Developing a 3D-printable inorganic polymer, derived from an Fe-rich slag

Glenn Beersaerts, Yiannis Pontikes

KU Leuven Department of Materials Engineering, Kasteelpark Arenberg 44, 3001 Leuven, Belgium

KU LEUVEN

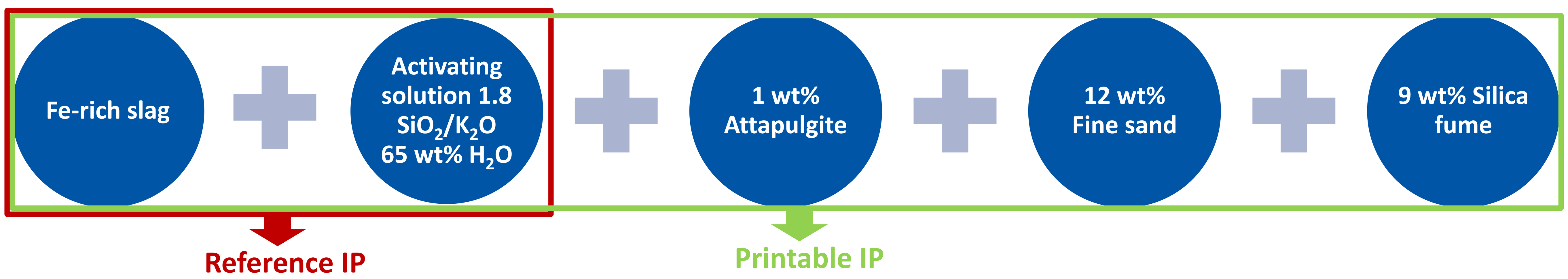
ABSTRACT

One of the latest state-of-the-art technologies used in construction is 3D printing. In order to make 3D printed constructions sustainable, an Fe-rich glassy metallurgic residue is used as a precursor to produce, after alkali activation, an inorganic polymer (IP). IP from Cu-slag can be used as an alternative binder to Ordinary Portland Cement because of the lower environmental footprint. In order to obtain an IP which can be extruded from a 1.2 mm nozzle, the mix design was optimized, with respect to the rheological behavior, by using several additives such as silica fume, needle shaped minerals and ultrafine sand. Rheological properties, such as elasticity, thixotropy and yield stress, of the printable IP were measured in an attempt to reach the rheology of the conventional printable clay. This research provides the first steps for further development in printing Fe-rich IP.

GOAL: Engineering the IP paste from a standard IP formulation (reference) in such a way that it has a rheological behaviour comparatively to the benchmark clay.

METHODS AND MATERIALS

Benchmark: Printable clay (Limoges)



Rheometer (Discovery HR-3, TA Instruments) to perform frequency sweep (100-0.01 rad/s Y=0.05 %) and thixotropic loop (0.01-100-0.01 s^{-1}) of IP paste.

RESULTS

Amorphous fraction is 92.7 wt% and the bulk chemical composition is (in wt%) 41 FeO, 32 SiO_2, 11 Al_2O_3, 4 CaO and 12 others.

Viscoelastic behavior in the linear regime and the paste network structure is measured by frequency sweeps (Figure 2a).

- Storage modulus G' is higher than loss modulus G" for all samples, indicating a more solid-like behavior of the paste
- G' clay > printable IP > reference IP.
- A higher G' is the result of lager numbers of crosslinks, indicating stronger network structure. This feature is important to avoid deformation after extrusion.
- Crossover point is reached at higher frequencies due to weaker attraction forces between particles

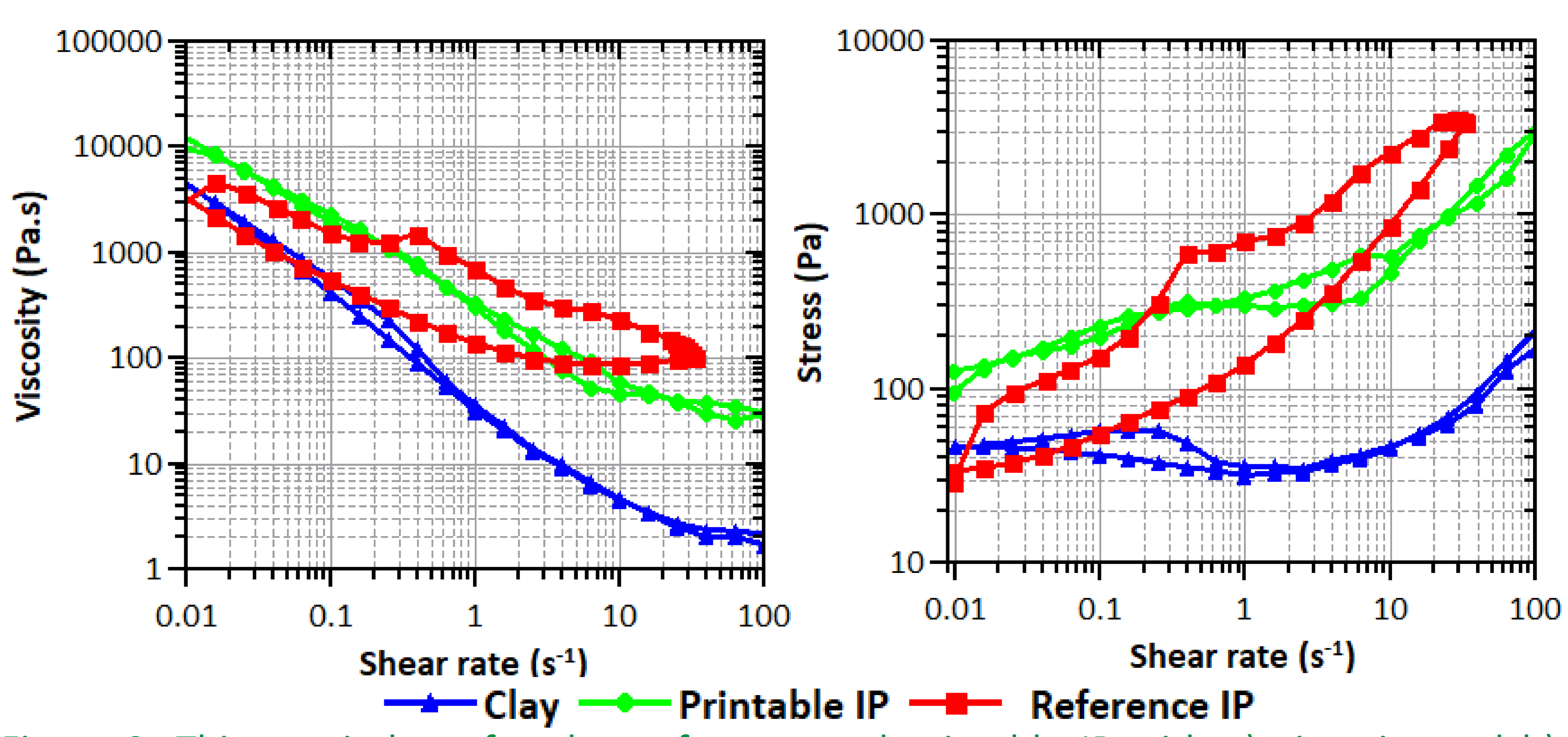


Figure 2: Thixotropic loop for clay, reference and printable IP with a) viscosity and b) stress.

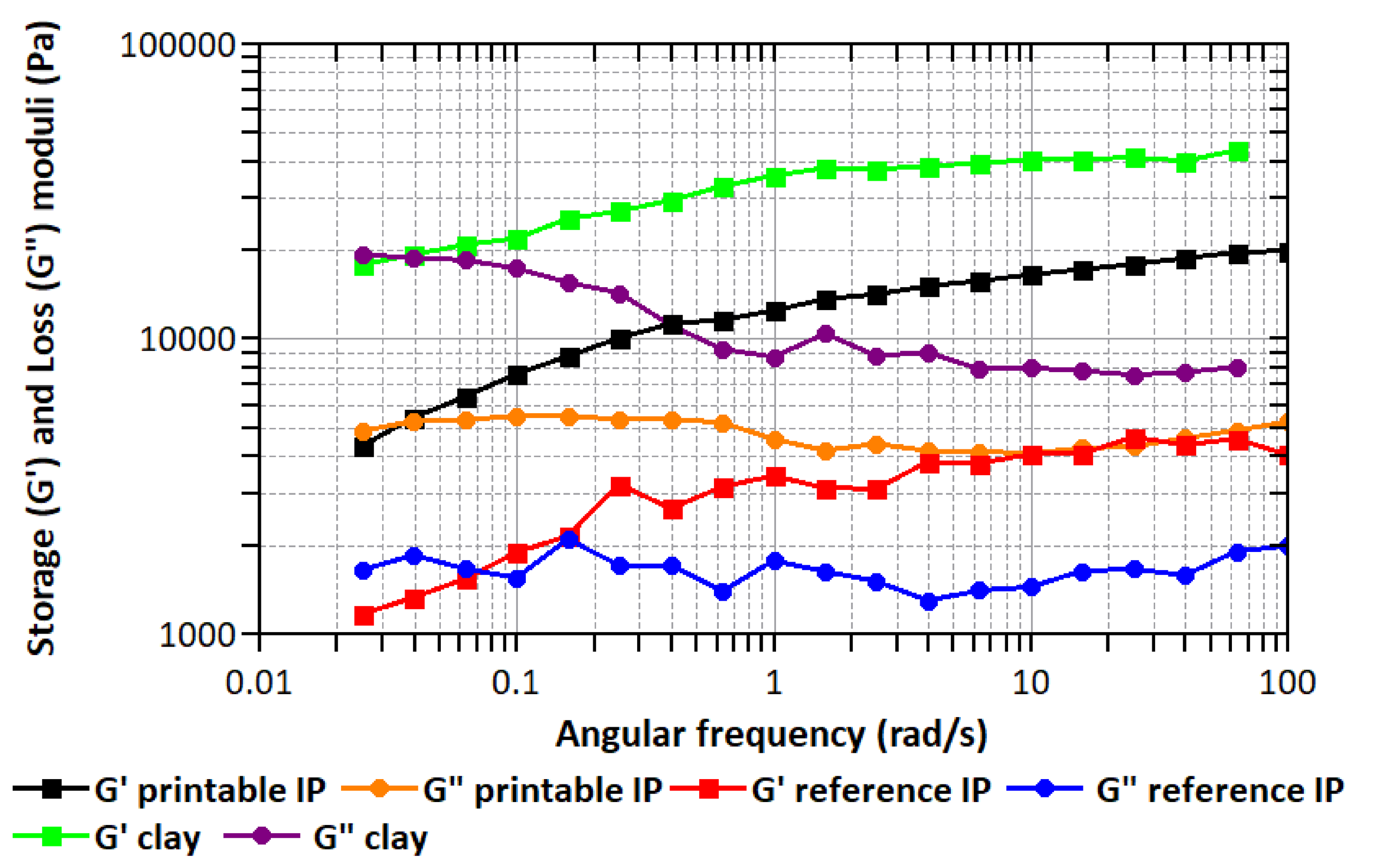


Figure 1: frequency sweep , with Storage G' and Loss modulus G" of the clay, reference and printable IP.

- Viscosity decrease when increasing shear rate due to break down of physical bonds, most pronounced for clay (Figure 2a).
- Reference IP exhibits a thixotropic loop, indicates a slow recovery when decreasing the shear rate (Figure 2a).
- Clay and printable IP show no thixotropic loop due to the immediate adaptation to new shear rate (Figure 2a).
- Clay has a low yield stress (72 Pa) which can be maintained up to 2.5 s^{-1} (Figure 2b). This feature is necessary to ensure deformation after extrusion can be avoided

CONCLUSIONS

✓Fine sand, silica fume and attapulgite resulted in higher elasticity compared to reference sample and evolved from thixotropic loop towards a non thixotropic mixture.
✓Silicate fume and attapulgite additions resulted in suitable rheological behaviour for 3D printing of inorganic polymers.
✓Further optimisation required to lower the viscosity but maintain high elasticity