Supporting Information

Design of 3D-Photoprintable, Bio- and Hemocompatible Non-Isocyanate Polyurethane Elastomers for Biomedical Implants

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Materials

3-methyl-1-penten-4-yn-3-ol (98%, Sigma-Aldrich), 4,4'-methylenebis(cyclohexylamine) (MBCHA) (95%, Sigma-Aldrich), ammonium sulfate (≥99%, Sigma-Aldrich), argon (Air Liquide), chloroform (≥99.8%, VWR Chemicals), CO2 (N27) (Air Liquide), dimethylformamide (99.8%, DMF) (Acros), deuterated chloroform (Eurisotop), dimethylsulfoxide-d_6 (Eurisotop), ethyl acetate (≥99.8%, Acros), methanol (≥98.5%, VWR), oxalic acid (98%, Sigma-Aldrich), petroleum ether boiling range 40-60°C (Acros), poly(propylene glycol) diglycidyl ether (PPGDE, 380 g/mol) (Sigma-Aldrich) , potassium hydroxide (85%, Acros), tetrabutylammonium bromide (≥98%, Sigma-Aldrich), tetrabutylammonium iodide (≥99%, Sigma-Aldrich) were received without any further purification.

Experimental Procedures

Synthesis of poly(propylene glycol) bis(cyclic carbonate)

Poly(propylene glycol) bis(cyclic carbonate) (PPG bisCC) was prepared according to Bähr and Mülhaupt's protocol [1,2] by the quantitative carboxylation of poly(propylene glycol) diglycidyl ether (PPGDE) by CO_2. PPGDE 380 g/mol (0.094 mol, 35.63 g, 1 eq.) and tetrabutylammonium iodide (4.7 mmol, 1.73 g, 0.05 eq.) were introduced in an 80 mL high pressure autoclave. The stainless-steel reactor was then filled with 100 bar of CO_2 and heated up to 80 °C. The reaction was kept at constant pressure for 24 hours to reach complete conversion. After depressurization of the reactor, the product was collected and tetrabutylammonium iodide was removed by liquid-liquid extractions. PPG bisCC was first solubilized in 400 mL of chloroform, washed with 4 x 400 ml of Milli-Q water and finally 400 mL of Milli-Q water with ammonium sulfate (10 g/L). The organic fraction was collected, dried over $MgSO_4$, and the solvent was removed by a rotary evaporator.

PPGDE: ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 3.99 – 3.33 (m, 8H), 3.14 (td, *J* = 6.7, 6.0, 2.7 Hz, 1H), 2.78 (p, *J* = 4.0 Hz, 1H), 2.61 (dq, *J* = 7.9, 4.2 Hz, 1H), 1.15 (q, *J* = 5.8, 4.9 Hz, 4H).

PPG bisCC: ^{1}H NMR (400 MHz, $CDCl_3$) δ (ppm) = 4.83 (d, *J* = 9.1 Hz, 1H), 4.58 – 4.39 (m, 2H), 3.99 – 3.56 (m, 6H), 3.56 – 3.34 (m, 2H), 1.15 (tt, *J* = 6.5, 3.5 Hz, 3H).

Synthesis of poly(propylene glycol)-polyhydroxyurethane

Poly(propylene glycol)-polyhydroxyurethane (PPG-PHU) was prepared in bulk by mixing PPG bisCC (0.0214 mol, 10 g, 1 eq.) and 4,4'-methylenebis(cyclohexylamine) (MBCHA, 0.0214 mol, 4.4948 g, 1 eq.) in a round bottom flask at 40 °C for 15 minutes. The mixture was then poured into a Teflon container, before being placed at 70 °C in an oven for 96 hours. The resulting prepolymer was analyzed by NMR (^{1}H- and HSQC, **Figure S1a** and **S1b**, respectively), FTIR (**Figure S2**) and SEC (**Figure S3**). The NMR spectra of the prepolymer show the appearance of the peaks corresponding to the ring-opening of the cyclic carbonates, namely b' (4.97 – 4.85 ppm), b (4.73 – 4.59 ppm), a (4.55 – 4.20) and g (3.53 – 3.41). In **Figure S2**, the bands corresponding to functional groups of PPG-PHU are also shown: O-H and N-H stretching (~ 3,500-3,200 cm^{-1}), C=O stretching of cyclic carbonate (chain-ends, ~ 1,795 cm^{-1}), H-bonded C=O in urethane (~ 1,700 cm^{-1}), N-H deformation (~ 1,530 cm^{-1}), asymmetric stretch N-CO-O and stretching of C-O-C (~ 1,235 cm^{-1}) and C-O-C of the PPG segment (~ 1,080 cm^{-1}). M_n = 7,200 g/mol, M_w = 16,100 g/mol, M_w/M_n = 2.23 (PS calibration). **Figure S4** shows the DSC thermogram of the PPG-PHU and **Figure S5** its thermogravimetric analysis.

PPG-PHU: ^{1}H-NMR (400 MHz, DMSO) δ (ppm) = 7.01 (d, J = 7.8 Hz, 1H), 4.91 (s, 1H), 4.78 – 4.57 (m, 1H), 4.02 – 3.07 (m, 27H), 1.89 – 0.75 (m, 27H).

Synthesis of tetrabutylammonium oxalate

Tetrabutylammonium oxalate (TBAOx) was prepared following Grignard's protocol [3] by mixing tetrabutylammonium bromide (0.0127 mol, 4.1006 g) and 10 mL of methanol in a 50 mL round bottom flask equipped with a magnetic rod until dissolution of the salt. A solution of potassium hydroxide (0.014 mol, 0.7858 g) in 10 ml of methanol was then added dropwise to the solution. The resulting solution was then heated gradually to 60 °C. After 24 h, the flask was cooled to room temperature and the precipitated potassium bromide was removed by filtration, obtaining a tetrabutylammonium hydroxide solution. Oxalic acid (0.007 mol, 0.6302 g) dissolved in 2 mL of methanol was introduced in a 50 mL round bottom flask placed in an ice bath. The tetrabutylammonium hydroxide solution was then added dropwise to the oxalic acid under agitation. After 48h at room temperature, the methanol was removed in vacuum and the obtained white solid was dried in vacuum at 50 °C for 24 h. Yield = 100%.

TBAOx: ^{1}H-NMR (400 MHz, $CDCl_3$) δ (ppm) = 3.41 – 3.22 (m, 8H), 1.80 – 1.56 (m, 8H), 1.45 (q, J = 7.3 Hz, 8H), 1.00 (t, J = 7.3 Hz, 12H).

Synthesis of 4-methyl-5-methylene-4-vinyl-1,3-dioxolan-2-one

4-methyl-5-methylene-4-vinyl-1,3-dioxolan-2-one (an α-alkylidene cyclic carbonate, αCC) was synthesized by the catalyzed carboxylative coupling of CO_2 to a propargylic alcohol following Grignard's protocol [3] by introducing 3-methyl-1-penten-4-yn-3-ol (46.29 mmol, 5 mL) and TBAOx (2.31 mmol, 1.3260 g) in a stainless-steel autoclave with a nominal volume of 12 mL equipped with a magnetic rod. The reactor was then filled with 50 bar of CO_2, and this pressure was kept constant for 24h at 80 °C. After reaction, the yellow liquid product was purified by chromatography onto silica by using a 95/5 petroleum ether (40 - 60 °C)/ethyl acetate mixture as

eluent. The solvent was then removed under vacuum. The obtained colorless liquid was analyzed by ^{1}H-NMR (**Figure S6**) and FTIR (**Figure S7**), which show the bands assigned to the C=O stretching mode typical of cyclic carbonates (~ 1,820 cm^{-1}), O-CO-O (~ 1,740 cm^{-1}) and C=C vibration (~ 1,680 – 1,640 cm^{-1}). Structural characterizations are identical to those reported in the initial protocol and confirm the chemical structure of the product. Isolated yield = 87%.

αCC: ^{1}H-NMR (400 MHz, $CDCl_3$) δ (ppm) = 5.91 (dd, J = 17.2, 10.7 Hz, 1H), 5.45 (d, J = 17.1 Hz, 1H), 5.29 (d, J = 10.7 Hz, 1H), 4.84 (d, J = 4.0 Hz, 1H), 4.33 (d, J = 4.0 Hz, 1H), 1.66 (s, 3H).

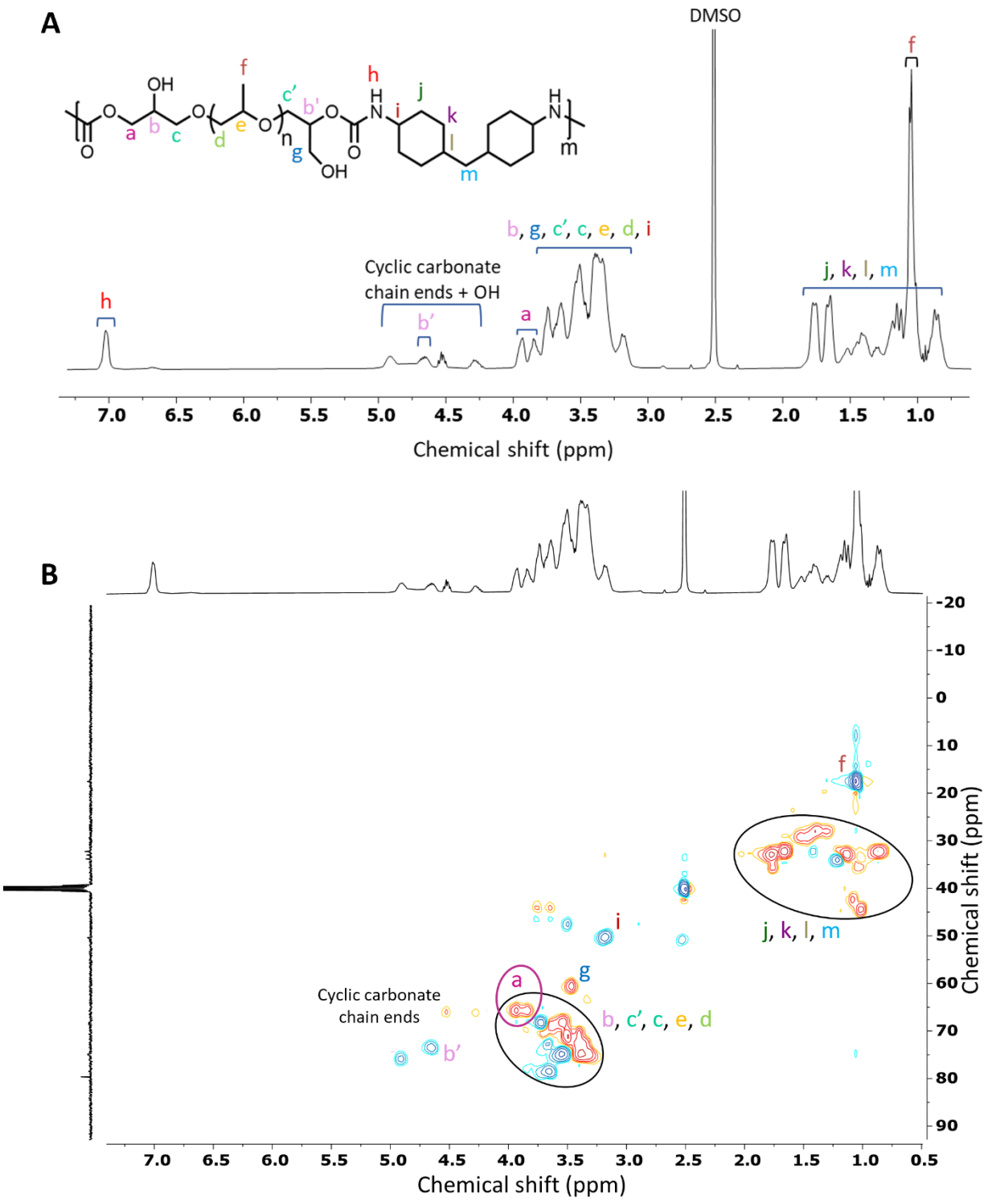

Figure S1a & b. ^{1}H- (A) and HSQC (B) NMR spectra of PPG-PHU in DMSO-d_6 (400 MHz).

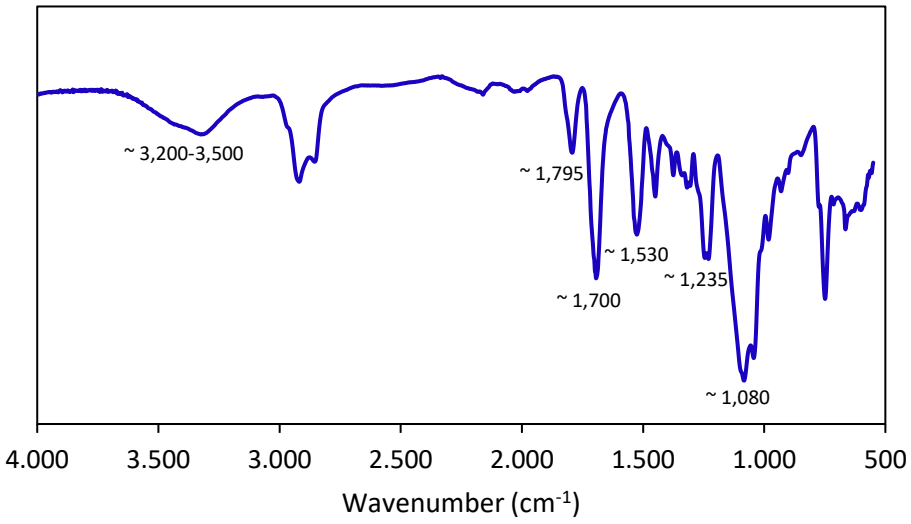

Figure S2. FTIR-ATR spectrum of PPG-PHU.

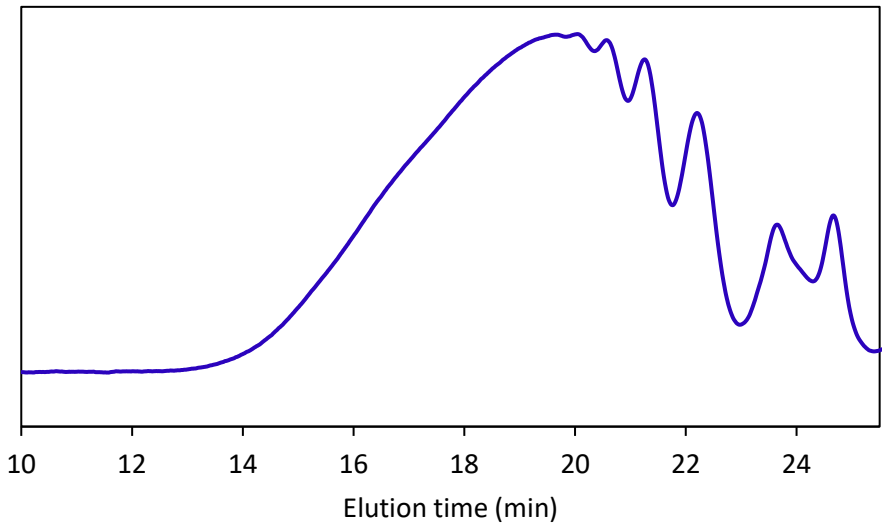

Figure S3. SEC chromatogram of PPG-PHU (M_n = 7,200 g/mol, M_w = 16,100 g/mol, M_w/M_n = 2.23 (PS calibration).

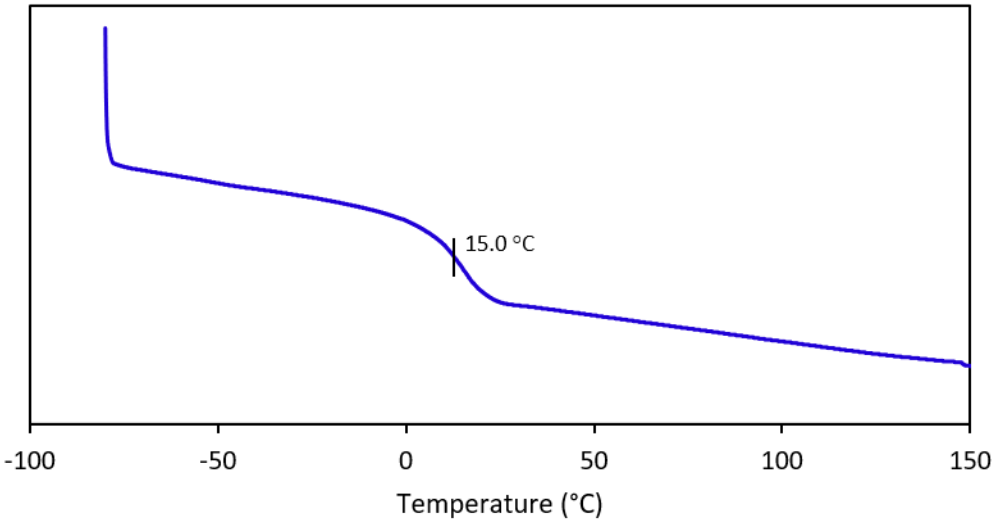

Figure S4. DSC thermogram of PPG-PHU.

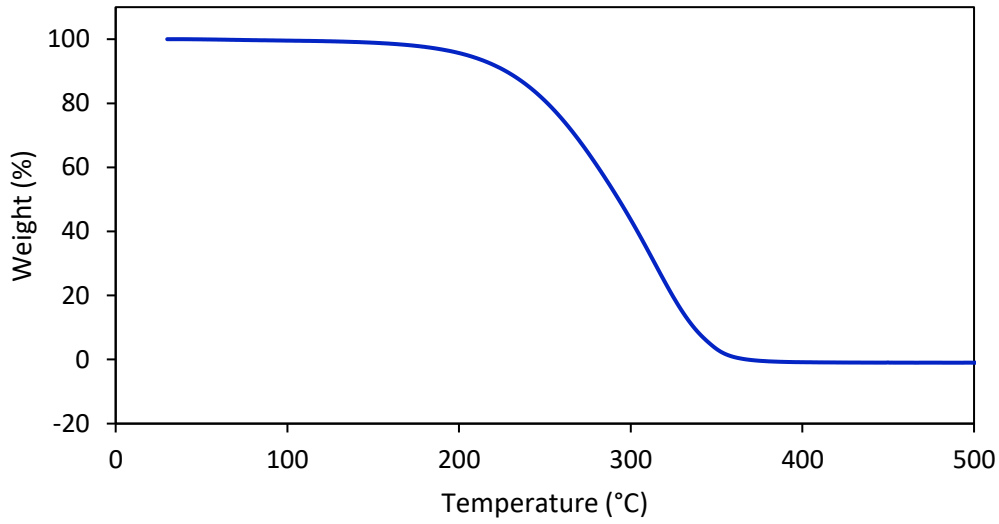

Figure S5. TGA curve of PPG-PHU.

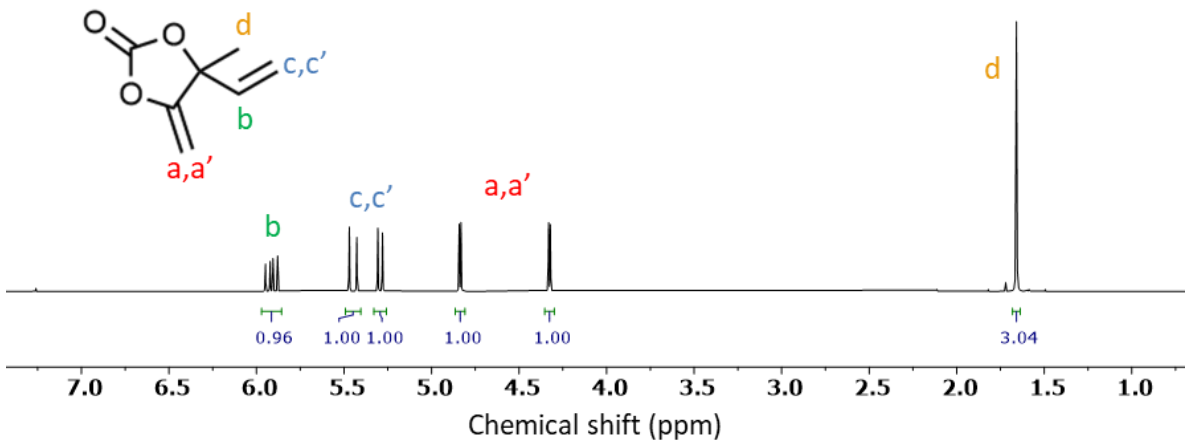

Figure S6. ^{1}H- spectrum of 4-methyl-5-methylene-4-vinyl-1,3-dioxolan-2-one (αCC) in $CDCl_3$ (400 MHz).

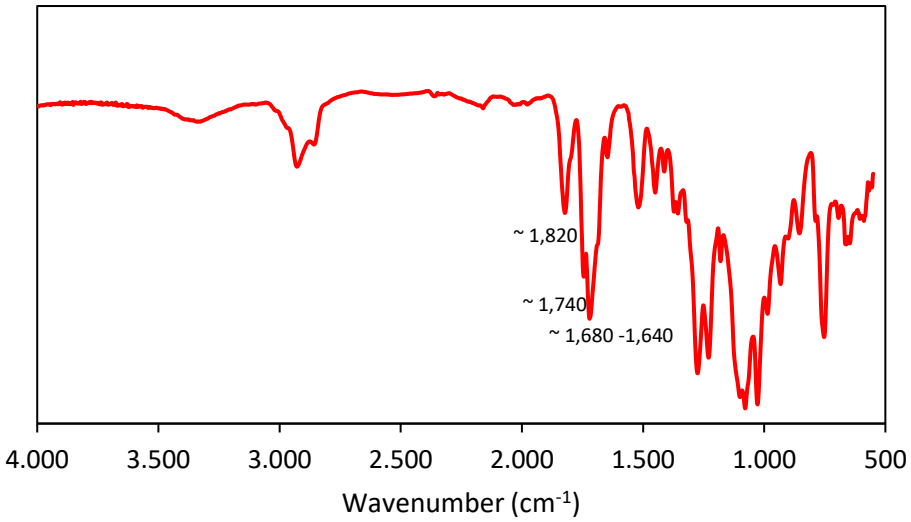

Figure S7. FTIR-ATR spectrum of 4-methyl-5-methylene-4-vinyl-1,3-dioxolan-2-one (αCC).

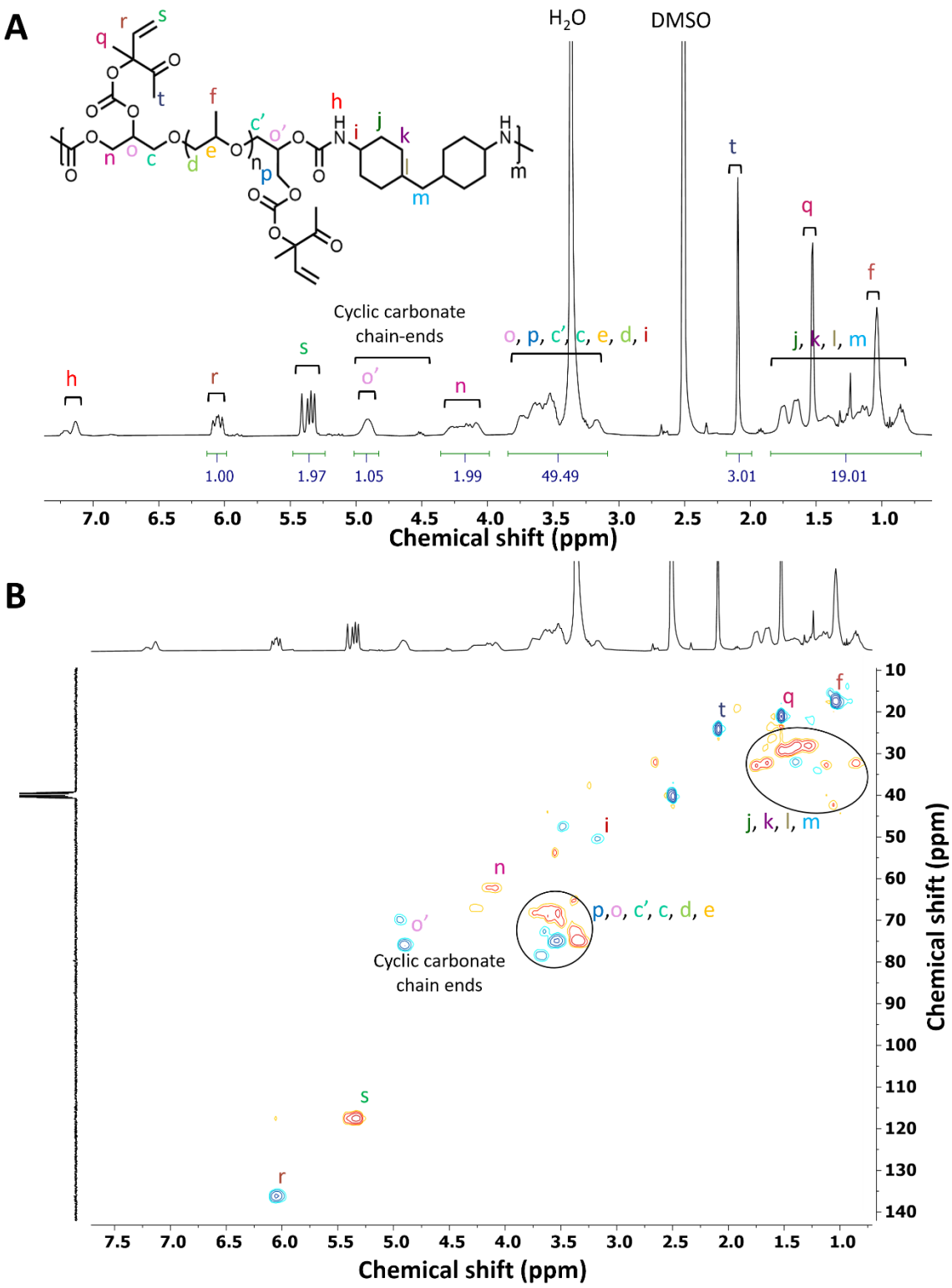

Figure S8a & b. ^{1}H- (A) and HSQC (B) NMR spectra of αCC-PPG-PHU in DMSO-d_6 (400 MHz).

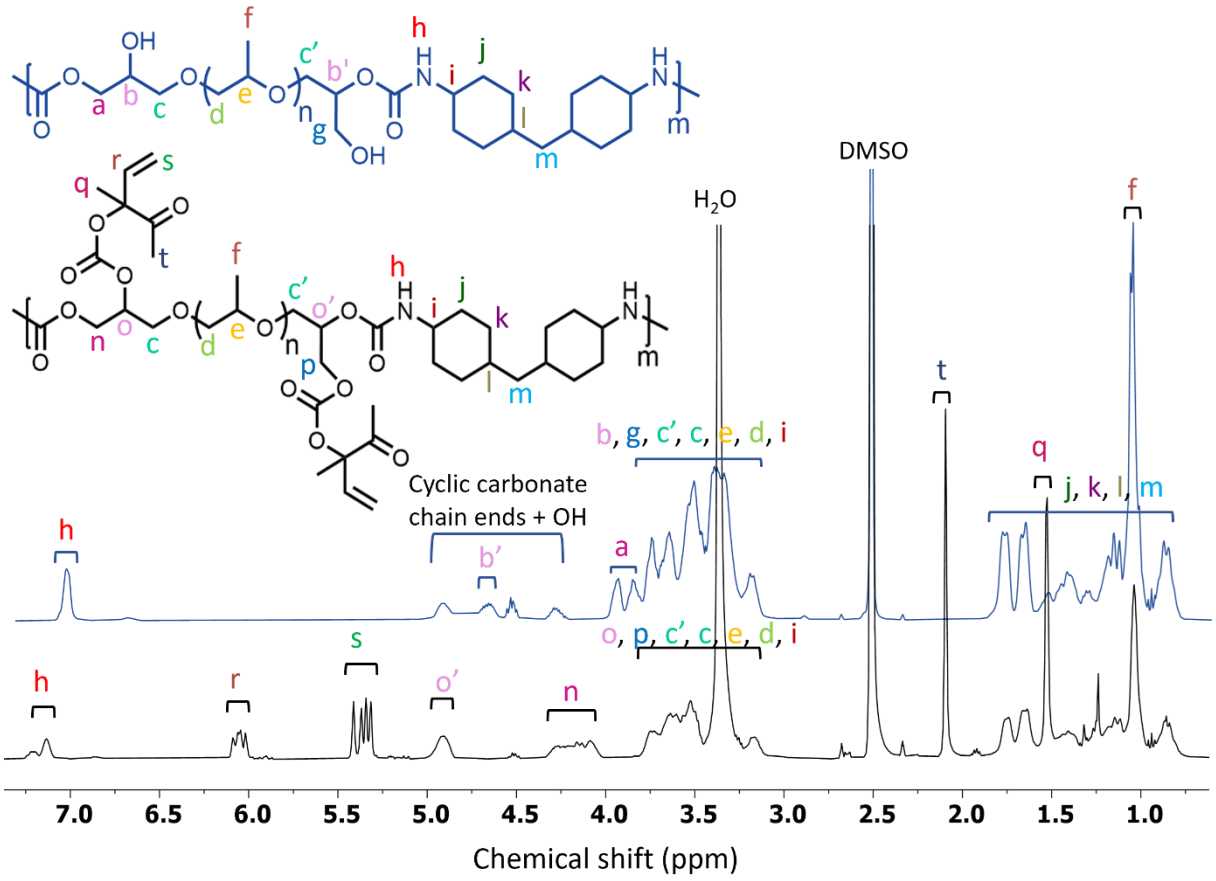

Figure S9. ^{1}H-NMR spectra of PPG-PHU (blue) and αCC-PPG-PHU (black) in DMSO-*d*$_6$ (400 MHz).

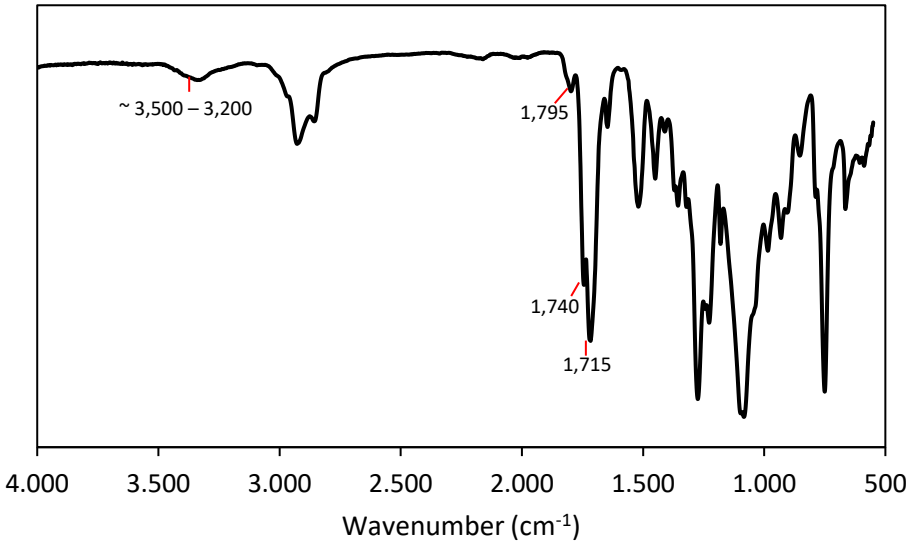

Figure S10. FTIR-ATR spectrum of αCC-PPG-PHU.

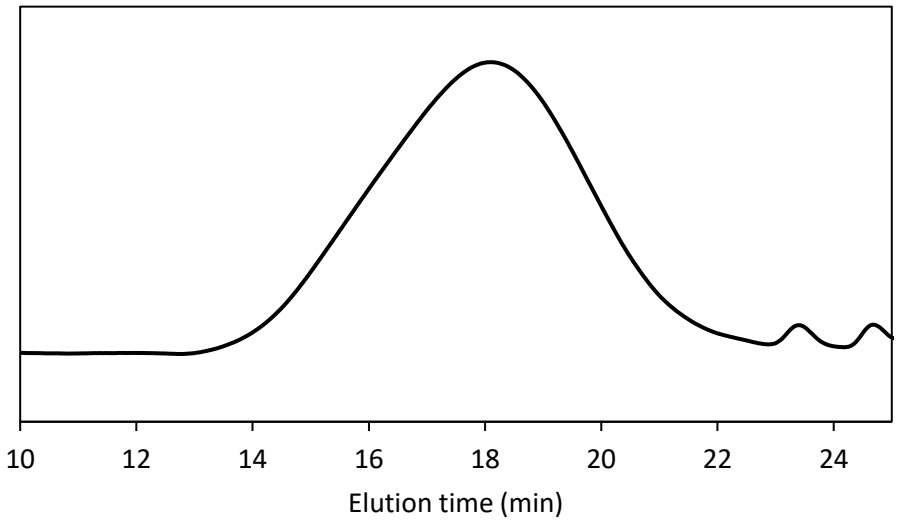

Figure S11. SEC chromatogram of αCC-PPG-PHU (M_n = 14,100 g/mol, M_w = 24,400 g/mol, M_w/M_n = 1.73 (PS calibration).

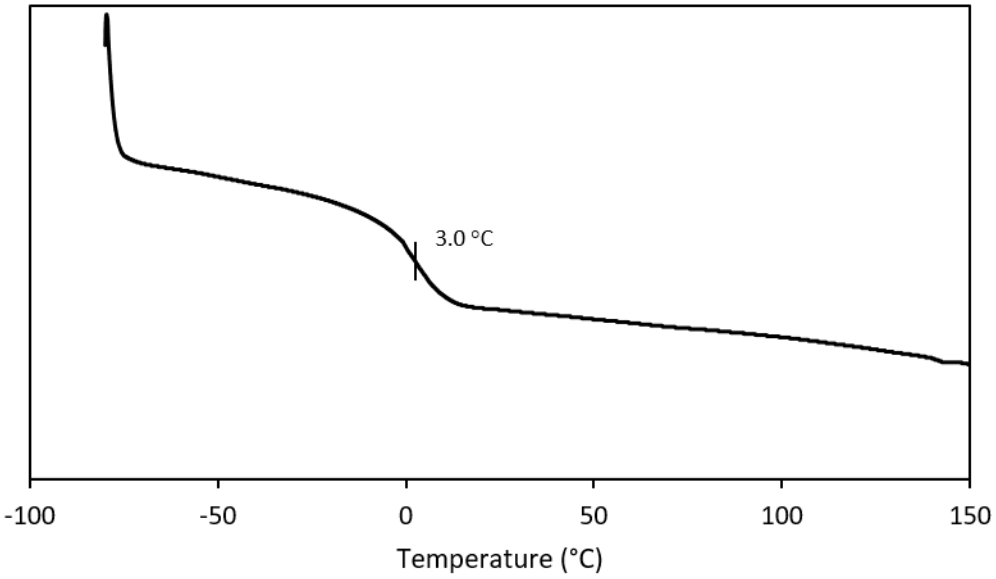

Figure S12. DSC thermogram of αCC-PPG-PHU.

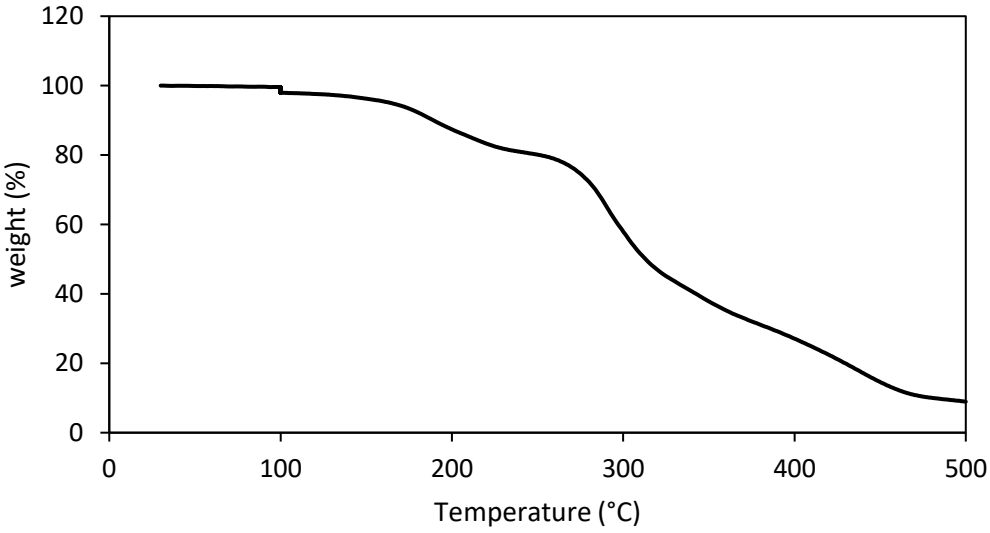

Figure S13. TGA curve of αCC-PPG-PHU.

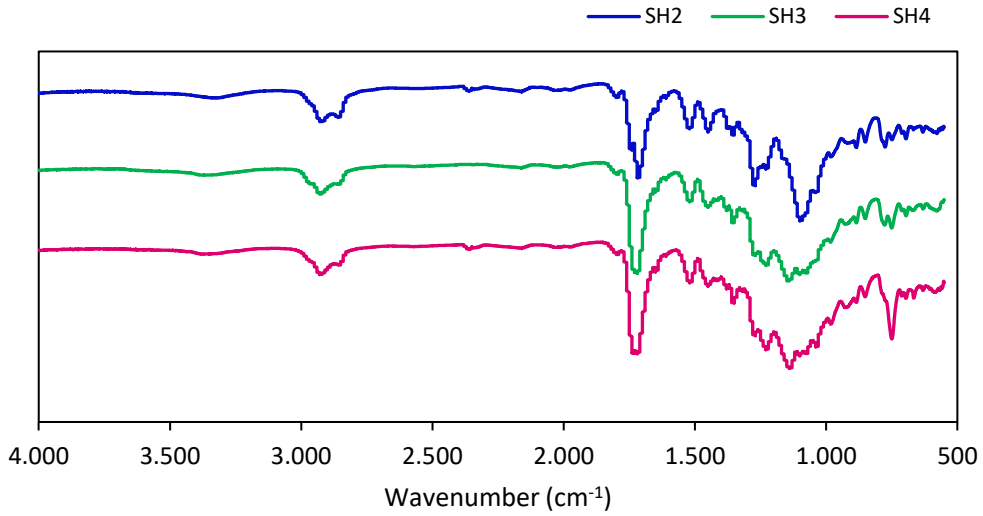

Figure S14. FTIR-ATR spectra of the PPG-NIPU networks formed with SH2, SH3 and SH4.

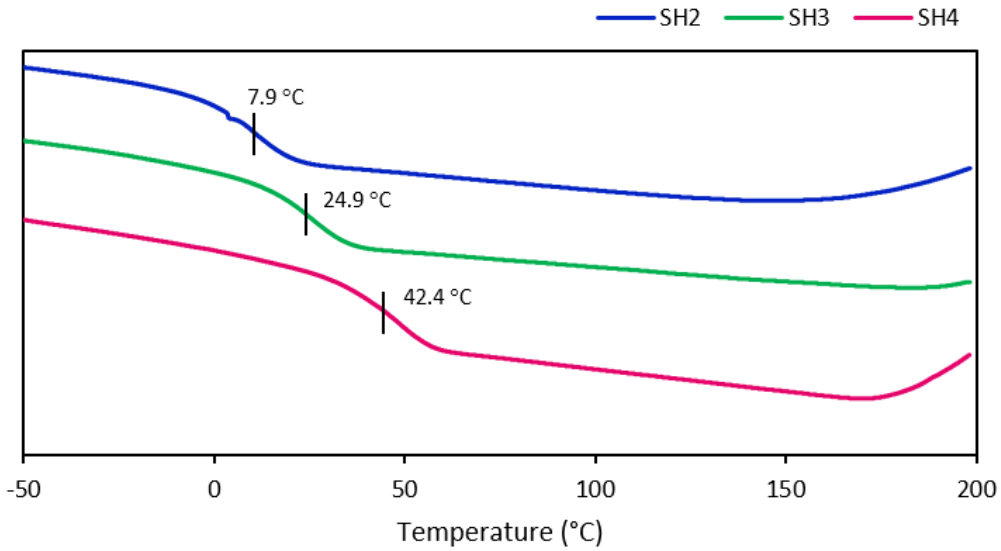

Figure S15. DSC thermogram of the PPG-NIPU networks formed with SH2, SH3 and SH4.

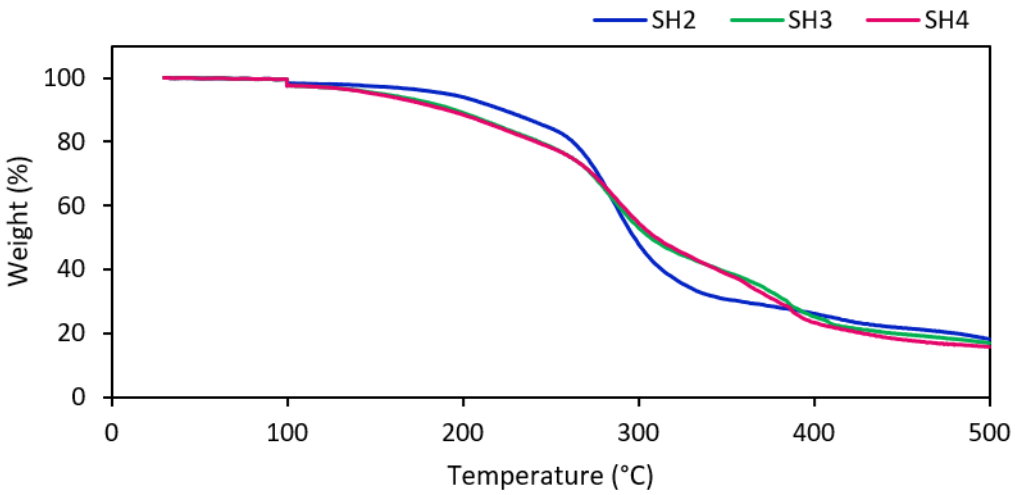

Figure S16. TGA curves of PPG-NIPU networks formed with SH2, SH3 and SH4.

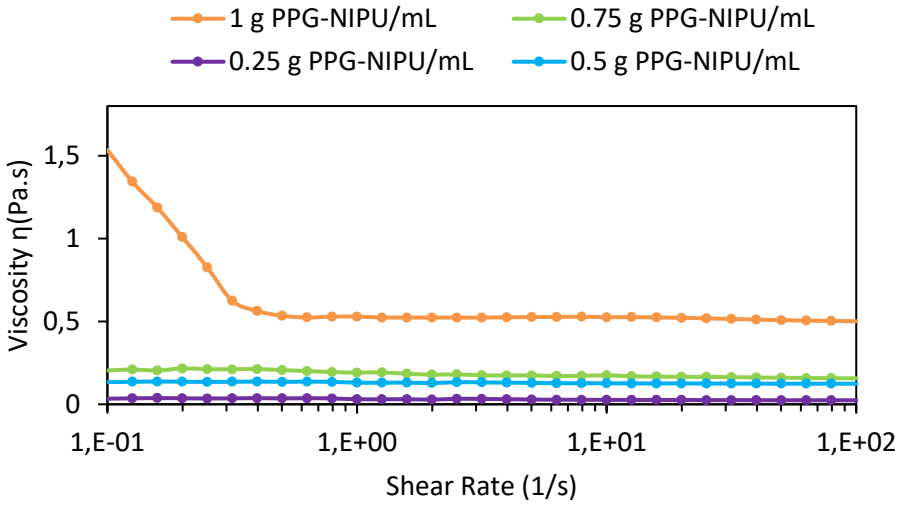

Figure S17. Viscosity as a function of shear rate for the formulation of PPG-NIPU with SH3 in NMP.

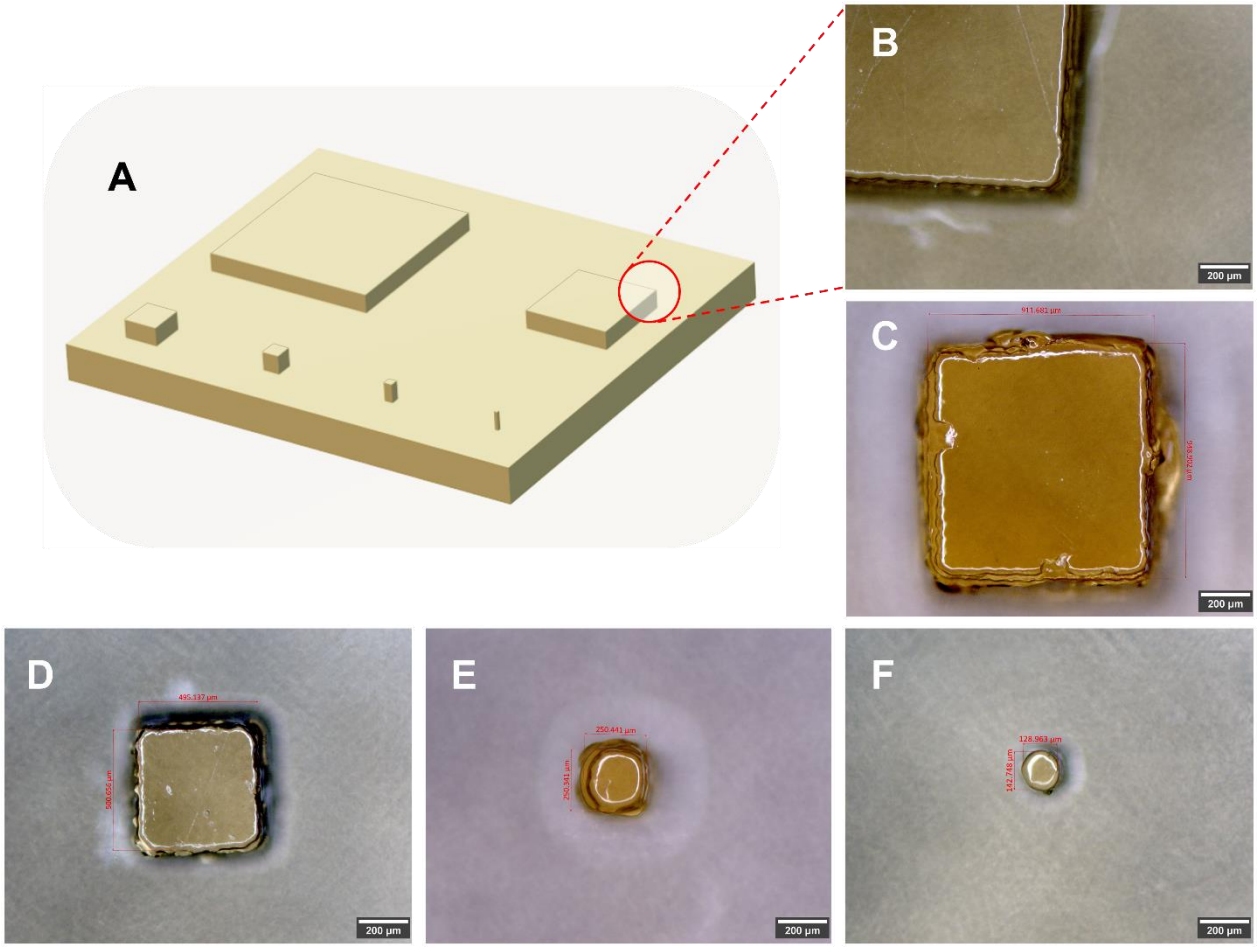

Figure S18. CAD showing the square-based geometry used for the 3D printing trials by DLP (A) and optical microscopy images of the PPG-NIPU-based 3D printed objects with different sizes: 2,500x2,500 µm (corner) (B), 1,000x1,000 µm (C), 500x500 µm (D), 250x250 µm (E) and 100x100 µm (F). Scale bar: 200 µm.

Theoretical X and Y dimension (mm)	Experimental X dimension (mm)	Experimental Y dimension (mm)
0.1	0.129	0.143
0.25	0.250	0.250
0.5	0.495	0.501
1	0.912	0.949

Table S1. Theoretical and experimentally determined sizes (in mm) of the DLP-printed square-based 3D objects in the X-Y plane.

References

(1) Bähr, M.; Mülhaupt, R. Linseed and Soybean Oil-Based Polyurethanes Prepared via the Non-Isocyanate Route and Catalytic Carbon Dioxide Conversion. *Green Chemistry* **2012**, *14* (2), 483–489. https://doi.org/10.1039/c2gc16230j.

(2) Pierrard, A.; Aqil, A.; Detrembleur, C.; Jérôme, C. Thermal and UV Curable Formulations of Poly(Propylene Glycol)–Poly(Hydroxyurethane) Elastomers toward Nozzle-Based 3D Photoprinting. *Biomacromolecules* **2022**, *24* (10), 4375–4384. https://doi.org/10.1021/acs.biomac.2c00860.

(3) Grignard, B.; Gennen, S.; Gilbert, B.; Rapha, M. Ø.; Jerome, C.; Tassaing, T.; Detrembleur, C. Boosting the Catalytic Performance of Organic Salts for the Fast and Selective Synthesis of a -Alkylidene Cyclic Carbonates from Carbon Dioxide and Propargylic Alcohols. *ChemCatChem* **2018**, *10*, 2584–2592. https://doi.org/10.1002/cctc.201800063.