3D Printing of Cement-Free Slag-Based Binder

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Outline

- 1. Research background
- 2. Methods
- 3. Results & discussion
- 4. Limitation & Future direction
- 5. Acknowledgement

1. Background

- **High Cement Consumption and Environmental Impact**

To achieve the required printability, 3DCP mixtures generally contain approximately **20% more cementitious materials** than conventional concrete, resulting in higher embodied carbon and material costs [1].

- **Performance Trade-offs**

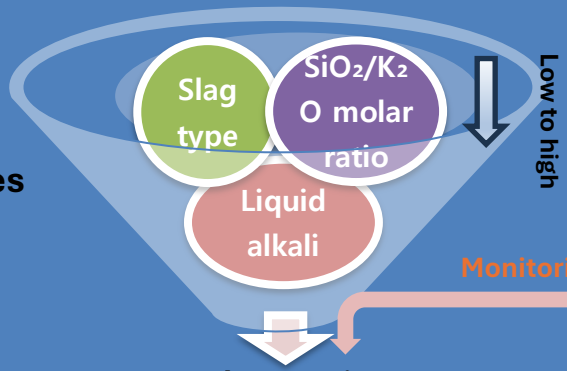
There exists a fundamental conflict between the **pumpability** (low shear stress) and **early strength** (rapid setting) of materials, often forcing compromises during construction—sacrificing strength for pumpability or causing nozzle blockages when prioritizing strength.

- **Therefore, achieving printable + cement-free + high-strength remains challenging → this study addresses this gap.**

[1] Y. Chen, S. He, Y. Gan, O. Copuroğlu, F. Veer, E. Schlangen, A review of printing strategies, sustainable cementitious materials and characterization methods in the context of extrusion-based 3D concrete printing, *J. Build. Eng.* 45 (2022) 103599.
DOI: 10.1016/j.jobe.2021.103599 | URL: sciencedirect.com

2. Methods

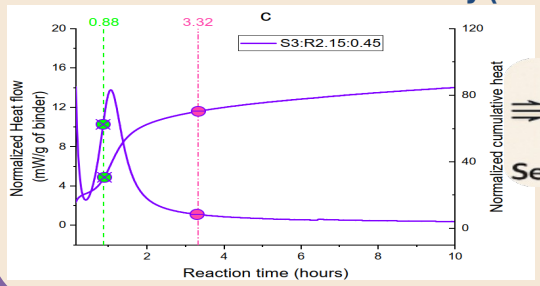
Variables

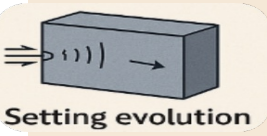


Monitoring

Early Reaction of binder

Isothermal Calorimetry (TAM Air)

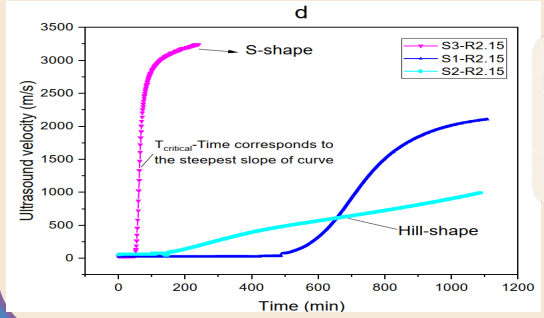


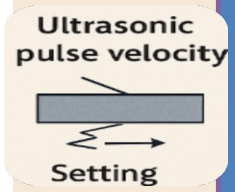


Hardened state evolution Analysis vs Variables

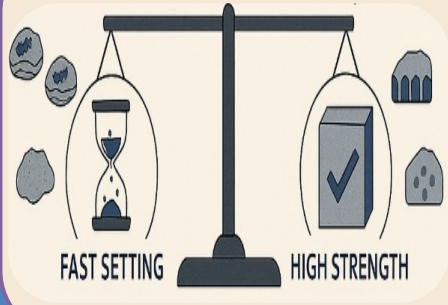
- **FTIR peaks** highlighting *Polymerization and carbonation*.
- **NMR** with labeled Q^4 absence.
- **MIP** highlighted the **unique pore structure**, contrast to hydrated CEM III mortar.

Fresh behavior showing setting evolution (UPV)



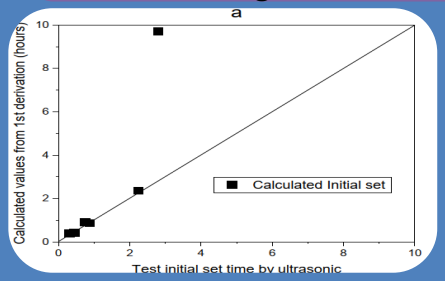


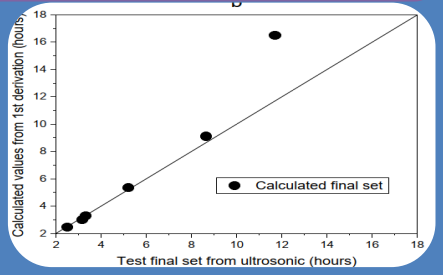
Target



- **Mitigate fast setting and rheology while maintaining strength** by optimizing **these variables and dosage,**
- **Regulate the printing window** for **future** designing binders suitable for 3DPC**.**

Correlating early reaction with setting behavior
1st derivative of the heat flow curve can indicate initial & final sets ⇨ Indicate printing window when conducting the binder design



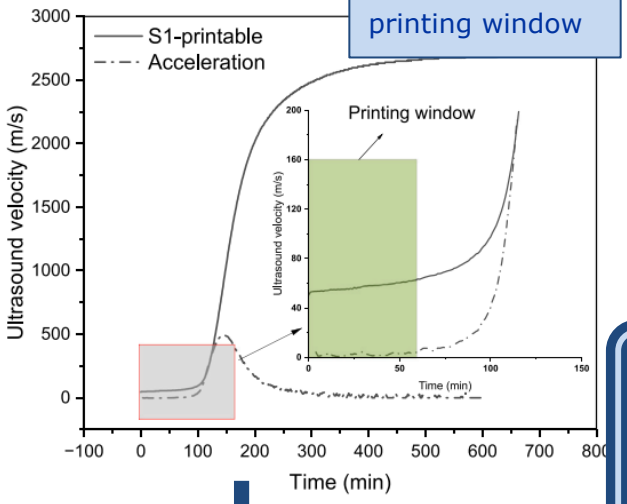


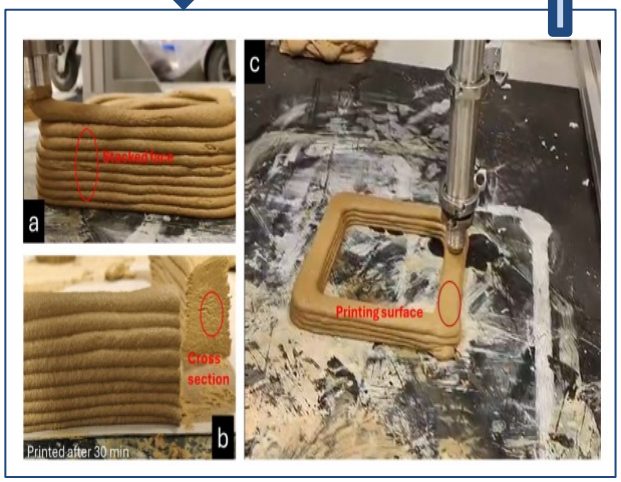
3. Results & Discussion

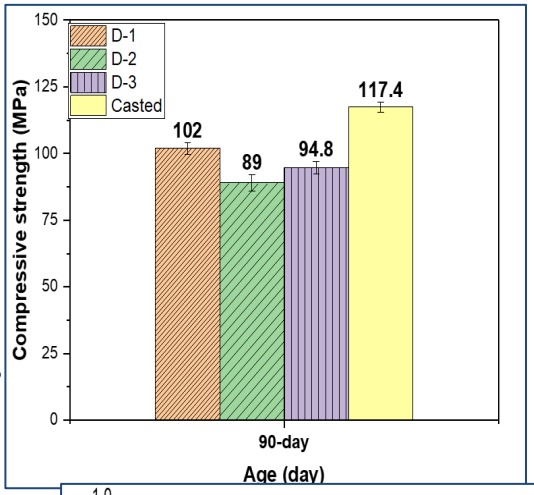
Zero-cement binder **design** for 3DPC(**≥100MPa**)

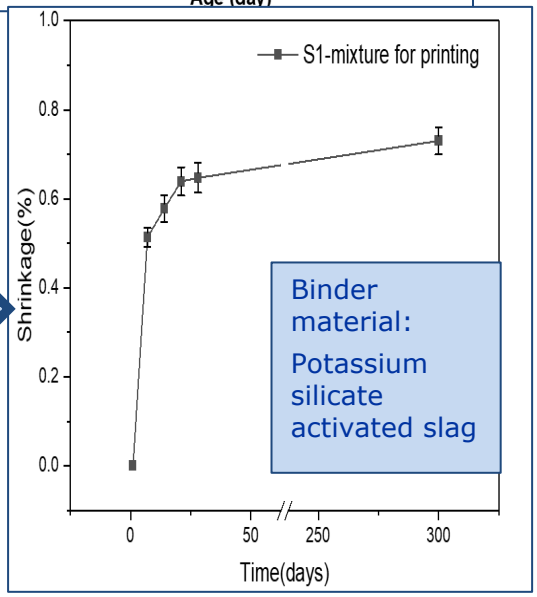
Published sep 2025

Determination of printing window







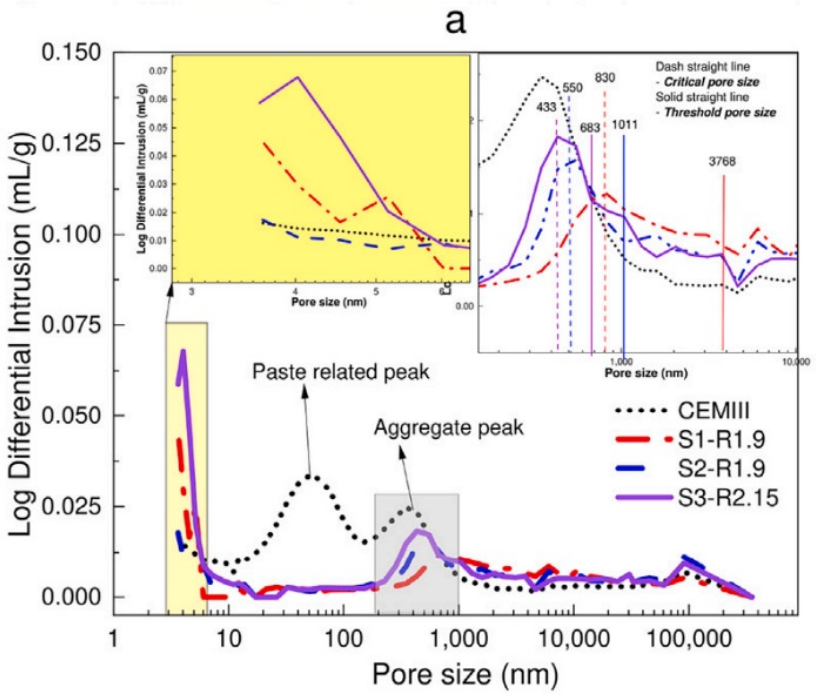


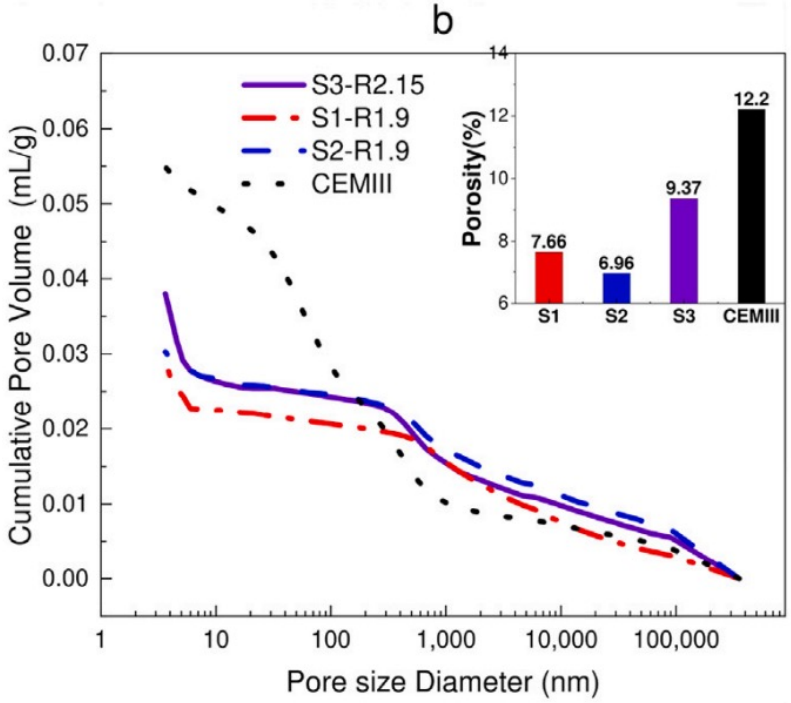
- The printed samples achieved high comp ressive strengths of 25 MPa at 1 day, 45 –70 MPa at 7 days, and **89–102 MPa** at 90 days,
- Along with a control led shrinkage of **less than 0.85%** at 300 days.

Ref : Chen, Yanjuan, Khadija El Cheikh, and H ubert Rahier. "Methodology for the design and optimization of potassium silicate-activated slag used as the binder of 3D printable materials." C onstruction and Building Materials 490 (2025): 142536.

3. Results & Discussion

- **This binder synthesized from GGBFS blended potassium silicate exhibits a distinct pore struc ture compared to hydrated CEM III mortar.**





- **The 29Si NMR analysis confirms the absence of Q4 and presence of few Q3 unit species in act ivated slag, aligning with FTIR findings..**

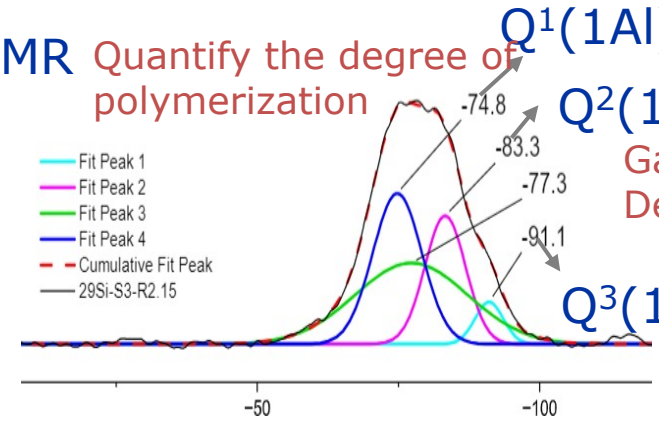
Correlate the early reaction with its setting behavior. (published in Nov 2025)

Reaction investigated

Bridge thermal analysis with the setting behaviors, help define printing window

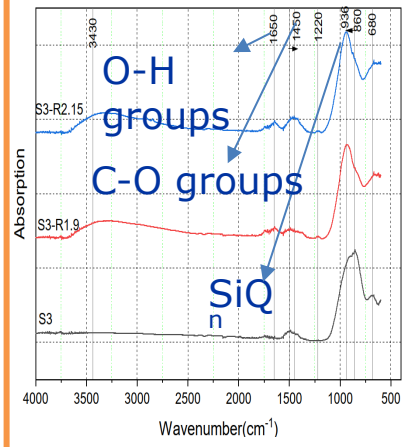
NMR

Quantify the degree of polymerization

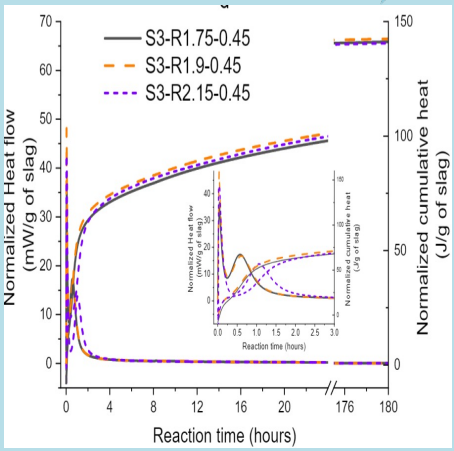


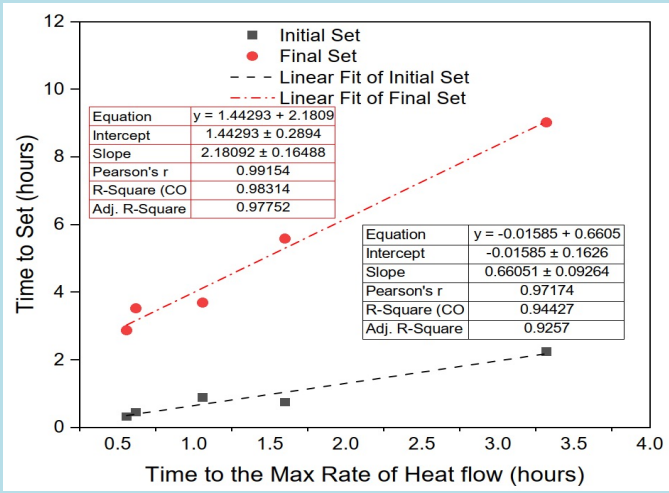
Gaussian Deconvolution

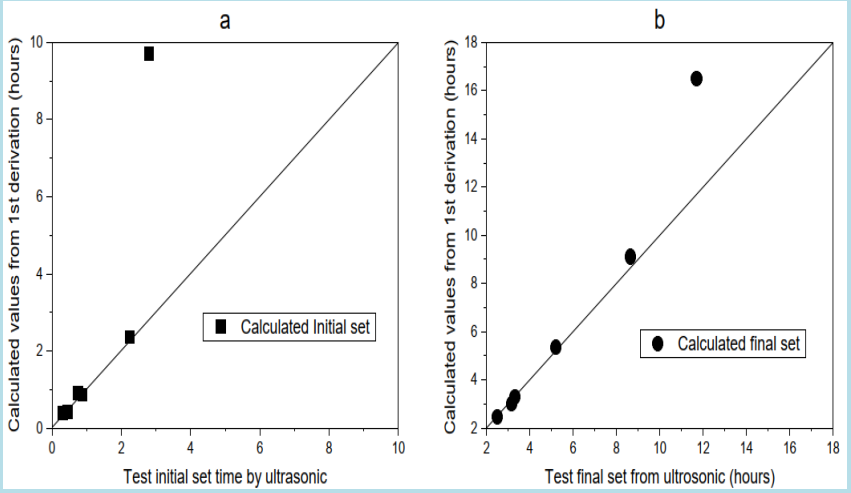
FTIR



TAM air (thermal analysis)







Ref: Chen, Yanjuan, et al. "Correlating the early reaction of potassium silicate-activated slag with its setting behavior and strength development." Materials & Design (2025): 114807.

4. Limitation & Future Direction

- **Long-term performance validation:**

Although this binder has demonstrated good potential for 3D concrete printing, the long-term d urability of the printed concrete has not yet been comprehensively investigated and warrants fu rther study.

- **Towards more sustainable printable binders:**

Develop greener (low-carbon) alkali activators and functional additives to improve the printabi lity and performance of alkali-activated slag binders while minimizing environmental impacts a nd costs.

5. Acknowledgement

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- **Special thanks to Carlos Rodriguez from CTCON, Spain, for his valuable contribution of providing the slags used in this res earch.**

Thank You

Looking forward to academic exchanges and collaborations

18th Geopolymer Camp | July 8–10, 2026 | Saint-Quentin, France