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Supplementary Materials for

Preparation of Waterborne Polyurethane/ Silsesquioxane /Carbon Nanotubes Aerogel with Rigid-Flexible Framework for Mechanically Tough and Wide Pressure-Range Properties for High-Performance Piezoresistive Sensing

Corresponding Author

Hongzhi Liu* — Email: liuhongzhi@sdu.edu.cn

This file includes:

Supplementary Text

Figs. S1 to S5

Tables S1 to S5

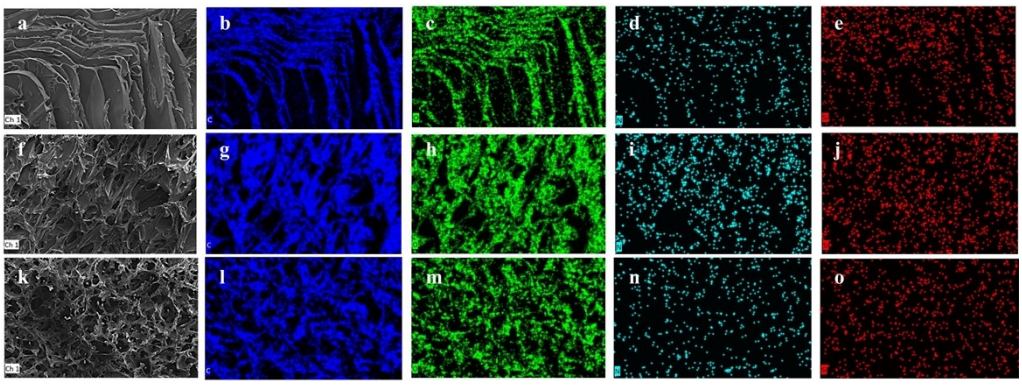

Fig. S1. EDS elemental mapping: (a–e) WPU-HSQ_8 aerogel, (f–j) and (k–o) WPU-HSQ_8/CNTs composite aerogel before and after compression state.

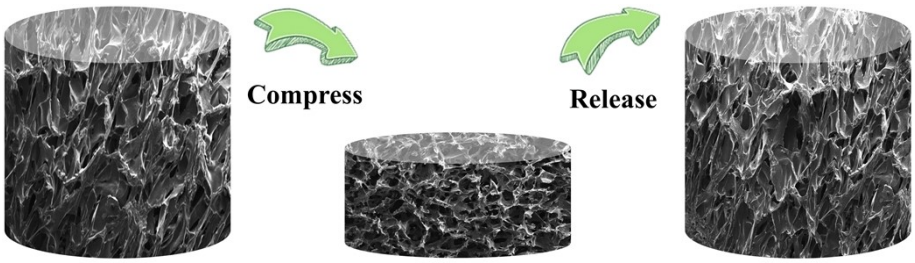

Fig. S2. Schematic diagram of the cyclic compression of WPU-HSQ_8/CNTs composite aerogel

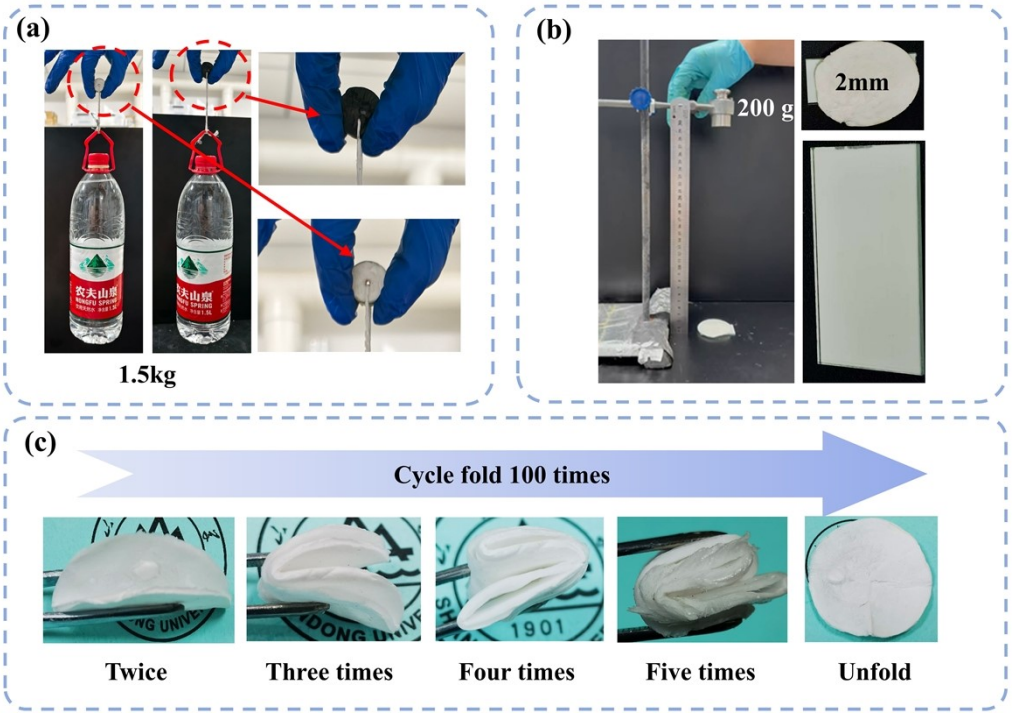

Fig. S3. Integrated performance demonstrations of the WPU-HSQ aerogel: (a) load-bearing (1.5 kg), (b) impact protection, and (c) folding durability (100 cycles).

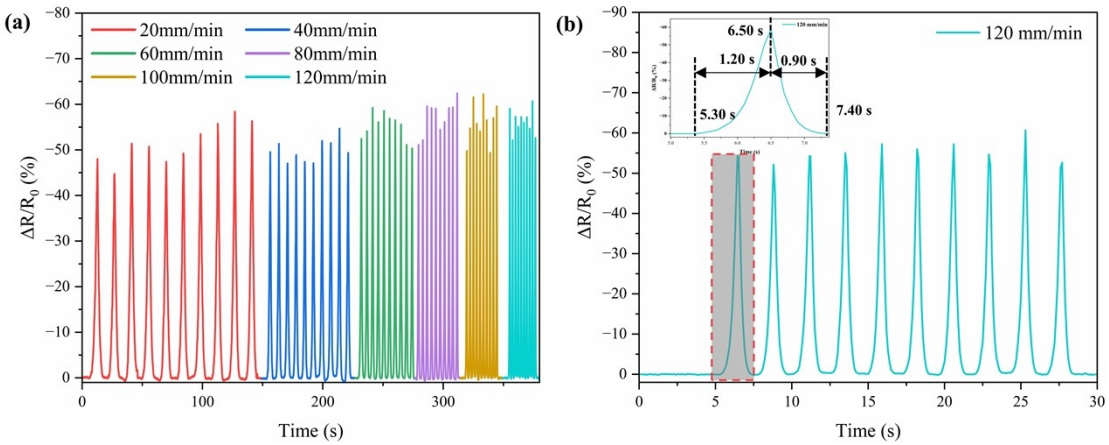

Fig. S4. Performance of the WPU-HSQ_8/CNTs sensor under low-rate cycling: (a) resistance response and (b) corresponding response time.

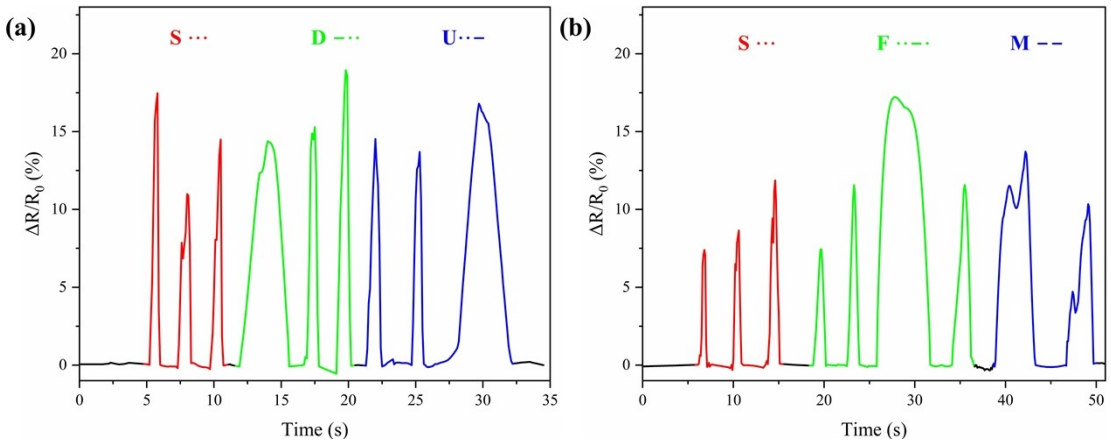

Fig. S5. Dynamic resistance signals in response to pressing the Morse code for “SDU” and “SFM”.

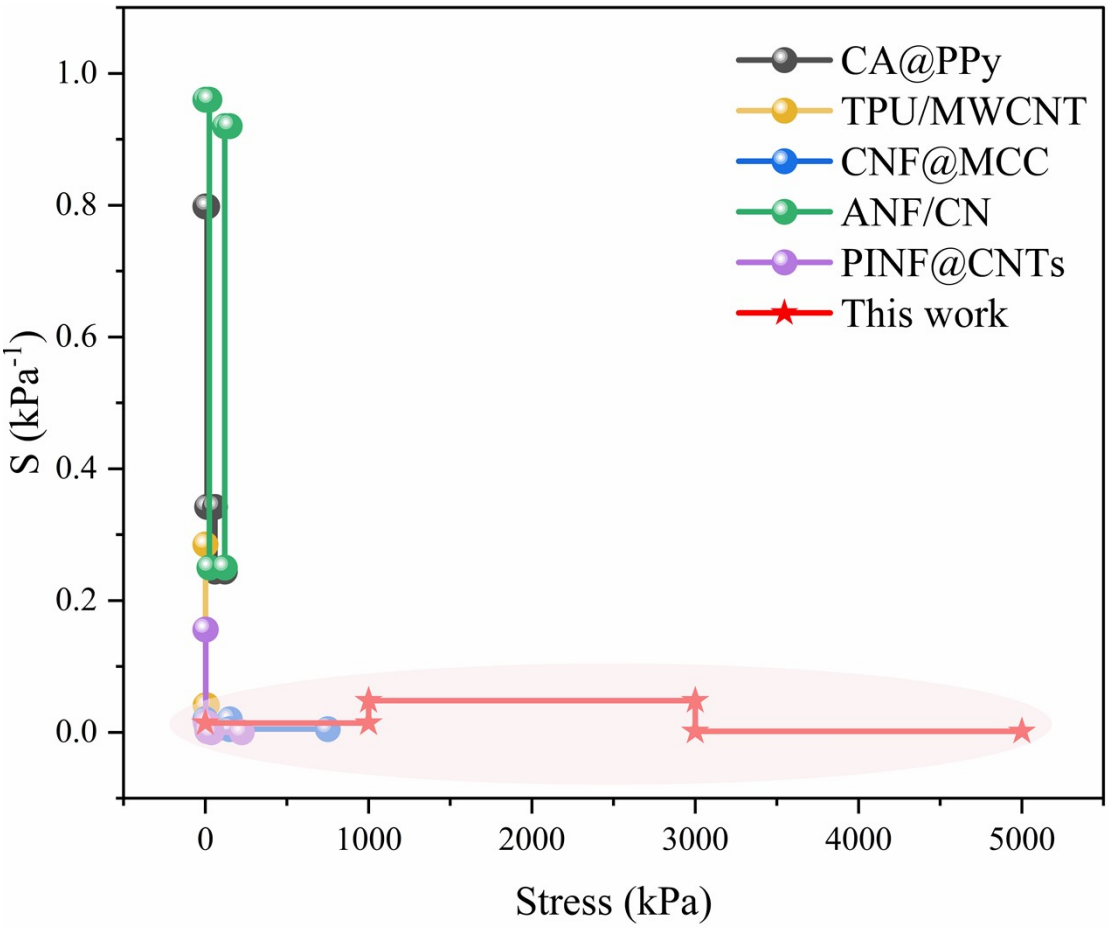

Fig. S6. Comparison of this work with other reported references in terms of scope and sensing performance

Table S1. Formulation of the WPU-HSQ composite

Samples	PCDL2000	DMBA	HMDI	TEA	HSQ
WPU-HSQ$_7$	6	0.5402	2.4625	0.3689	0.7061
WPU-HSQ$_8$	6	0.5402	2.4625	0.3689	0.8157
WPU-HSQ$_9$	6	0.5402	2.4625	0.3689	0.9278

Table S2. Deconvolution of the FTIR spectra in the carbonyl stretching region of WPU-HSQ_x.

Sample	Wavenumbers（cm^{-1}）/ C=O Fraction（%）			X_b (%)
	C=O, Free	C=O, HB (Disordered)	C=O, HB (Ordered)	
WPU-HSQ_7	1743/80.44	1714/6.43	1701/13.13	12.45
WPU-HSQ_8	1744/68.15	1724/3.42 1712/13.67	1698/14.76	21.45
WPU-HSQ_9	1743/74.74	1720/3.80 1708/10.59	1695/10.87	16.50

The relative concentration of hydrogen-bonded carbonyls is represented by X_b, which can be determined using the formula:

$$X_b(\%) = \frac{\left[\left(A_D + A_O\right)/1.71\right]}{\left[A_F + \left(A_D + A_O\right)/1.71\right]} \times 100\% \quad (1)$$

where A_O represents the peak area of an ordered hydrogen bond-bound carbonyl characteristic peak, A_F represents the peak area of a free carbonyl characteristic peak, and A_D represents the peak area of a disordered hydrogen bond-bound carbonyl characteristic peak. Meanwhile, the Beer-Lambert law equation indicates that α_{HB}/α_F=1.71 since the extinction coefficients of free carbonyl (α_F) and hydrogen bonded carbonyl (α_{HB}) differ.

Table S3. Porosity parameters of the WPU-HSQ8 and WPU-HSQ_8/CNTs composite aerogels.

Sample	Bulk density (g/cm^3)	Apparent density (g/cm^3)	Porosity (%)	Average pore size (nm)	Total hole area (m^2/g)
WPU-HSQ-8	0.2498	1.0132	87.51	19800	8.125
WPU-HSQ-8/CNTs	0.4434	1.0418	77.83	27220	9.0410

Table S4. Thermal degradation parameters of WPU-HSQ_8 and WPU-HSQ_8/CNTs composite aerogels.

Samples	$T_{5\%}$ (℃)	$T_{50\%}$ (℃)	T_{max1} (℃)	T_{max2} (℃)	Residual carbon content
WPU-HSQ_0	233.20	328.44	343.53	-	0.33%
WPU-HSQ_7	272.08	367.45	337.29	422.53	1.51%
WPU-HSQ_8	287.17	377.55	342.26	427.54	2.37%
WPU-HSQ_9	267.10	392.58	337.31	427.55	7.44%
WPU-HSQ_7/CNTs	267.12	372.56	337.31	427.56	5.63%
WPU-HSQ_8/CNTs	257.07	377.48	327.26	427.50	6.91%
WPU-HSQ_9/CNTs	287.18	377.53	337.19	422.49	10.71%

Table S5. Mechanical property parameters of WPU-HSQ_8 and WPU-HSQ_8/CNTs composite aerogels.

Samples	Compression pressure （MPa）	Resilience （kJ/m³）	Young's modulus （MPa）
WPU-HSQ_7	2.24	294.40	0.47
WPU-HSQ_8	3.43	536.40	0.90
WPU-HSQ_9	2.98	448.19	0.81
WPU-HSQ_7/CNTs	4.35	508.53	1.08
WPU-HSQ_8/CNTs	4.61	731.16	1.66
WPU-HSQ_9/CNTs	4.76	716.65	1.73