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Architecture-controlled carbon nanotube/bottlebrush elastomer–silver nanowire-based multilayer composites for skin-interfaced applications

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Supplementary materials

In addition to these findings reported in Figure 5a–b, Table S1 summarizes the baseline through-plane electrical properties of the carbon nanotube/bottlebrush elastomer–silver nanowire (CNT/BBE–AgNW) sandwich structures with different thickness configurations. The regular, thin, and double-sandwich architecture exhibit distinct electrical behaviors, as in their mean resistance, resistivity, and conductivity values with corresponding standard deviations. Columns 3–4 in Table S1 summarize the measured electrical resistance, calculated by dividing the applied current by the resulting voltage. The resistance is dependent on both material properties and geometries, including the sample thickness and electrode configuration. Columns 5–6 show the corresponding resistivity values. The resistivity accounts for geometric differences between composite samples and allows comparison of intrinsic electrical behavior across different architectures. Conductivity in Columns 7–8 is calculated as the inverse of resistivity, providing a complementary representation of electrical transport.

Overall, reducing thickness and increasing interfacial layer resulted in lower resistance, with the double-sandwich structural design showing the most enhanced electrical transport. These results suggest a clear relationship between structural design and intrinsic electrical properties, thus providing a reference for evaluating electromechanical performance under deformation.

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Table S1. Baseline electrical measurements of the CNT/BBE-AgNW sandwich composites with varying thickness configurations and AgNW interlayers. Mean resistance, resistivity, and conductivity values (± standard deviation, or SD) are summarized for the regular, thin, and double architectures measured under through-plane conditions. Resistivity and conductivity were calculated using an electrode contact area of 6.35 mm × 25 mm and the respective sample thickness, the resistivity/conductivity is an approximate because the through-plane configuration may produce a non-uniform current path.

Structure	Thickness (mm)	Resistance Mean (Ω)	Resistance SD (Ω)	Resistivity Mean (Ω·m)	Resistivity SD (Ω·m)	Conductivity Mean (S/m)	Conductivity SD (S/m)
Regular	3	6618.1	192.58	350.21	10.19	0.0028555	8.3089e-05
Thin	2	3043.7	31.066	161.59	2.4658	0.0041392	4.2248e-06
Double	3	2023.2	17.119	107.06	0.9059	0.0093402	7.9031e-05

To evaluate response retention during repeated bending tests, Figure S1 compares representative cycles collected over 500 tests that are near the beginning and end of repeated manual bending sessions for the regular CNT/BBE–AgNW composite. These beginning- and end-of-session traces are plotted using the same time window and axis scale within each comparison in order to allow direct visual comparison of response magnitude, waveform shape, and baseline recovery. The tested composite maintained cyclic resistance responses after repeated bending, with generally comparable waveform shape, peak response, and recovery behavior. Small variations in peak amplitude and baseline level are expected because the bending tests were performed manually and may include minor differences in bending angle, contact position, deformation rate, and skin contact. In brief, these data support short-term response retention under repeated manual bending but should not be interpreted as a complete long-term fatigue assessment.

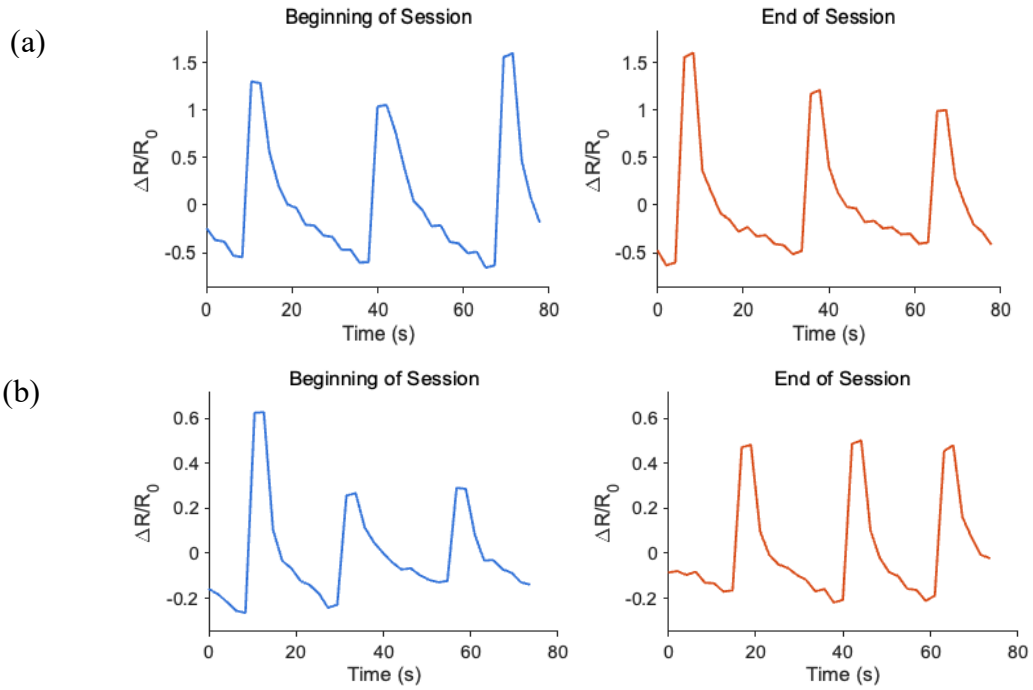


Figure S1. Response retention after repeated manual bending. Representative cycles collected near the beginning and the end of repeated bending sessions are compared for **(a)** finger bending and **(b)** wrist bending.

Although direct stress–strain curves and modulus measurements are not reported for the CNT/BBE–AgNW multilayer composites, the mechanical suitability of BBE as a compliant matrix is supported by prior literature. To provide context for future skin-interfaced applications, Table S2 summarizes reported mechanical properties of related PDMS-based BBEs and conductive BBE composites. These literature values may provide benchmarks for the expected compliance range of BBE-based materials.

Table S2. Literature-reported mechanical properties of related PDMS-based BBEs and conductive BBE composites. (Bracketed numbers [19] and [26] represent the literature sources in the reference section of the article, from which the associated information was extracted.)

Literature material systems	Conductive fillers	Young's modules	Stretchability or cyclic information	Relevance to current work
PDMS BBE [19]	/	~0.63 kPa	Elastic range up to 400% strain ~1000 loading test cycles	Supports BBE as ultra-soft matrix
SWCNT/BBE (0.2 wt%) [19]	SWCNT	~2.98 kPa	/	Closest conductive BBE benchmark
SWCNT/BBE (0.4 wt%) [19]	SWCNT	~5.29 kPa	/	Conductive BBE benchmark
SWCNT/BBE (0.6 wt%) [19]	SWCNT	~10.65 kPa	/	Conductive BBE benchmark
Silicone BBE [26]	/	~1.2–7.4 kPa	/	Supports broader low-kPa BBE stiffness range