Direct and indirect 3D printing with geopolymers

G. Franchin¹, H. Elsayed¹, P. Scanferla¹, A. De Marzi¹, F. Gobbin¹, L. Zeffiro¹, A. Conte¹, A. Italiano², P. Colombo¹,³

¹ Industrial Engineering Dept., University of Padova, Italy
² Desamanera, Borsea (RO), Italy
³ Dept. of Material Science and Engineering, The Pennsylvania State University, PA, USA
Advanced Ceramics and Glasses

Heads: Prof. Paolo Colombo and Prof. Enrico Bernardo

Research topics:
- Additive manufacturing of ceramics and glasses
- Highly porous ceramic structures and foams
- Polymer derived ceramics and geopolymers
- Biosilicates
Indirect 3D printing for ceramics

Direct 3D printing for ceramics

Direct and indirect AM - pros and cons

**Direct AM**

**PROS**
- better adhesion between layers
- rheology optimisation
- higher densities
- higher spatial flexibility

**CONS**
- limited by reaction times
- limited complexity without support material
- heat development can cause issues

**Indirect AM**

**PROS**
- higher speeds
- simpler rheology requirements
- higher material and design flexibility
- filler can adsorb heat

**CONS**
- poorer adhesion between layers
- higher residual porosity
- lower spatial flexibility
- complex powder mixture required to assure flowability:

\[ H = \frac{\rho_{\text{Tapped}}}{\rho_{\text{Bulk}}} \]
FEATURES:
- Cheap and sustainable raw materials (wastes)
- room T consolidation
- fast setting reactions
- low CO\textsubscript{2} emissions during production
- dense gel-like structure with intrinsic pseudo-plasticity

CHALLENGE: **4D PRINTING**

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reactive mixture \rightarrow \text{geopolymerization proceeds with time} \rightarrow \text{time-dependent rheology}
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Large scale indirect 3DP

DESAMANERA
Original binder

- Magnesium oxide in the powder bed
- Chlorurate solution as liquid binder
- Adequate mechanical properties
- High residual porosity
- Slow setting
- Non-hydraulic cement
Validation of the lab procedure

- original binder → same density and mechanical properties as printed parts
- constant volume of binder
Samples: 10x1.5x1.5 cm³
Na-based MK-750 geopolymer

**Water** content optimisation

→ influence on reactivity, wettability, rheology

Water content not optimised
- Interface between layers still visible
- Lower residual porosity
Original binder

Geopolymer
Mechanical properties

transverse

Interface between layers

→ anisotropic behaviour

longitudinal
- Significant increase of mechanical properties and durability
- Significant decrease of residual porosity
- Need of adapting the printer for the new binder
CHALLENGE

thin walls and spanning features

→ optimisation of the ink rheology
→ use of additives

Nozzle size: 100 to 1500 µm
X & Y axis resolution: 120 µm
Z axis resolution: 4 µm
- Formation of 3D poly(sialate-siloxo) network → viscosity increase with time
- Intrinsic **pseudo-plastic behaviour** + additives
- Limited working time
Ink features

- physical, reversible gel formation
- initial yield stress → prevents spontaneous flow
Fast increase in viscosity after extrusion

→ low deflection for printed overhang structures or spanning features

Spanning distance: 2 mm
Filament diameter: 0.84 mm
Deflection \(\sim 0.25\) mm
Regular structure

No sagging of filaments

→ increasing spanning lengths

Good interface between filaments
Results

Increased complexity

Proposed application: filters
Experimentation on different inks

Fly ashes addition
+ pseudo-plasticiser, retarding agent

K-based geopolymer
leucite formation after heat treatment
Experimentation on different inks

Porous struts
Hierarchical porosity

Na-based geopolymer
nepheline formation after heat treatment
- Geopolymers have been used as binders for indirect AM

- Geopolymer inks have been printed via DIW

**FUTURE GOALS:**
- increase repeatability
- widen materials window
Thank you for your attention!