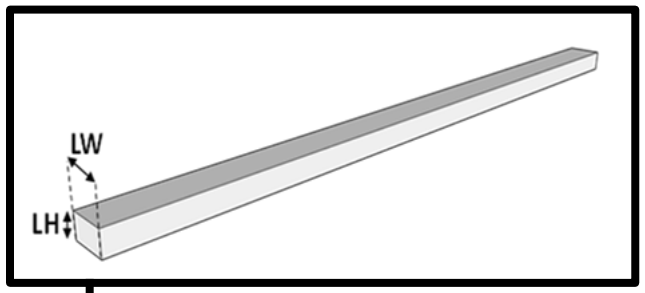


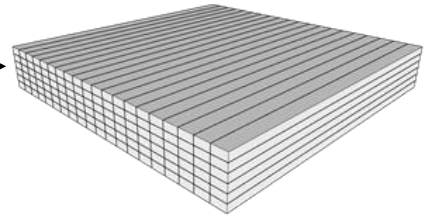
S-shaped Staggered (S-S)



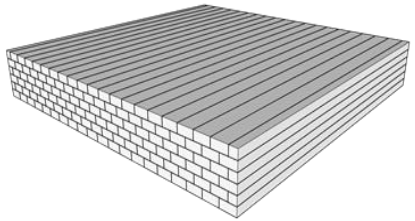
Presented at The Spring ACI convention, San Francisco, April 2023

Layering type

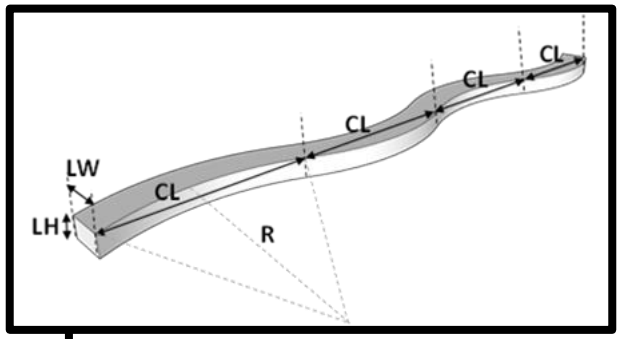


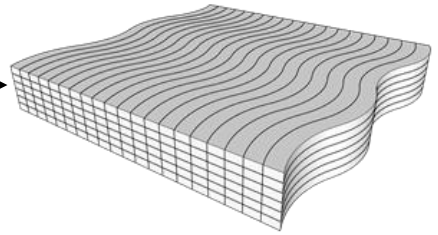


Linear Conventional (L-C)

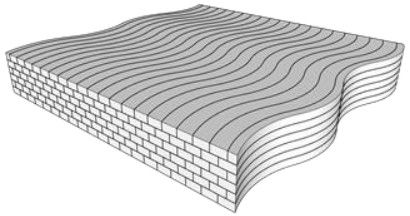


Linear Staggered (L-S)

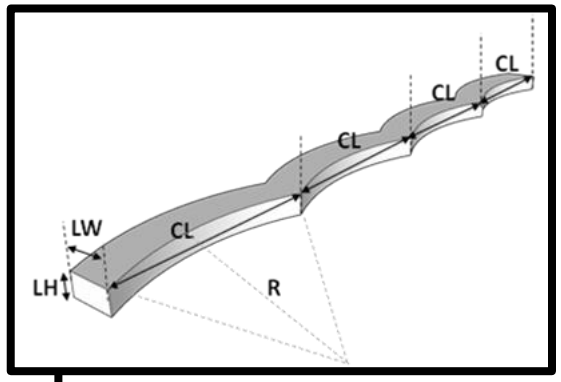


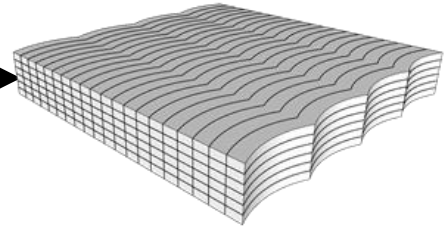


S-shaped Conventional (S-C)



S-shaped Staggered (S-S)



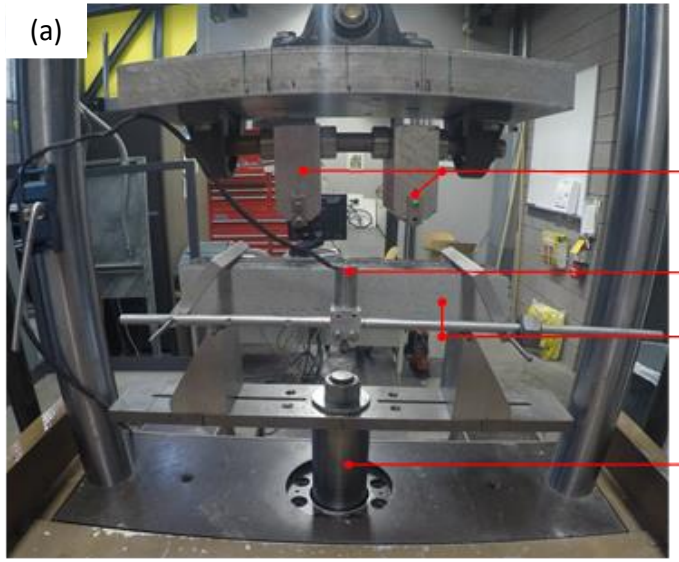


3-shaped Conventional (3-C)

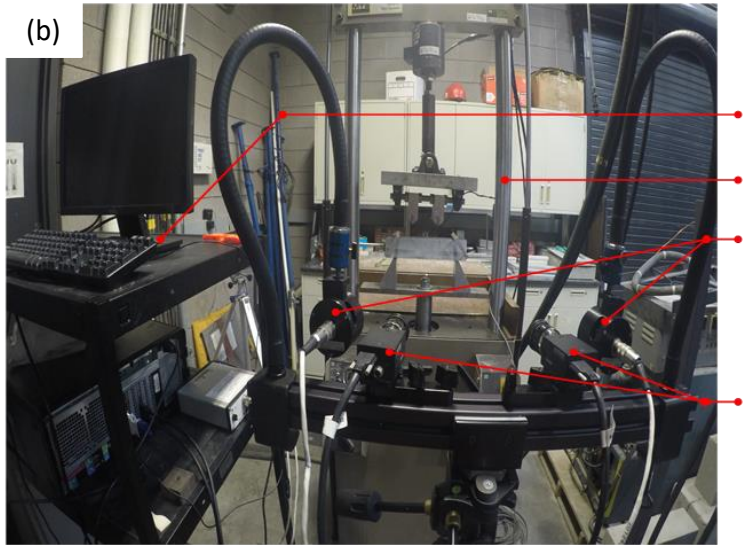
Presented at The Spring ACI convention, San Francisco, April 2023

Geometry modification effect

(a)



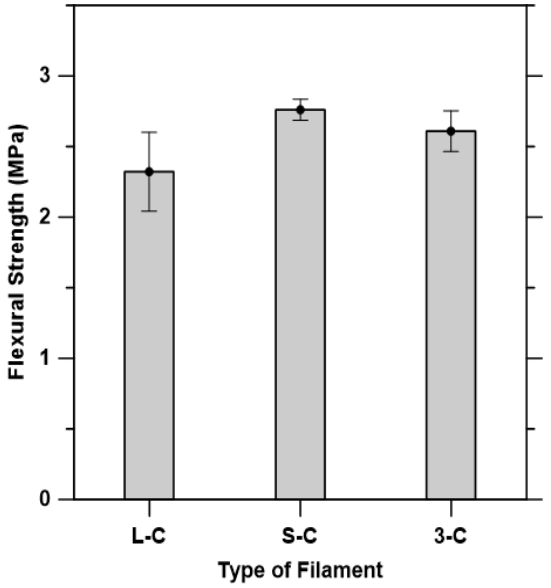
(b)

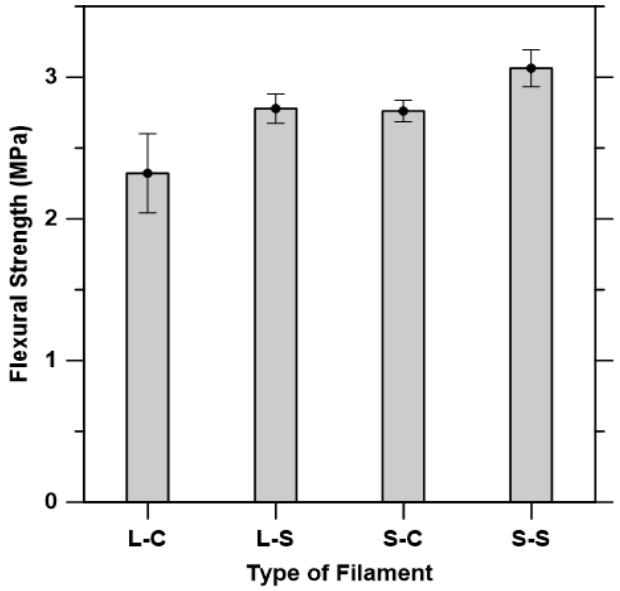


Mixture ID	Mass Fraction of Ingredients			Chopped Steel Fiber (SF)+	Chopped Basalt Fiber (BF)+	Water-to-binder ratio (w/b) by mass	SP solid to binder ratio (SP%) by mass of the binder
	OPC	Limestone (L)	Sand (M)				
L_{30}	0.35	0.15	0.5	-	-	0.35	0.05
$L_{30\text{- SF}}$	0.35	0.15	0.5	0.28	-	0.35	0.07
$L_{30\text{- BF}}$	0.35	0.15	0.5	-	0.28	0.35	0.07
+Percentage by volume of the mixture.							

Flexural Strength

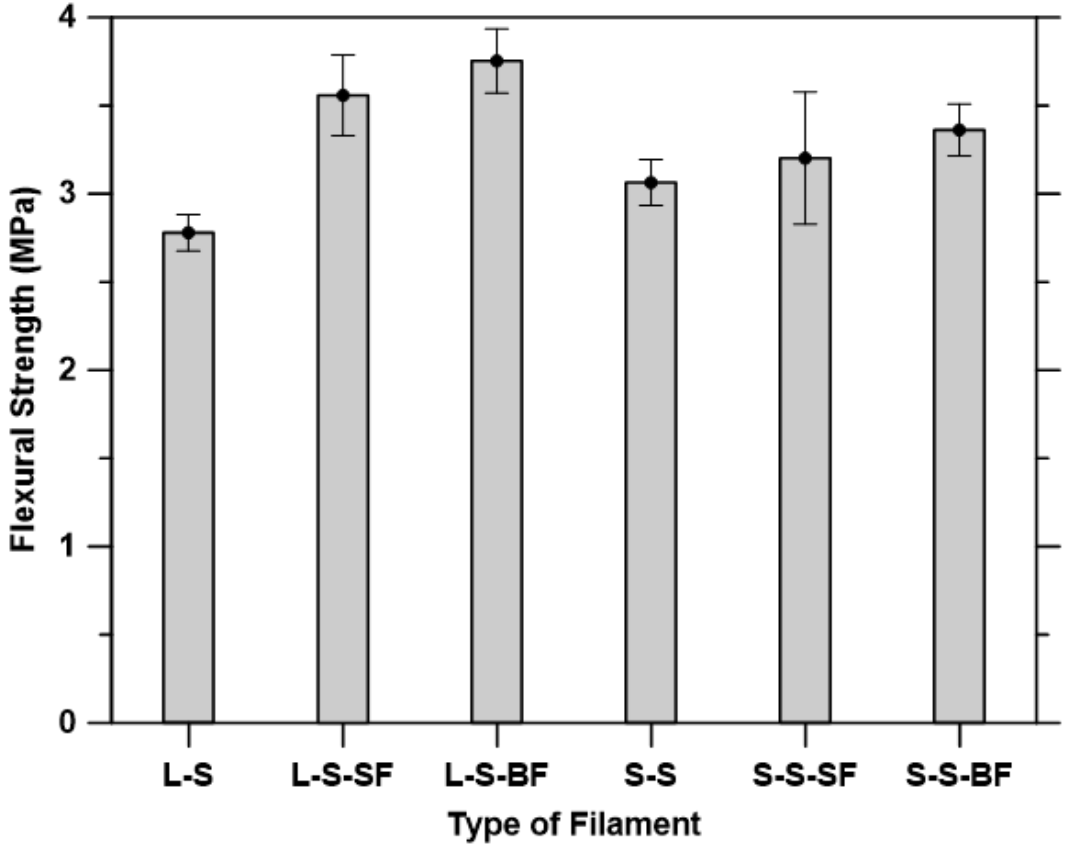
- Beam tested (60 x 60 x 300 mm).
- For L-C, inter filament joint runs parallel to the length direction.
- For S-C and 3-C, inter filament joints do not align completely to the length of the beam.
- Curved nature ensuring that the stress required to failure is higher due to the tortuosity introduce.
- Staggering of the filament ensures reduction of voids which could be formed between four filaments sitting side by side between two layers.





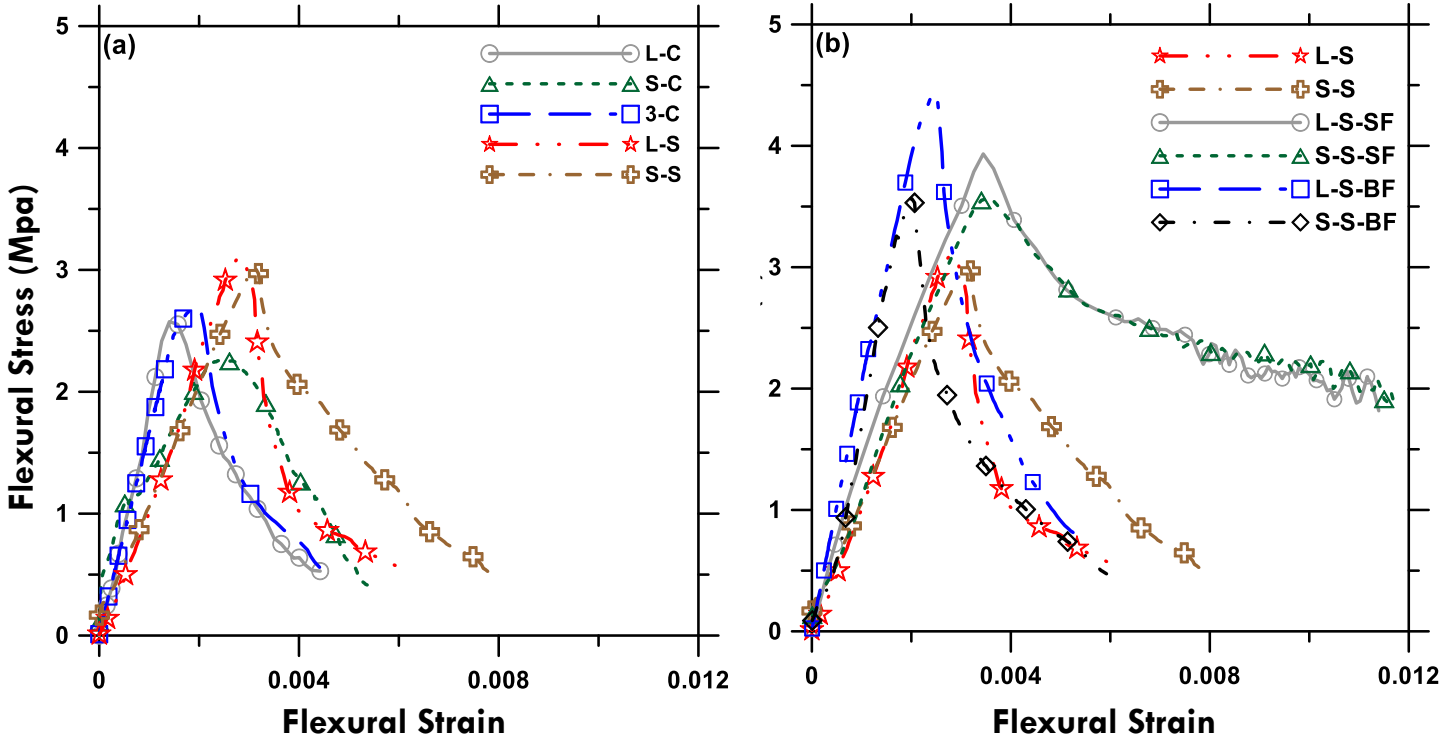
Fiber effect (at low dosage)

- Near 10-30% enhancement when fibers are used.
- Alignment of fiber along the print path meant reduced efficiency of the S-shaped filament.
- At lower percentage, use of basalt fiber resulting in higher increase in the flexural strength than using steel fiber.
- For the same volume percentage content, 13 times the number of basal fibers in the mixture as compared to steel fibers.



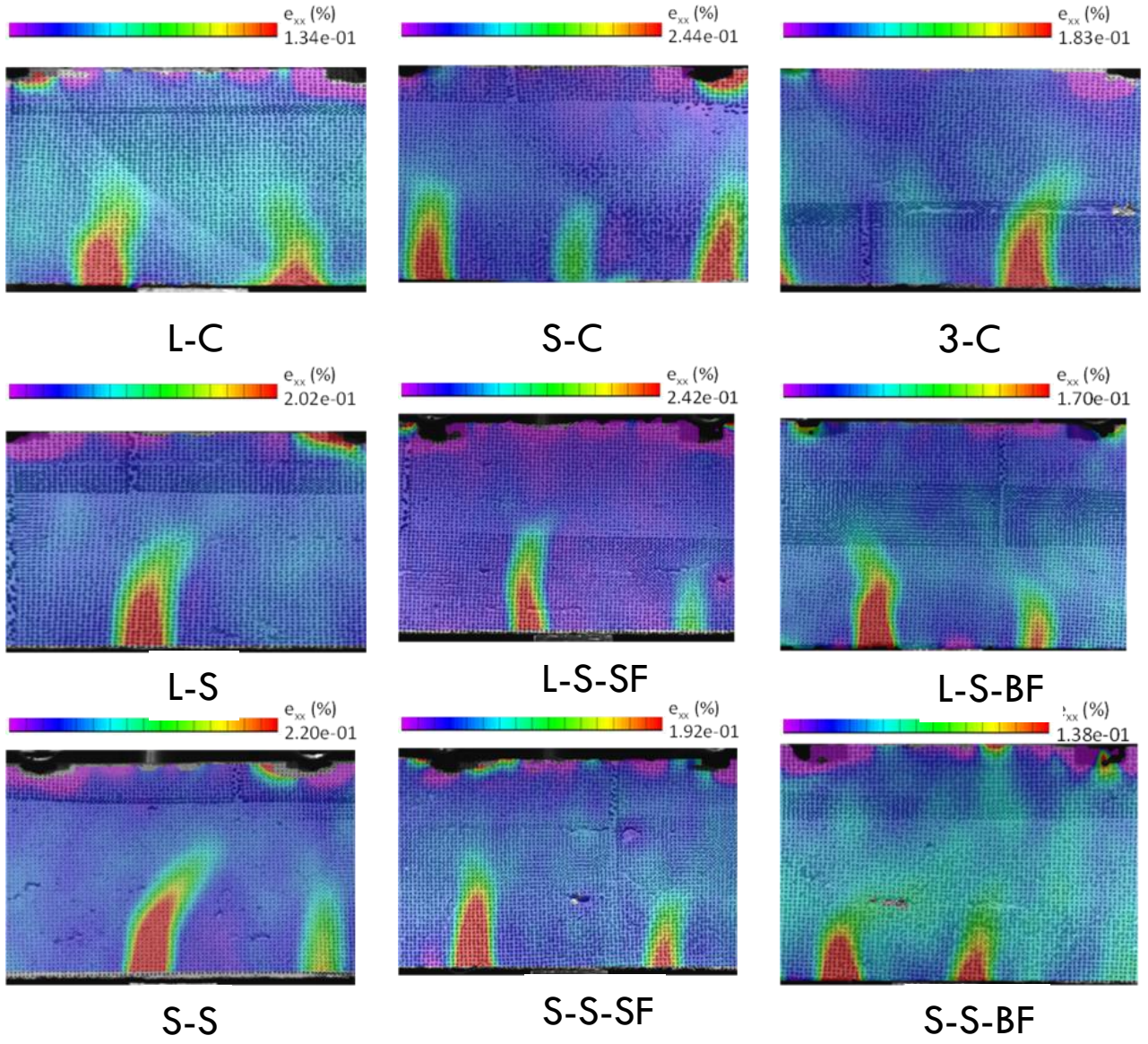
Flexural response

- Increase in flexural strain for S- and 3- shaped prints
- Basalt fiber, despite providing better flexural strength, did not provide ductility to the beams.
- Steel fiber provides ductility (providing higher toughness than with basalt fiber)
- Similar observation made from digital image correlation



Strain profile at peak

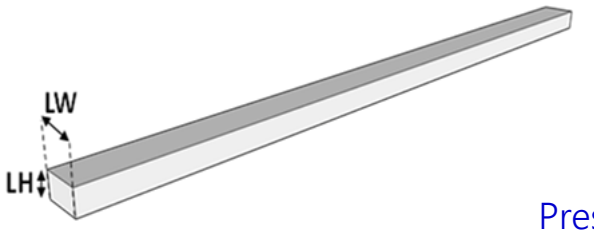
- Strain profile observed through DIC analysis agrees with the flexural response
- Redistribution of strain occurs when a crack forms, hence maximum strain at peak stress are not indicators of average strain across the depth when LVDTs or strain gages are used.
- Multiple strain concentration location observed, finally one dominates and crack initiates from that place



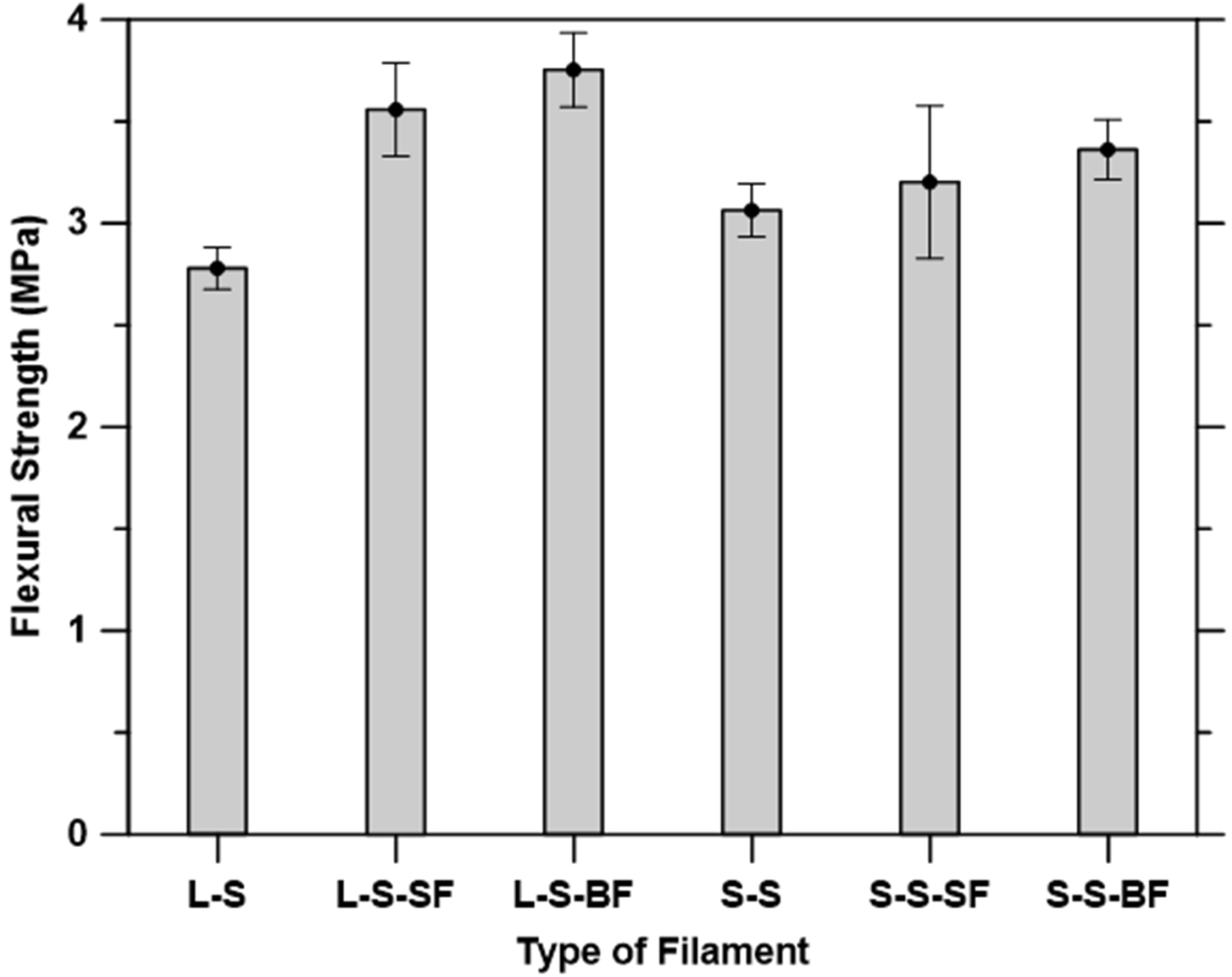
UHPC mixture (high fiber dosage)

Mixture ID	Mass Fraction of Ingredients					Chopped Steel Fiber (SF)*	Chopped Basalt Fiber (BF)*	Water-to-binder ratio (w/b) by mass	SP solid to binder ratio (SP%) by mass of the binder
	OPC	Fly Ash (F)	Limestone (d_{50}=1.5 µm) (L_f)	Slag (S)	Sand (M)				
$F_{10}S_{10}(L_f)_{10}$	0.42	0.06	0.06	0.06	0.4	-	-	0.19	0.22
$F_{10}S_{10}(L_f)_{10}$-$SF_{1\%}$	0.42	0.06	0.06	0.06	0.4	1	-	0.19	0.22
$F_{10}S_{10}(L_f)_{10}$-$SF_{1.5\%}$	0.42	0.06	0.06	0.06	0.4	1.5	-	0.19	0.22
$F_{10}S_{10}(L_f)_{10}$-$BF_{1.5\%}$	0.42	0.06	0.06	0.06	0.4	-	1.5	0.19	0.22

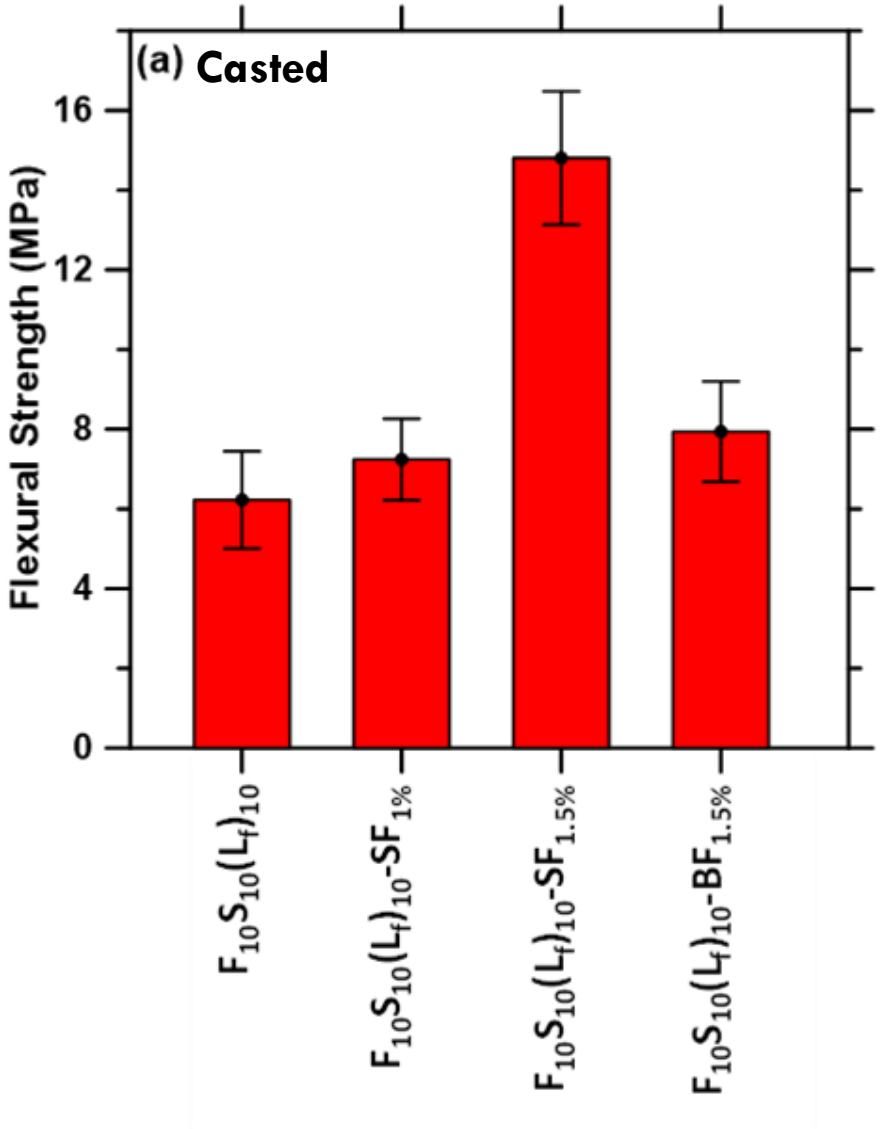
* Percentage by volume of the mixture

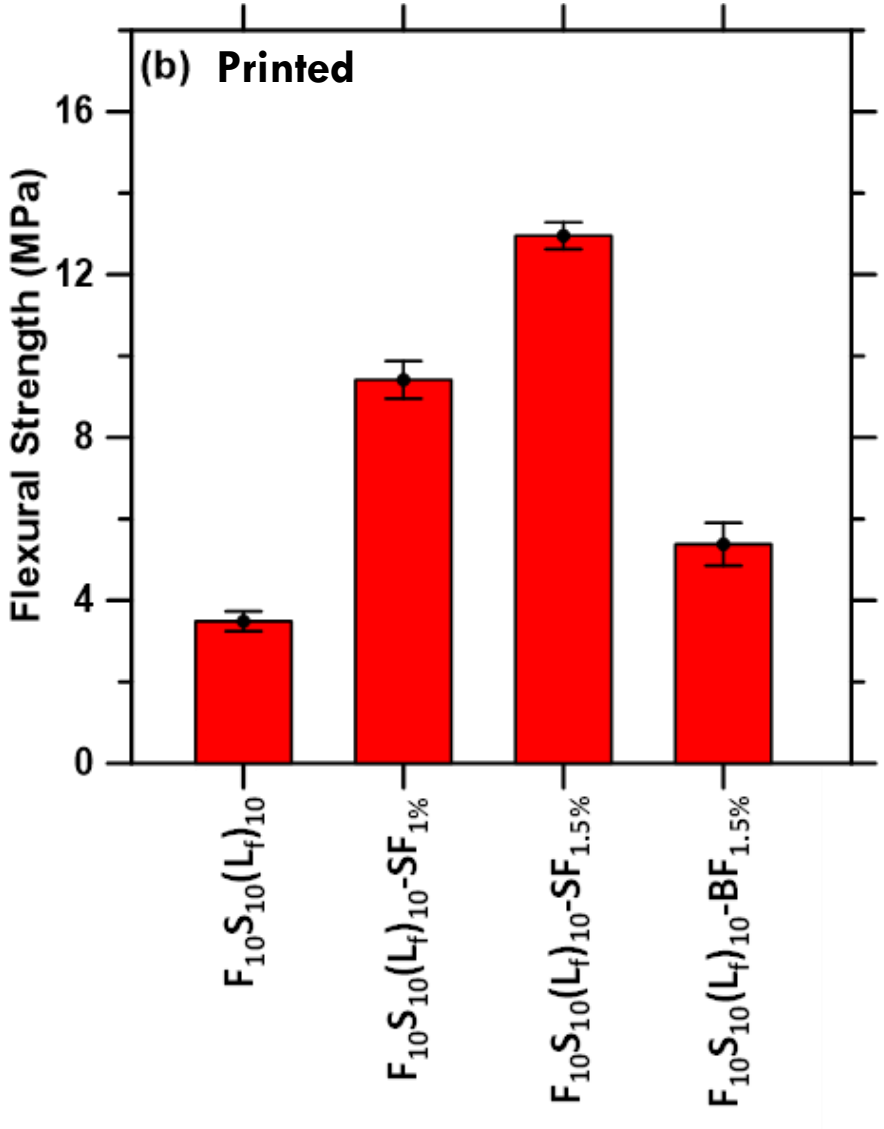


Previous flexural strength (low dosage)



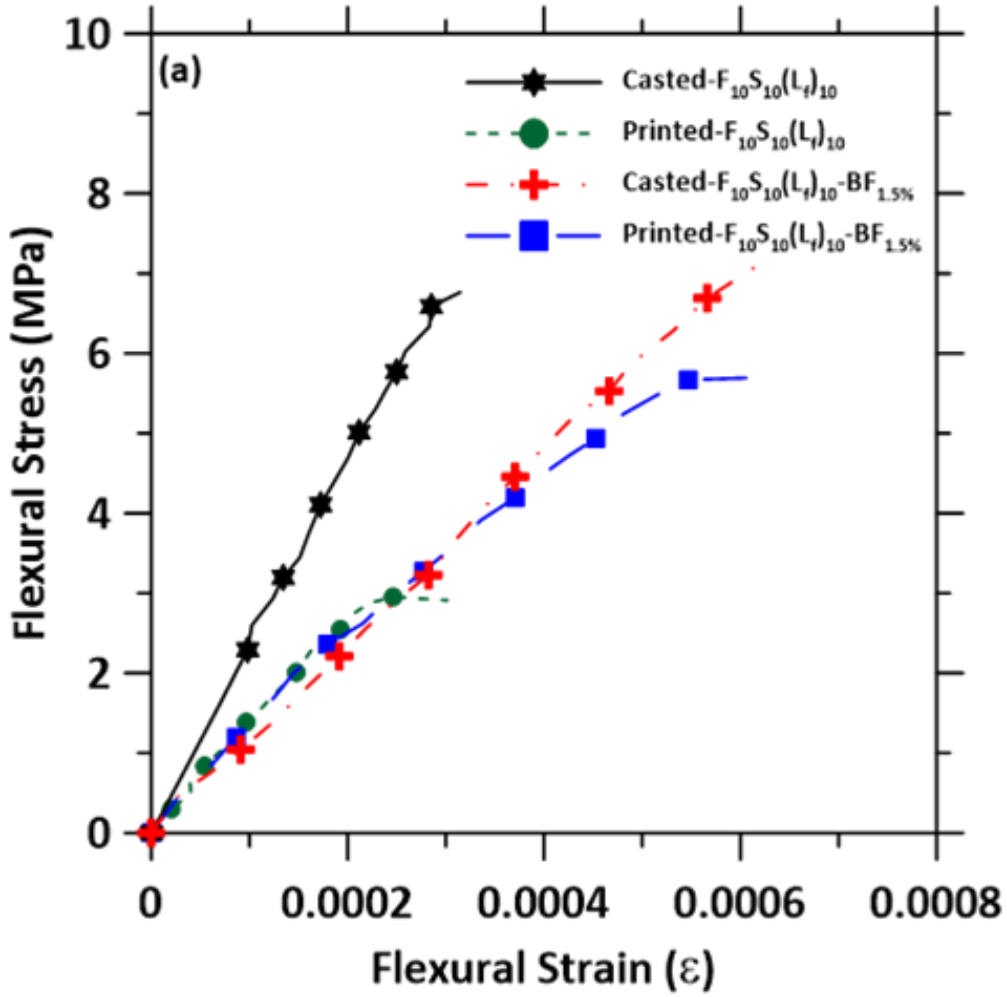
Flexural strength

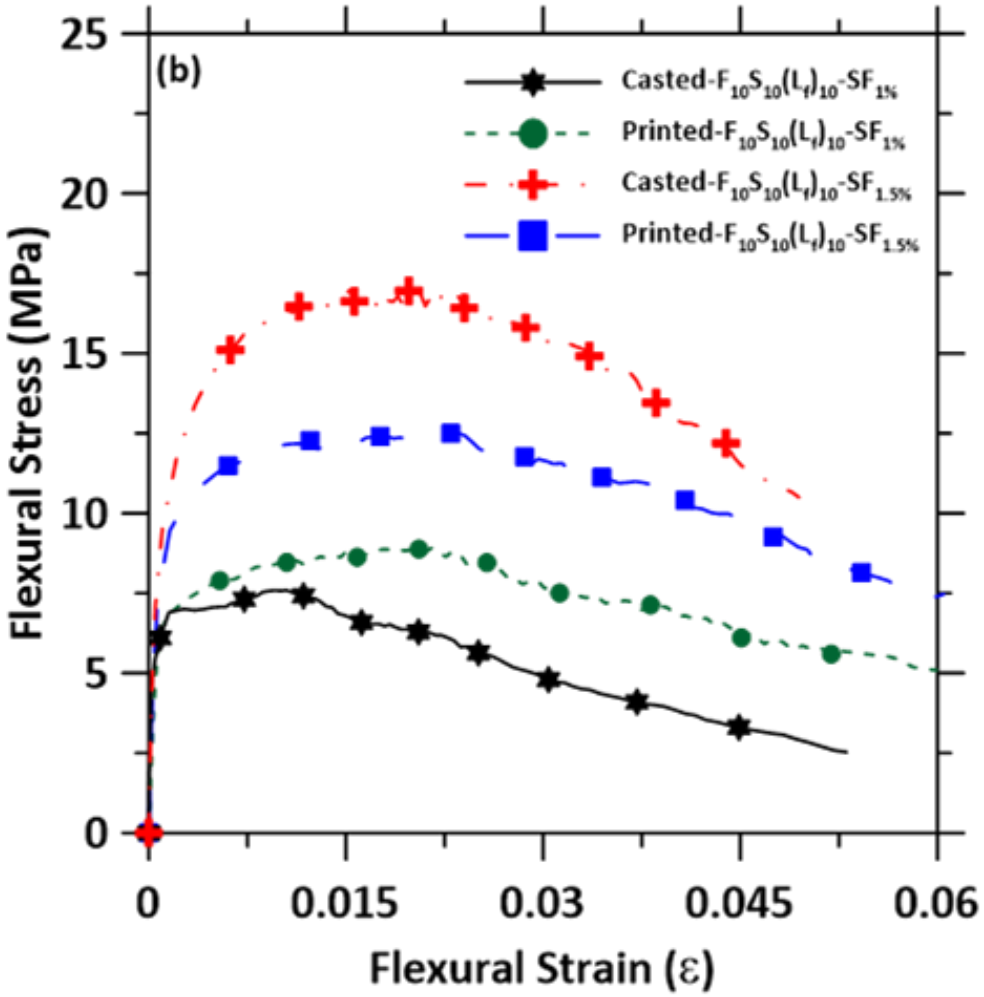




Presented at The Spring ACI convention, San Francisco, April 2023

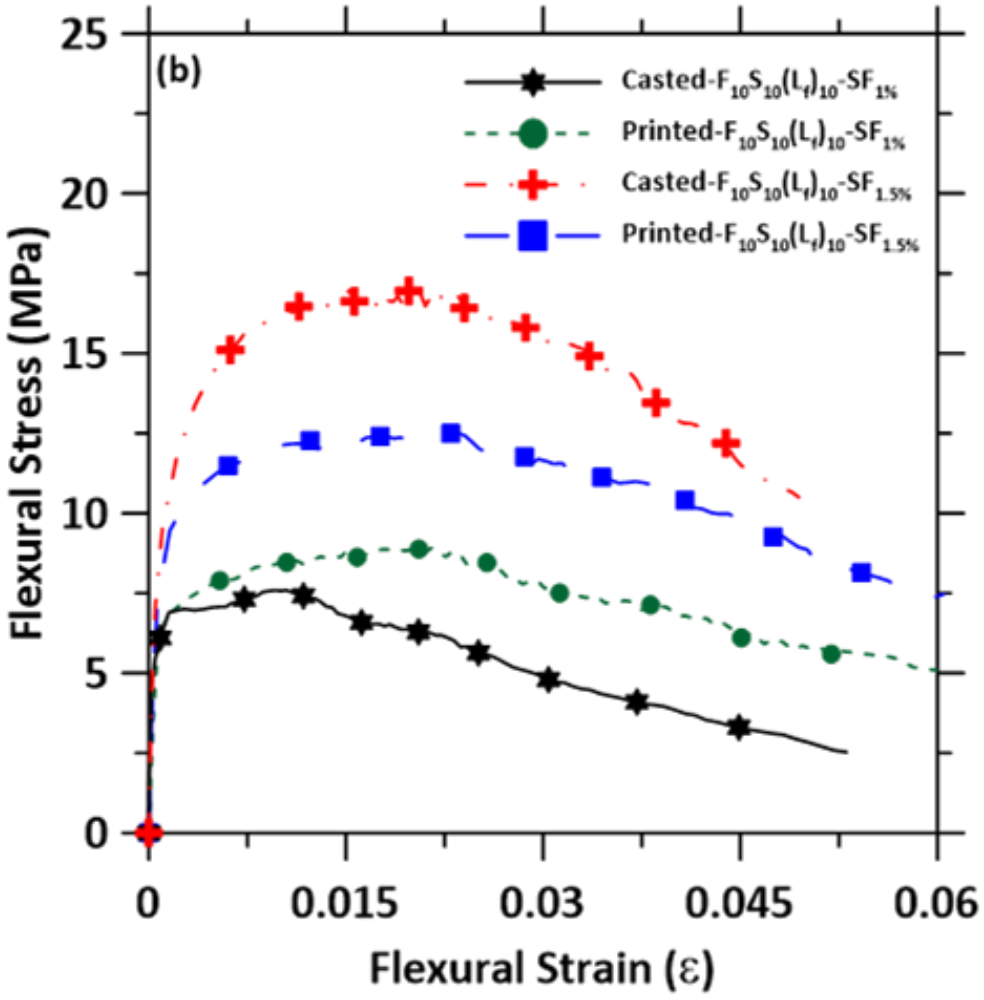
Flexural response





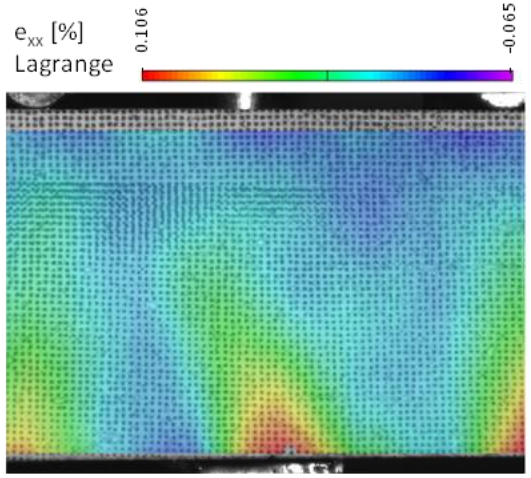
Flexural response

- Presence of basalt fiber resulted in higher flexural strain at failure
- Basalt underperforms at high fiber content (due to less tensile capacity and brittle nature)
- Printed steel fiber at 1% outperformed mold casted specimen with 1% steel fiber (attributed to alignment of fibers along the length resulting in proper crack bridging)
- Steel fiber providing high ductility, load carrying capacity increases still after the mortar matrix cracks

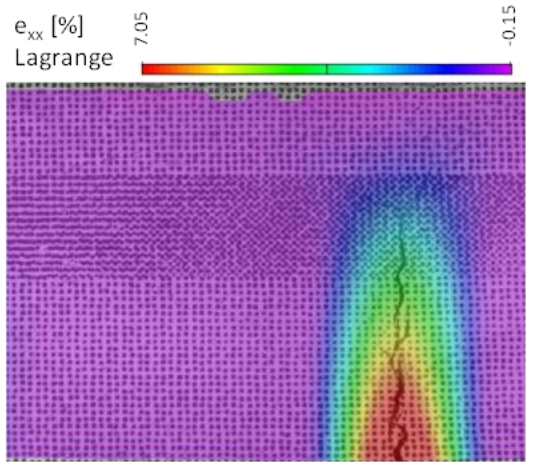


DIC peak and post peak analysis

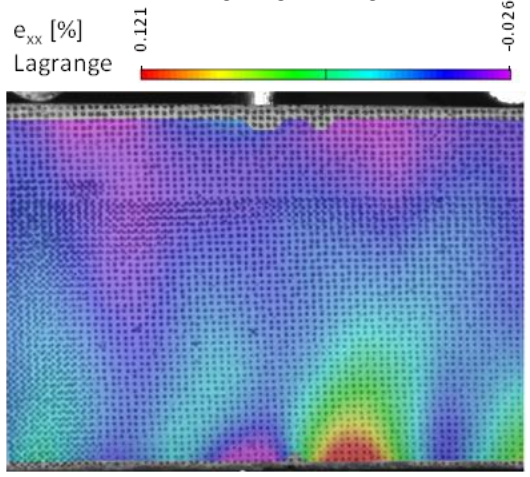
At peak load



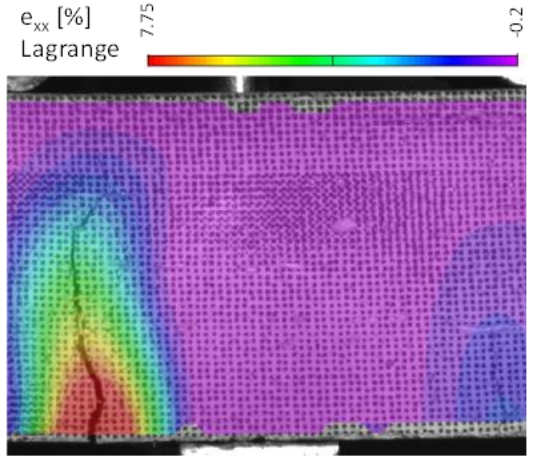
$F_{10}S_{10}(L_f)_{10}$



$F_{10}S_{10}(L_f)_{10}$-$SF_{1\%}$

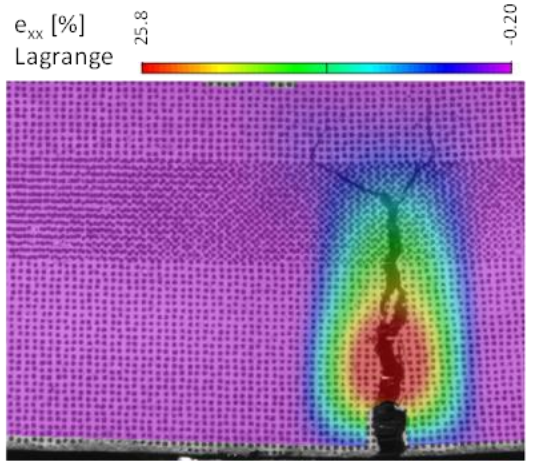


$F_{10}S_{10}(L_f)_{10}$-$BF_{1.5\%}$

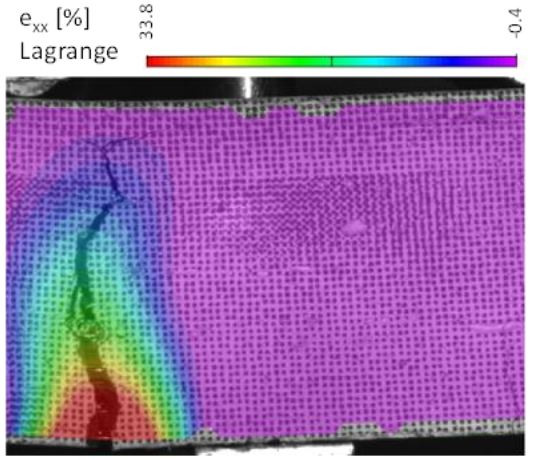


$F_{10}S_{10}(L_f)_{10}$-$SF_{1.5\%}$

At 4 mm central deflection



$F_{10}S_{10}(L_f)_{10}$-$SF_{1\%}$



$F_{10}S_{10}(L_f)_{10}$-$SF_{1.5\%}$

Presented at The Spring ACI convention, San Francisco, April 2023

Conclusion

- Enhancement of mechanical response of 3D printed element can be achieved through simpler methods
- Chopped fiber in concrete mortar used for printing helps enhance mechanical response*
- Tendency of fiber to orient in print direction could be used to advantage

Narayanan.Neithalath@asu.edu

An NSF AccelNet Collaborative Effort

QUESTIONS?