Supplementary information

Designing PANI modified PU films coupled with CNTs for the enhanced shape memory properties

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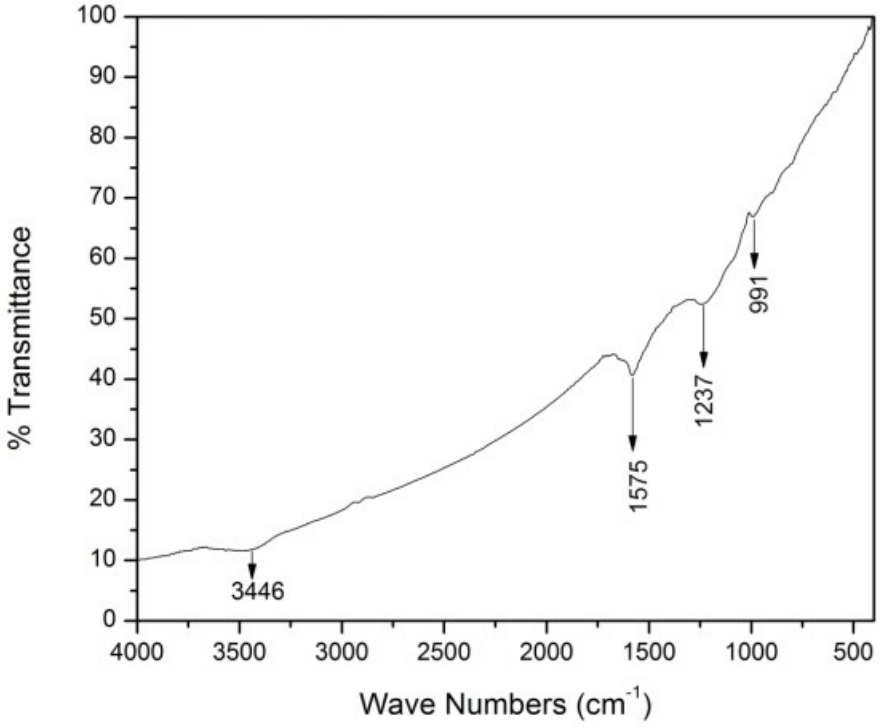
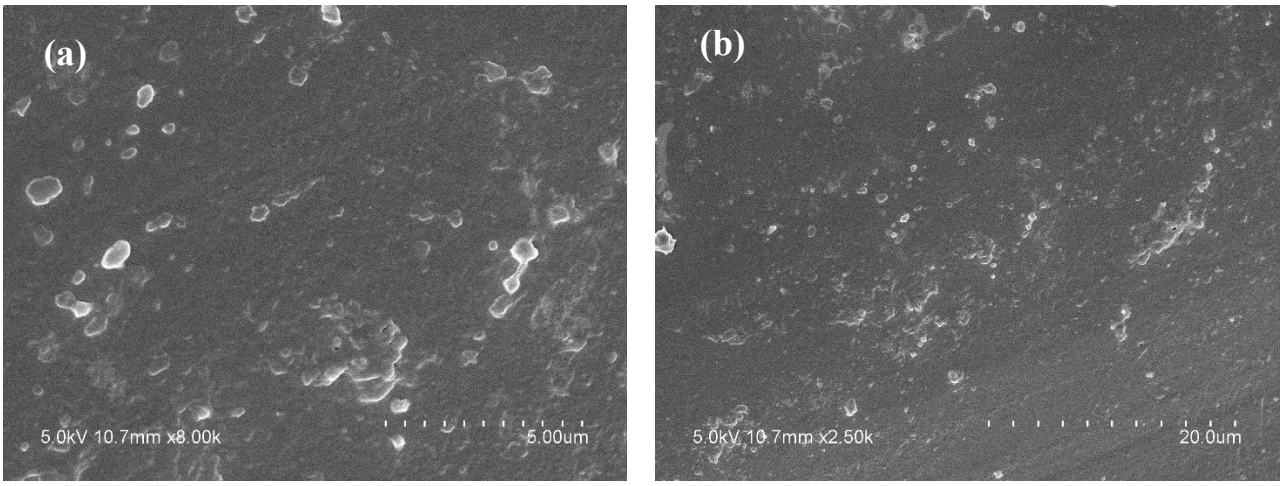


Figure S1: FTIR spectrum of f-CNTs



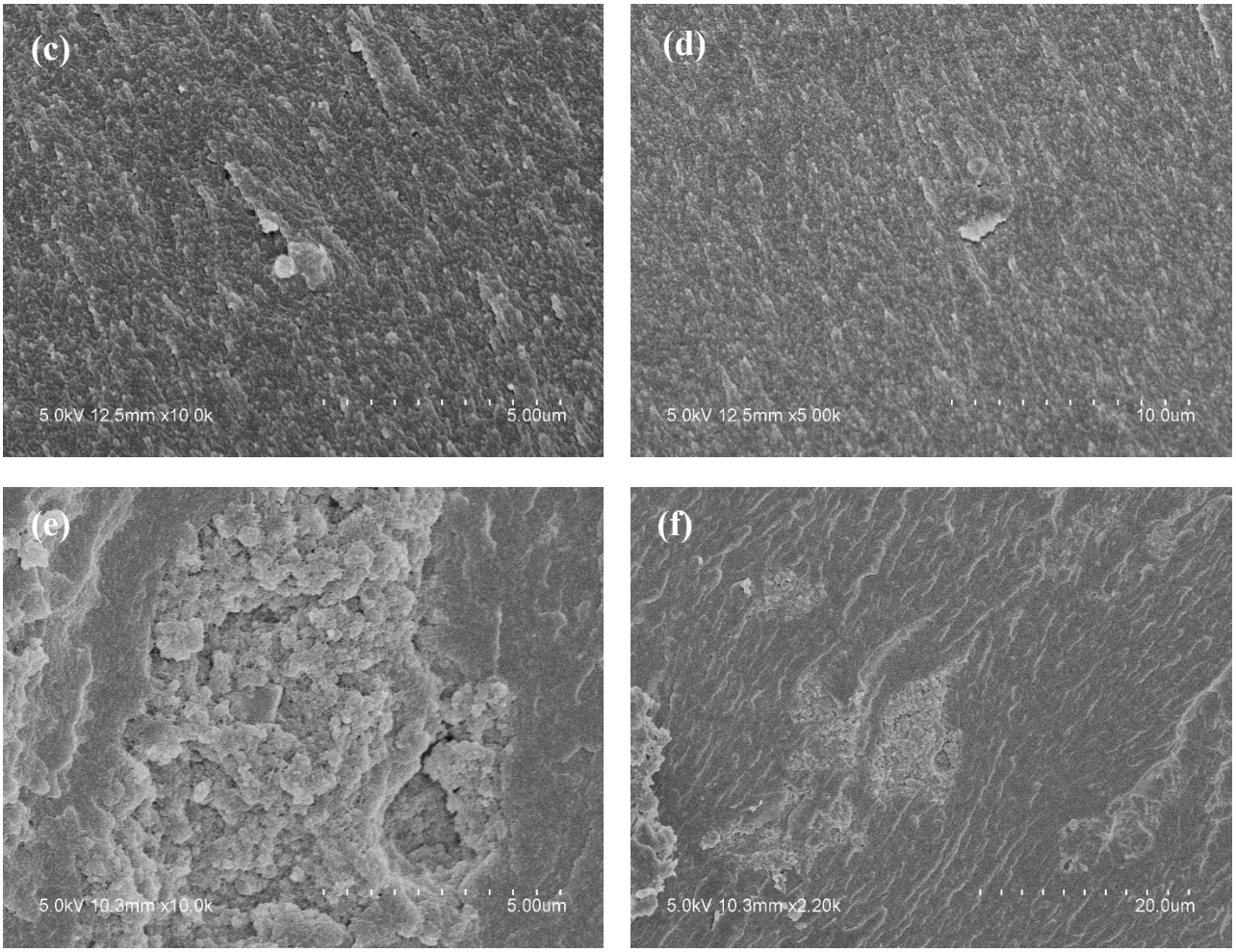


Figure S2: SEM of f-CNTs@PU and 0.1 %PANI/f-CNTs@PU and 1.0%PANI/f-CNTs@PU at different magnifications

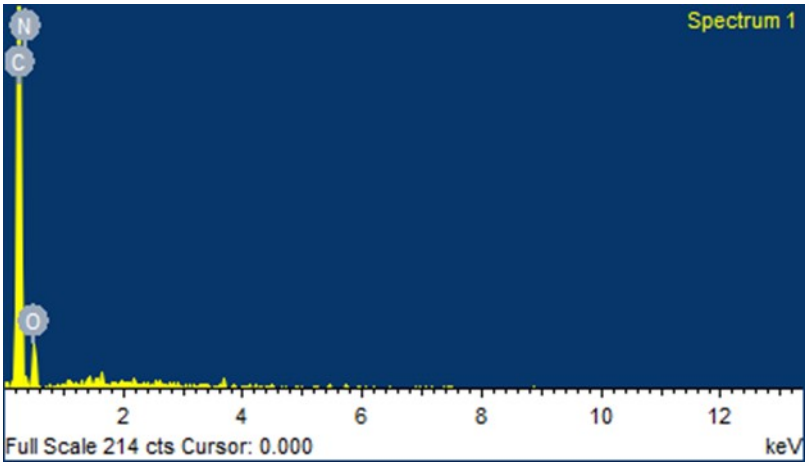


Figure S3: EDX spectrum of 1.0%PANI/f-CNTs@PU

Table 1S FTIR peaks assignment for PU, f-CNTs@PU and PANI/f-CNTs@PU

Assignments	Wave number (cm^{-1})		
	PU	**f-CNTs@PU**	**PANI/f-CNTs@PU**
Ring deformation	511	510	509
ωC—H (aromatic)	729–550	710, 661	706, 660
subst Aromatic Ring	820 759	816, 758	814, 756
υC—C	950	948	933
υC—O—C	1022	1015	1005
NQN (CH,CN^{+})	-	-	1109
δC—H (aromatic)	1210	1200	1198
υC—N	1245	1241	1236
υC—O	1310	1309	1307
δ_{sym}C—H	1378, 1349	1375, 1347	1374, 1346
δCH_2 & CH_3	1418	1416	1411
δ_{as}C—H	1460	1457	1454
δN—H	1544	1541	1538
υC=C—C (aromatic)	1600, 1514	1593, 1510	1591, 1509
υC=O (H-bonded)	–	1680	1673
υC=O (Free)	1720	1716	1707
υNCO	2353	–	–
υ_{sym}C—H	2880	2873	2868
υ_{as}C—H	2972	2969	2967
υC—H (aromatic)	3158	3031	3028
υN—H	3430–3250	3361	3332

subst = substituted, as = asymmetric, sym = symmetric, ω = out-of-plane bending, δ = in-plane bending, υ = stretch, NQN=Q= quinone,NQN (CH,CN^+)

Table 2S Mechanical properties of PU and f-CNTs@PU and PANI/f-CNTs@PU composite films

Sample Code	Ultimate Tensile Strength (MPa)	Elongation at Break (%)	Young's Modulus (MPa)
PU	16.36 ± 0.49	7.93 ± 0.32	299.29 ± 8.98
f-CNTs@PU	21.16 ± 0.63	10.15 ± 0.41	423.79 ± 12.71
0.1%PANI/f-CNTs@PU	26.49 ± 0.79	18.35 ± 0.73	456.49 ± 13.69
0.3%PANI/f-CNTs@PU	25.55 ± 0.77	11.05 ± 0.44	414.62 ± 12.44
0.5%PANI/f-CNTs@PU	23.41 ± 0.70	14.10 ± 0.56	363.65 ± 10.90
1.0%PANI/f-CNTs@PU	13.65 ± 0.41	4.95 ± 0.20	324.44 ± 9.73

Table 3S TGA results of pristine PU and f-CNTs@PU and PANI/f-CNTs@PU composite films

Sample Code	1st Step Degradation			2nd Step Degradation			Y_c at 700 °C
	T_o (°C)	T_e (°C)	T_{max} (°C)	T_o (°C)	T_e (°C)	T_{max} (°C)	(wt. %)
PU	320.81	429.38	409.87	429.38	534.93	482.30	16.83
f-CNTs@PU	323.24	431.11	413.27	431.11	544.86	485.91	19.41
0.1 %PANI/f-CNTs@PU	328.46	434.64	412.26	434.64	555.12	489.44	19.35
0.3 %PANI/f-CNTs@PU	331.32	442.21	420.91	442.21	563.70	495.07	19.35
0.5 %PANI/f-CNTs@PU	335.19	446.08	421.26	446.08	565.55	500.52	21.03
1.0 %PANI/f-CNTs@PU	341.91	452.81	431.29	452.81	569.42	502.72	19.36

T_o: Temperature for on-set decomposition, T_e: Temperature for end-set decomposition, T_{max}: Temperature for maximum decomposition, Y_c: weight of polymer remained/Char yield.

Table 4S DSC data of decomposition of PU, f-CNTs@PU and PANI/f-CNTs@PU composite films

Sample Code	T_g (°C)	T_m (°C)	ΔH_m (J g^{-1})	T_c (°C)	ΔH_c (J g^{-1})
PU	5.28	56.94	3.97	17.58	3.44
f-CNTs@PU	7.46	59.29	4.24	35.59	3.57
0.1 %PANI/f-CNTs@PU	8.49	61.16	3.26	41.47	3.51
0.3 %PANI/f-CNTs@PU	8.27	60.90	3.96	41.07	3.02
0.5 %PANI/f-CNTs@PU	7.81	60.73	3.72	40.40	2.80
1.0 %PANI/f-CNTs@PU	7.76	60.65	1.32	39.78	1.13

T_g: Glass transition temperature, T_m: Melting temperature, ΔH_m: Heat of melting
T_c: Crystallization temperature, ΔH_c: Heat of crystallization

Table 5S Electrical conductivity (S cm^{-1}), shape recovery (%) and shape fixity of PU, f-CNTs@PU and PANI/f-CNTs@PU composite films.

Sample Code	Electrical Conductivity (S cm^{-1})	Shape Recovery (%)	Shape Fixity
PU	4.06×10^{-7}	83	87
f-CNTs@PU	5.30×10^{-6}	86	88
0.1 %PANI/f-CNTs@PU	1.68×10^{-4}	87	91
0.3 %PANI/f-CNTs@PU	2.49×10^{-4}	89	92
0.5 %PANI/f-CNTs@PU	2.60×10^{-4}	92	95
1.0 %PANI/f-CNTs@PU	5.00×10^{-2}	97	98

Table 6S A concise comparison of CNTs, PU and other conducting polymer hybrids showing shape recovery and electrical conductivity values.

Sr No	Material name	Conducting polymer	Filler	Fabrication technique	Shape memory actuation	Shape recovery (%)	Electrical Conductivity (S cm^{-1})	Ref
1	PU	Pth (0.1-1% wt)	-	Solution mixing	thermal	80-85	-	[1]
2	PU	Pth (0.1-1% wt)	CNTs	In situ polymerization	thermal	89-92	-	[1]
3	PU	PCL	Amine trimer (1% wt)	-	electrical	95	10^{-5} - 10^{-3}	[2]
4	PEO/P(P-E-P)G/TDI	Ppy (0.1-1% wt)	-	In situ polymerization +Solution blending	thermal	85-89	3.48×10^{-6} - 2.84×10^{-4}	[3]
5	PEO/P(P-E-P)G/TDI	Ppy (0.1-1% wt)	f-CNTs	In situ polymerization +Solution blending	thermal	87.7-94	7.69×10^{-4} - 6.25×10^{-2}	[3]
6	PU	PCL	Graphene	Mechanical compounding	Electrical/thermal	87	10^{-2}	[4]
7	PU	Polylactide (PLA)	CNTs	Melt blending	thermal	90	10^{-3}	[5]
8	PU	-	2%RGO	-	thermal	89	10^{-2}	[6]
9	PU	-	CNTs	Melt compounding	thermal	71	10^{-3}	[7]
10	PVA	-	10% CNTs	Simple casting	thermal	70	10^{-3}	[8]
11	PU	PANI (0.1-1% wt)	f-CNTs	In situ polymerization	thermal	84-98	1.68×10^{-4} -5.00×10^{-2}	Current work

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Data availability statement

The data supporting this article have been included as part of the Supplementary Information.