Supporting Information

C_o	β_o	β	After preparation			In water		
			E / kPa	σ_f / MPa	λ_f	E / kPa	σ_f / MPa	λ_f
15	0.125	0.089	14 (1)	4.49 (0.39)	0.0357 (0.0034)	320 (100)	22 (2)	0.0493 (0.0056)
20	0.125	0.088	27 (4)	8.24 (0.59)	0.0390 (0.0014)	594 (113)	27 (2)	0.0550 (0.0030)
30	0.125	0.085	83 (3)	9.69 (0.37)	0.0378 (0.0017)	720 (150)	26 (2)	0.0627 (0.0037)
30	0.100	0.065	95 (7)	7.88 (0.59)	0.0474 (0.0062)	410 (65)	24 (2)	0.0626 (0.0060)
30	0.125	0.085	83 (3)	9.69 (0.37)	0.0378 (0.0017)	720 (150)	26 (2)	0.0627 (0.0037)
30	0.167	0.120	51 (8)	6.17 (1.08)	0.0349 (0.0032)	2200 (480)	27 (3)	0.0661 (0.0028)

Table S1. Compressive mechanical properties of PAAc hydrogels after preparation and after equilibrium swelling in water. C_o = initial monomer concentration (in w/v %). β_o and β = CTAB/AAc molar ratio in the feed and in the polymer, respectively. E = Young's modulus, σ_f = fracture stress, λ_f = compression at break. Standard deviations are given in the parenthesis, while for the values of β, they are less than 5 %.

C_o	β_o		N %	C %	H %	CTA wt. %	β
15	1/8	found	1.20	60.4	8.9	24.4	1/11.2
		calc	1.20	59.2	8.3		
20	1/8	found	1.20	59.8	8.9	24.2	1/11.3
		calc	1.20	59.1	8.3		
30	1/8	found	1.16	58.7	8.8	23.4	1/11.8
		calc	1.16	58.9	8.2		
30	1/10	found	0.94	58.1	8.3	19.0	1/15.4
		calc	0.94	57.7	7.8		
30	1/8	found	1.16	58.7	8.8	23.4	1/11.8
		calc	1.16	58.9	8.2		
30	1/6	found	1.50	60.9	9.2	30.3	1/8.3
		calc	1.50	60.8	8.8		

Table S2. Elemental analysis results of dried polymers isolated from PAAc hydrogels after extraction in water. C_o = initial monomer concentration (in w/v %). β_o and β = CTAB/AAc molar ratio in the feed and in the polymer, respectively. Standard deviations are less than 5 %.

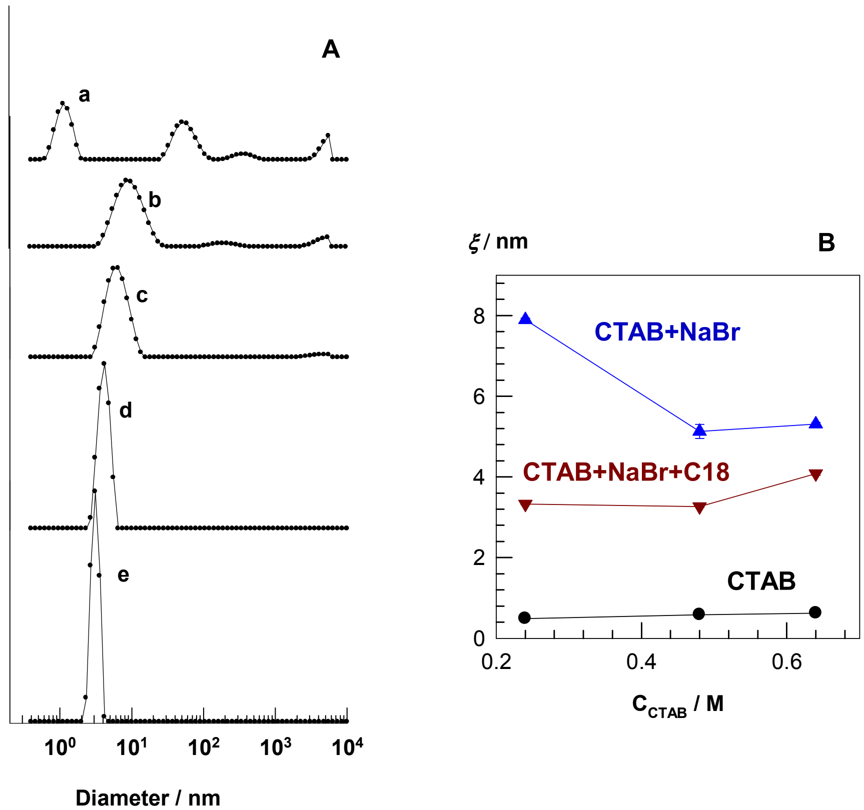

Figure S1. A: Typical particle size distributions of the gelation solution prepared at C_o = 30 w/v % and β_o = 1/8. Measurements were conducted on aqueous solutions of CTAB (a), CTAB + NaBr (b), CTAB + NaBr + C18 (c), CTAB+NaBr+C18+AAc at 35°C (d), and after heating to 50°C (e). The mean particle diameters are 1.1, 8.7, 5.6, 4.2, and 3.1 nm, respectively. The decrease of the particle size after addition of the monomers into the micellar solution is due to the oil-induced structural change of wormlike micelles, as we reported before (Refs.[35, 36] in the text). Even visual inspection of the solutions provided evidence that the solubilization of C18 reduces the viscosity of CTAB-NaBr solutions. This change likely occurs due to the accumulation of the monomers in the surfactant palisade layer and in the core of micelles, which increases the curvature of the micelle making rod-sphere transition in micellar shape favorable.[35, 36] **B:** Hydrodynamic correlation length ξ_H of CTAB solutions at 35°C before and after addition of NaBr and NaBr+C18 plotted against CTAB concentration.

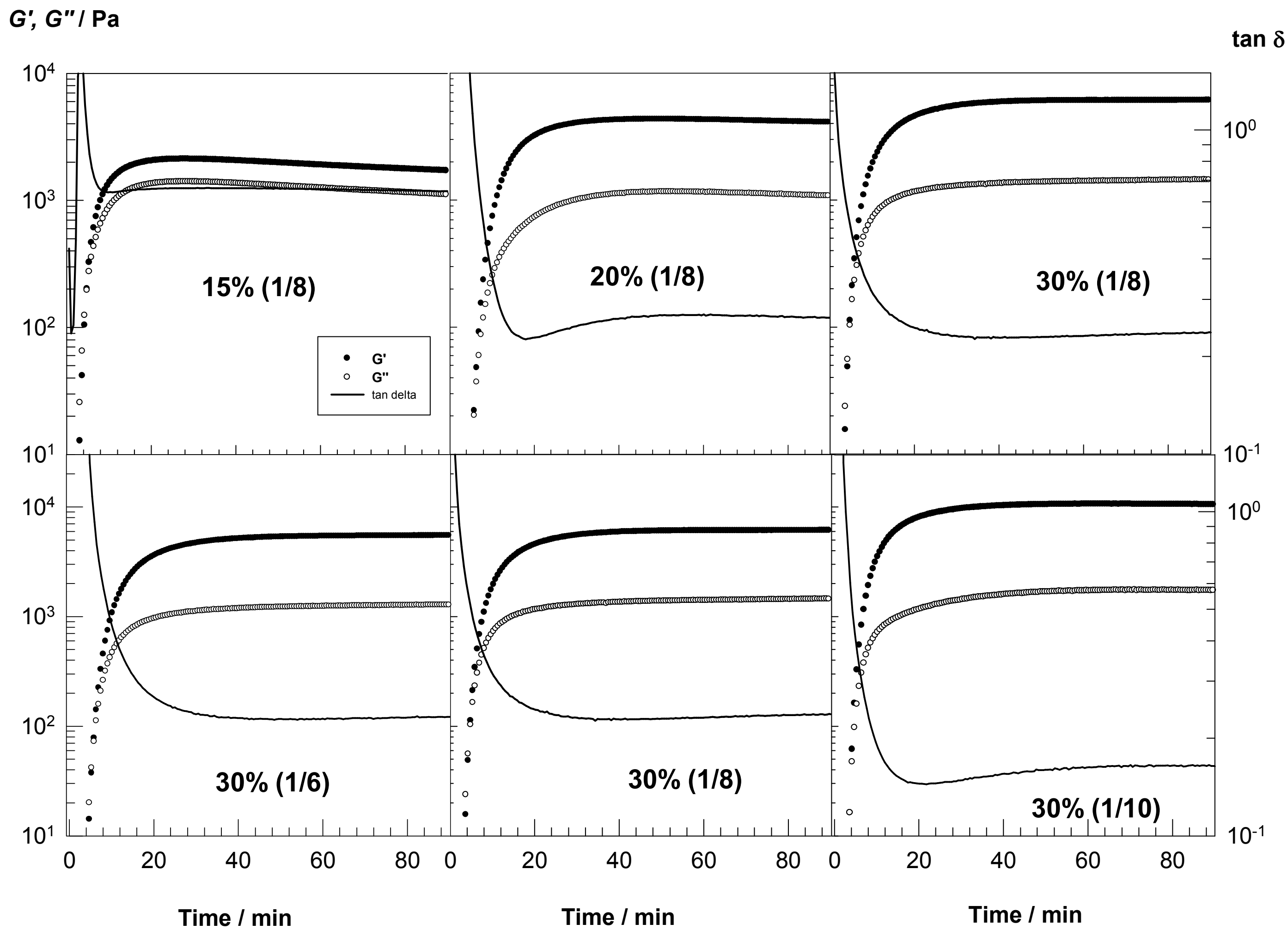

Figure S2. (**A**): Elastic modulus G' (filled symbols), the viscous modulus G'' (open symbols), and loss factor $\tan\ \delta$ (lines) during the micellar copolymerization of AAc with 2 mol % C18 at 50°C in CTAB-NaBr solution shown as a function of the reaction time. C_o and β_o (in parenthesis) are indicated. $\omega = 6.3$ rad.s^{-1}. $\gamma_o = 0.01$.

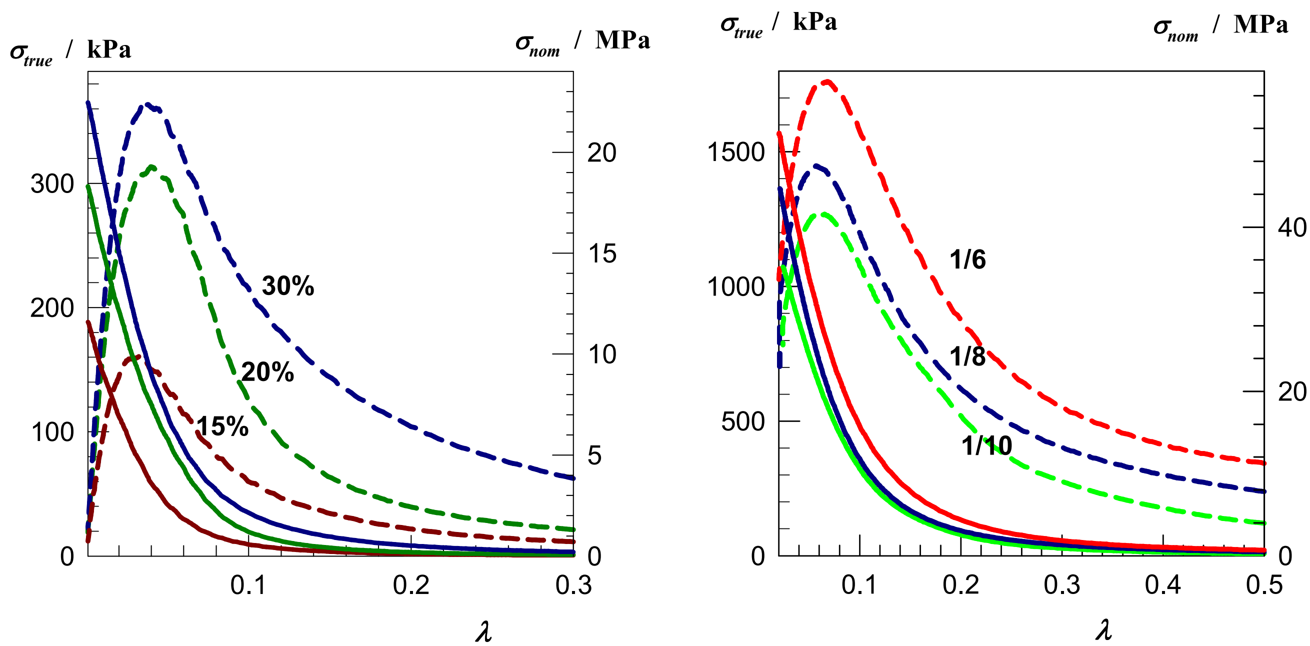

Figure S3. Typical stress-strain curves of PAAc hydrogels after preparation (left) and after equilibrium in water (right) under compression as the dependences of nominal σ_{nom} (solid curves) and true stresses σ_{true} (dashed curves) on the deformation ratio λ. Left: β_o = 1/8. C_o = 15 (dark red), 20 (dark green) and 30 w/v % (dark blue). Right: C_o = 30 w/v %. β_o = 1/10 (green), 1/8 (dark blue) and 1/6 (red).

Figure S4. Photographs of a PAAc hydrogel sample formed using SDS instead of CTAB after swelling in water (a), and after preparation (b). For comparison, the photograph of a PAAc gel sample formed using CTAB after equilibrium swelling in water is also shown (c). C_0 = 20%. β_o = 1/8.

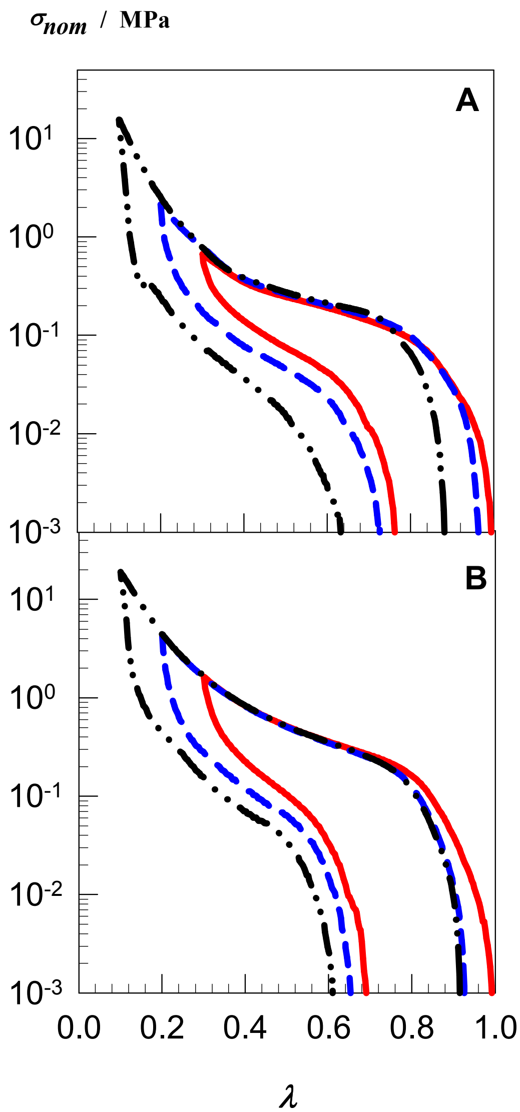

Figure S5. σ_{nom} vs λ curves from cyclic compression tests for PAAc hydrogels in equilibrium with water. Three successive loading / unloading cycles with increasing maximum strain from λ_{max} = 0.3 to 0.1 (70 to 90% compression) are shown. A: C_0 = 15%. β_o = 1/8. B: C_0 = 30%. β_o = 1/10.

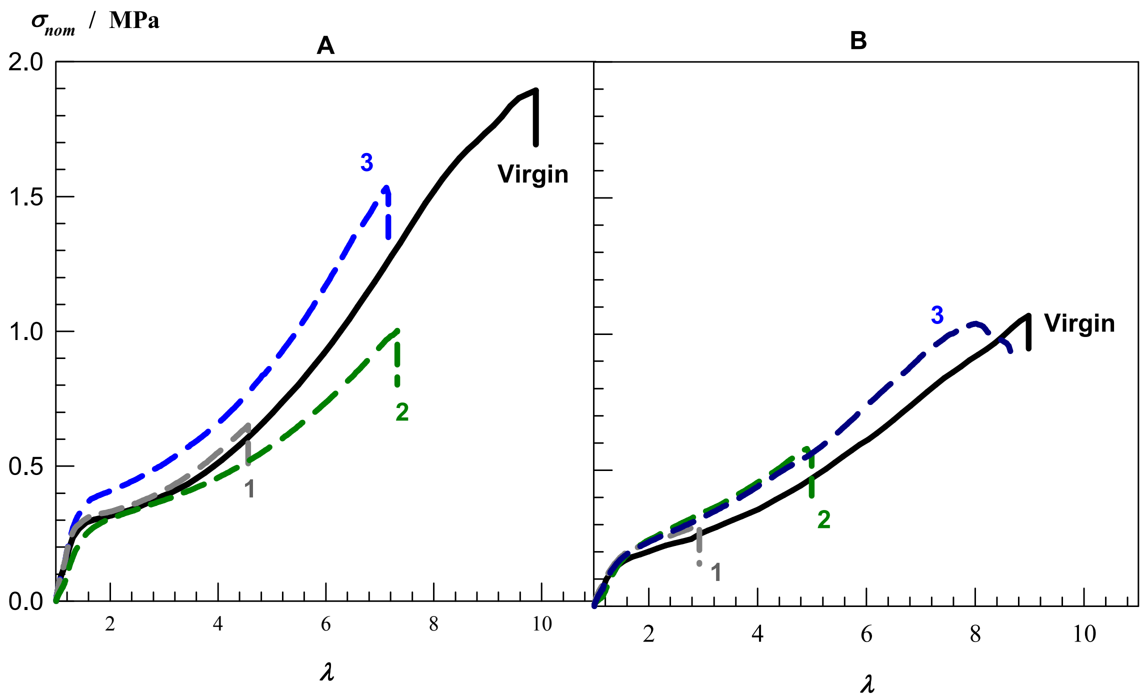

Figure S6. Stress-strain curves of virgin (solid curves) and healed gel samples in equilibrium with water (dashed curves). **(A):** C_0 = 30%. β_o = 1/6. **(B):** C_0 = 20%. β_o = 1/8. Healing time in acid or surfactant solutions = 60 (A) and 30 min (B). Conditions of healing tests: Heating to 80°C (1). Treatment of the cut surfaces with acid solutions of pH = 1 before heating to 80°C (2). Treatment of the cut surfaces with 10 w/v % CTAB solutions of pH = 1 before heating to 80°C (3).

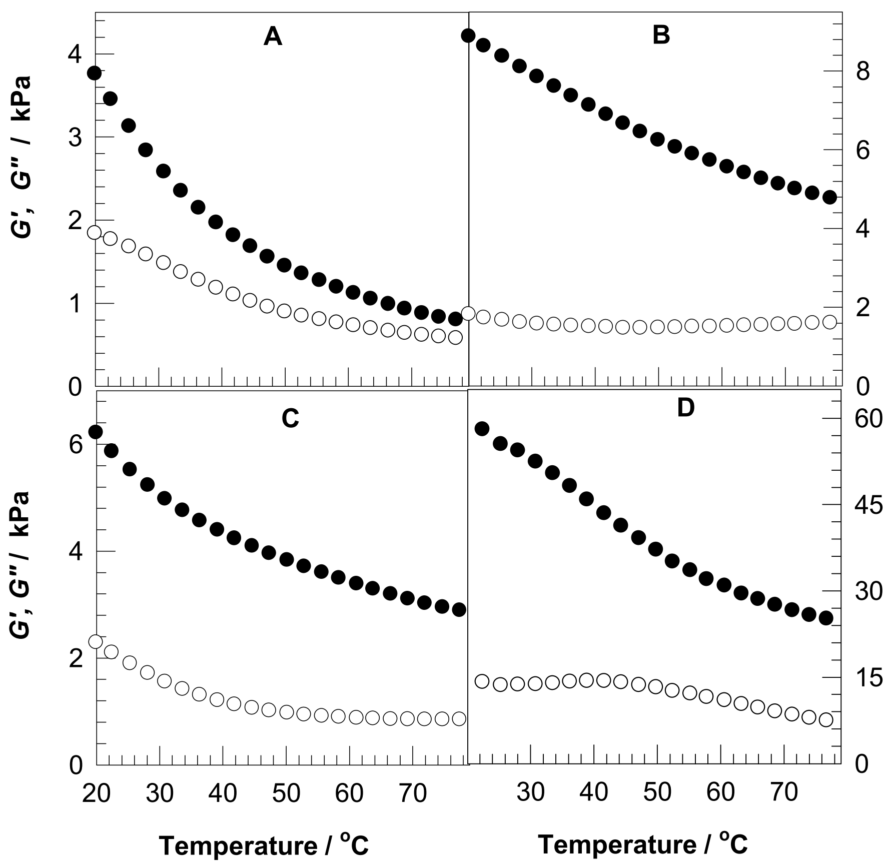

Figure S7. *G'* (●), and *G''* (○) of PAAc hydrogels after preparation (A-C) and after equilibrium in water (D) shown as a function of the temperature. $\omega = 6.28$ rad.s^{-1}. $\gamma_o = 0.01$. (A): $C_0 = 15$ %. $\beta_o = 1/8$. (B): $C_0 = 30$ %. $\beta_o = 1/8$. (C, D): $C_0 = 20$ %. $\beta_o = 1/8$.