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3D printing of geopolymer binder based concrete structures by adapting tabletop clay printers

Siim Koor

Co-authors: Hans Priks, Prof. Tarmo Tamm

Intelligent Materials and Systems Lab,
Institute of Technology, University of Tartu

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State-of-the-art
The utilization of commercial clay 3D printers for GP

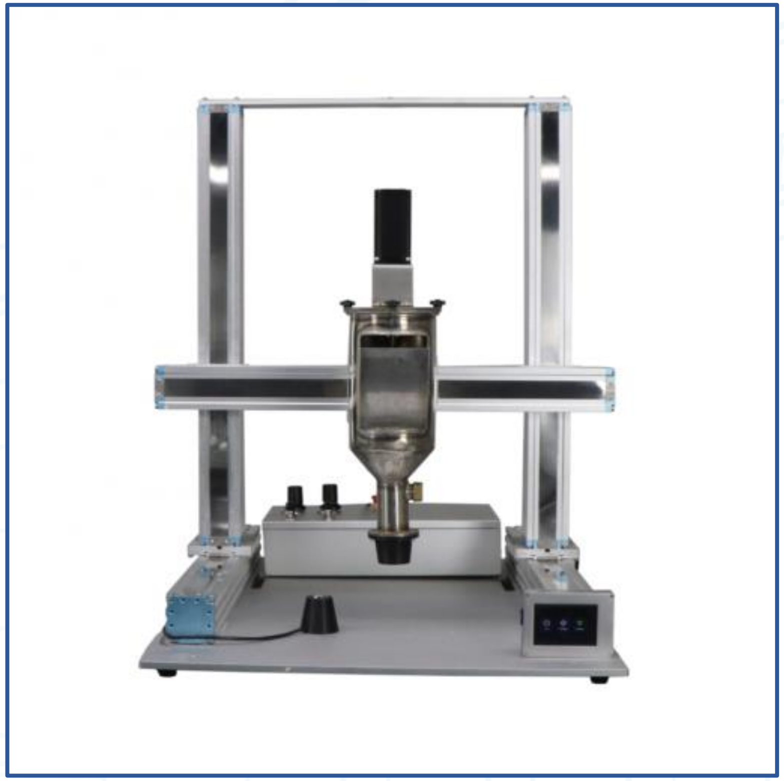
- Archez et al. (2020) „Adaptation of the geopolymer composite formulation binder to the shaping process“ → (PotterBot 7) Extrudability governed by silicate content. Balance defines printability window.
- Archez et al. (2021) „Shaping of geopolymer composites by 3D printing“ → (PotterBot 7) Further mix design and recipe optimization. Layer adhesion.
- N’Cho et al. (2024) „Extrudability of geopolymers and control of the formed networks by zeta potential and NMR spectroscopy“ → (Delta WASP 2040 and PotterBot 7) Local scale structure. Extrudability correlation with zeta potential and alkali cation concentration.
- Lazorenko and Kasprzhitskii (2022) „Geopolymer additive manufacturing: A review“ → Most cited review → no direct mention of commercial printers

Identified Research Gaps:

- No systematic use of low-cost commercial printers
- Lack of tensile testing and visual microstructural defect mapping
- Limited understanding of CMC impact on print geometry

Lab-scale printing – OPC printers

- OPC and GPC printers have broadly similar hardware requirements
- Smallest commercial printers:
  - expensive
  - complex
  - proprietary or custom software
  - auger screw extrusion
- Some selection options



Eazao Mega Tong
15 000 €
350 x 400 x 490 mm
40 mm nozzle
+ pumps, mixer, etc.

CERAMBOT Tong
20 000 €
1650 × 1650 × 1650 mm
30 mm nozzle
self-contained system

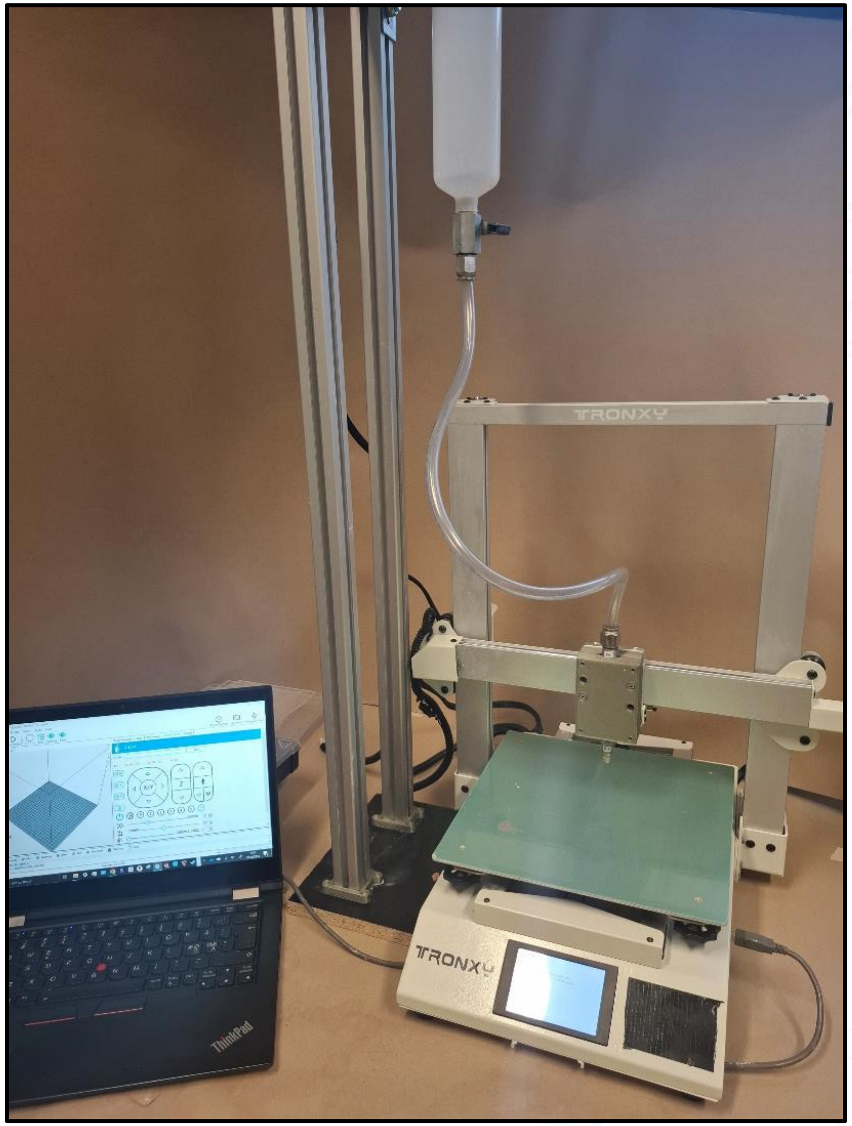
Lab-scale printing – clay/ceramic printers

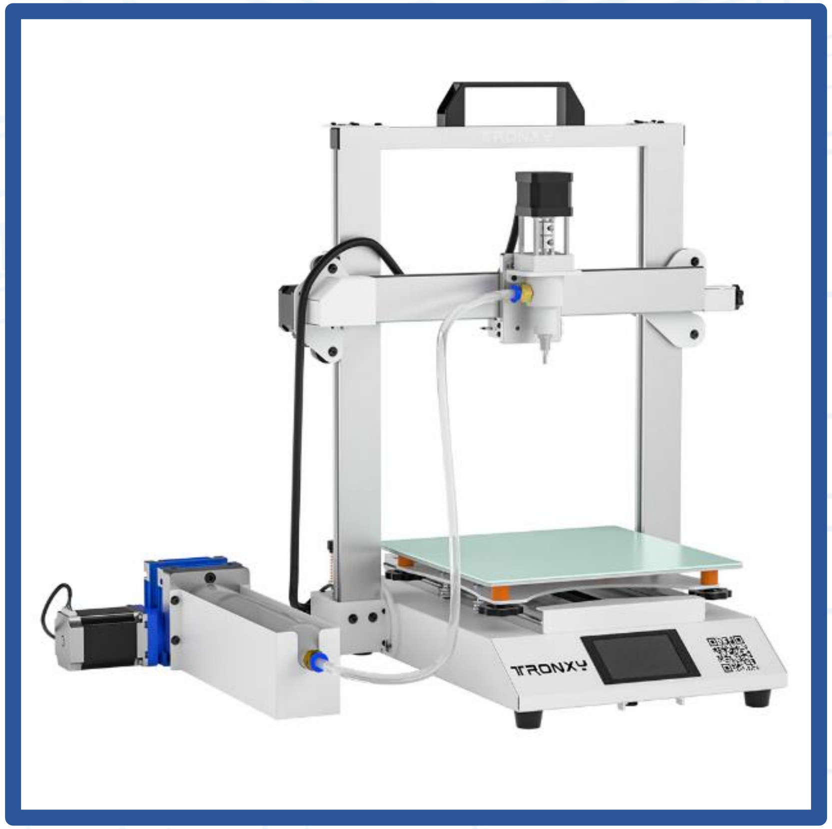
- Hardware requires modification
  - frame rigidity
  - alkalinity resistance
- Operates on open-source software
  - extensive calibration needed
- Very affordable
- Some selection, but design options are limited
- Liquid displacement modelling
  - syringe/piston
  - pneumatic

3D PotterBot 10 Pro
7000 €
415 x 405 x 500 mm
5 mm nozzle
self-contained system

Tronxy Moore 2 Pro
520 €
255x255x260 mm
5 mm nozzle
self-contained system

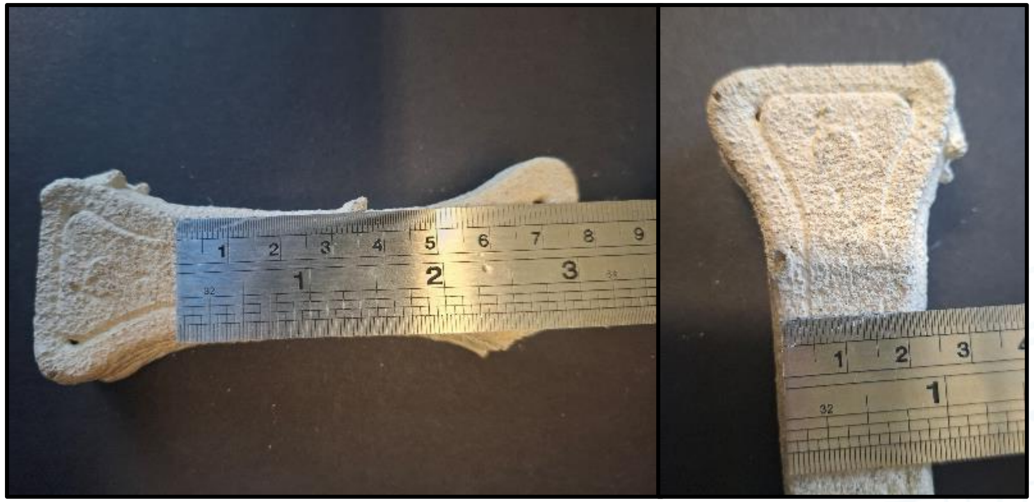
Most affordable option

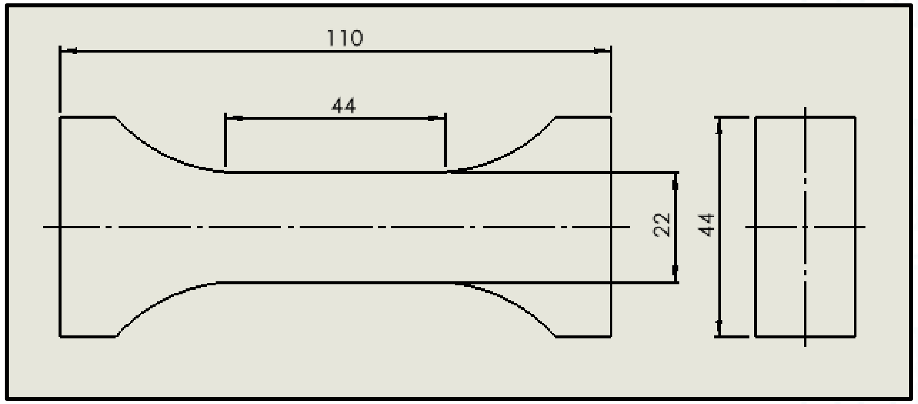




Tronxy Moore 2 Pro
520 €
255x255x260 mm
5 mm nozzle
self-contained system

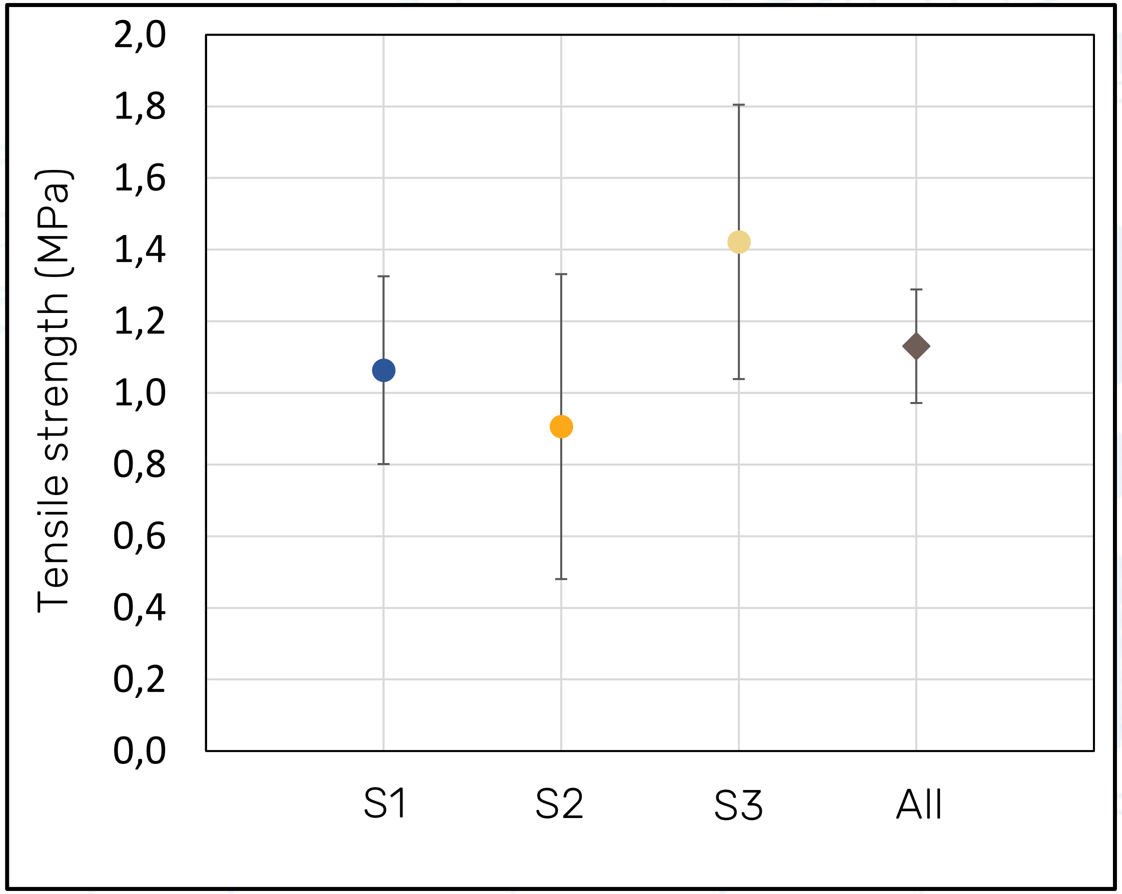
Dog bone prints





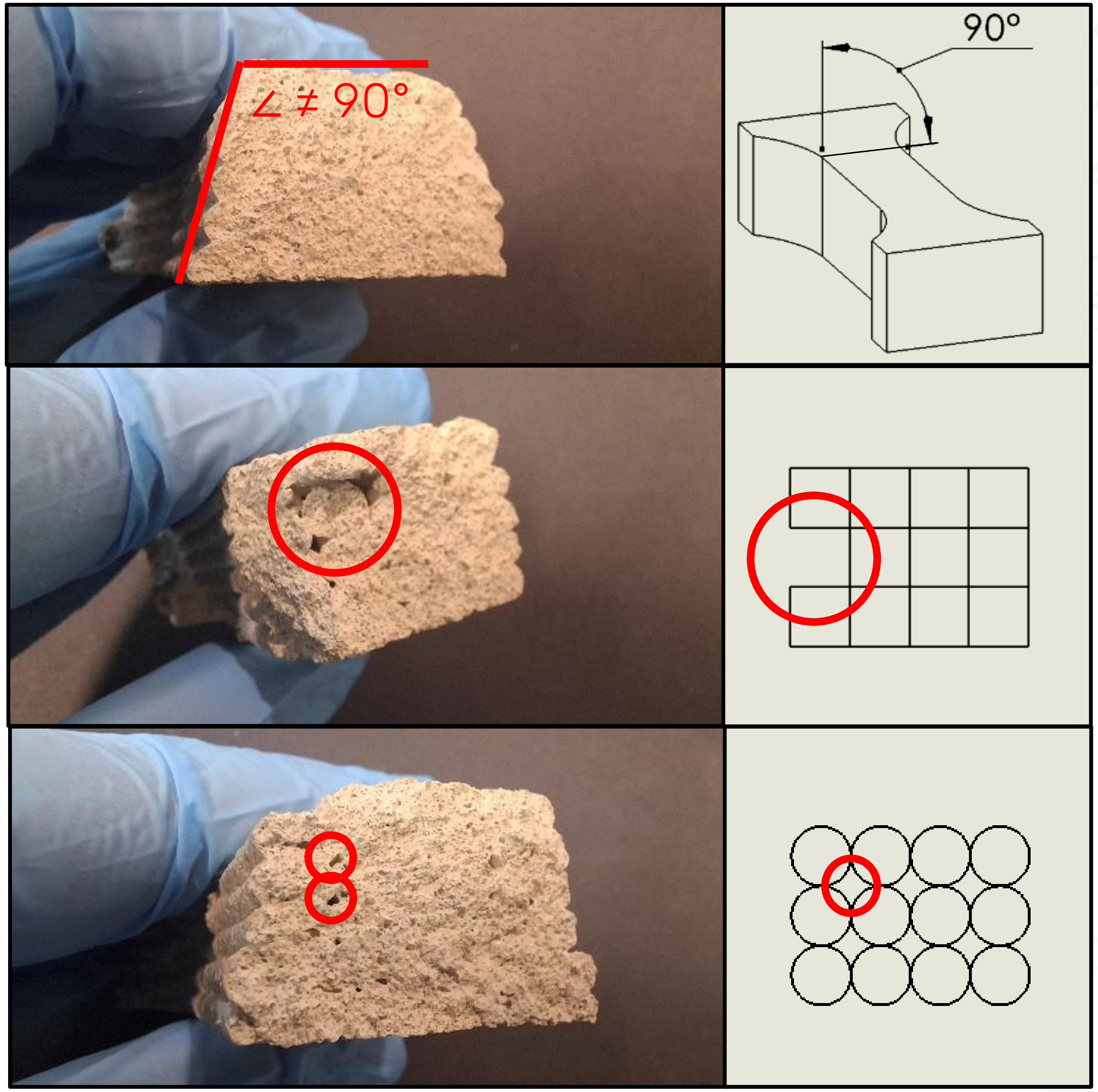
Tensile strength

- Testing method:
  - direct uniaxial tensile stress
  - friction gripping
- Samples:
  - 7-day strength
  - 3 sets of samples
  - 4 samples per set
- Results:
  - moderate variation within set
  - clear overall average with low variation
  - 1,1±0,2 MPa (95%, k=1,796)



Graph 1. Tensile strength of different test sets

Print defects - macroscale



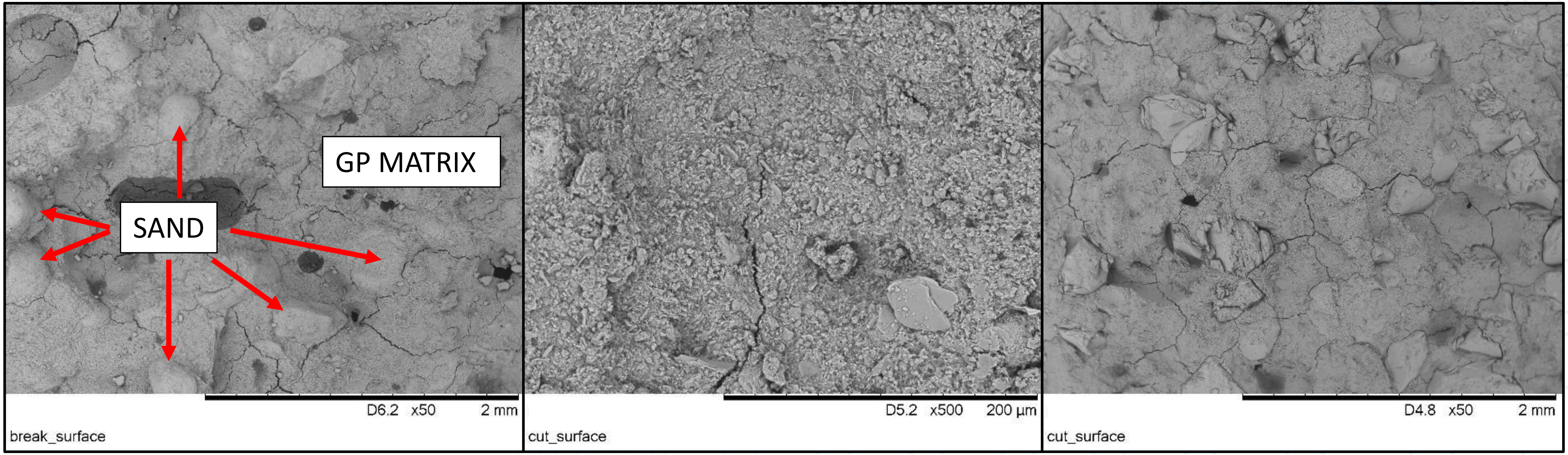
First layer compression artifact
aka „elephants' foot"

- negligible after second layer

Voids

- either from (partial) under extrusion (pressure drop or syringe lag)
- or from geometric underfill (rare and negligible)

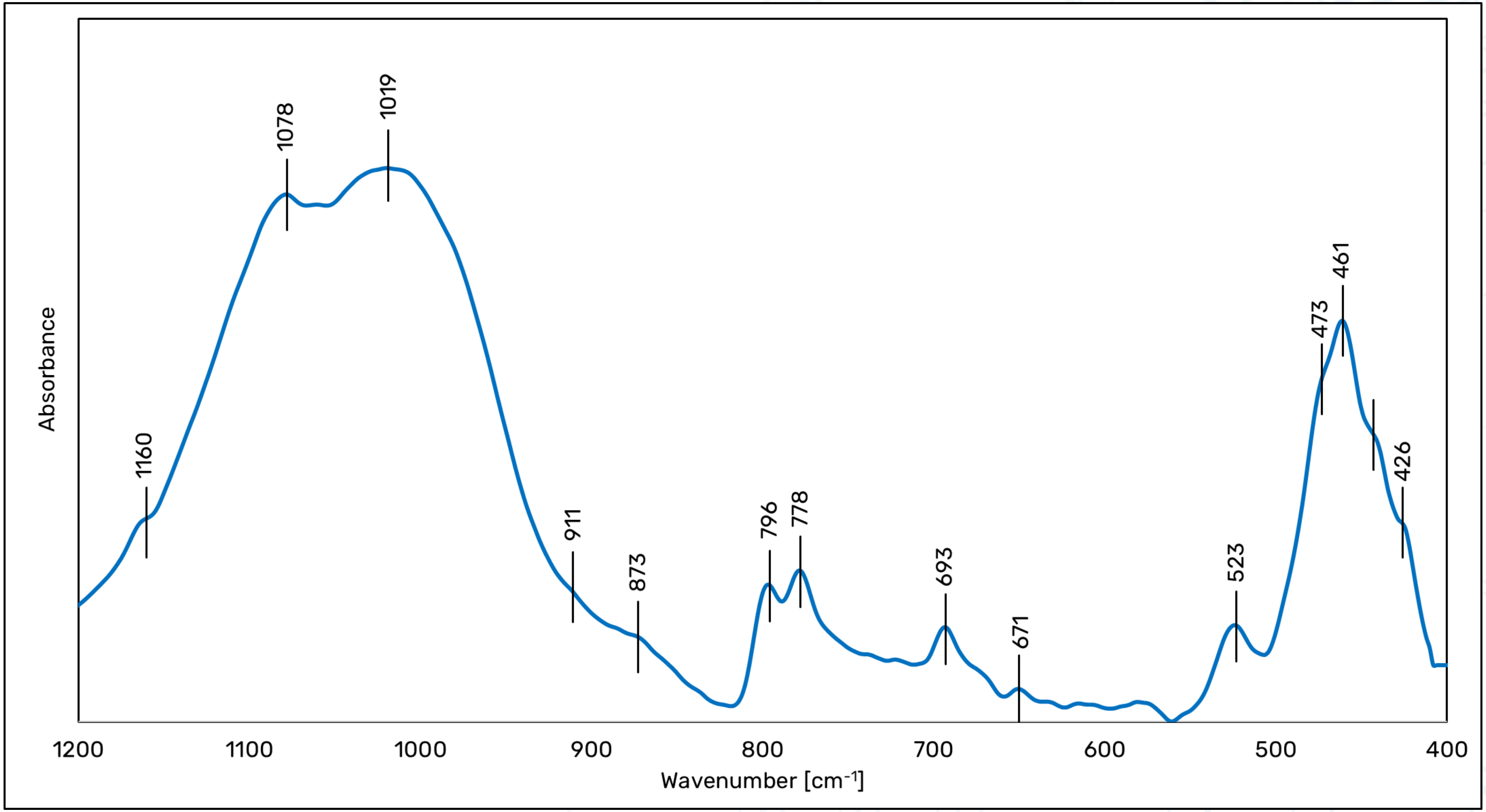
Material defects - mesoscale



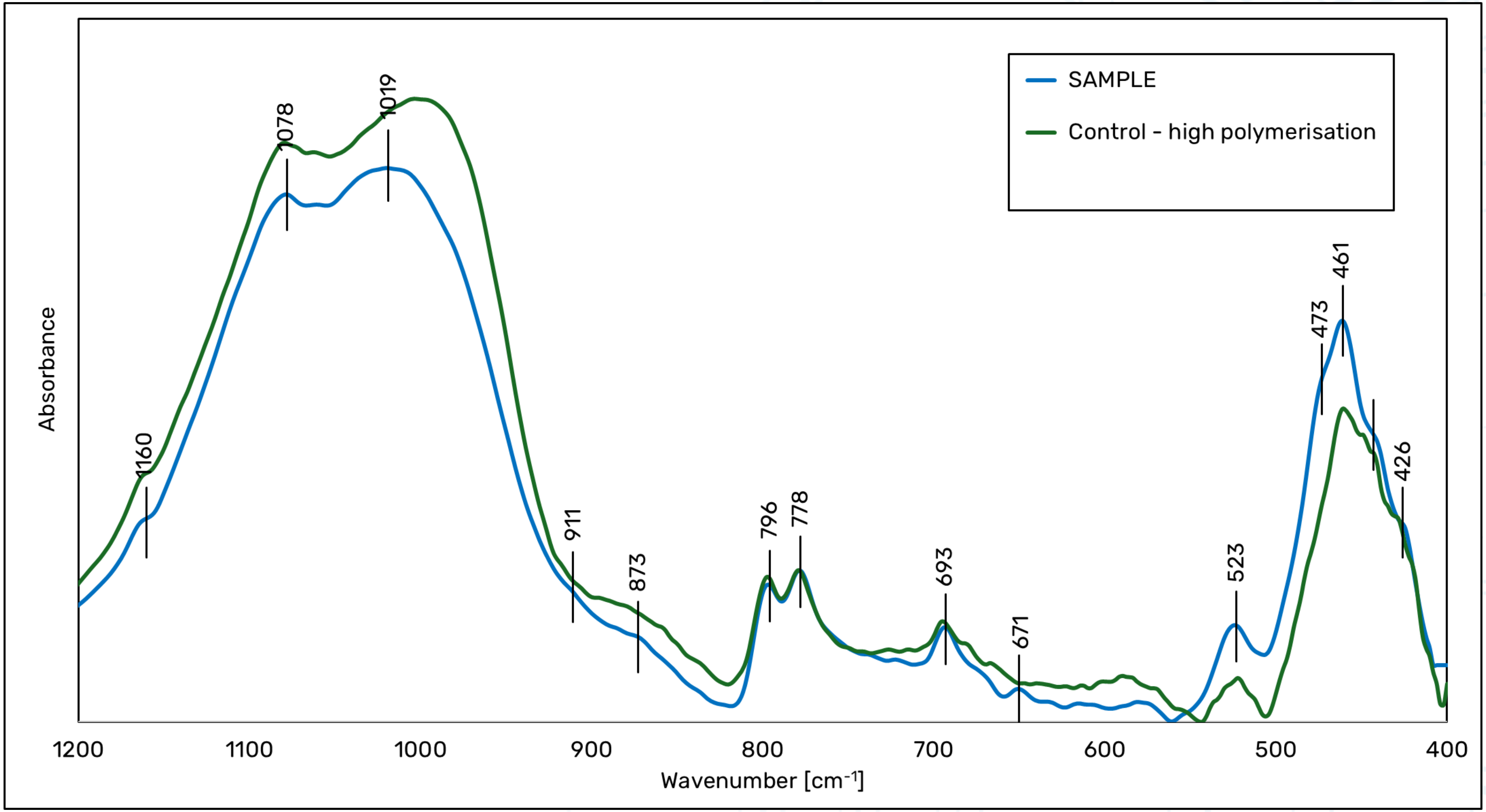
Micrographs 1. Aggregate–matrix interactions and mesoscale cracking

- Radial cracking from filler
  - weak bonding at interfacial transition zones (ITZs)
- Drying cracking in GP matrix
  - likely due to ambient curing

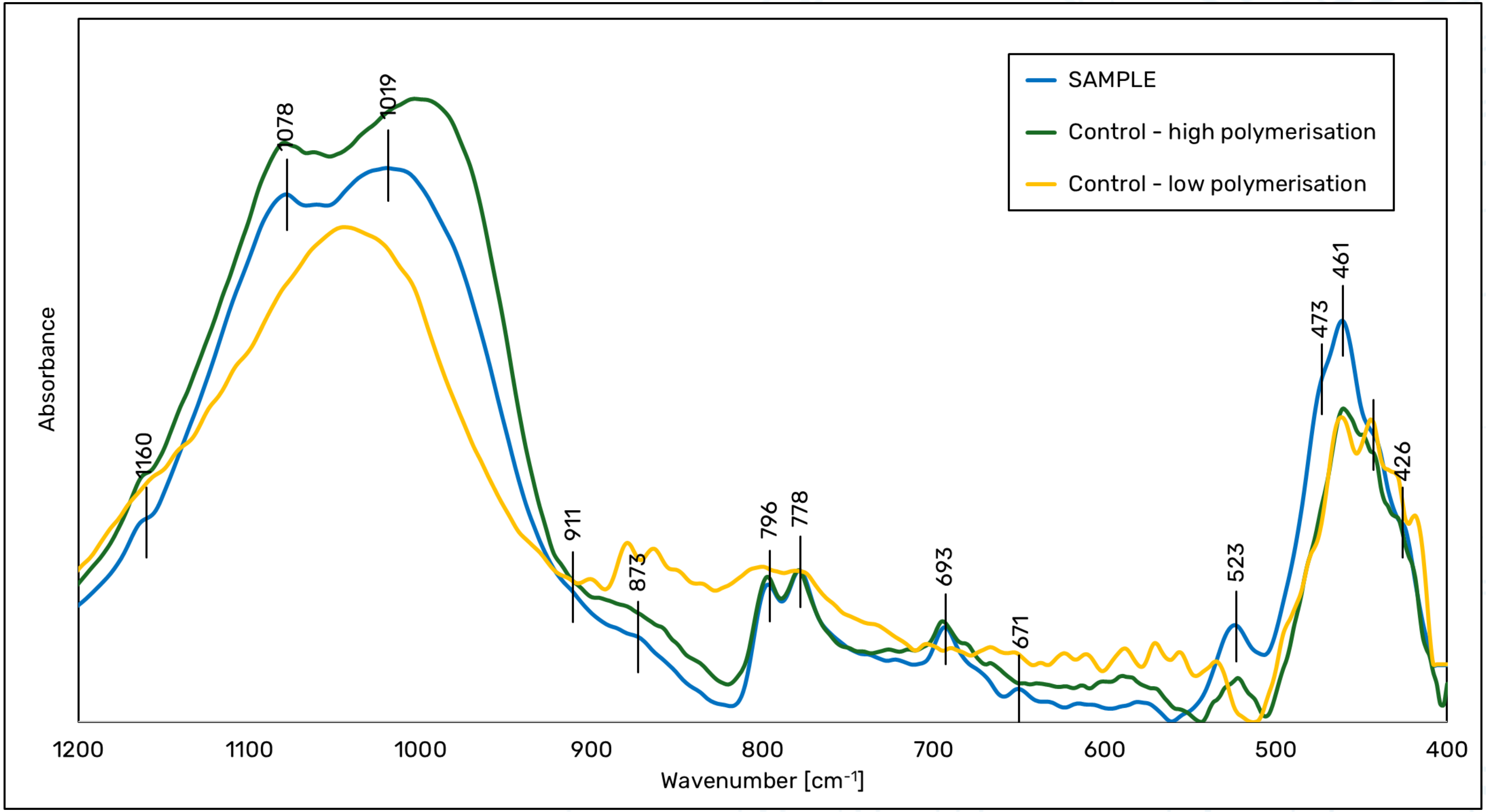
ATR-FTIR spectroscopy



ATR-FTIR spectroscopy



ATR-FTIR spectroscopy



Summary

- Broadly accessible geopolymer printing platform
  - Successful adaptation of a low-cost 3D clay printer, lowering the barrier to entry for geopolymer printing
  - Simple, reproducible setup with high interstudy comparability

- Utilization of a conventional recipe with good rheology control
  - CMC controlled viscosity, slump, and bleed without altering base chemistry (confirmed by FTIR and strength analysis)
  - Achieved 1,1 ± 0,2 MPa ambient-cured 7-day tensile strength

- Critical multiscale defect analysis for further recipe development

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