Electronic Supplementary Information

Harnessing peptide-cellulose interactions to tailor the performance of self-assembled, injectable hydrogels

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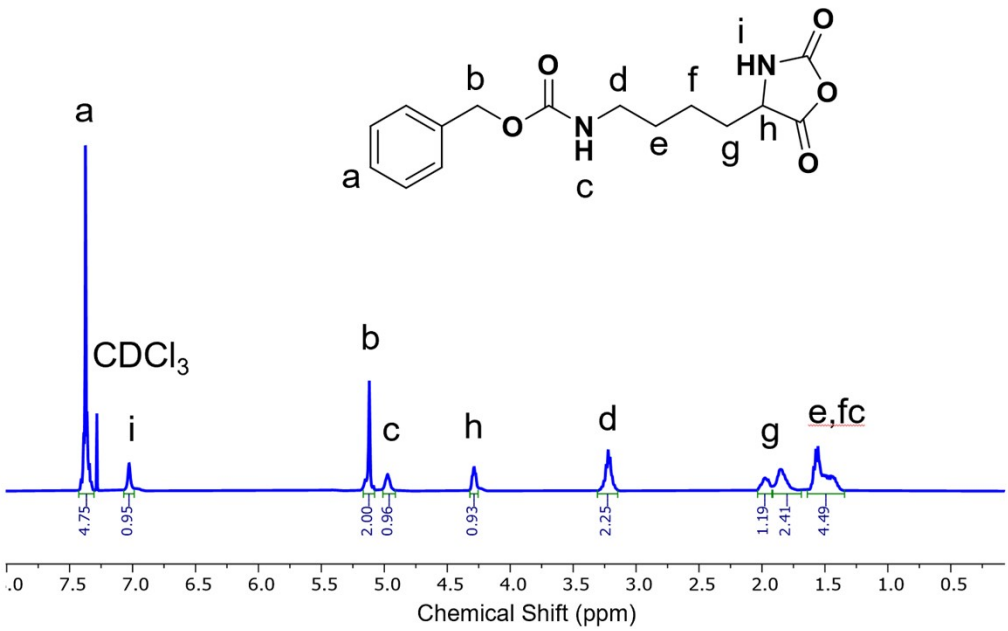

Figure S1: ^{1}H NMR of ZLY-NCA in $CDCl_3$. δ= 7.26 ppm (s, $CDCl_3$), δ= 7.48 ppm (m, 5H, Ph), δ= 7.02 ppm (NH) δ= 5.12 ppm (s, 2H, $PhCH_2O$), δ= 4.92 ppm (NH), δ= 4.28 ppm(t, 1H, CH), δ= 3.22 ppm (q, 2H, CH_2CH_2NH), δ= 1.90 ppm (m, 2H, CH_2CH_2CH), δ= 1.51 ppm (m, 4H, $CH_2CH_2CH_2$)

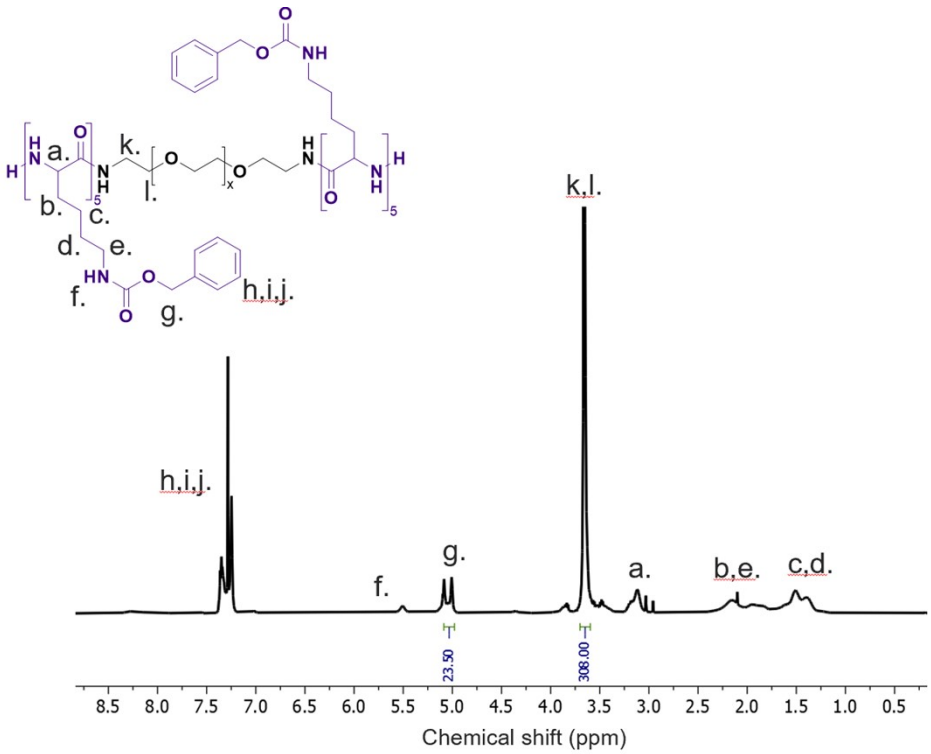

Figure S2: ^{1}H NMR of $PZLY_5$-*b*-PEG-*b*-$PZLY_5$ triblock copolymer. PZLY repeat length was confirmed *via* end group analysis of the carbobenzyloxy group, specifically the benzyl-adjacent

protons (peak at ~5.0 ppm) compared to the PEG backbone signal (3.64 ppm). δ= 7.26 ppm ($CDCl_3$), δ= 7.34 ppm (m, Ph), δ= 5.5 ppm (NH) δ= 5.04 ppm (broad s, $PhCH_2O$), δ= 3.64 ppm (CH_2CH_2O), δ= 3.12 ppm (m, CH_2CH_2CH), δ= 2.15 ppm (m, CH_2CH_2CH), δ= 2.0 (DMAc) δ= 1.48 ppm (m, CH_2CH_2CH)

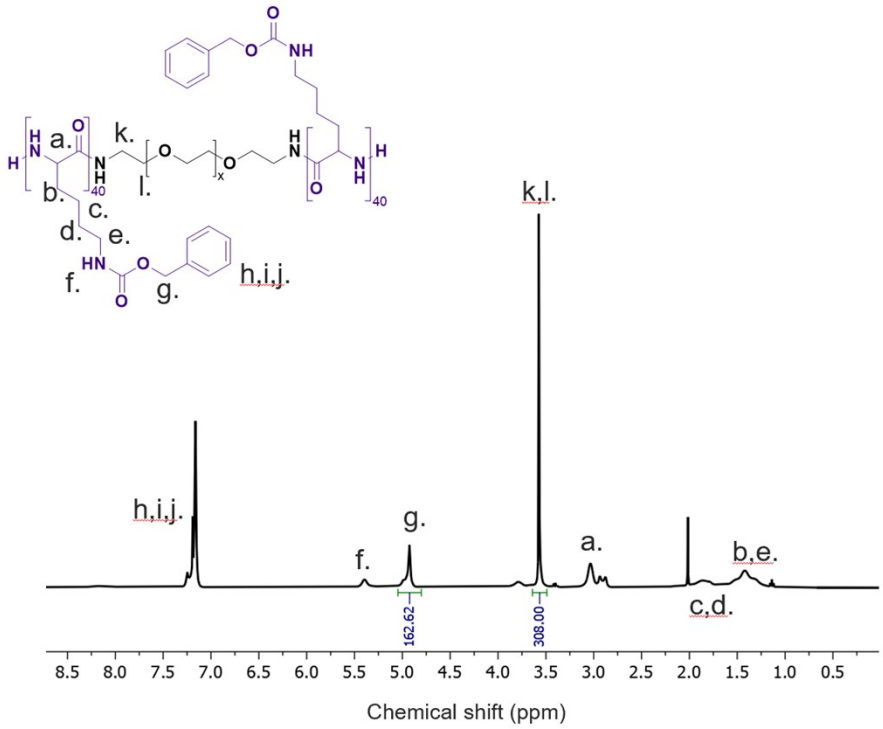

Figure S3: ^{1}H NMR of $PZLY_{40}$-*b*-PEG-*b*-$PZLY_{40}$ triblock copolymer. PZLY repeat length was confirmed *via* end group analysis of the carbobenzyloxy group, specifically the benzyl-adjacent protons (peak at ~5.0 ppm) compared to the PEG backbone signal (3.64 ppm). δ= 7.26 ppm ($CDCl_3$), δ= 7.34 ppm (m, Ph), δ= 5.5 ppm (NH) δ= 5.04 ppm (broad s, $PhCH_2O$), δ= 3.64 ppm (CH_2CH_2O), δ= 3.12 ppm (m, CH_2CH_2CH), δ= 2.15 ppm (m, CH_2CH_2CH), δ= 2.0 (DMAc) δ= 1.48 ppm (m, CH_2CH_2CH)

Weight fractions of peptide in peptide polyurea hybrids (PPUs) are calculated using eqn S1, where *x*, *y* and *z* are the molar quantities of the PZLY triblock, PEG and HDI, respectively, and M_{ZLY}, M_{PEG} and M_{HDI} are the molecular weights of PZLY, PEG and HDI, respectively.

$$wt\%(peptide) = 100\left(\frac{xM_{PZLY}}{xM_{PZLY} + yM_{PEG} + zM_{HDI}}\right) \quad \text{(S1)}$$

Table S1: Number-average molecular weight, weight-average molecular weight, and dispersity of PPU hybrids calculated from gel permeation chromatography (GPC) using 0.5 wt% LiBr in DMAc as the mobile phase. Molecular weight distributions were generated using the calibration curve constructed for six poly(methyl methacrylate) standards (Agilent) in the range of 0.885 to 2,210 kg mol^{-1}.

Polymer	Number-Average Molecular Weight, M_n (kg mol^{-1})	Weight-Average Molecular Weight, M_w (kg mol^{-1})	Dispersity, $Đ$ (M_w/M_n)
Z5-10	41.6	110.3	2.6
Z40-10	43.2	109.0	2.5

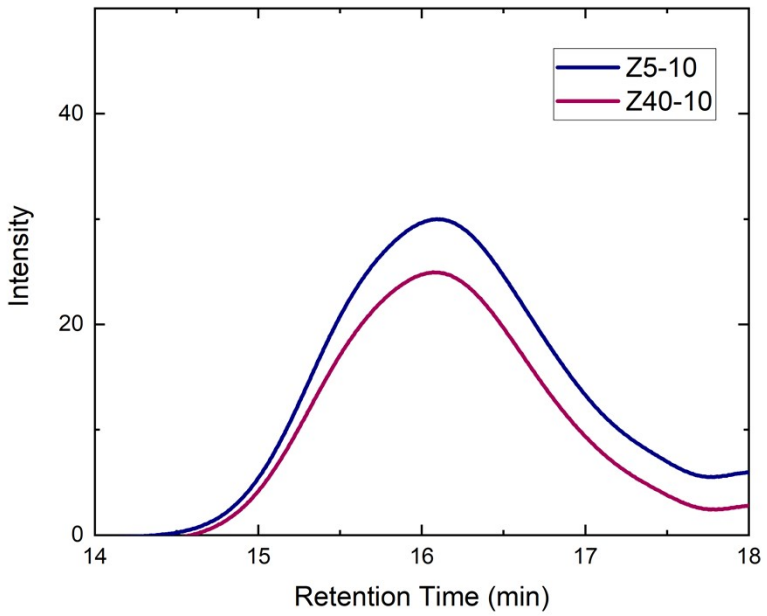

Figure S4: GPC traces of synthesized PPUs.

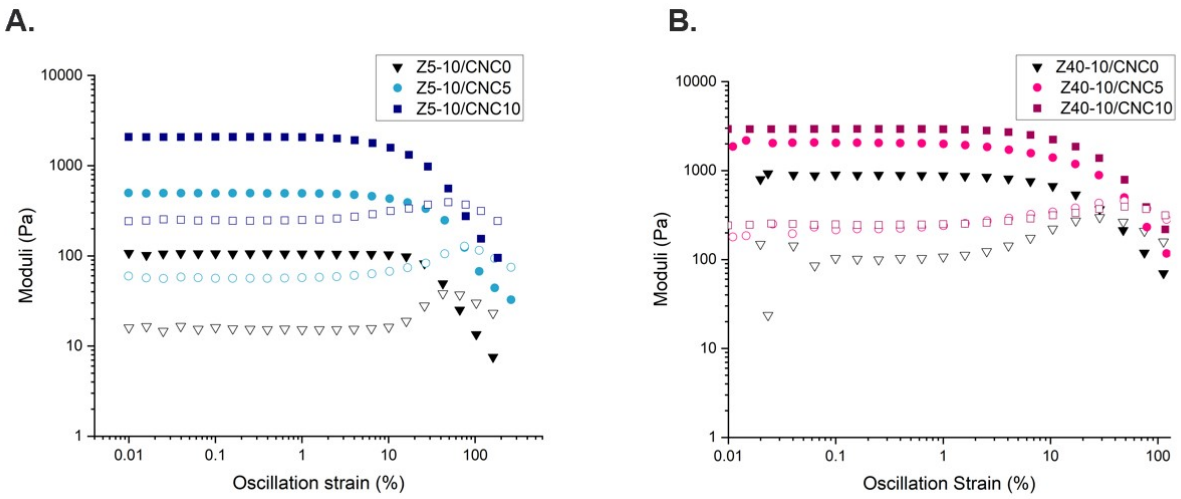

Figure S5: Amplitude sweeps of A. Z5-10/CNC series and B. Z40-10/CNC series. Closed symbols indicate storage moduli (*G'*), while open symbols indicate loss moduli (*G''*).

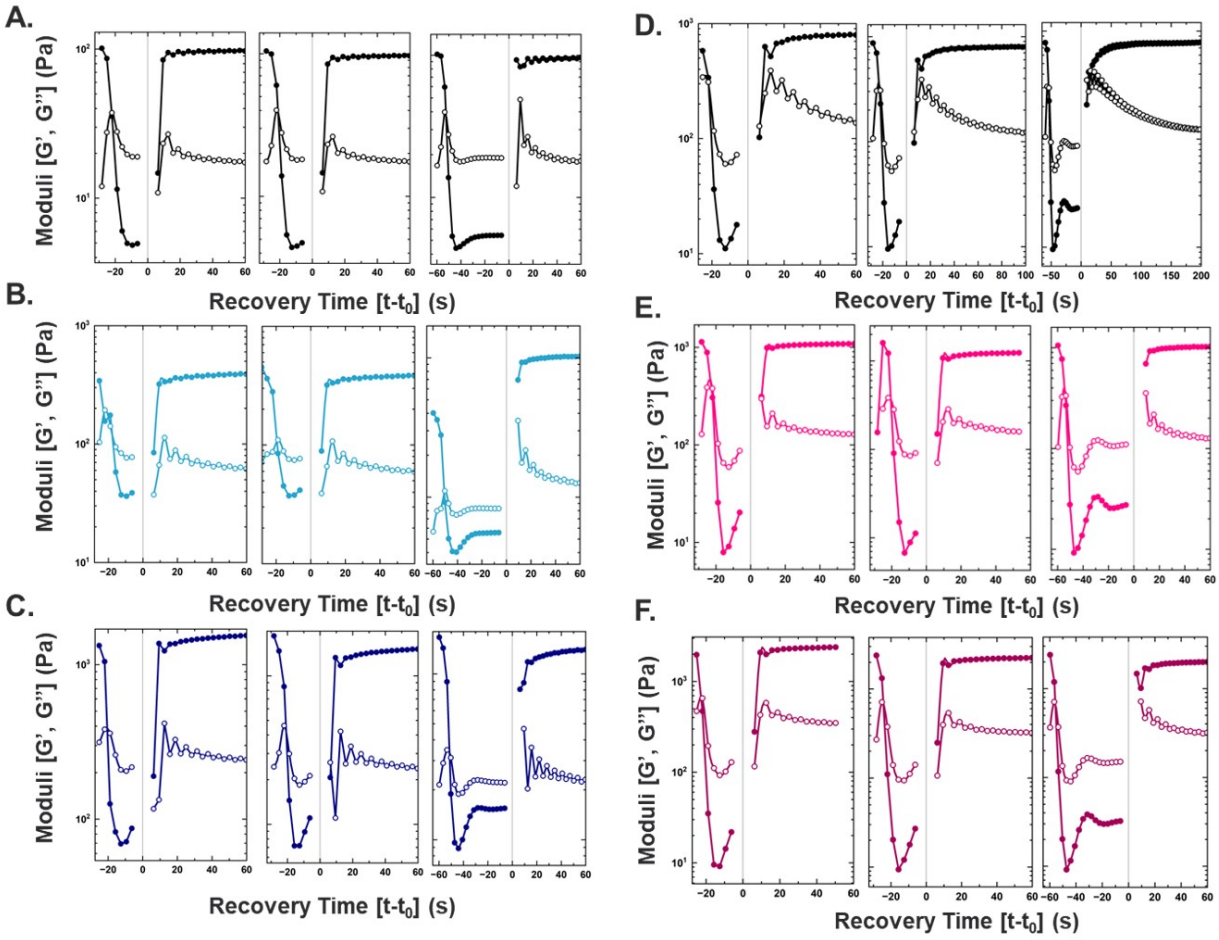

Figure S6: Injection simulation experiments of A. Z5-10/CNC0, B. Z5-10/CNC5, C. Z5-10/CNC10, D. Z40-10/CNC0. E. Z40-10/CNC5, F. Z40-10/CNC10. Closed symbols indicate storage moduli (*G'*), while open symbols indicate loss moduli (*G''*).

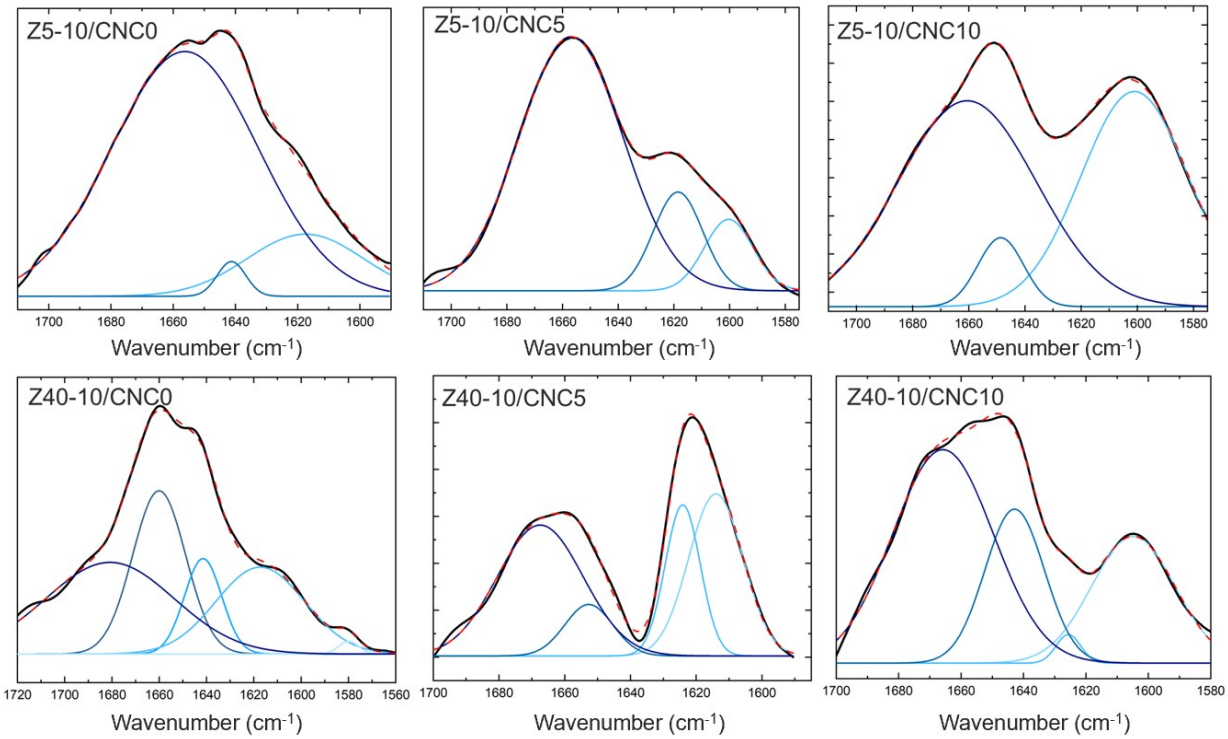

Figure S7: Gaussian deconvolutions of the amide I region of PPU/CNC hydrogels. The solid black line indicates the original curve, and the dashed red line is the integrated result of deconvoluted curves. All fits converged with an R^2 value ≥ 0.99.

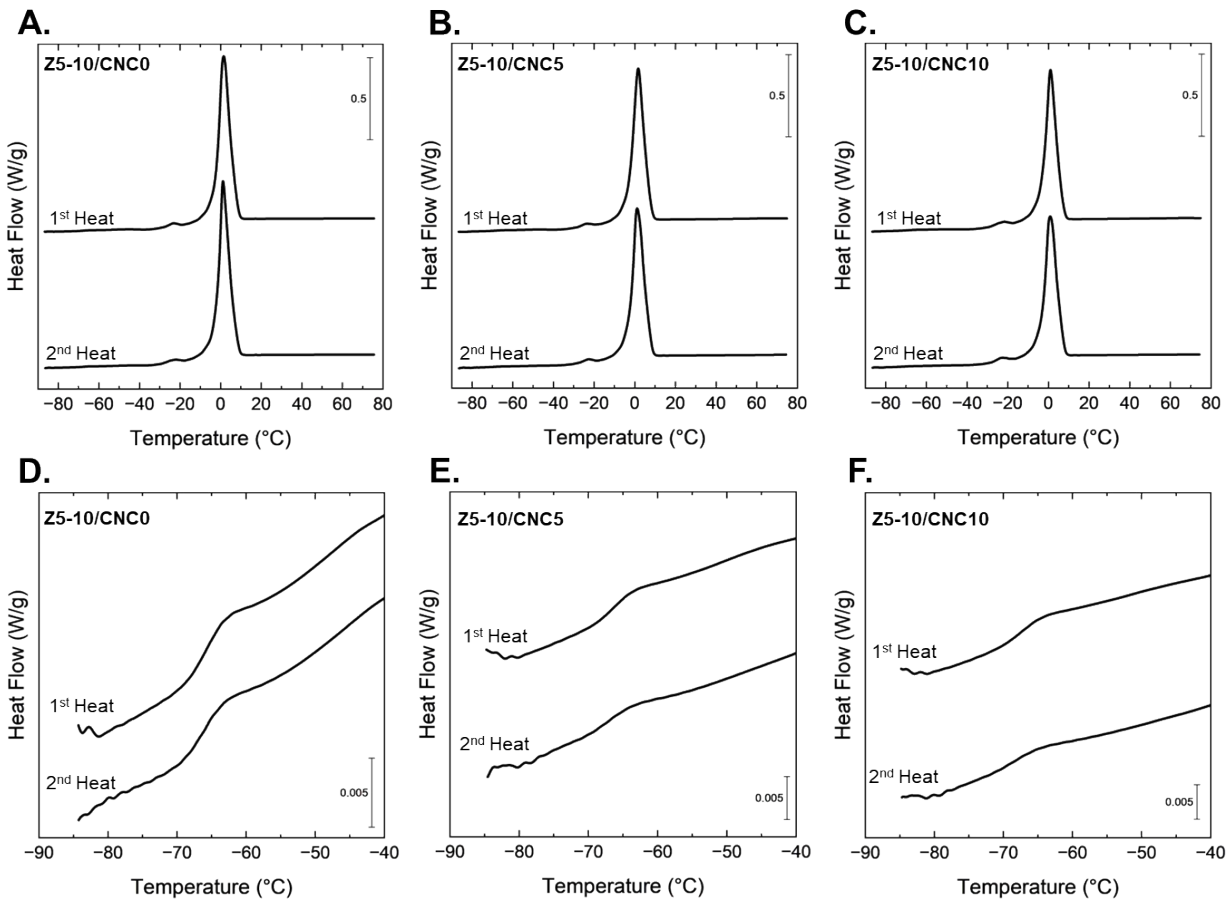

Figure S8: DSC plots of the Z5-10/CNC hydrogel series. Total heat flow curves for the 1st and 2nd heating traces highlight the water melting peaks of A. Z5-10/CNC0, B. Z5-10/CNC5, and C. Z5-10/CNC10. Reversing heat flow curves for the 1st and 2nd heating traces, highlighting the T_gs of D. Z5-10/CNC0, E. Z5-10/CNC5, and F. Z5-10/CNC10.

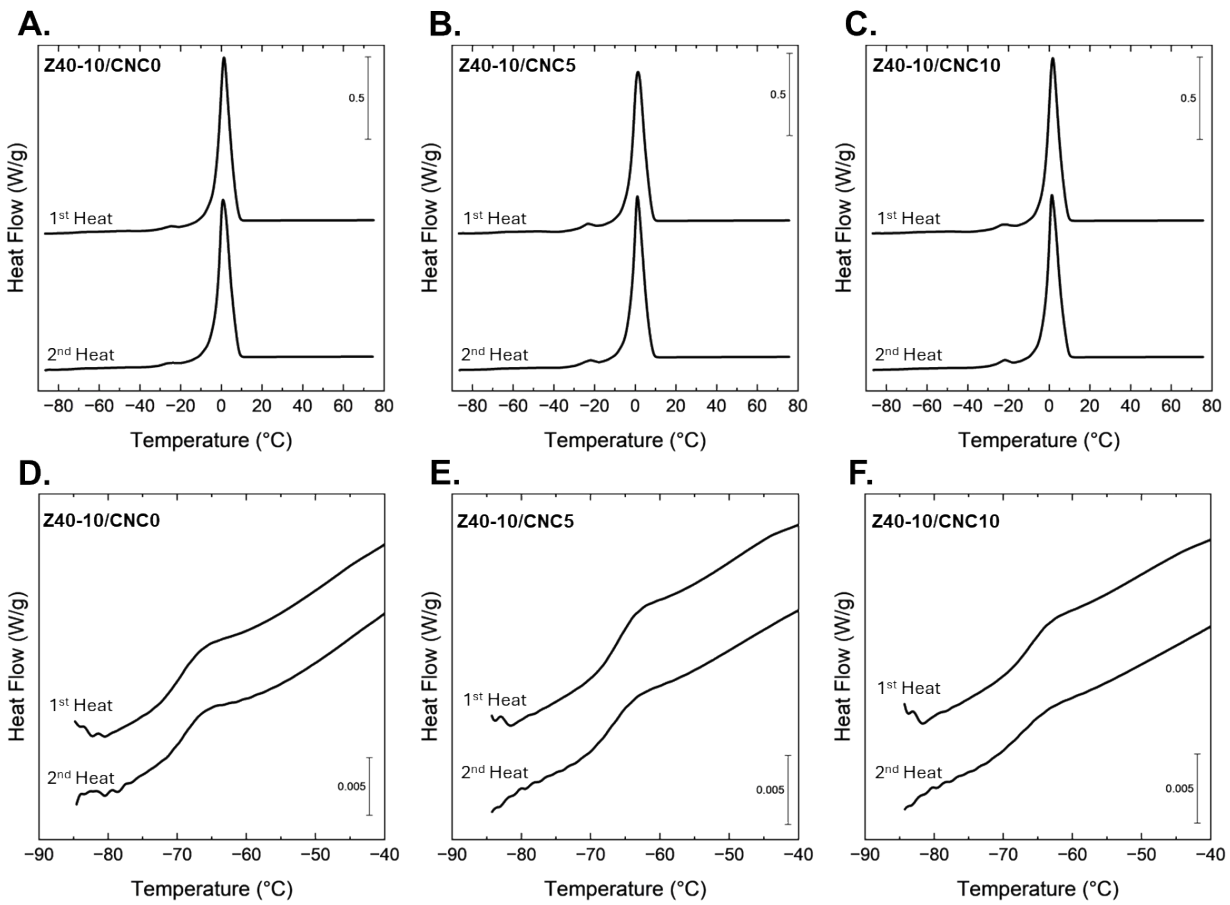

Figure S9: DSC plots of the Z5-10/CNC hydrogel series. Total heat flow curves for the 1st and 2nd heating traces highlighting the water melting peaks of A. Z40-10/CNC0, B. Z40-10/CNC5, and C. Z40-10/CNC10. Reversing heat flow curves for the 1st and 2nd heating traces, highlighting the T_gs of D. Z40-10/CNC0, E. Z40-10/CNC5, and F. Z40-10/CNC10.

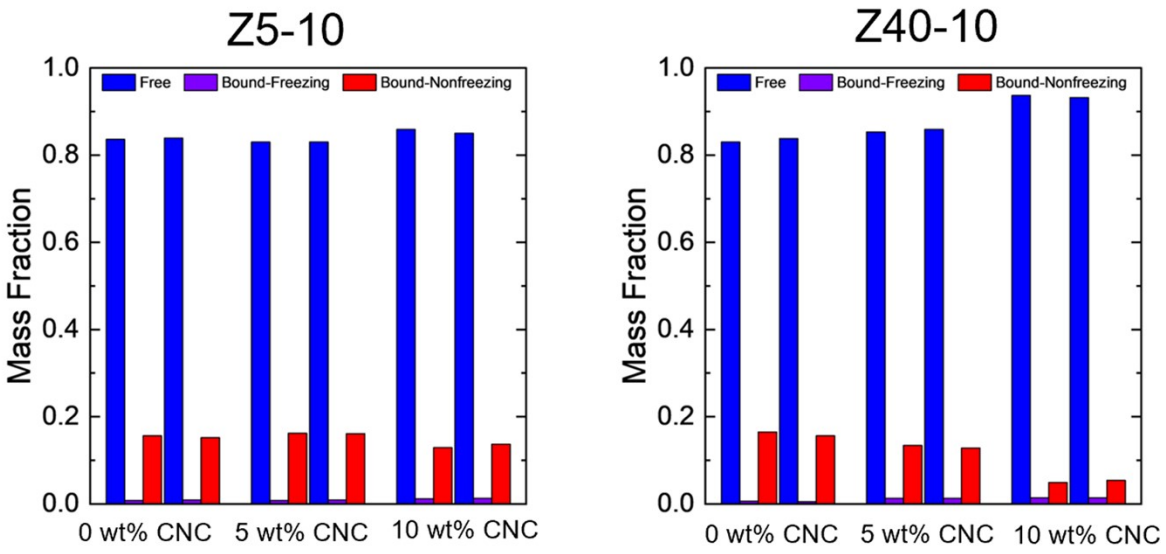

Figure S10: Fractions of free, bound-freezing, and bound-nonfreezing water in PPU hydrogels

Calculations of bound/unbound water in PPU hydrogels:

Three forms of water are assumed to exist within hydrogels: 1) freezable free water, 2) freezable bound water, and 3) non-freezable water. Differential scanning calorimetry (DSC) can identify free water and freezable bound water by melting peaks at 0 °C and -20 °C, respectively. Non-freezable water is not detectable *via* DSC. The total water content (m_{H2O}) in the hydrogel is defined as,

$$m_{H2O} = m_w - m_d \tag{S2}$$

wherein, m_w is the mass of the wet sample after equilibrium hydration, and m_d is the mass of the dry sample prior to submersion. The three forms of water present will sum to the total water content, written as,

$$m_{H2O} = m_{ff} + m_{fb} + m_{nf} \tag{S3}$$

wherein, m_{ff} is the mass of free water, m_{fb} is the mass of freezable bound water, and m_{nf} is the mass fraction of non-freezable bound water. Freezable water fraction, can be described as,

$$x_f = x_{ff} + x_{fb} \quad \text{(S4)}$$

by division of the equilibrium melting enthalpy of water ($\Delta H^{0}_{m,H2O}$= 333.5 J/g), written as,

$$x_f = \frac{\Delta H_{hydrogel}}{\Delta H^{0}_{m,H2O}} \quad \text{(S5)}$$

wherein, $\Delta H_{hydrogel}$ is the melting enthalpy of water in hydrogel sample. x_f must be less than or equal to 1, with the remainder assumed to be the non-freezable water fraction.

Table S2: T_gs and ΔC_p of PPU hydrogels

Sample	**Scan**	$\boldsymbol{T_g}$ **(°C)**	$\boldsymbol{\Delta C_p}$ **(J/g$_{PPU}$ °C)**
Z5-10	1st Heat	-66	1.62
	2nd Heat	-66	1.39
Z5-10/CNC5	1st Heat	-66	1.31
	2nd Heat	-67	0.99
Z5-10/CNC10	1st Heat	-68	1.63
	2nd Heat	-68	1.13
Z40-10	1st Heat	-70	1.46
	2nd Heat	-69	1.27
Z40-10/CNC5	1st Heat	-66	1.56
	2nd Heat	-67	1.27
Z40-10/CNC10	1st Heat	-66	1.28
	2nd Heat	-67	1.06

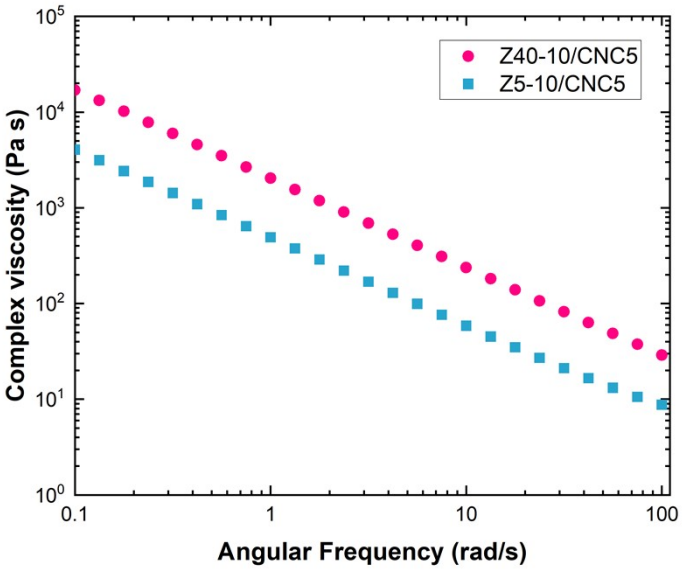

Figure S11: Example of shear-thinning behavior of PPU/CNC hydrogels.

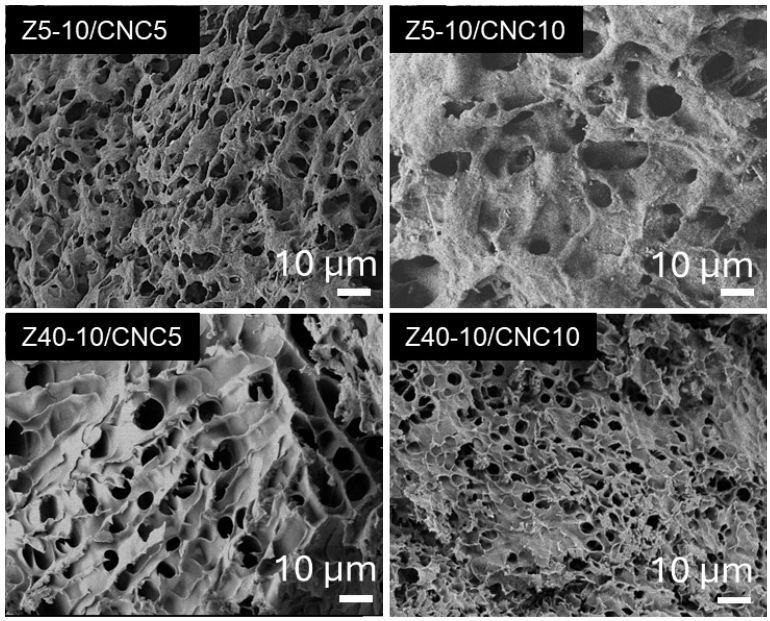

Figure S12: Additional SEM images of lyophilized hydrogels showing continuous porous networks.

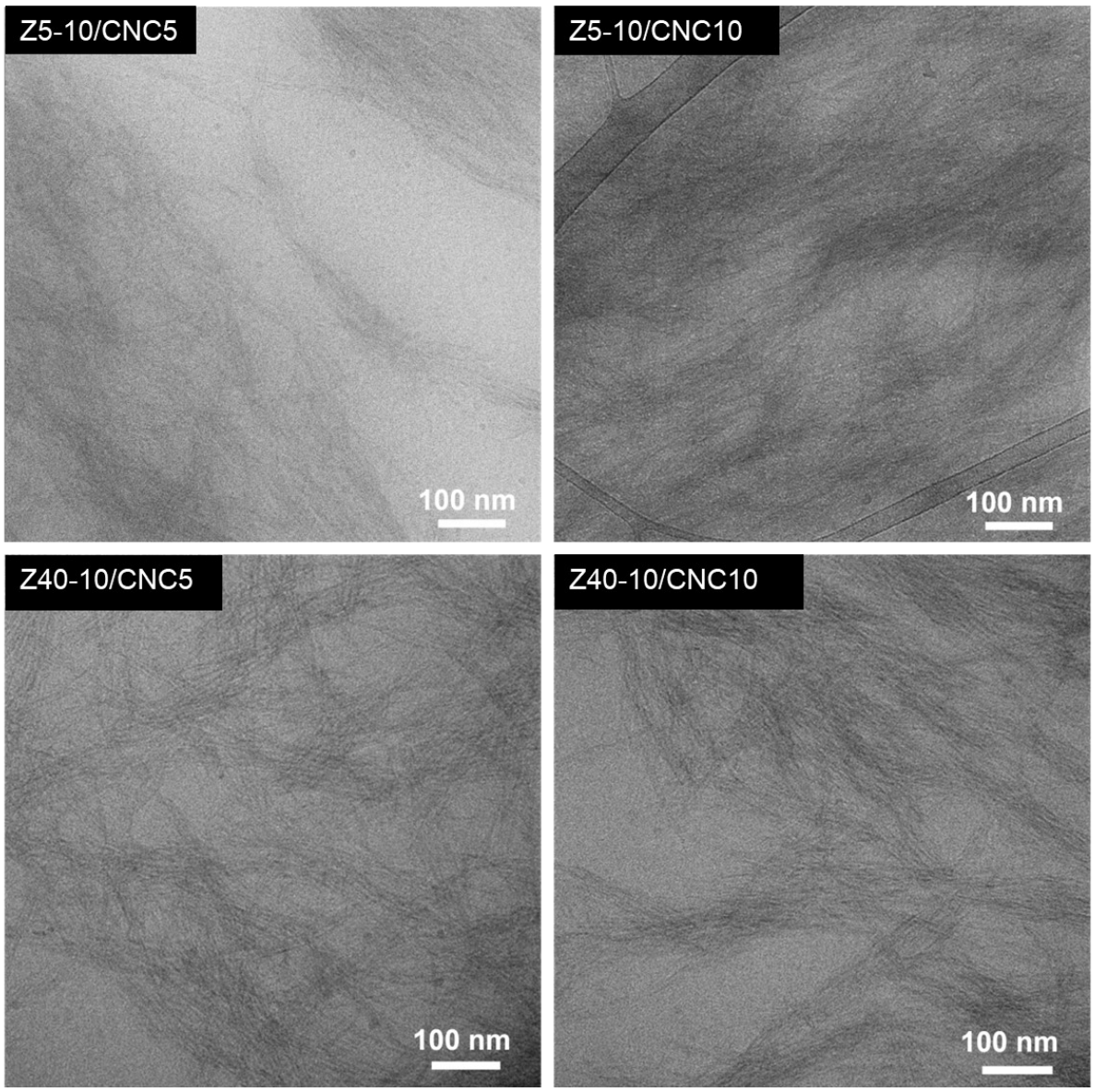

Figure S13: Enlarged cryo-TEM images of hydrogels without contrasting adjustments, showcasing the fibrous networks.

Abbreviations:

$CDCl_3$	Deuterated chloroform
CNC	Cellulose nanocrystal
DSC	Differential scanning calorimetry
GPC	Gel permeation chromatography
HDI	Hexamethylene diisocyanate
NMR	Nuclear magnetic resonance
PEG	Poly(ethylene glycol)
PPU	Peptide-polyurea
PTIR	Photothermal infrared spectroscopy
PZLY	Poly(ε-carbobenzyloxy-L-lysine)
ZLA-NCA	Carbobenzyloxy-L-lysine N-carboxyanhydride
T_g	Glass transition temperature
SEM	Scanning electron microscopy
Cryo-TEM	Cryogenic transmission electron microscopy

PPU hydrogel samples are labeled with the nomenclature Z**N-X**/CNC**Y,** where **N** denotes the peptide repeat length, **X** represents peptide weight percent in the polyurea, and **Y** denotes the CNC wt% loading.