

Supporting information for publication

Tough and electro-responsive hydrogel actuators with bidirectional bending behavior

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Tab. S1 Compositions of the initial pre-gel solutions for AI-NC gels.

Hydrogels	DMAA/g	AA/g	AH NPs sol /g ^{a)}	H ₂ O /g	IR2959 ^{b)} /mg
A30D70-AI5	2.08	0.66	0.50	10	30
A30D70-AI10	2.08	0.66	1.00	10	30
A30D70-AI15	2.08	0.66	1.50	10	30
A20D80-AI15	2.38	0.44	1.50	10	30
A10D90-AI15	2.68	0.22	1.50	10	30

a) The concentration of the prepared AH NPs sol is 17 wt%. b) IR2959 is 2-hydroxy-4'-(2-hydroxyethoxy)-2-methyl-propiophe.

Tab. S2 Mechanical properties of AI-NC gel with different AH NPs content and AA molar ratio

Hydrogels	Tensile Strength (kPa)	Elongation at break (%)	Young's modulus (kPa)	Fracture energy(KJ/m ³)
A30D70-AI5	377.5±24.9	1236±118.7	30.8±8.8	2.12±0.28
A30D70-AI10	1234.1±106.8	1092±107.4	130.8±20.5	6.98±0.55
A30D70-AI15	1958.7±116.4	744±39.6	447.6±19.9	7.56±0.65
A20D80-AI15	1119.1±90.7	1153±116.3	81.6±12.8	5.72±0.68
A10D90-AI15	328.5±18.7	1360±127.5	12.6±6.7	1.54±0.17

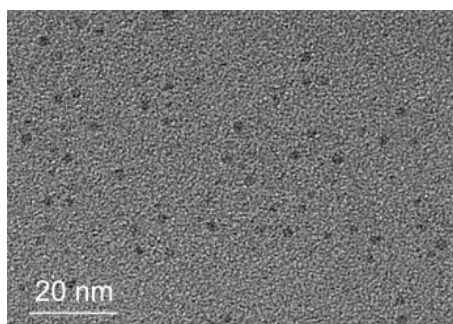


Fig. S1 The TEM image of the AH NPs in the solution.

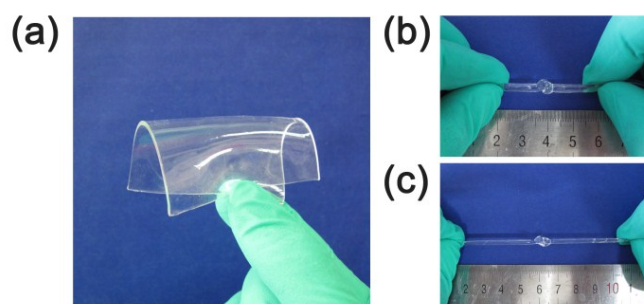


Fig. S2 The transparent Al-NC gel film and the tough Al-NC gel (AD30-AI15) bearing knotting and stretching.

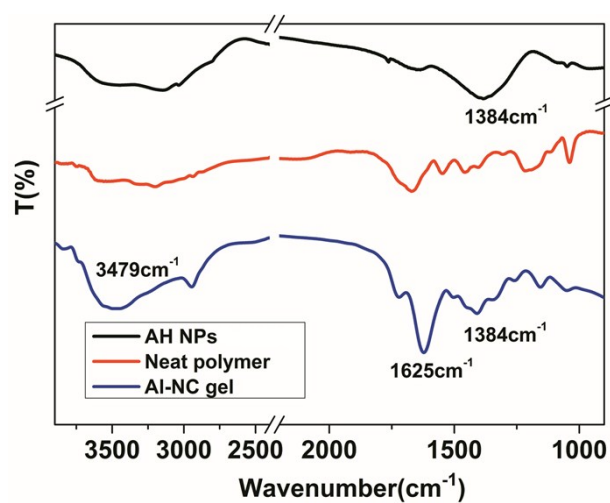


Fig. S3 The FTIR spectra of AH NPs solution, neat polymer and Al-NC gel (AD30-AI15).

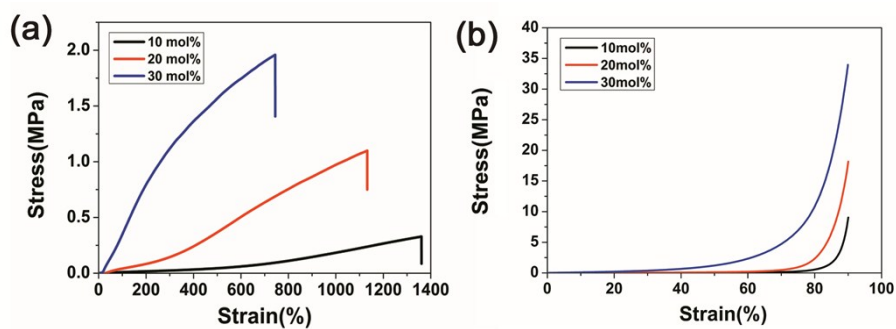


Fig. S4 The tensile and compression stress-strain curves of Al-NC gels (AD30-AI15) with different molar ratio of AA of (a) 10 mol%, (b) 20 mol%, (c) 30 mol%.

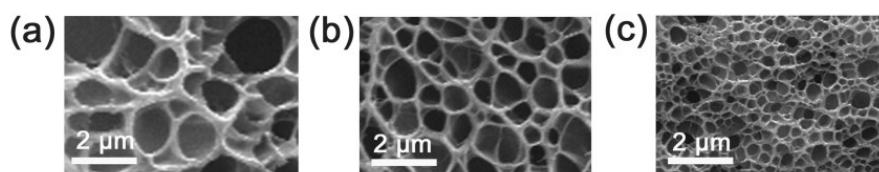


Fig. S5 SEM images of Al-NC gels (AD10-AI) with different AH NPs concentration (5wt%, 10wt%, 15wt%).

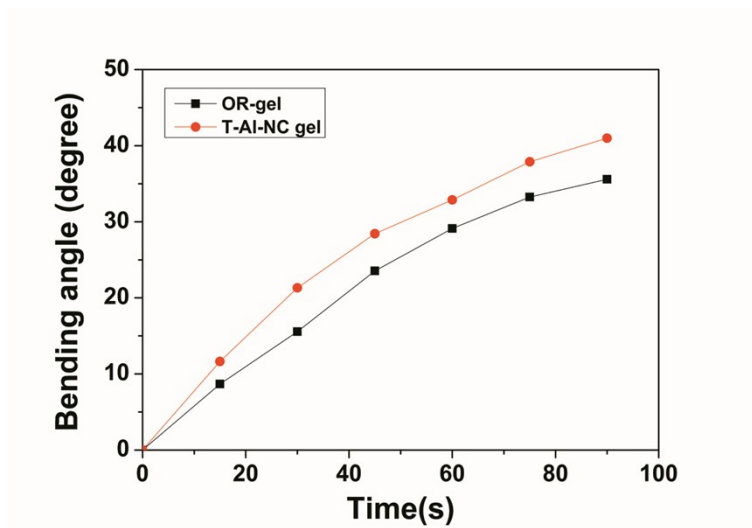


Fig. S6 The bending angles of OR gel and T-AI-NC gel (AD30-AI15).

Tab. S3 The concentration of NO_3^- in the solution A and B measured by the ion chromatography test.

Sample	Ret. Time min	Area $\mu\text{S} \cdot \text{min}$	Amount mg/L	Height μS	Rel. Area %	Resolution
A(NO_3^-)	12.287	0.0326	0.0976	0.105	0.04	9.78
B(NO_3^-)	12.284	0.0717	0.4168	0.221	0.09	9.88

The sample A and B used for the ion chromatography test were taken from the solution near the anode when the AI-NC gel bend towards cathode and anode respectively during the directional bending test. The solution used for the ion chromatography was diluted 100 fold.