Examining influence of the printing directionality on the freeze-thaw response of 3D-printed cement paste

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GENERAL INTRODUCTION

EXPERIMENTAL DESIGN AND DATA DISCUSSION

GENERAL CONCLUSION

GENERAL INTRODUCTION

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Conventional vs Printed

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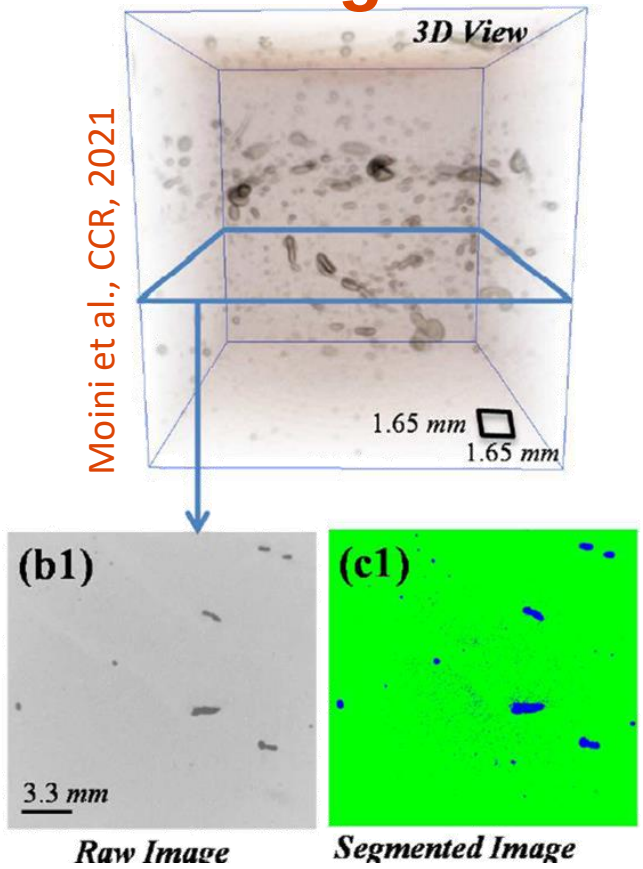
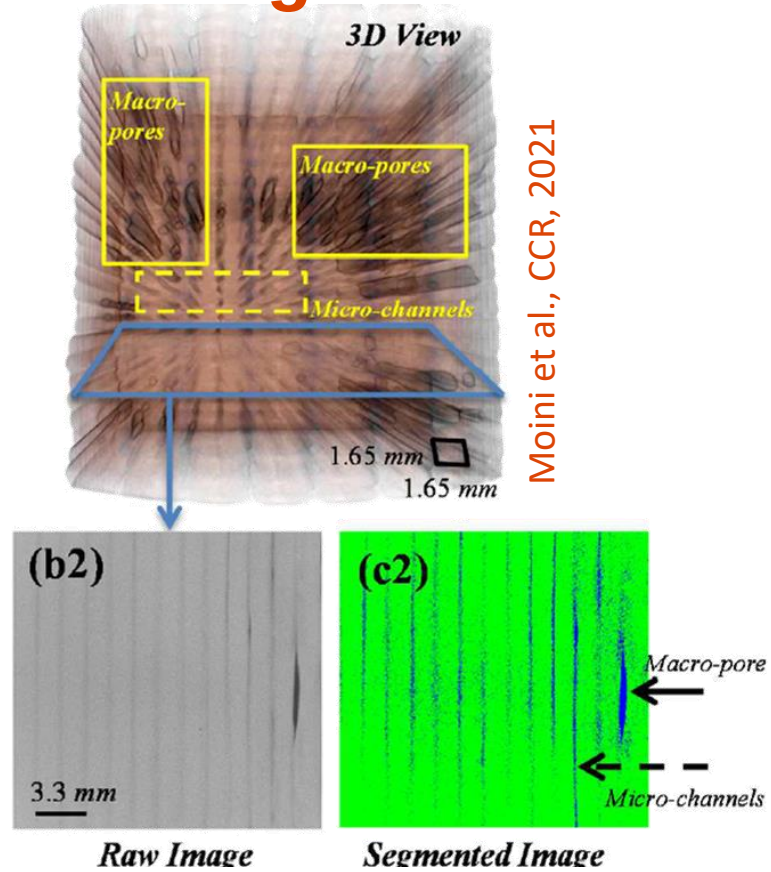
Conventionally cast cement paste sample
homogenous



How does anisotropy impact printed elements durability (**freeze thaw damage**, fluid transport, etc.) ?

3D printed cement paste sample
heterogenous



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Evaluating Freeze-Thaw

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Conventional Freeze-Thaw Testing of Concrete (ASTM C666 / C666M)

This method insensitive to anisotropy caused by printing directionality

Need to separate rate of absorption and freezing at a DOS

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Critical Saturation Model

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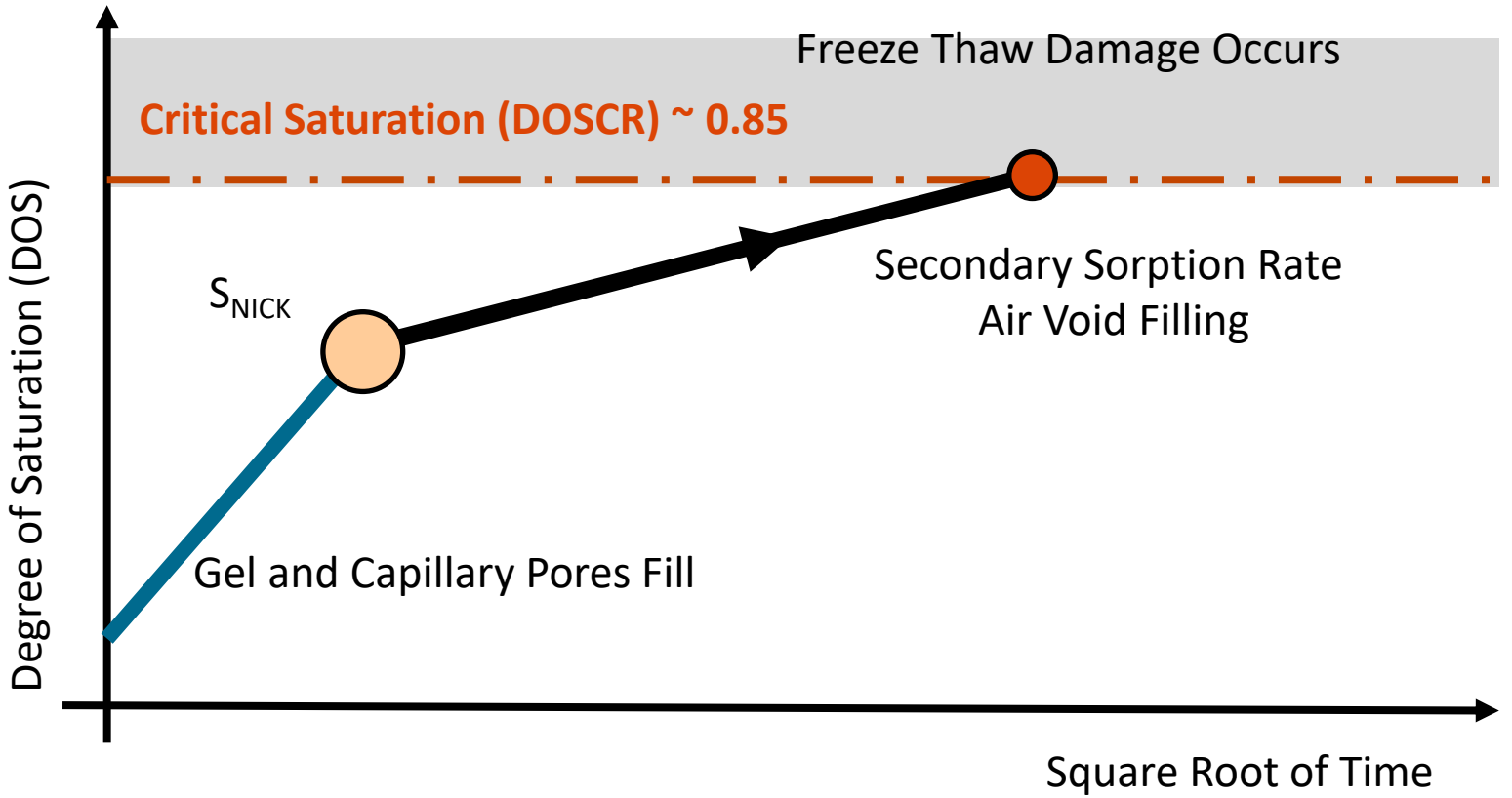

- Freeze thaw damage occurs in samples with a $DOS > DOS_{CR}$
- Are the DOS_{CR} value and time to reach critical saturation levels dependent on the anisotropy in printed elements?

Li et al., Journal of Materials in Civil Engineering, 2012
Fagerlund G., Lund institute technology, 2004

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Determining DOS_{CR}

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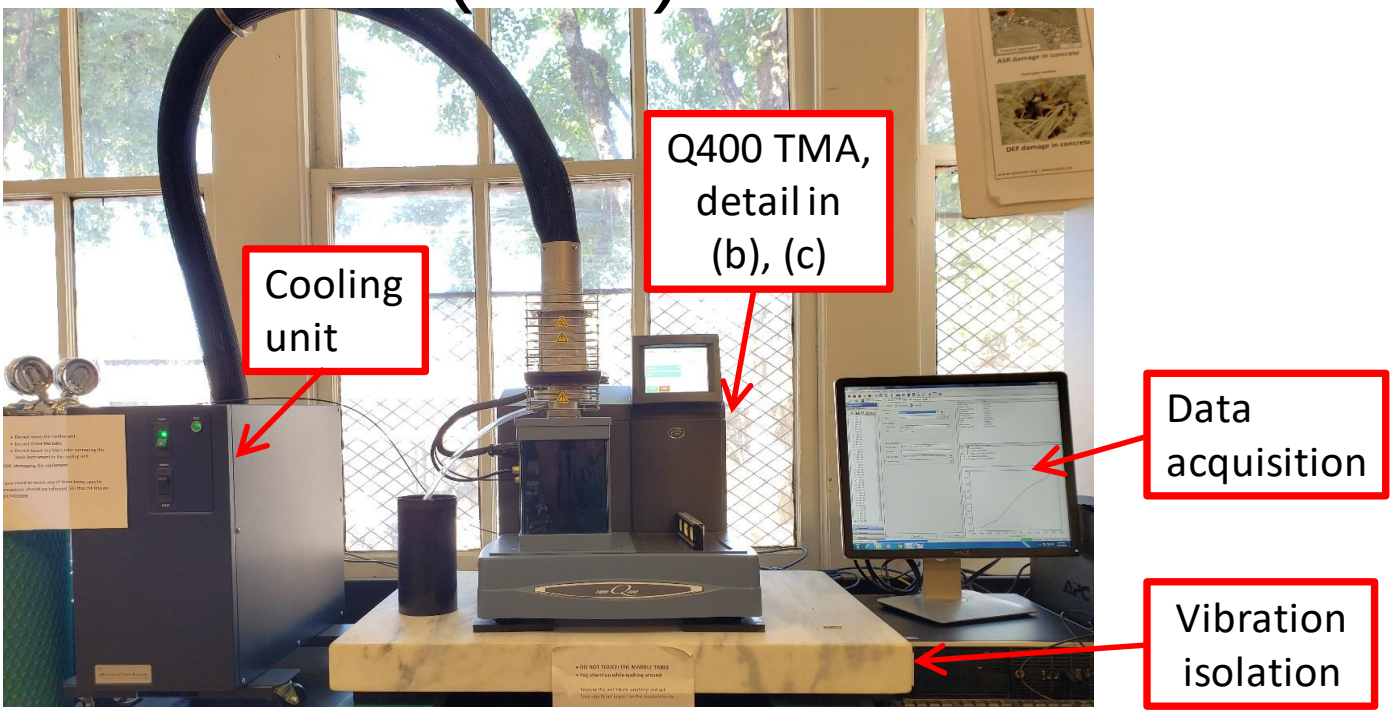
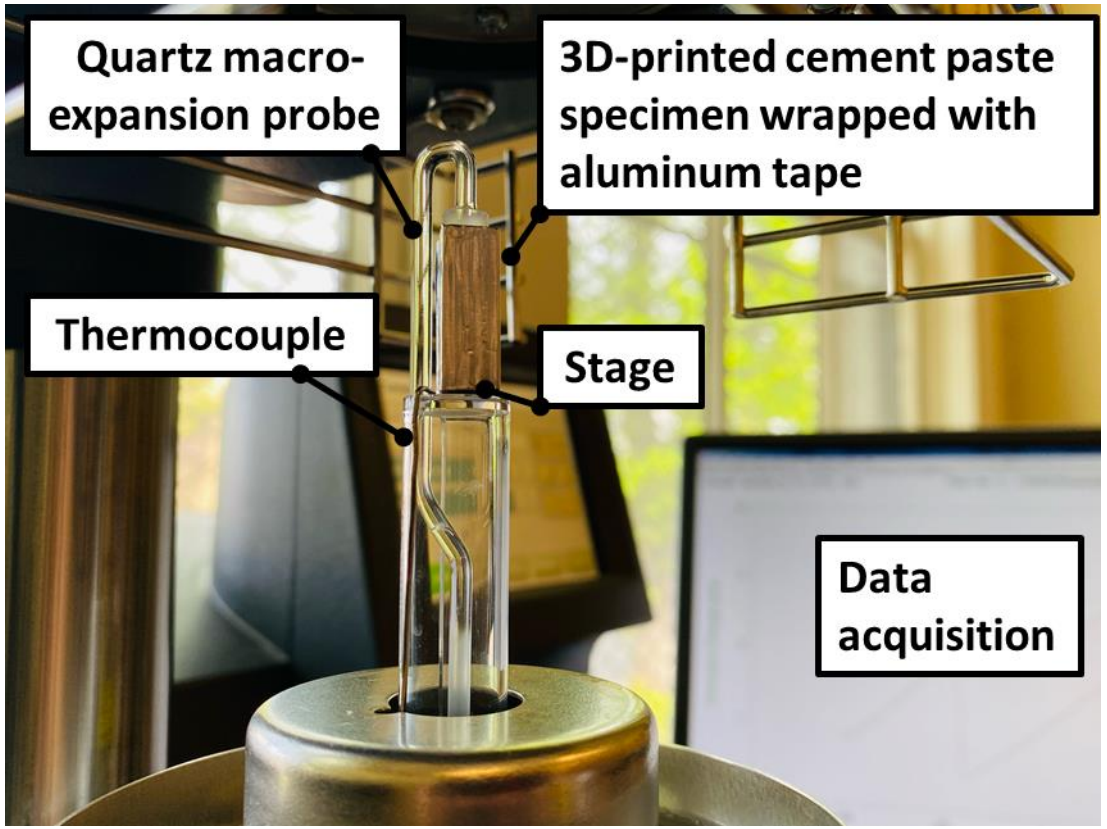
Thermomechanical analyzer (TMA)



Ghantous et al., ACEM, 2019
Ghantous et al. CCC, 2021



High precision LVDT

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Determining DOS_{CR}

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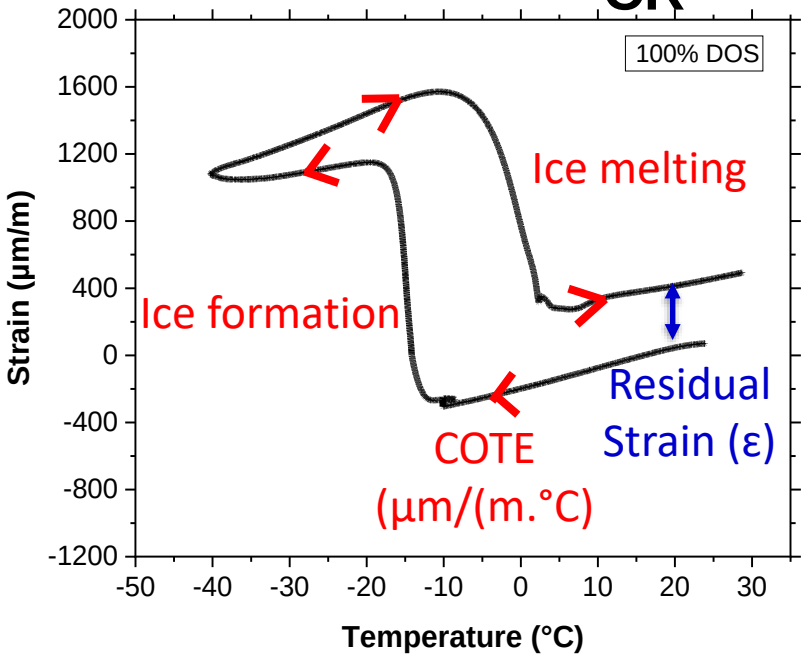
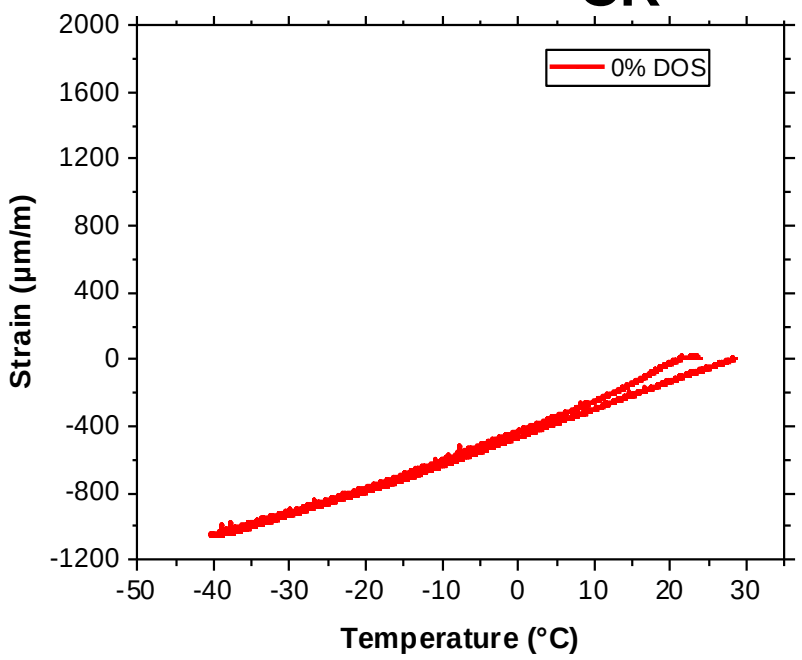
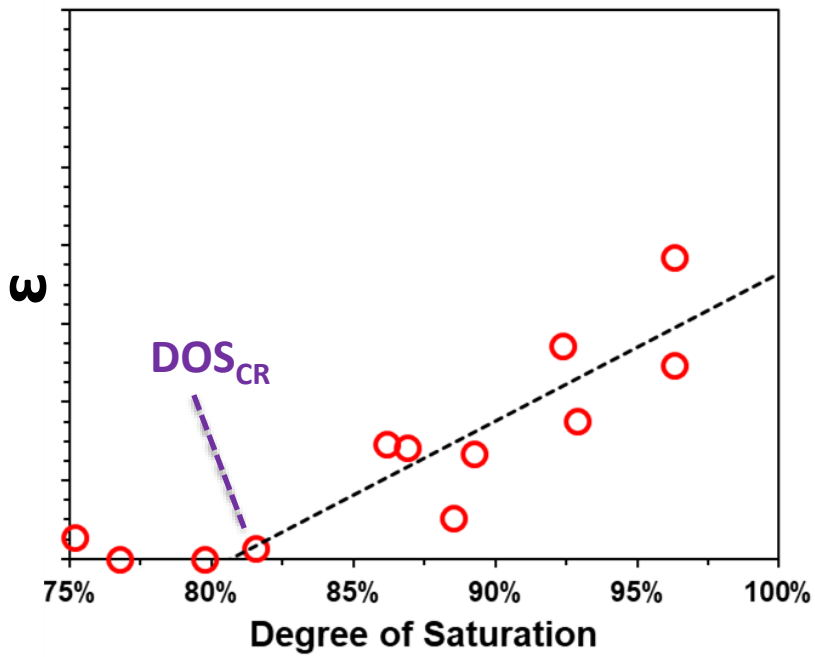
$DOS>DOS_{CR}$



$DOS<DOS_{CR}$





This study uses this technique to study the impact of anisotropy on freeze thaw behavior of printed elements

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Sample preparation

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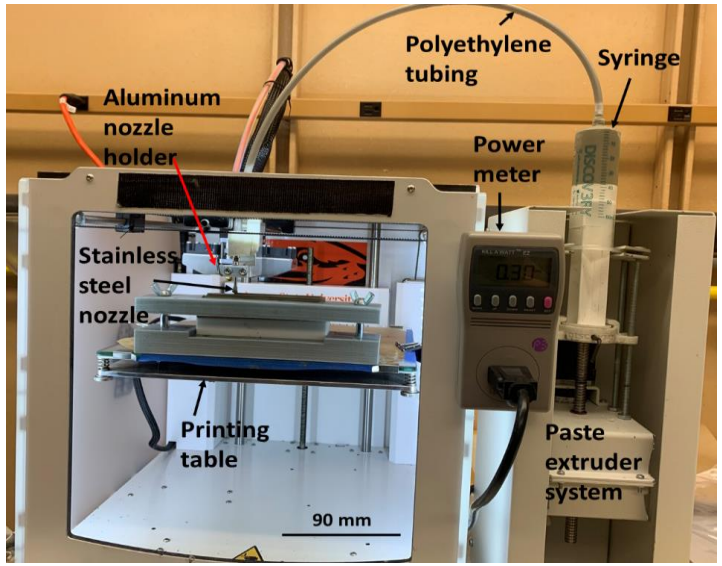
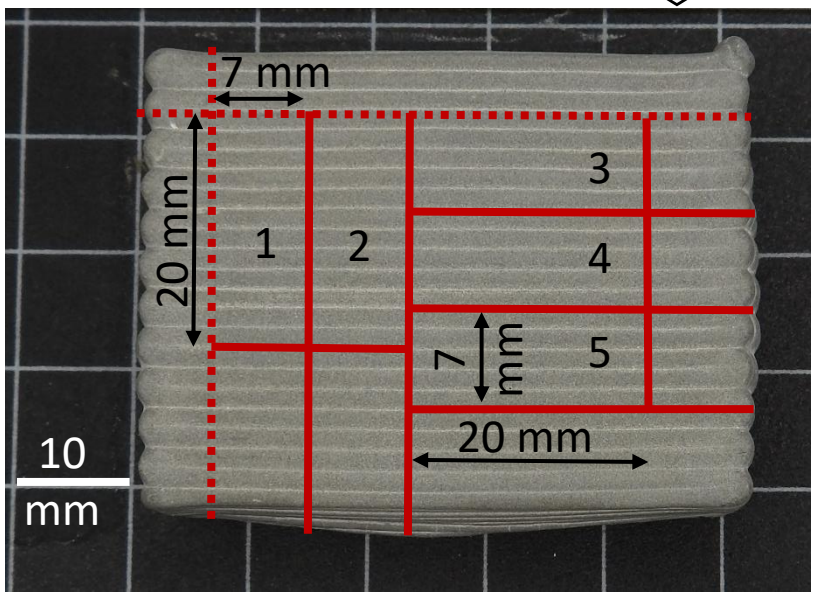
Mixture proportions

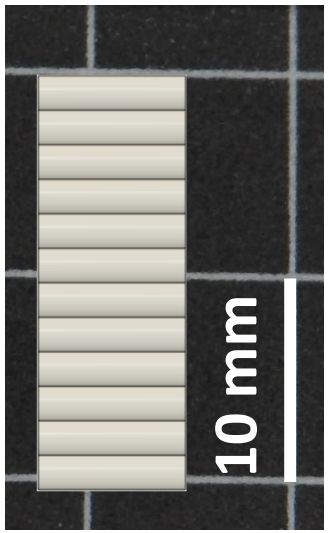
- 250 g of cement
- 1.47 g of HRWR
- 2.38 g of VMA
- 65.50 g of water

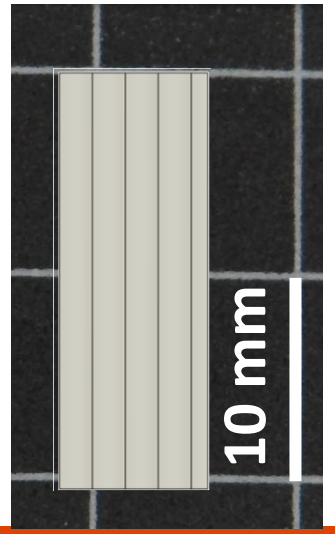
→ w/c=0.275

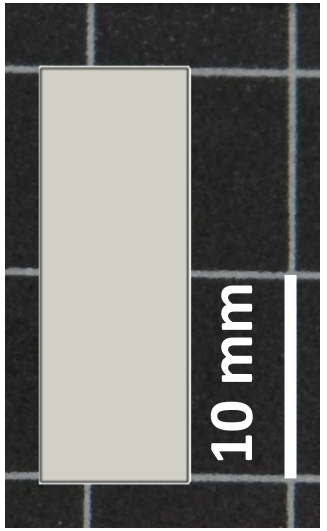




20% overlapping between printed filaments







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Freeze thaw damage results

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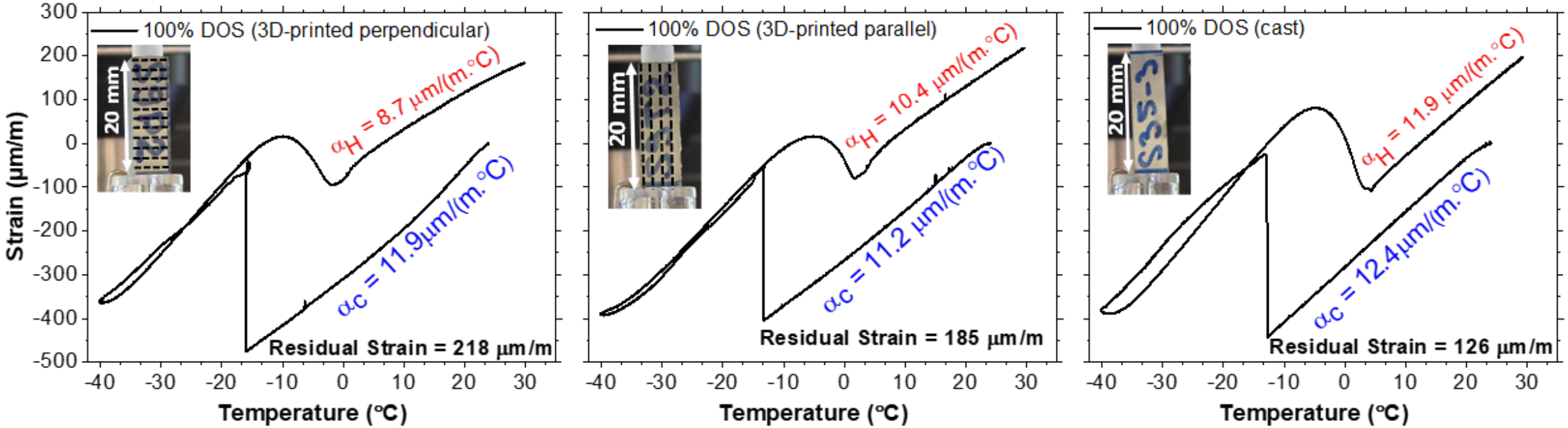

- At 100% DOS, the specimens tested with filament perpendicular to the longitudinal direction showed the highest residual strain value.
- This could be due to the fact that FT damage is primarily localized along the weak interfaces

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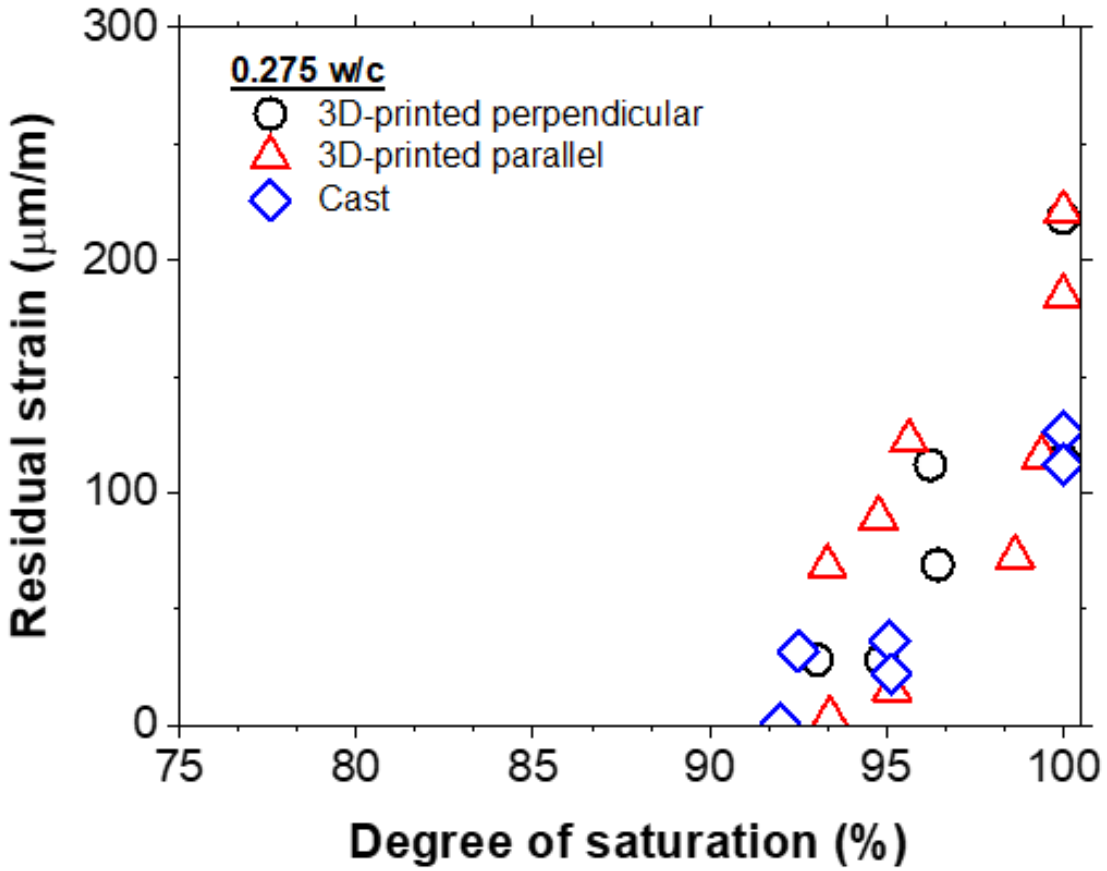
Measured Strain - DOS_{CR}



- DOS_{CR} for both cast and 3D-printed specimens is approximately 91% and appears to be independent of the printing directionality.
- Based on ANOVA Single Factor and Tukey Test, there is no significant difference in the FT response of cast and 3D-printed specimens independently from the printing directionality.

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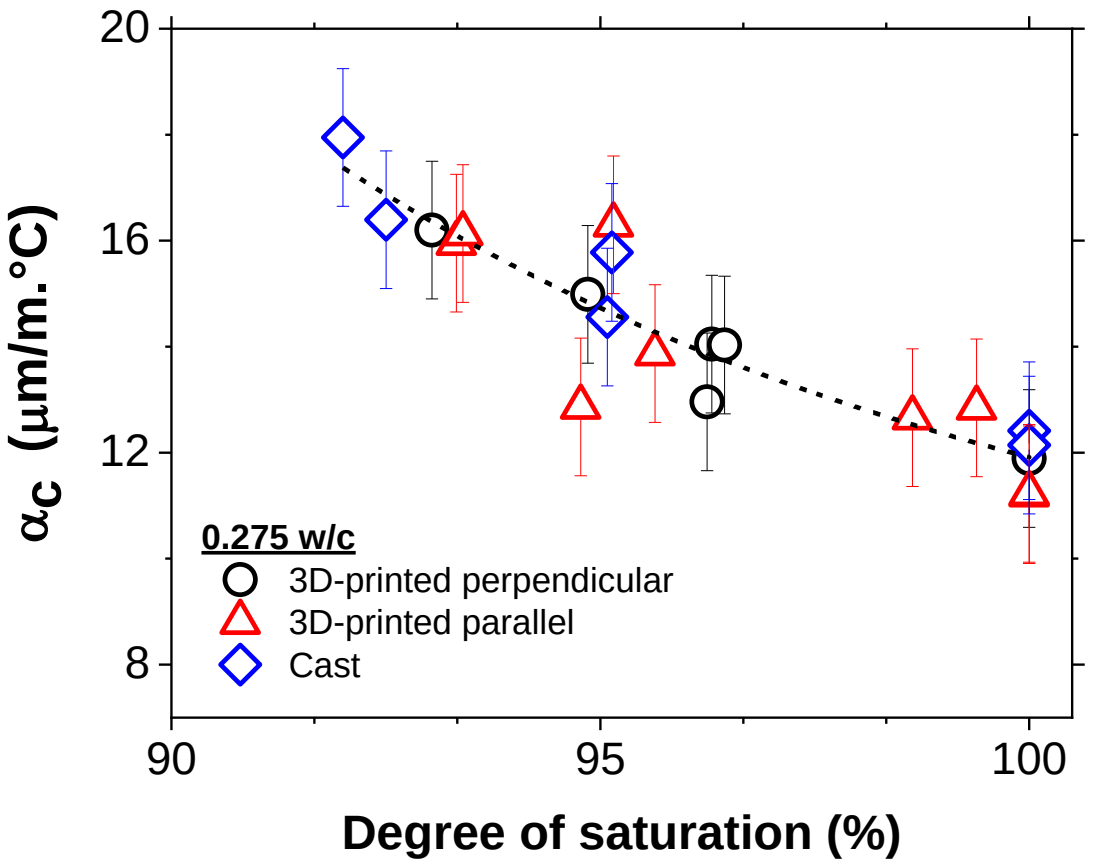
Measured COTE



- The COTE of all samples tested in this study fall within the range of values measured on mature cement paste in the literature
- No significant difference can be noted between the COTE values measured on cast specimens as compared to printed specimens independently of the printing directionality.

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Freezable solution

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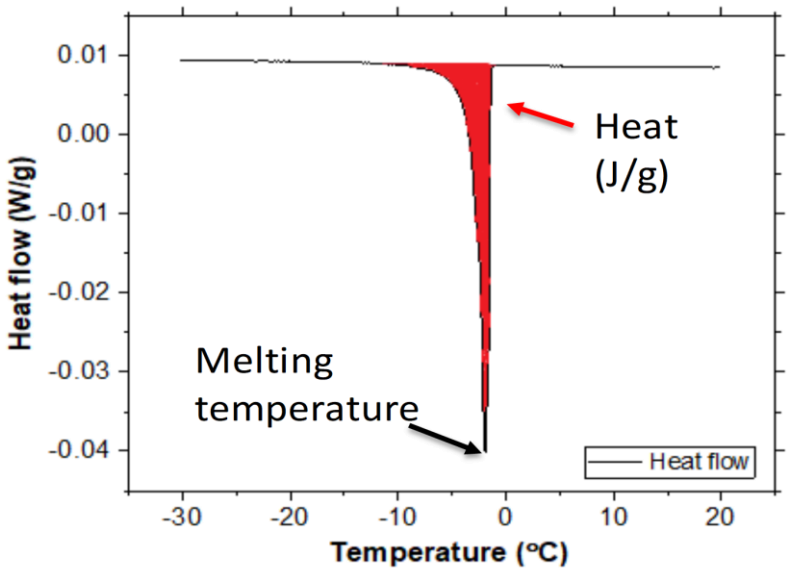
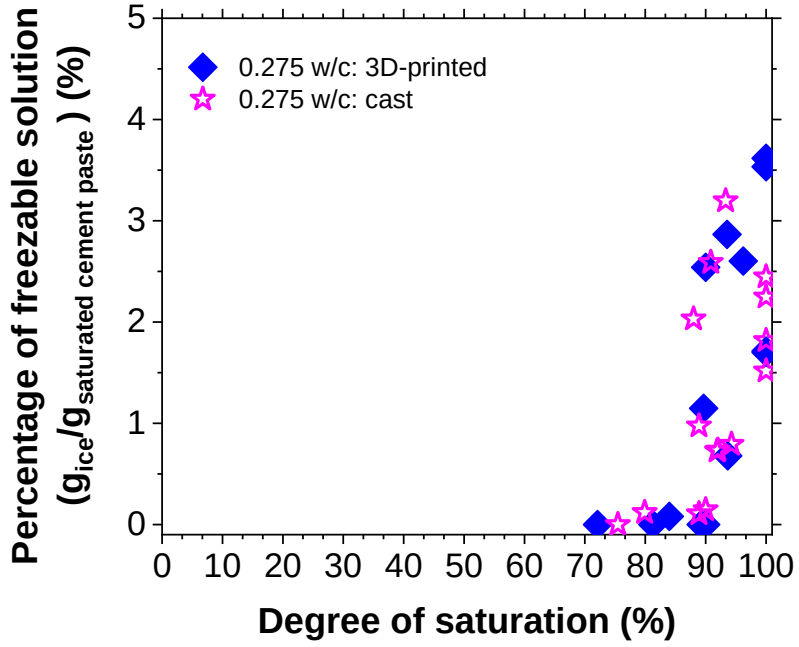
Using the Low-Differential Scanning Calorimetry (LT-DSC)





No statistical difference can be noted between the percentage of freezable pore solution in 3D-printed and cast specimens

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Freeze thaw damage

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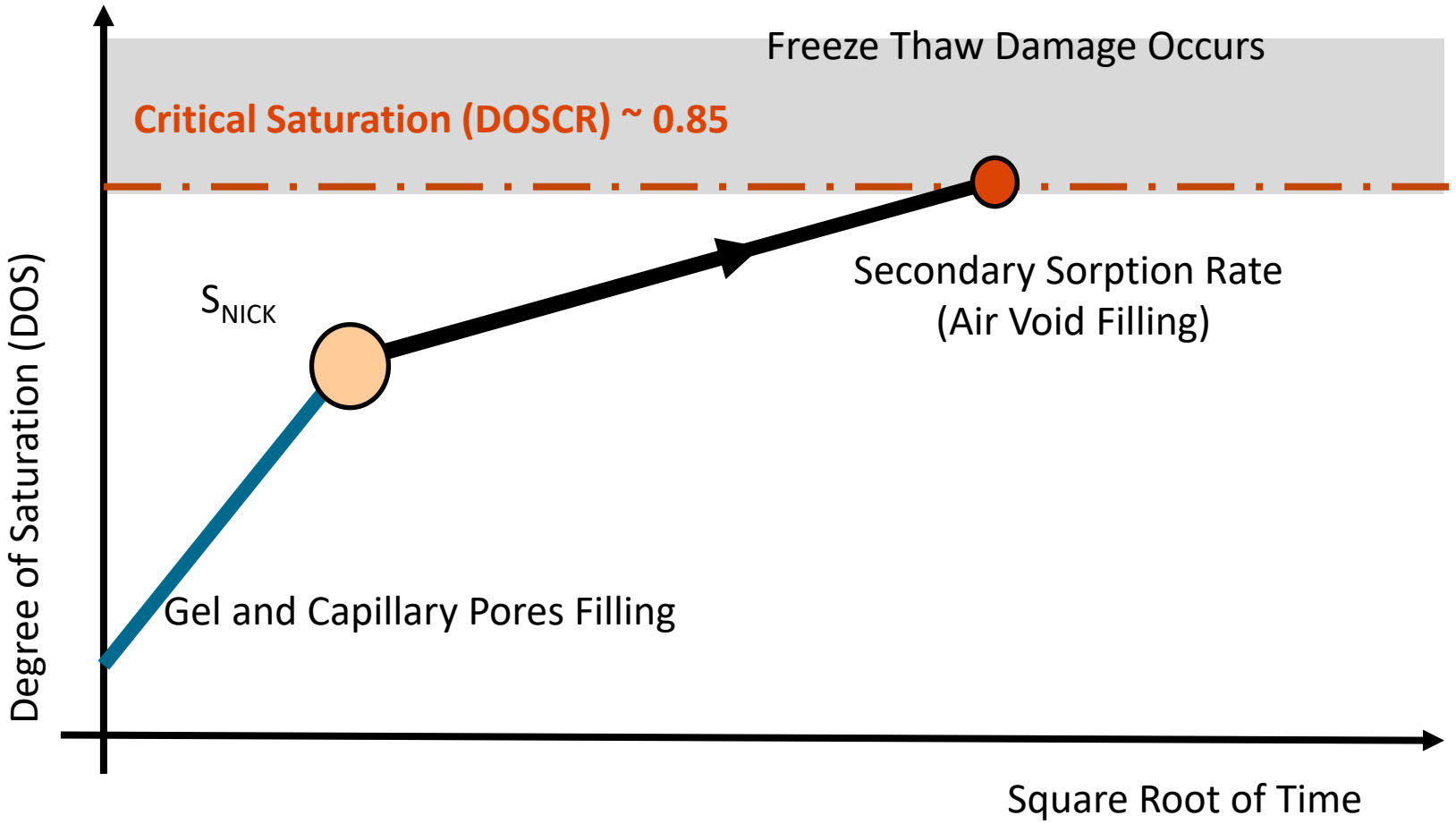

Li et al., Journal of Materials in Civil Engineering, 2012
Fagerlund G., Lund institute technology, 2004

Anisotropy in printed elements does not impact the DOS_{CR} in well printed samples.

However, does anisotropy impact fluid transport in printed samples and thus time to reach DOS_{CR}?

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Fluid transport

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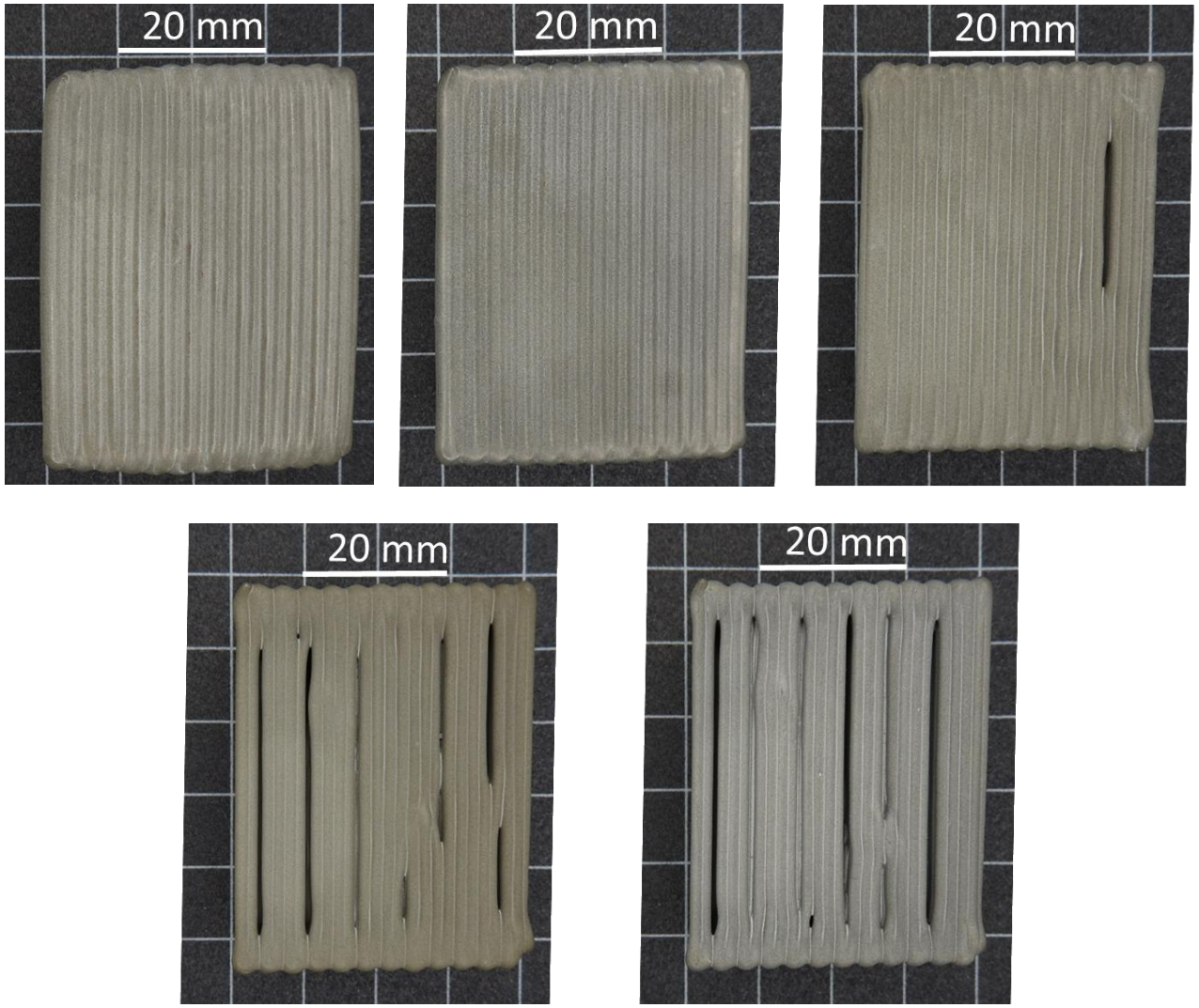
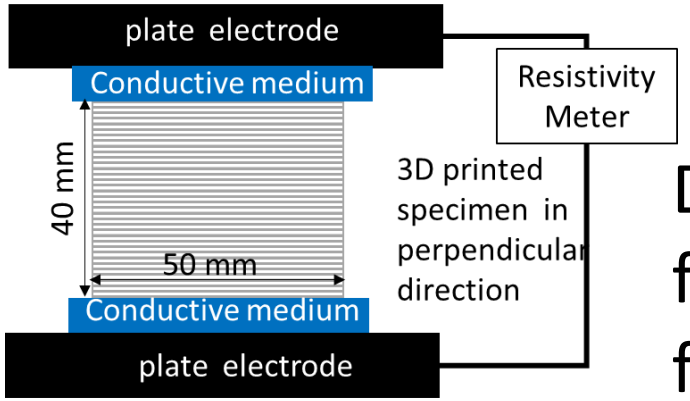
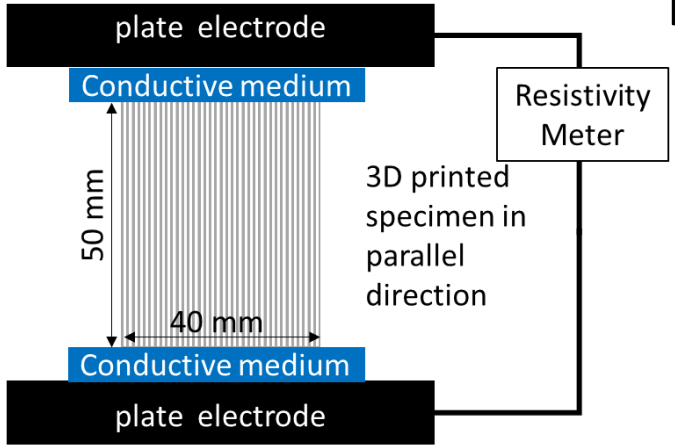


Perpendicular direction



Parallel direction



Determine the formation factor which is an indicator for fluid transport

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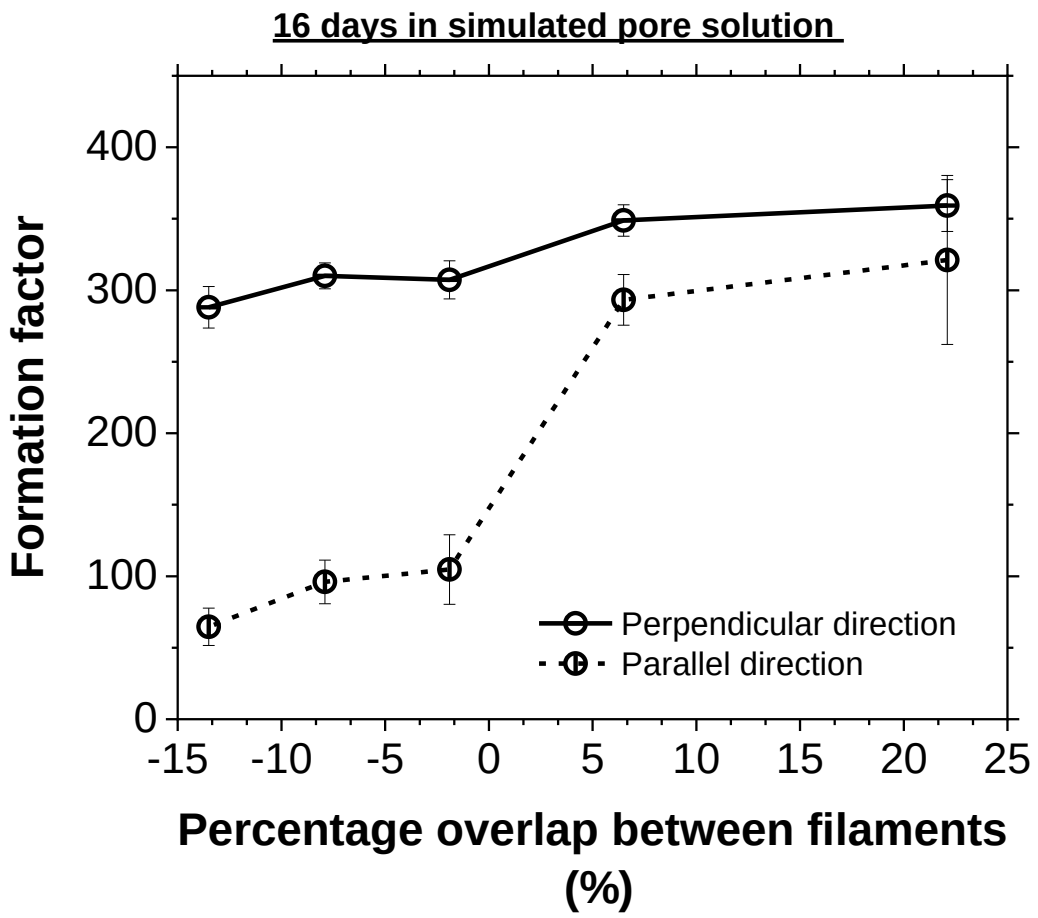
Fluid transport



Anisotropy influence formation factor values, i.e., fluid ingress, especially when filaments overlap are not done properly.

Printed elements in which filaments overlap is not done properly may exhibit earlier freeze thaw damage due the weak interface as well as the lower resistance to fluid ingress, especially in the parallel direction

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CONCLUSIONS

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- 3D-printed cement paste specimens with a low w/c (0.275) and no visible printing defects (20% overlapping between printed filaments) have similar DOS_{CR}, percentage of freezable solution, and COTE as compared to conventionally cast specimens independently from printing directionality.

- The low w/c in the mixture designs of the 3D-printed cement paste can be beneficial in increasing the FT resistance due to a reduction in the capillary porosity and the percentage of freezable pore solution.

- Print process parameters should be well defined to achieve a suitable overlap between printed filaments, minimize the impact of anisotropy on fluid ingress and time to reach critical saturation.

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THANK YOU FOR YOUR ATTENTION

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GENERAL INTRODUCTION

CASE STUDIES FOR CONCRETE

GENERAL CONCLUSION

Appendix

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ABSORPTION OF WATER

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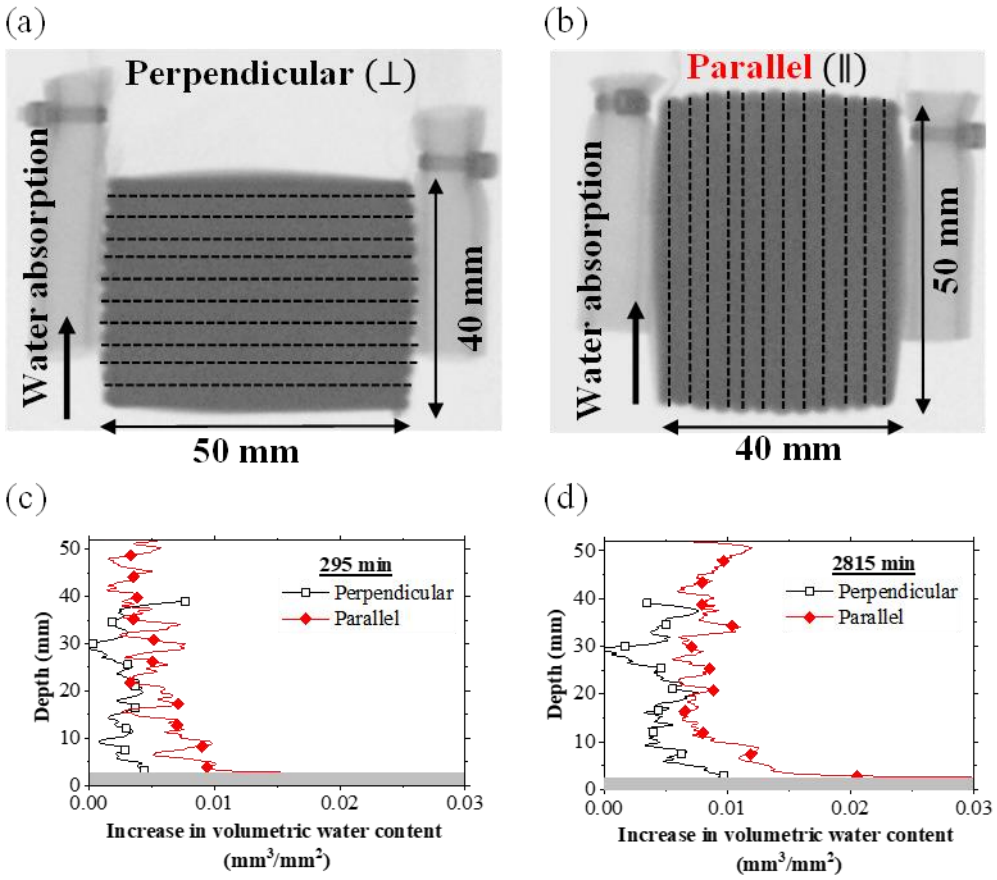
Does printing directionality impact fluid absorption in 3D printed cement paste samples ?

- Immerse the sample in water
- Collect radiographs at various immersion time
- Calculate the increase in volumetric water content

$$V_w = \frac{\ln\left(\frac{I_t}{I_{0min}}\right)}{\frac{\sum w}{X_s}}$$



Water absorption in printed elements varies with the direction of filament

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