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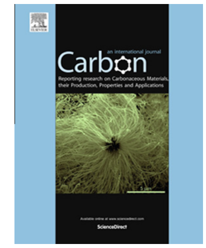

Real-time deformation of carbon nanocoils under axial loading

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ABSTRACT

Tensile tests were performed on nine carbon nanocoils (CNCs) using a focused-ion-beam (FIB) technique. In each experiment, an individual CNC was picked up using an FIB, and a CNC bridge formed between a tungsten probe and the spring-table substrate. Real-time observations of the CNC elongation and subsequent fracture under prolonged stretching enabled us to estimate the elastic limit, the spring constant, the shear modulus, and the ultimate strength of each CNC and their mean values. The mechanics of CNCs was also compared to that of macroscopic springs.

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1. Introduction

In 1998, Motojima et al. synthesized helical carbon microcoils (CMCs) on a graphite substrate coated with a Ni powder catalyst [1]. It is now possible to synthesize much smaller helical carbon nanofibers; typical carbon nanocoil (CNC) fiber diameters and coil radii are 100–200 nm and 300–900 nm, respectively. Motivated by the unique shape of CNCs, several groups have studied the electrical characteristics of small helical elements such as nanosprings [2–8], carbon microcoils [1,9], and carbon nanocoils [10,11]. Potential nanoscale applications for CNCs include resonant elements, nanosolenoids [11], and field emitters [10].

Besides the electronic properties, the CNC mechanics has generated much interest from both theoretical [12–14] and experimental [15–20] viewpoints, partly because it might be applicable in manifold utilities including pressure sensors [21] and nanoreinforcement for composites [22,23]. For instance, the seminal work of Chen et al. [16] showed that the CNC spring constant was 0.12 N/m, the samples were ~10 μm in length and ~600 nm in coil diameter, and the experiment was conducted using cantilever atomic-force microscopy. Poggi et al. reported the mechanical response of a multi-walled carbon nanospring to axial compression [19,20]. Nevertheless, subsequent experimental efforts to determine the mechanical properties of CNCs have been sparse compared to the intensive computational work carried out in recent years [24–26]. In particular, the CNC response to prolonged stretching, which includes initial elastic elongation to large-scale deformation in the plastic regime and subsequent tensile fracture followed by post-fracture contraction and the release of the applied strain, remains undetermined.

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