Anisotropic chloride transport in 3D printed concrete and its dependence on layer height and interface types

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Presentation Outline

- Introduction: 3D Concrete Printing
- Background & Research Objective
- Experimental Program
- Results & Discussions
- Conclusions

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Introduction: 3D Concrete Printing

Building structures ***layer-by-layer using 3D printers***, capable of creating ***complex geometries*** that would be difficult to achieve with traditional construction methods while allowing several benefits such as:

i) ***Design optimization*** allows the use of material only where it is structurally/functionally needed, reducing overall material usage

ii) ***Formwork-efficient*** and ***waste-reducing approach*** to construct complex structures

iii) ***High-end technology-based jobs*** are created in the construction industry while ***enhancing field safety conditions*** by eliminating dangerous activities

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Background & Research Objective

- Layer-by-layer extrusion method of 3D printing has the potential to result in increased void fraction, especially at the interface of the layers and filaments
- Interfacial zone acts similar to cracks, and offers minimal resistance to the transport of deleterious species
- Variation in print parameters results in differences in the bulk microstructure within a layer, the interface type, the orientation of the interfaces, and the length of transport through these interfaces

<u>Research Objective:</u>

Examine the influence of layer dimensions and the directional dependence on the chloride transport resistance of plain and basalt fiber-reinforced 3D printed mortars

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Experimental Program

Materials and mixtures:

Chemical composition and physical properties of the mortar components used

Components of the binders	Chemical composition (% by mass)							d_{50} (mm)	Specific gravity
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI*		
OPC	19.60	4.09	3.39	63.21	3.37	3.17	2.54	10.4	3.15
Limestone(L)	$CaCO_3$>99%							1.5	2.70
Medium Sand (M)	SiO_2>99%							200	2.40
*Loss of Ignition									

Properties of chopped basalt fibers

Diameter (mm)	0.04-0.06
Length (mm)	15
Specific gravity	2.36
Tensile strength (GPa)	0.28
Young's modulus (GPa)	18

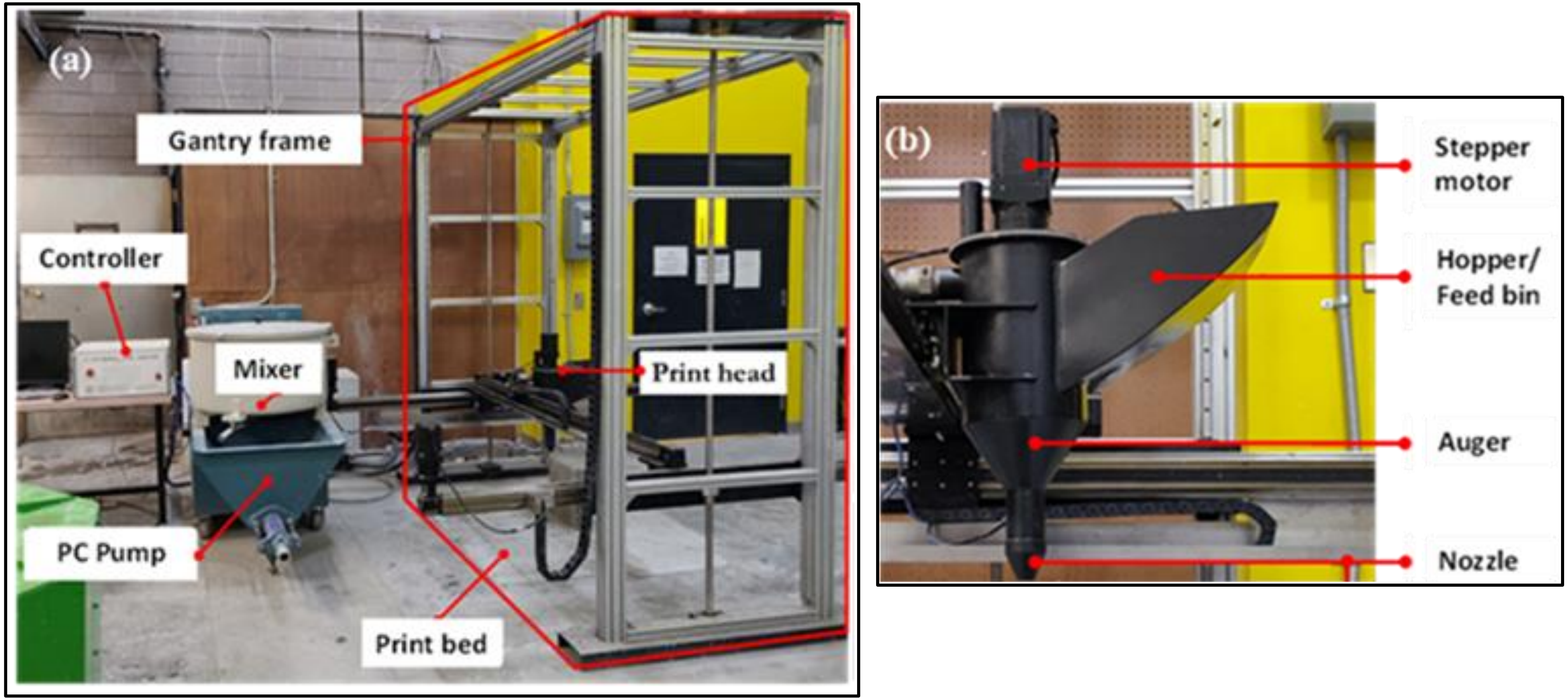
Mortar mixture proportions used in the study

Mixture ID	Mass Fraction of Ingredients			Chopped Basalt Fiber (BF)+	Water-to-binder ratio (w/b) by mass	SP to binder ratio (SP%) by mass of the binder
	OPC	Limestone (L)	Sand (M)			
L_{30}	0.35	0.15	0.5	-	0.35	0.25
L_{30-BF}	0.35	0.15	0.5	0.28	0.35	0.35
+Percentage by volume of the mixture						

Experimental Program

Ira A. Fulton Schools of Engineering
Arizona State University

3D printing of mortars:



Printer setup showing: (a) the gantry printer with the controller and the mixer, and (b) close-up of the print head

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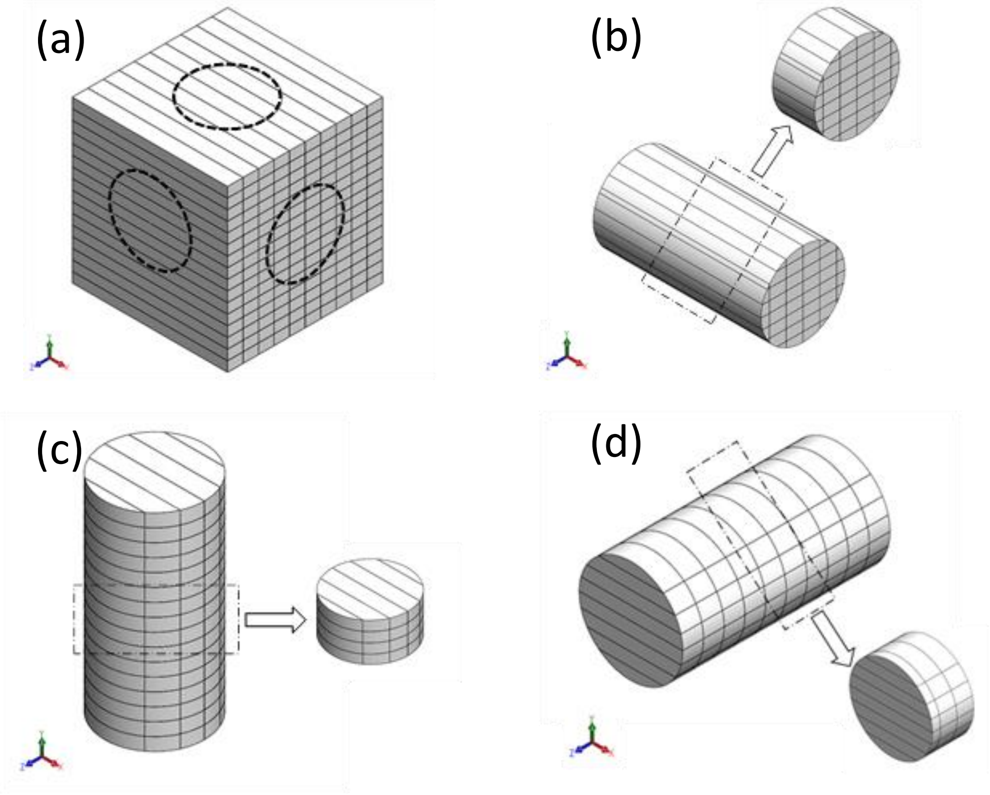
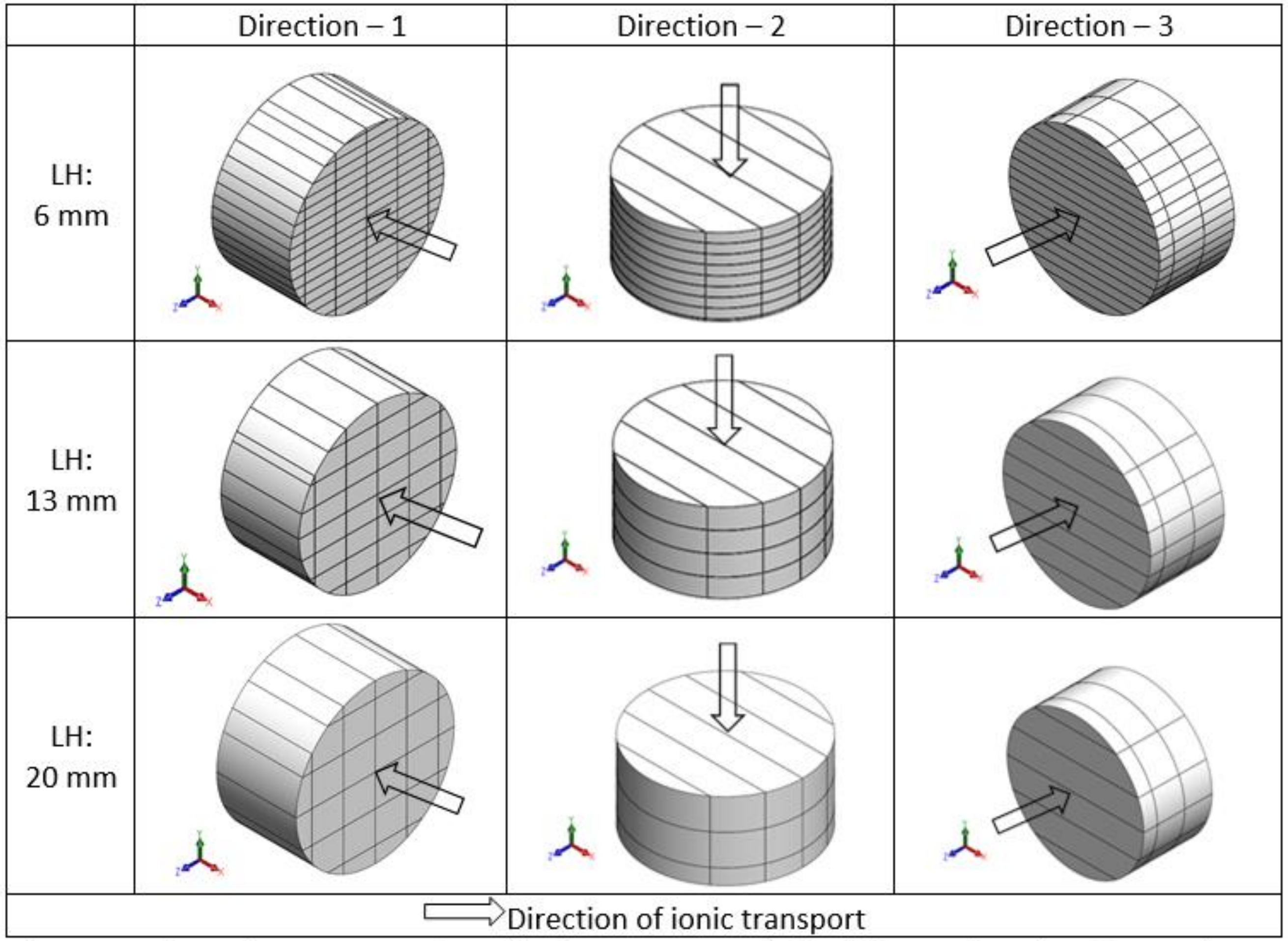


Test specimen preparation details: (a) representation of three coring directions in the 3D printed slabs. Sliced 50 mm thick discs from 200 mm × 100 mm cylinders cored in directions: (b) D1, (c) D2, and (d) D3

Schematic representation of ionic transport paths in different directions for specimens printed using different layer heights



Experimental Program

Test methods and experimental matrix:

<table>
<tr><th>Experiments</th><th>Test standard</th><th>Parameters studied</th><th>Specimen geometry</th><th>Specimens tested</th></tr>
<tr><td>Non-steady state migration test</td><td>NT BUILD 492</td><td rowspan="4">• Specimen preparation method (Cast and 3D printed)
• Mixtures (L_{30} and $L_{30\text{ - }BF}$)
• Layer height (6, 13, and 20 mm)
• Directions (D1, D2, and D3)</td><td>Cylindrical discs (100 × 50 mm)</td><td>40</td></tr>
<tr><td>Vacuum saturation</td><td>RILEM CPC 11.3</td><td>Cylindrical discs (100 × 50 mm)</td><td>40</td></tr>
<tr><td>Mercury intrusion porosimetry</td><td></td><td>Small pieces taken from layer bulk</td><td>16</td></tr>
<tr><td>Bulk electrical resistivity</td><td>ASTM C1876</td><td>Cylindrical discs (100 × 50 mm)</td><td>40</td></tr>
</table>

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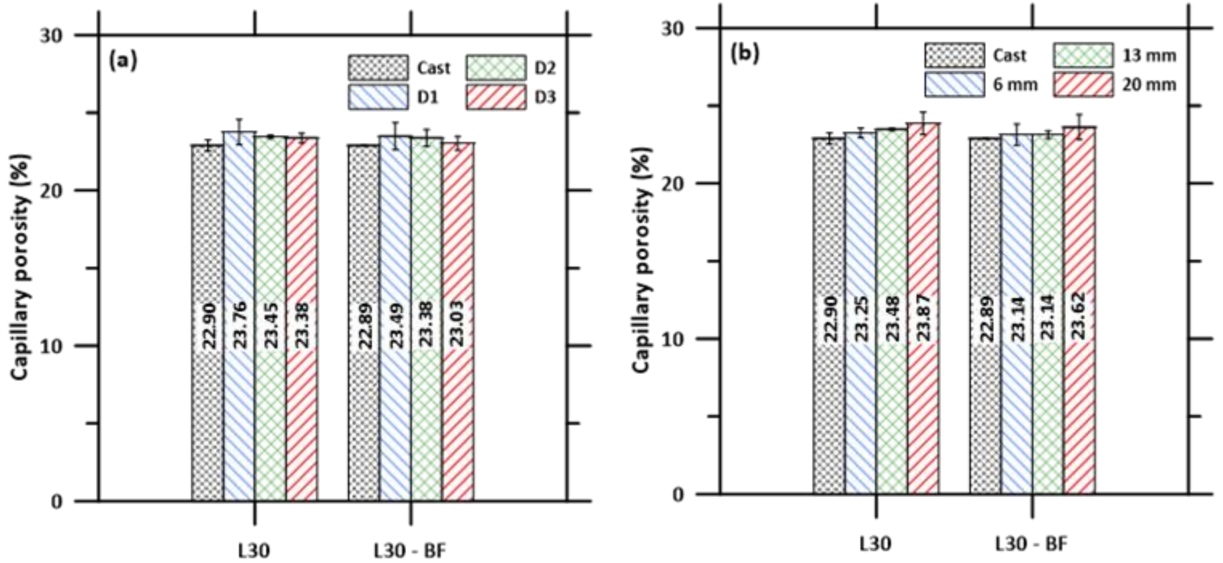
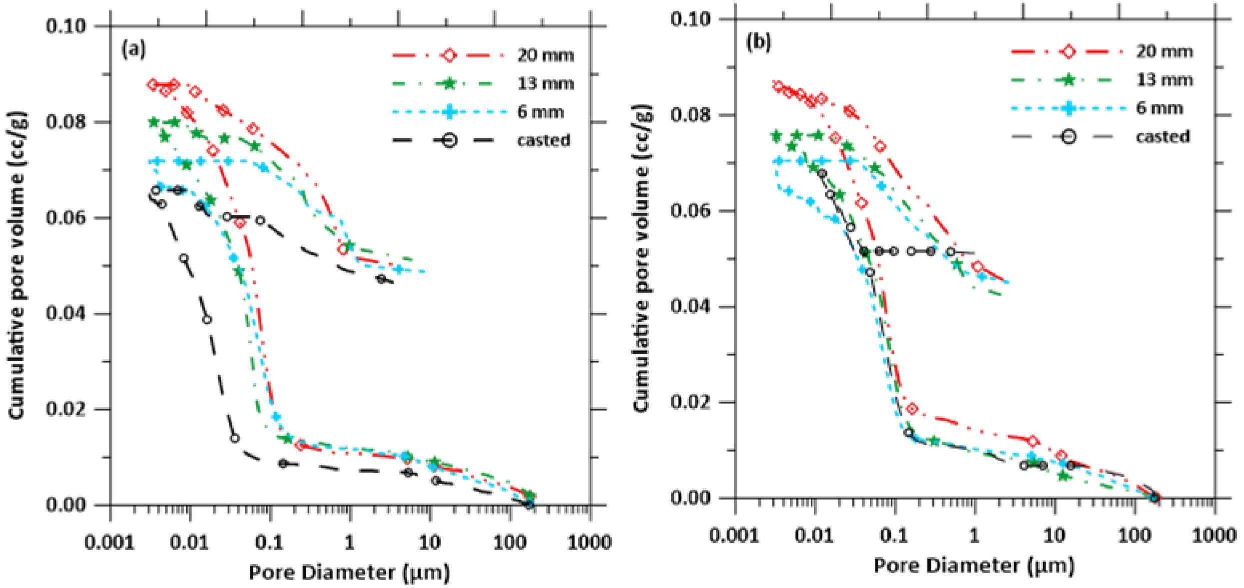
Porosity and pore structure:



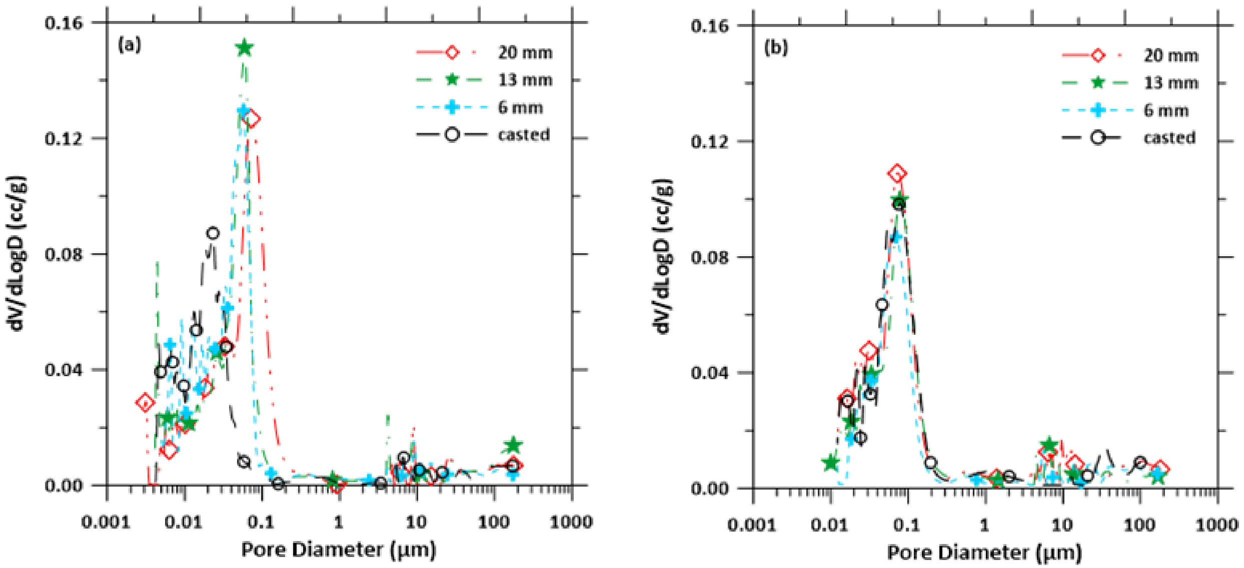
Capillary porosity of the printed samples: (a) along the three directions of testing, and (b) with varying layer heights



Representative cumulative pore volume curves for: (a) L_{30} mixture, and (b) L_{30-BF} mixture. Both the intrusion (bottom) and extrusion (top) curves are shown

Results & Discussions

Porosity and pore structure:



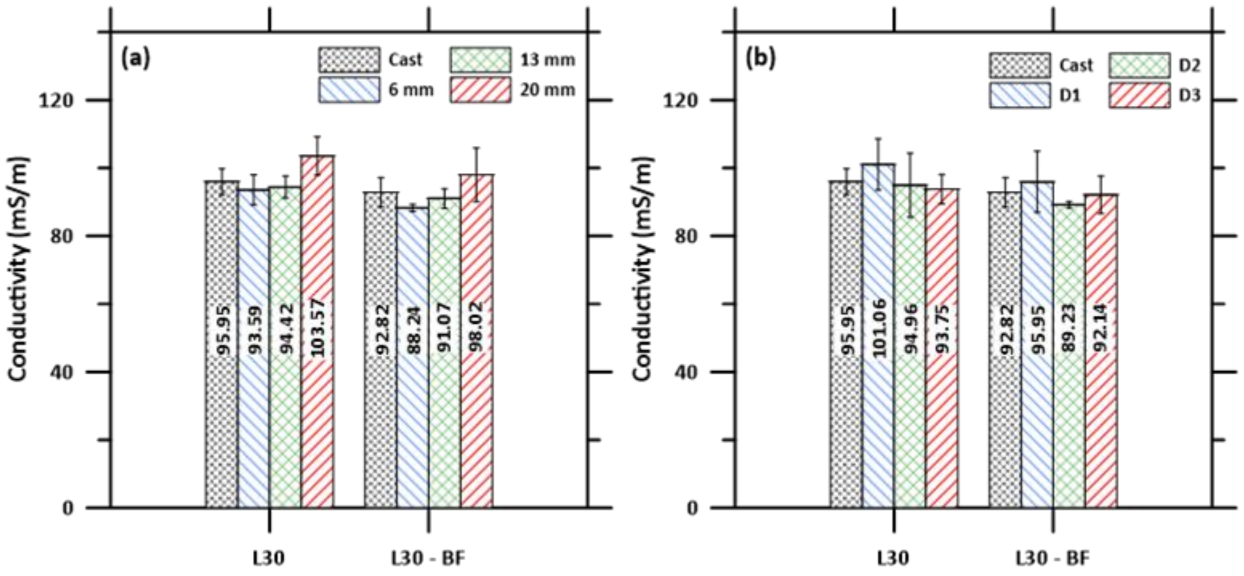
Pore size distribution curves for: (a) L30 mixture, and (b) L30 – BF mixture

Pore structure information from MIP

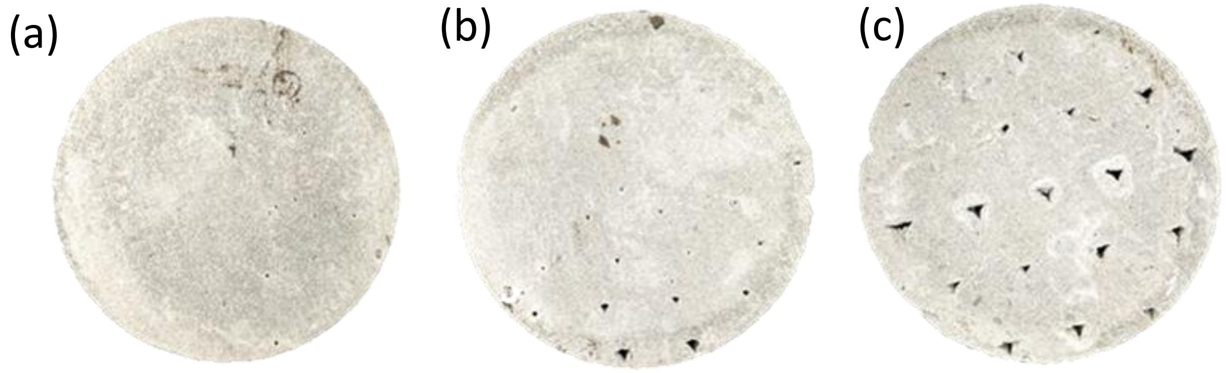
Mixture	Specimen preparation method	Layer height (mm)	Cum. vol. intruded (cc/g)	Vol. of mercury retained (cc/g)	Porosity (%)	Critical pore diameter (nm)	Retention factor, R (%)
L_{30}	Cast	-*	0.066	0.039	14.48	22.91	59.09
	Printed	6	0.072	0.039	15.82	57.72	54.17
		13	0.080	0.041	17.60	60.35	51.25
		20	0.088	0.040	19.34	74.91	45.45
$L_{30\text{-}BF}$	Cast	-*	0.068	0.042	14.96	78.46	61.76
	Printed	6	0.070	0.036	15.47	66.26	51.43
		13	0.076	0.033	16.72	78.57	43.42
		20	0.087	0.032	19.23	76.45	36.78
	* Layer height parameter not applicable for casted specimens						

Results & Discussions

Bulk electrical properties:



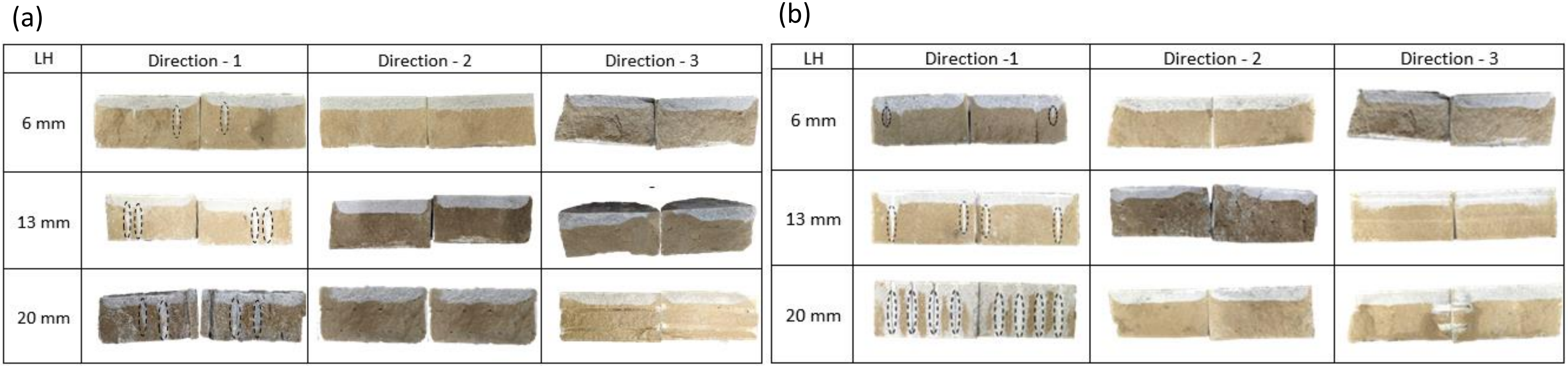
Bulk electrical conductivity of the printed specimens obtained from resistivity meter as a function of: (a) layer heights, and (b) directions based on samples extracted to carry out the chloride ion transport tests



Representative cross-sections showing voids formed at the inter-filament interfaces for layer heights of: (a) 6 mm, (b) 13 mm, and (c) 20 mm. The figures show cross-sections along direction D1, which is into the plane of the images

Results & Discussions

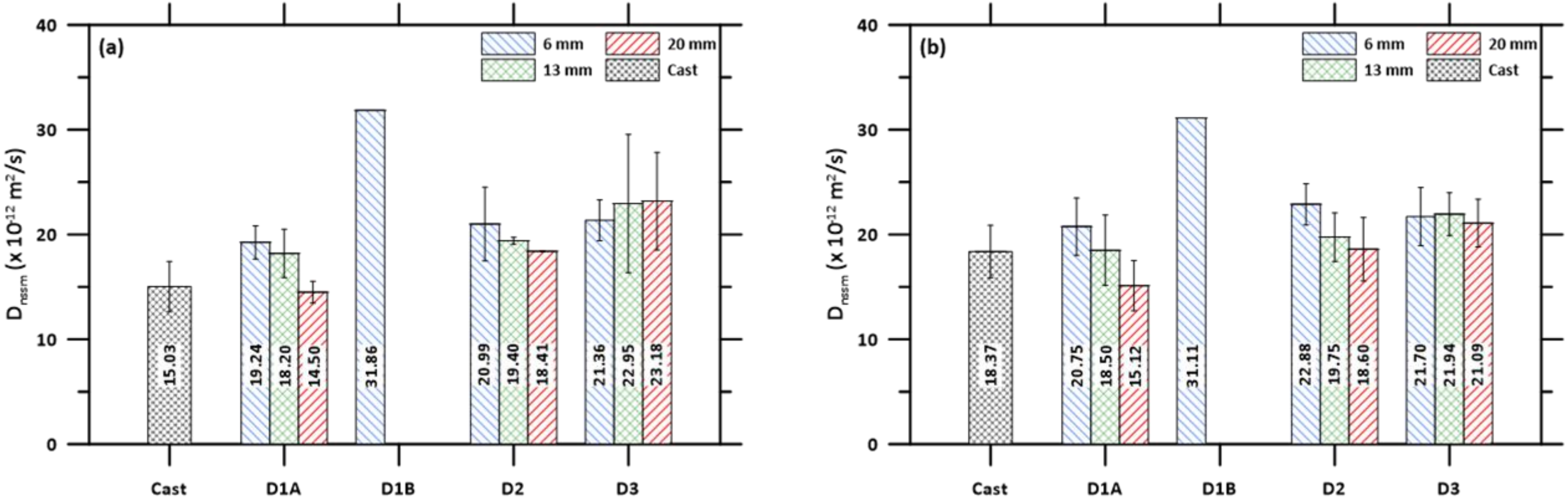
Non-steady state migration (NSSM) coefficients:



Axially split samples, along the three directions, of 3D printed (a) L_{30} mortar samples and, (b) $L_{30\text{-}BF}$ after the NSSM test and spraying silver nitrate. The oval highlights the chloride ingress path in the samples tested in – direction D1 for all layer heights

Results & Discussions

Non-steady state migration (NSSM) coefficients:



Non-steady state migration coefficients for the 3D printed samples: (a) L30 mixture, and (b) L30 – BF mixture. D1B is not indicated for the 13 mm and 20 mm layer height samples because the chlorides penetrated the entire depth of the specimen

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Conclusions

- Investigate the influence of inter-layer and inter-filament interfaces on the chloride transport resistance of 3D printed concrete specimens using NSSM testing.
- Capillary porosity was relatively invariant with layer heights but the porosity and critical pore sizes in the bulk region of the layers decreased with decreasing layer heights due to improved consolidation.
- Anisotropy in the transport paths observed in 3D printed concrete specimens indicated the influence of direction on transport characteristics.
- The non-steady state migration coefficients (D_{nssm}) were found to depend on the layer height and direction of testing
- Inter-filament interfaces need to be minimized to ensure desirable transport characteristics.

- ***Reference:***

S. Surehali, A. Tripathi, A. S. Nimbalkar, and N. Neithalath, "Anisotropic chloride transport in 3D printed concrete and its dependence on layer height and interface types," Addit. Manuf., vol. 62, p. 103405, Jan. 2023, doi: 10.1016/j.addma.2023.103405

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THANK YOU FOR YOUR ATTENTION!