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Supporting Information

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Stretchable and Energy-Efficient Heating Carbon Nanotube Fiber by Designing a Hierarchically Helical Structure

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Supporting Information

Experimental Section

The structures of the heating fibers were characterized by scanning electron microscope (S-4800, Hitachi) and optical microscopy (BX51, Olympus). Photographs were taken by a digital camera (J1, Nikon). The thermal properties and images were produced by an infrared camera (PI 450, Optris). Direct current (DC) bias voltage was supplied by a programmable DC source meter (M8813, Maynuo) at currents below 1 A and a DC source meter (PWS2323, Tektronix) at currents above 1 A. The stretching measurements were operated at a table-top universal testing instrument (HY-0350, Hengyi). The statistical distribution of the micrometer-scaled voids among the neighboring fibers and helixes was made by taking about 100 points of the voids in the SEM images of HHFs.

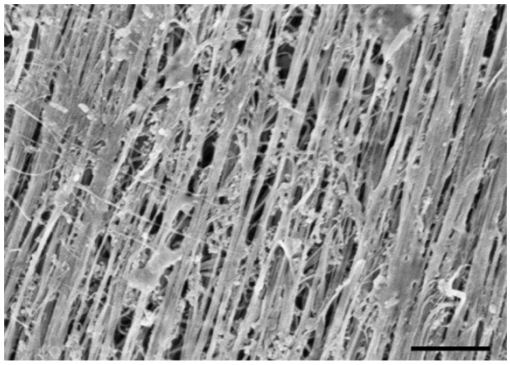

Figure S1. SEM image of the CNT fiber at high magnification. Scale bar, 500 nm.

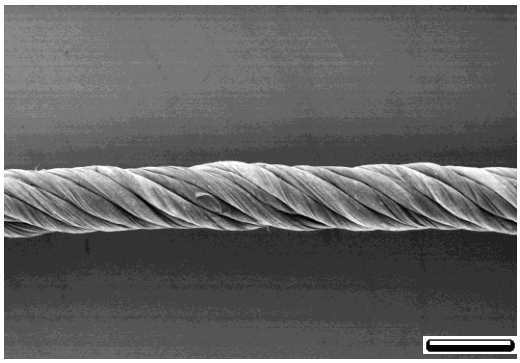

Figure S2. SEM image of 10 primary CNT fibers twisted together. Scale bar, 150 μm.

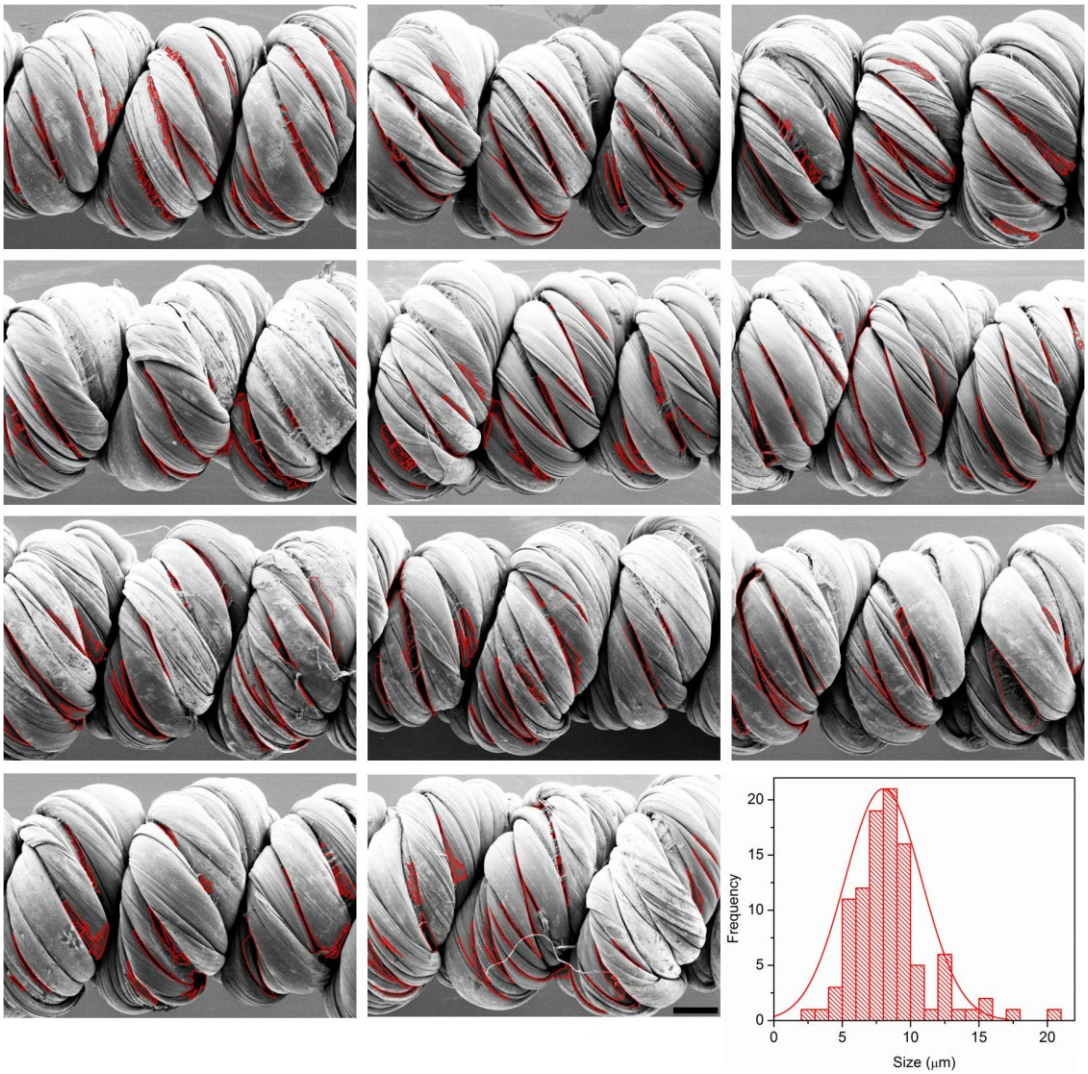

Figure S3. SEM images of the HHFs and the statistical distribution of the size of voids among the neighboring primary CNT fibers. Scale bar, 50 μm.

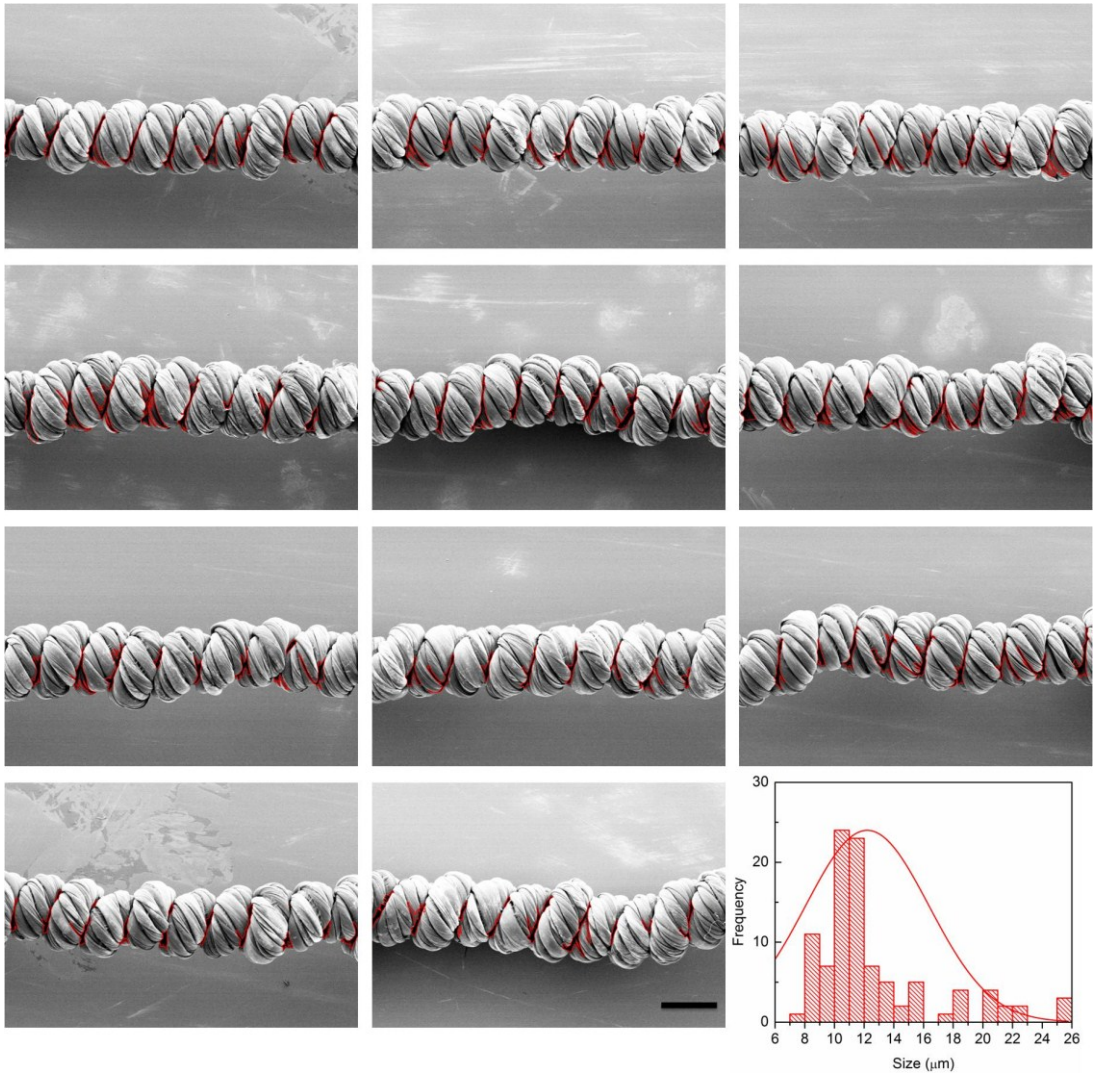

Figure S4. SEM images of the HHFs and the statistical distribution of the size of voids among the neighboring helixes. Scale bar, 200 μm.

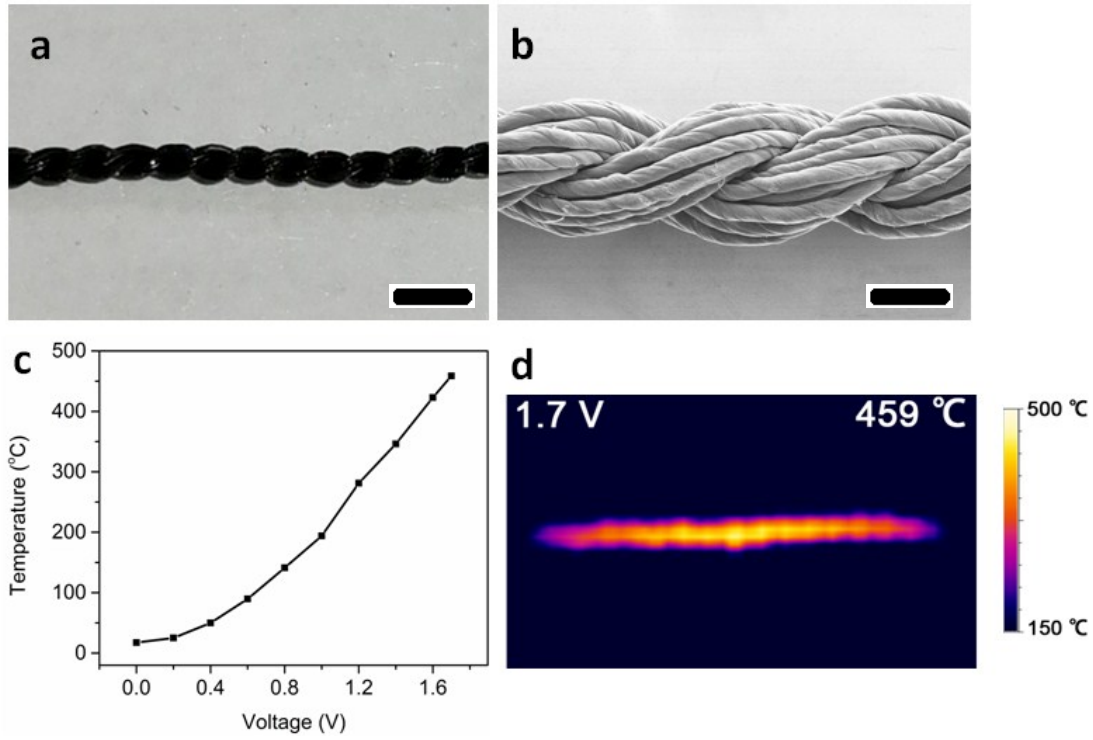

Figure S5. Characterization of the multi-ply CNT fiber twisted from 32 primary CNT fibers. **a**, **b**) Photograph and SEM image, respectively. Scale bar, 1 mm (a) and 250 μm (b). **c**) Dependence of saturated temperature on input voltage. **d**) Infrared image at 1.7 V.

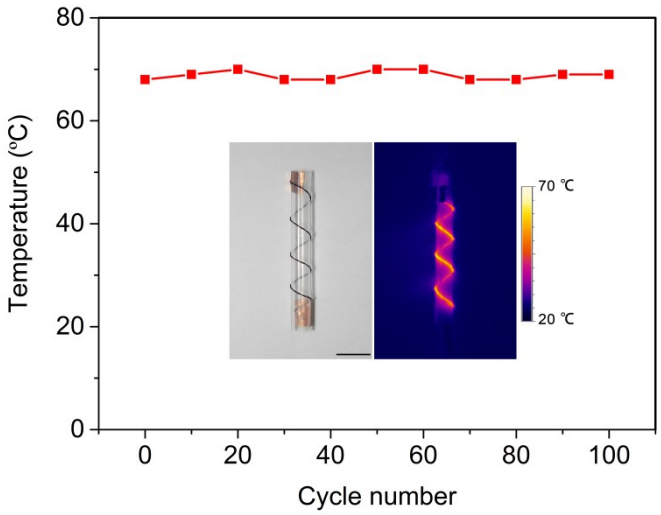

Figure S6. Dependence of saturated temperature on wrapping cycle number of the HHF (length of 10 cm) at 7 V (inserted, photograph and infrared image of the HHF wrapped on a plastic tube at the left and right, respectively). Scale bar, 1 cm.

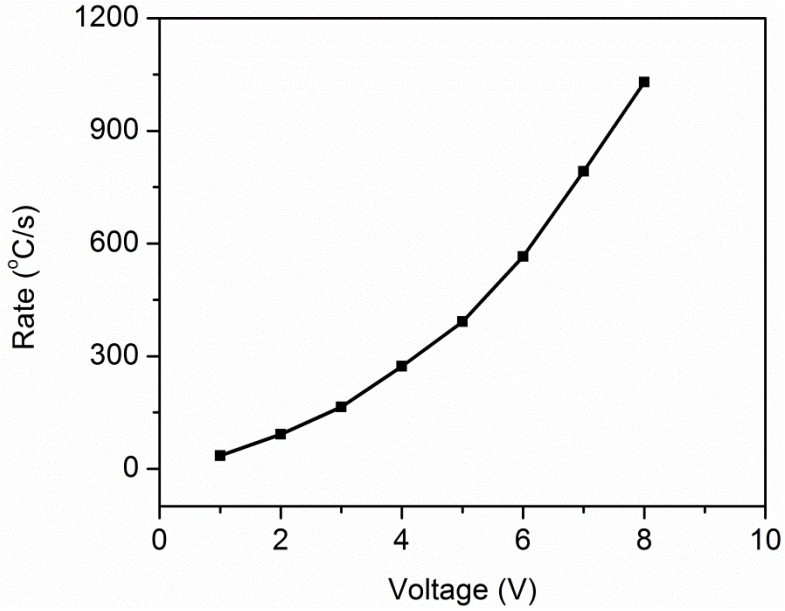

Figure S7. Dependence of maximal heating rate of HHF (length of 2 cm) on input voltage.

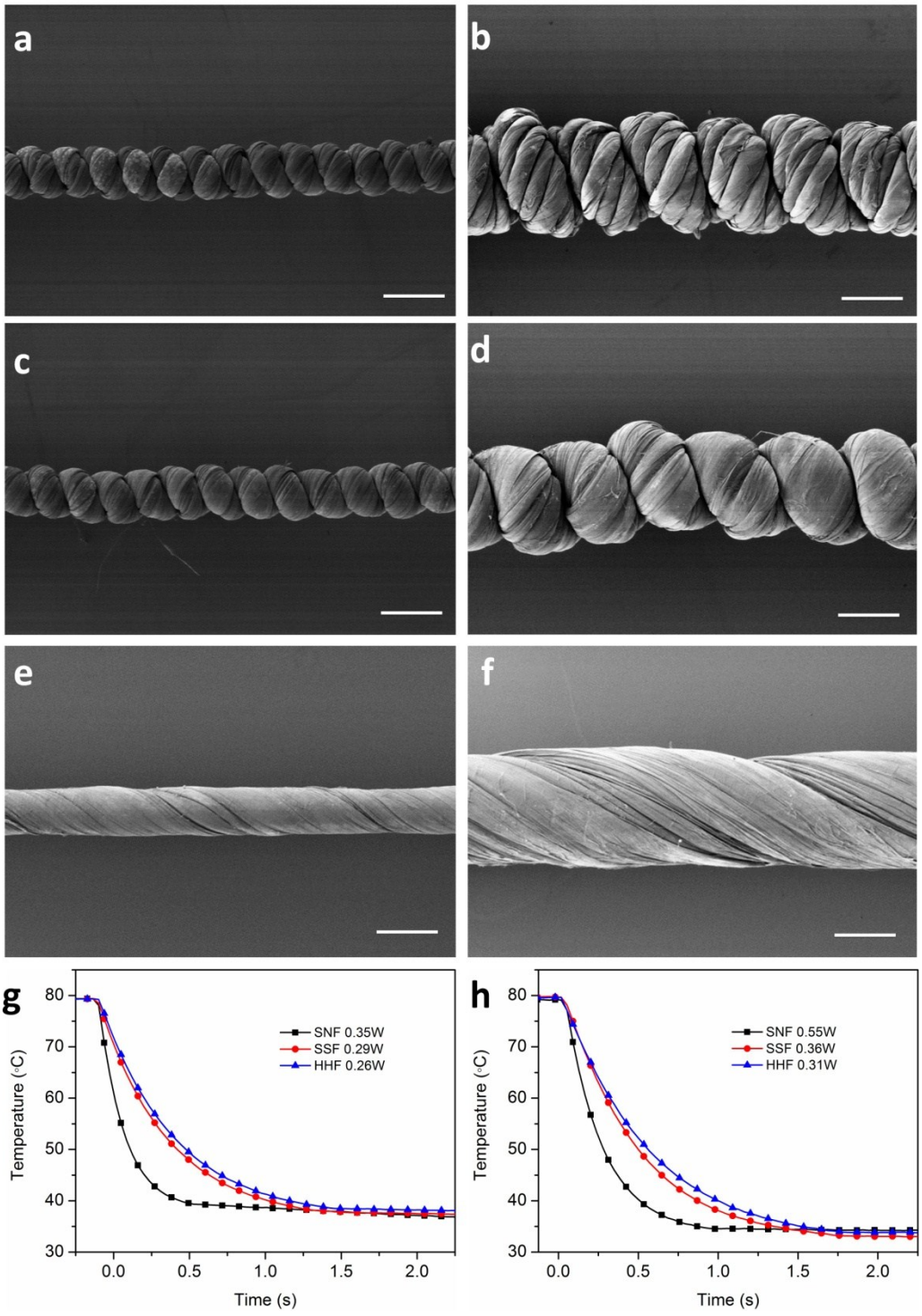

Figure S8. a, **b**) SEM images of HHFs twisted from 5 and 15 primary CNT fibers, respectively. **c**, **d**) SEM images of SSF with the same diameter as HHF. **e**, **f**) SEM images of SNF with the same diameter as HHF. Scale bar**,** 150 μm (a-f)**. g**, **h**) Cooling curves of HHF, SSF and SNF (inserted markers show the input power to maintain the fibers at 80 ^{o}C).

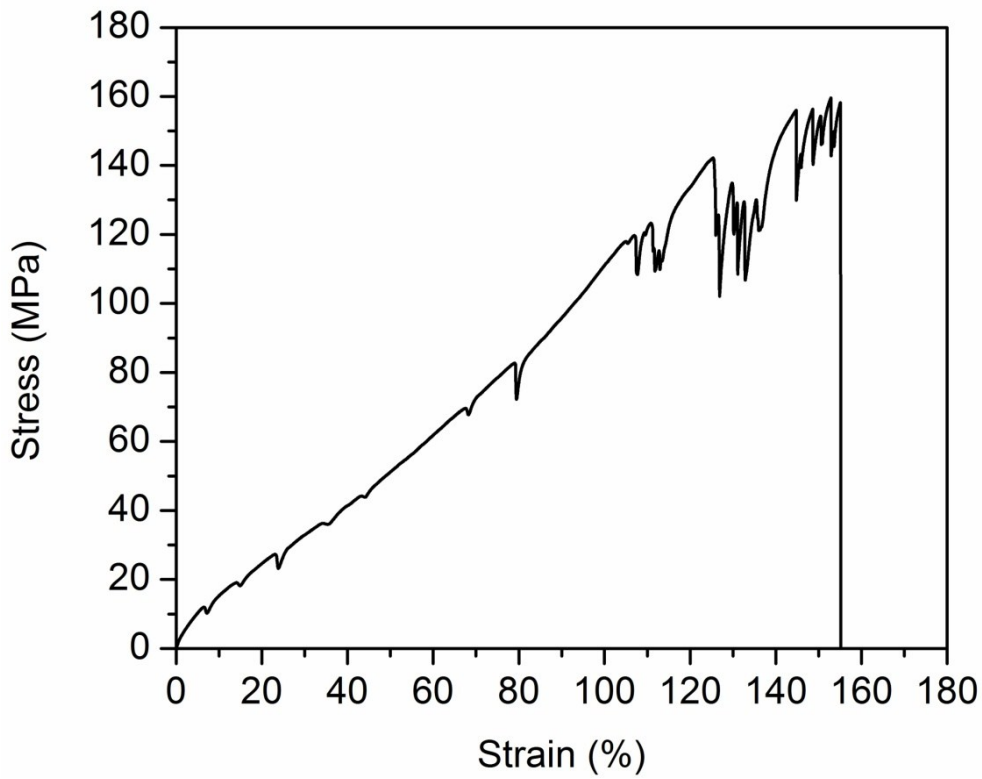

Figure S9. Stress–strain curve of the HHF.

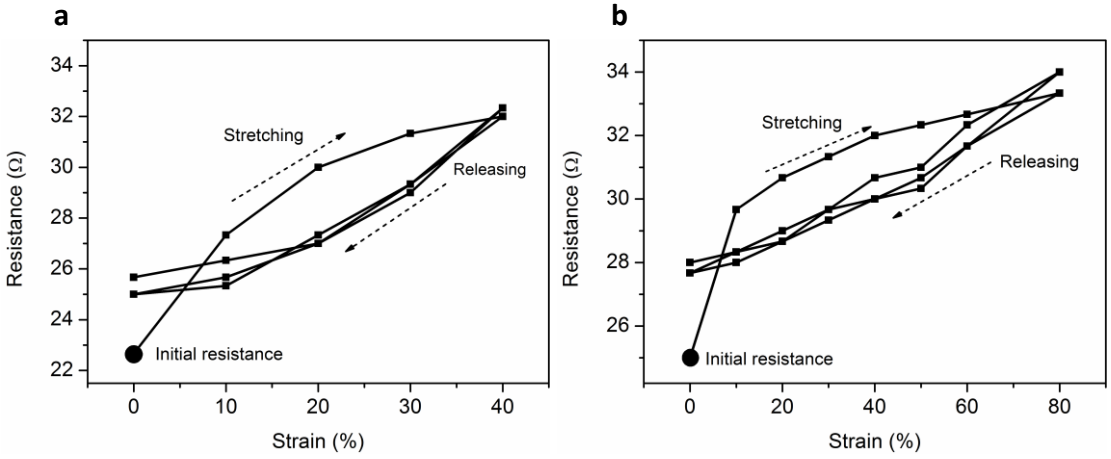

Figure S10. Resistance evolution of the HHF (length of 2 cm) under the first and second stretching/releasing cycle at strains of 40% (**a**) and 80% (**b**).

Table S1. The comparison about heating rate between HHF and the other materials.

Material	Heating rate ($^{o}C \cdot s^{-1}$)	Voltage (V)	Reference
CNT fiber（this work）	**1030**	**8**	
Kanthal (commercial)	29.1	5	[S1]
Nichrome (commercial)	23.7	5	[S1]
Graphene fiber	571	5	[S1]
Graphene/PI	16	60	[S2]
Graphene/PET	0.8	12	[S3]
CNT/PET	3.7	15	[S4]
CNT/glass	3.5	/	[S5]
PEDOT:PSS fiber	63	14	[S6]
Metal mesh/quartz	15.8	15	[S7]
AgNW/glass	3.4	4	[S8]
AgNW/PET	1.7	7	[S9]

PI, polyimide; PET, poly (ethylene terephthalate); AgNW, silver nanowire.

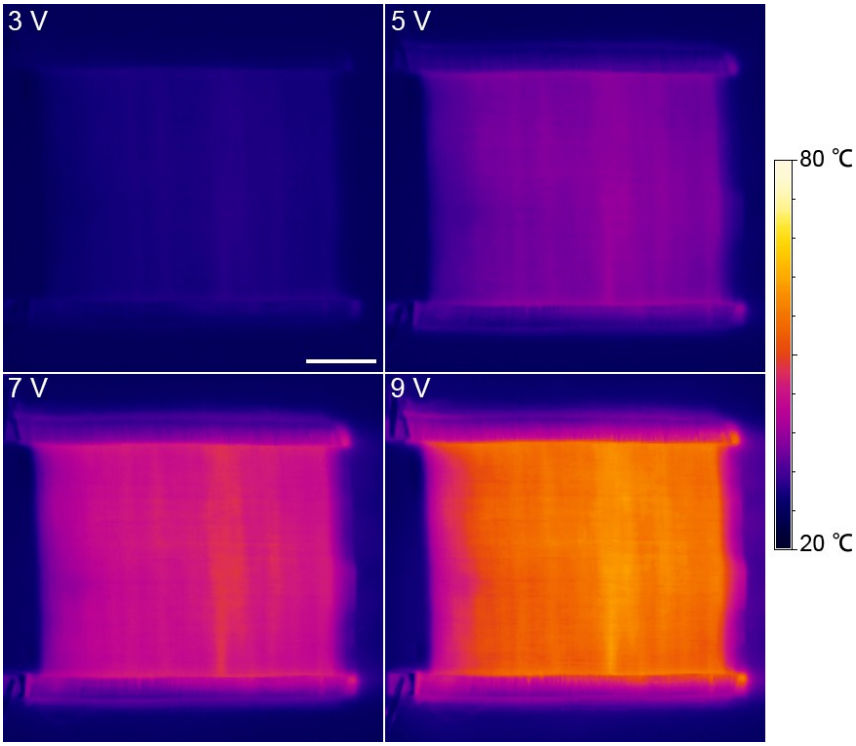

Figure S11. Infrared images of the heating textile woven from CNT fibers and cotton threads at 3, 5, 7 and 9 V. Scale bar, 3 cm.

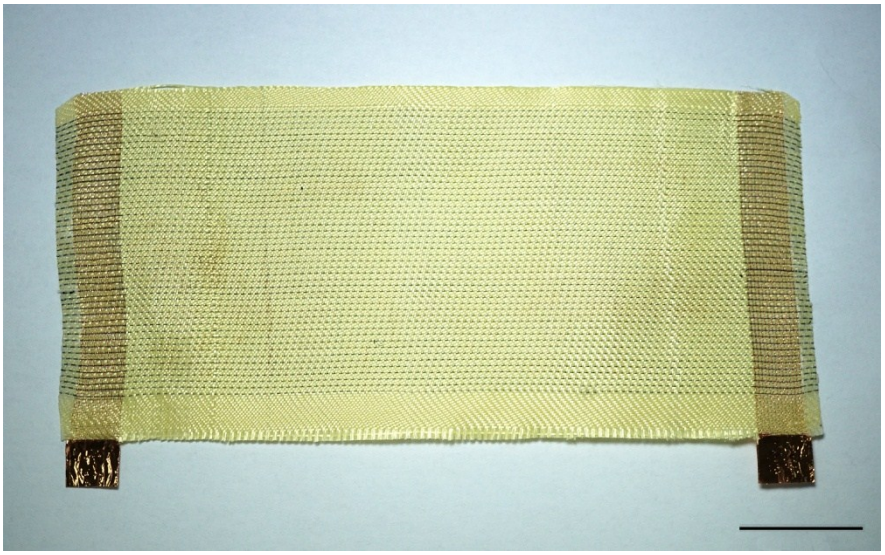

Figure S12. Photograph of the heating textile woven from CNT fibers and Kevlar fibers. Scale bar, 3 cm.

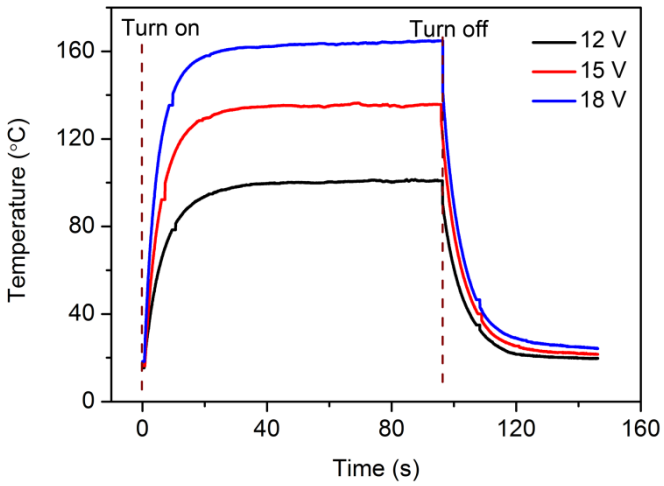

Figure S13. Temperature-time curves of the heating textile woven from CNT fibers and Kevlar fibers.

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