Electronic Supplementary Material (ESI) for Nanoscale.

Support information

Super-strong CNT composite yarn with tight CNT packing via compress-stretch process

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CNT film was produced using the chemical vapor deposition (CVD) method. The ferrocene (0.4 wt%) and thiophene (0.8 wt%) were dissolved in ethanol (98.8 wt%), the solution was injected into the tubing (1280 °C) at a feeding rate of 0.15ml/min, and the gaseous mixture of Ar/H2 (volume ratio 1:1) at a speed of 4000 sccm were injected to a furnace. Thus, the entangled CNT networks were formed, which could be carried out by the gas flow. Finally, CNTs were collected by a roller and densified by ethanol forming a CNT film [1].

Since CNTs can be dispersed uniformly with a relatively low volume fraction (~0.05-0.1) due to agglomeration characteristics of CNTs [2]. However, CNT Y can be arranged uniformly in the polymer at a higher volume fraction (~0.4-0.6, CNT yarn tight packing) because of the higher volume fraction of CNTs in the CNT yarn [3]. The CNT/PVA Y in this paper shows a high volume fraction ($V_f = 0.38 \pm 0.02$).

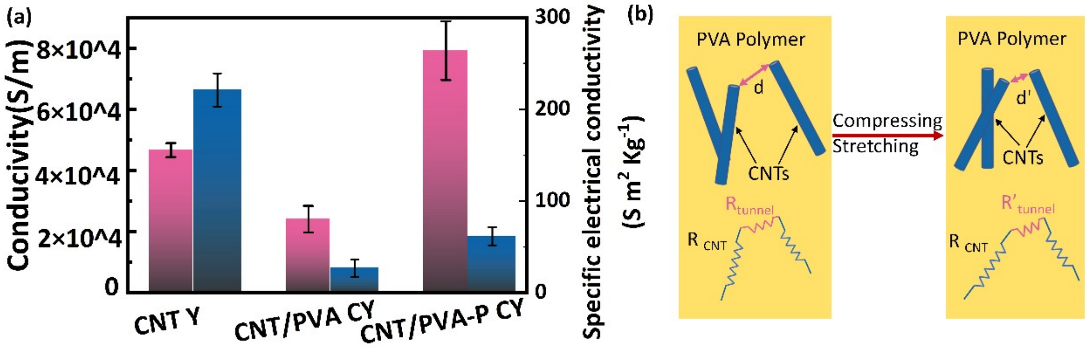

Fig.S1 (a) Electrical conductivity (left y-axis) and specific electrical conductivity (right y-axis). (b) tunneling effect among CNTs in the nanocomposites; (b) Schematic illustration of the possible tunneling resistance and contact resistance in CNT/PVA composites yarn under compressing and stretching.

Fig.S1 shows the conductivity and specific electrical conductivity of the yarn. The electrical conductivity of pristine CNTY is 46657 S/m. By introducing the conductor-insulator PVA polymer into CNTY, there is a noticeable decrease in the electrical conductivity (24075 S/m) of CNT/PVA CY due to the insulation characteristic of PVA polymer. Strikingly, the electrical conductivity of CNT/PVA-P CY soars to 79237 S/m, which is 329% higher than that of a CNT/PVA CY. It is considered that the electron tunnel effect within the composites yarn is the primary electron conduction mechanism. Thus, the increase of electrical conductivity in CNT/PVA composites yarn before and after passing through dies can be explained based on electron tunneling resistance, as shown in Fig.S1b. The formula is as follows:

$$R_{tunnel} = \frac{V}{AJ} = \frac{h^2 d}{Ae^2\sqrt{2m\lambda}} \exp\left(\frac{4\pi d}{h}\sqrt{2m\lambda}\right) \quad (1)$$

where V is the electrical potential difference; h is Planck's constant; d is the distance between CNTs; A is the cross-sectional area of the tunnel (the cross-sectional area of

CNT is approximately used here); J is the tunneling current density; e is the quantum of electricity; m is the mass of electron; and λ is the height of the barrier. According to Eq. (1), the exponential function illustrates that a significant decrease of d causes a considerable reduction of tunneling resistance. Therefore, the CNT/PVA-P composite yarn exhibits increased conductivity by compressing and stretching due to a decreasing tunneling gap and the reduction of R_{tunnel}.

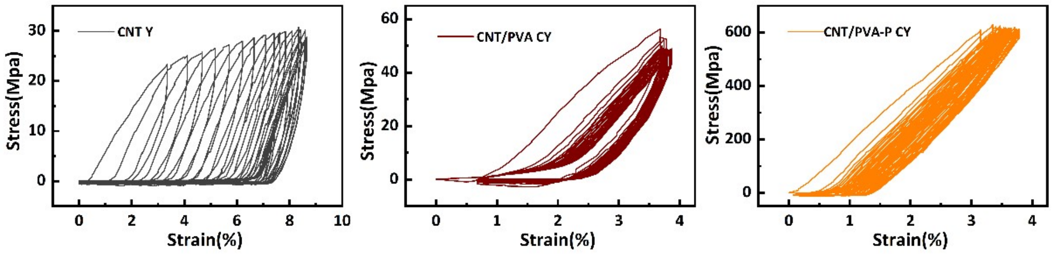

Fig.S2 Typical stress changes of (a) CNTY (b) CNT/PVA CY (c) CNT/PVA-P CY during 22 stretching cycles as a function of the applied tensile strain (3%).

References

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