Development of highly printable GelMA/Laponite bioinks by a rheology-guided design strategy: impact of the GelMA synthetic procedure

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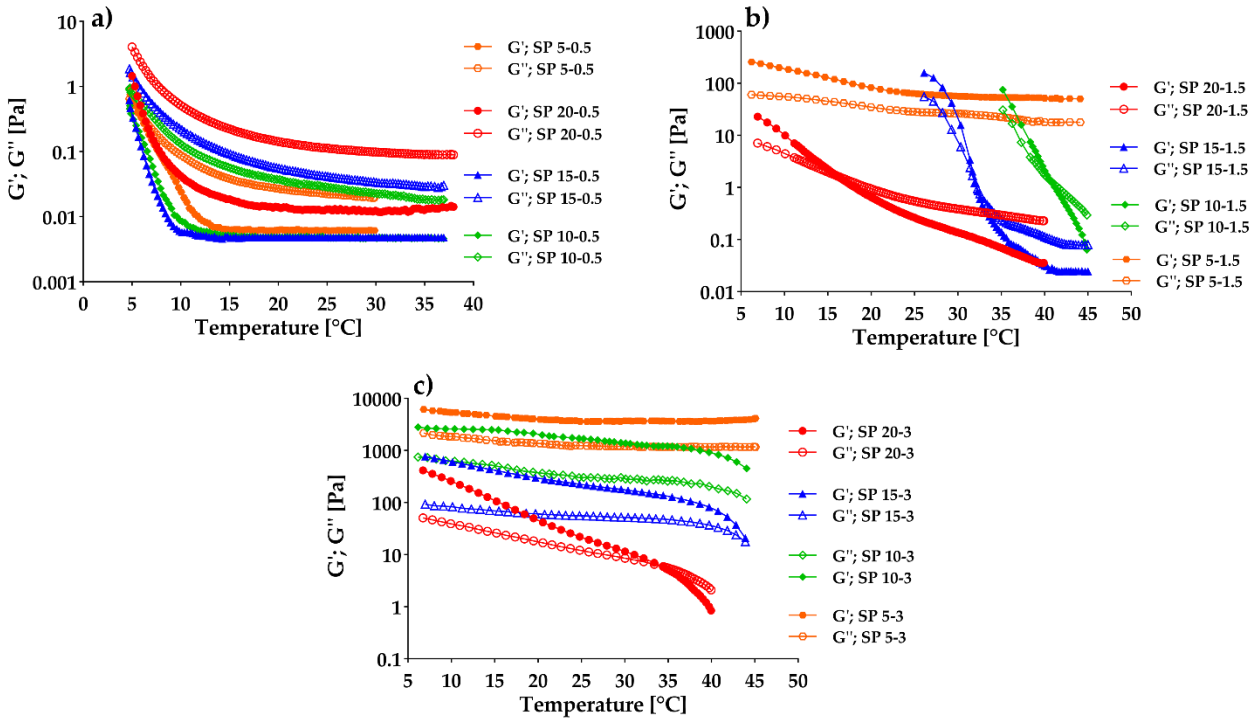


Figure S1. Oscillation temperature-ramp analysis of (a) SP-based biomaterial inks with Lapo at 0.5% w/V, (b) 1.5% w/V and (c) 3.0% w/V (C).

S2

For steady laminar flow in a cylindrical capillary, the apparent wall shear rate can be defined as:

$$\dot{\gamma}_{app} = \frac{4Q}{\pi R^3} \quad (1)$$

Where Q is the volumetric flow rate into the extrusion needle and R is its radius (0.205 mm, see section 2.5). By using the mean axial velocity into the needle $\bar{v}=\frac{Q}{\pi R^2}$ the apparent shear rate at the walls of the extrusion capillary for a Newtonian liquid can be expressed as:

$$\dot{\gamma}_{app} = \frac{4\bar{v}}{R} \quad (2)$$

Assuming a flow velocity perfectly matching the deposition speed of the extruder (7 mm/s) and replacing the corresponding extrusion parameters into equation (2) leads to an apparent shear rate of ~136 s^{-1}.

In the second approach, by assuming an elliptical cross section of the strands, having width w and height h, the volumetric flow rate can be rewritten as:

$$Q = \frac{\pi w h}{4} v_{print} \quad (3)$$

Where v_{print} represents the printing stage speed. By plugging the previous expression into equation (1) the apparent shear rates for the different inks can be obtained.

The actual wall shear rate within the needle can be then derived, by applying the Rabinowitsch correction, as:

$$\dot{\gamma}_w = \dot{\gamma}_{app}\left(\frac{3n+1}{4n}\right) \quad (4)$$

Where n represents the "local" power law index, as calculated by modelling the shear thinning inks through the well-known Ostwald-de Waele equation for non-Newtonian fluids:

$$\eta = K\dot{\gamma}^{n-1} \quad (5)$$

being η and K the apparent viscosity and consistency index, respectively. Both n and K were calculated for the various inks employed for the final printing tests, based on flow sweeps as assessed through rheological measurements. In fact, by converting the previous power law (5) into a ln-ln relationship leads to:

$$\ln \eta = \ln K + (n-1) \ln \dot{\gamma} \quad (6)$$

By linear fitting of the $\ln \eta$-$\ln \dot{\gamma}$ plot, for values around 136 s^{-1}, n and K for the inks were calculated for each sample and are reported in Table S2.

Table S3. Power law index n and consistency index K extracted from flow curves of each printed sample.

Sample	n	K [Pa.s^n]
DP15	0.0677	311.00
DP20	0.0902	516.46
DP20-05	0.0573	204.90
DP15-05	0.1185	81.71
SP15-1.5	0.1058	19.61
SP20-3	0.0692	88.50

Apparent and true shear rates at the walls for the printed inks are reported in Table S3. The maximum true wall shear rates (~800 s^{-1}) fall well within the measured range of the flow sweep measurements.

Table S4. Apparent and true wall shear rates calculated using geometric strand parameters and shear thinning flow correction.

Sample	$\dot{\gamma}_{app}$ [1/s]	$\dot{\gamma}_{w}$ [1/s]
DP15	175.99	781.89
DP20	151.21	532.50
DP20-05	156.62	800.79
DP15-05	166.51	476.16
SP15-1.5	124.98	389.05
SP20-3	113.77	496.35

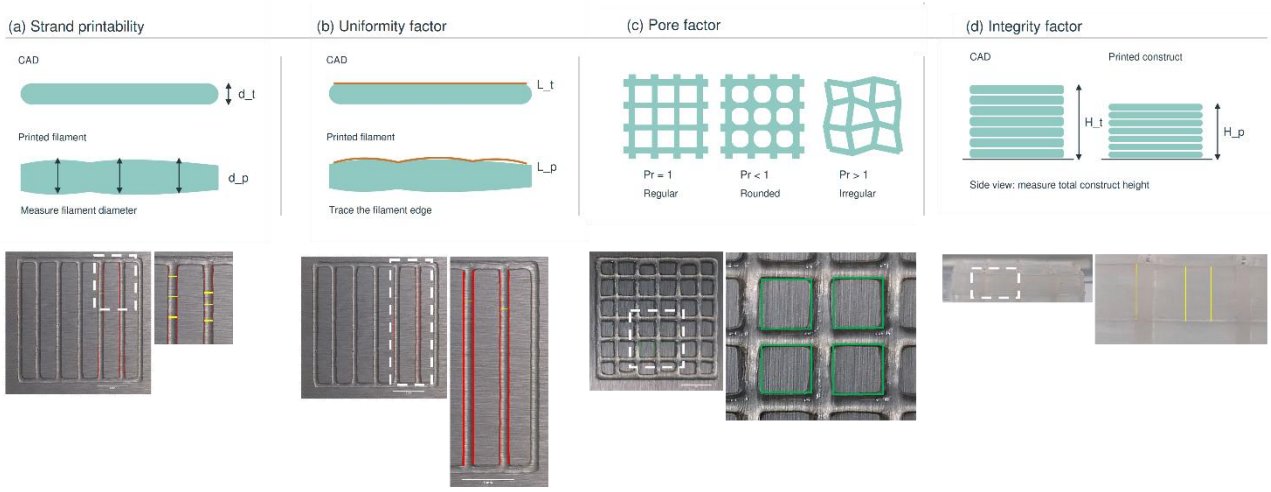


Figure S5. Illustration of the measurements used to evaluate printability and shape fidelity, using SP20-3 as a representative formulation. Schematic diagrams (top) and annotated experimental images with enlarged views (bottom) show the measurements for (a) strand printability, (b) uniformity factor, (c) pore factor, and (d) integrity factor. Yellow lines indicate filament diameter and construct height measurements, red lines trace filament edges, and green contours outline pores for perimeter and area determination. Measurements were obtained using ImageJ 1.53k.