Continuous Macroscopic Fibres of Carbon Nanotubes for Smart Textiles and Ballistic Protection

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Abstract (Arial 10)

We report on the synthesis of kilometers of continuous macroscopic fibers made up of carbon nanotubes (CNT) of controlled number of layers, ranging from singlewalled to multiwalled, tailored by the addition of sulfur as a catalyst promoter during chemical vapor deposition in the direct fiber spinning process. The progressive transition from single-walled through collapsed double-walled to multiwalled is clearly seen by an upshift in the 2D (G′) band and by other Raman spectra features. The increase in number of CNT layers and inner diameter results in a higher fibre macroscopic linear density and greater reaction yield (up to 9%).

We present a method to spin highly oriented kilometres of continuous fibers of adjustable carbon nanotube (CNT) type, with mechanical properties in the high-performance range. The synthesis of these macroscopic fibers is carried out by directly spinning an aerogel of CNTs during growth by chemical vapour deposition. CNT number of layers, ranging from singlewalled to multiwalled, is tailored by the addition of sulfur as a catalyst promoter during CVD. By lowering the concentration of nanotubes in the gas phase, through either reduction of the precursor feed rate or increase in carrier gas flow rate, the density of entanglements is reduced and the CNT aerogel can thus be drawn (up to 18 draw ratio) and wound at fast rates (>50 m/min). This is achieved without affecting the synthesis process, as demonstrated by Raman spectroscopy, and implies that the parameters controlling composition in terms of CNT diameter and number of layers are decoupled from those fixing CNT orientation. Applying polymer fiber wet-spinning principles then, strong CNT fibers (1 GPa/SG) are produced under dilute conditions and high draw ratios, corresponding to highly aligned fibers (from wide- and small-angle X-ray scattering). This is demonstrated for fibers either made up of predominantly single-wall CNTs (SWCNTs) or predominantly multiwall CNTs (MWCNTs), which surprisingly have very similar tensile properties. By adjusting the composition of the carbon precursor we further show evidence of fibre with superior specific tensile strength to Kevlar 49 and about twice its toughness, combined with high electrical conductivity and a very large surface area. These results demonstrate a route to control CNT assembly and reinforce their potential as a high-performance fiber for ballistic applications.

Finally, we discuss the properties of CNT fibres in the context of ballistic protection, and show examples of the exploitation of their properties as sensors, supercapacitors and other devices.

References

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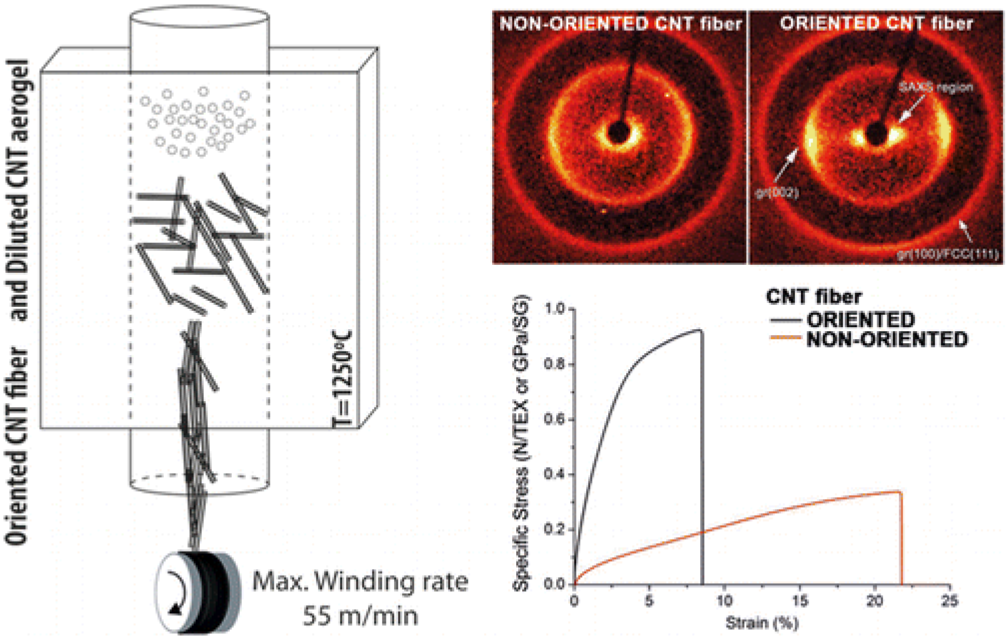
ACS Nano Qiu et al 2013, 7(10), 8412-8422

ACS Nano Belén et al 10.1021/acsnano.5b02408 2015

Figures


Oriented CNT fiber and Diluted CNT aerogel
T=1250ºC
Max. Winding rate
55 m/min
NON-ORIENTED CNT fiber
ORIENTED CNT fiber
SAXS region
gr(002)
gr(100)/FCC(111)
CNT fiber
ORIENTED
NON-ORIENTED
Specific Stress (N/TEX or GPa/SG)
Strain (%)