Università degli Studi Salerno
Dottorato di Ricerca in Ingegneria delle Strutture e del Recupero Edilizio ed Urbano
Course on "Carbon nanotubes (CNTs) as components in bulk materials":

Lecturers

Jordan R. Raney, California Institute of Technology
Fernando Fraternali, Università degli Studi di Salerno

Timetable of lectures

Martedi 25 Ottobre 2011 - Tuesday October 19, 2011
3pm, Room 112 - Ore 15.00, Aula 112 del Dipartimento di Ingegneria Civile
Lecture 1) Synthesis and properties of CNTs
Lecture 2) Applications

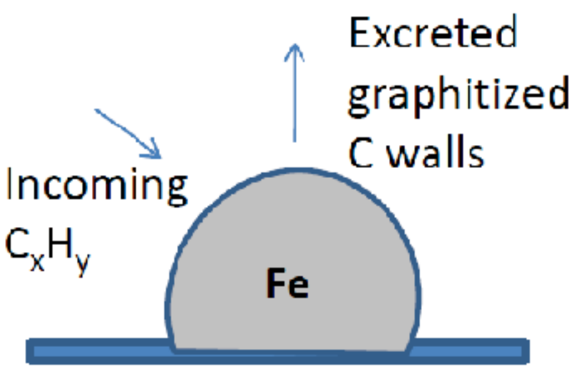
Mercoledi 26 Ottobre 2011 - Wednesday October 26, 2011
3pm, Room 112 - Ore 15.00, Aula 112 del Dipartimento di Ingegneria Civile
Lecture 3) CNT arrays
Lecture 4) Modifying CNT arrays and creation of multilayer materials

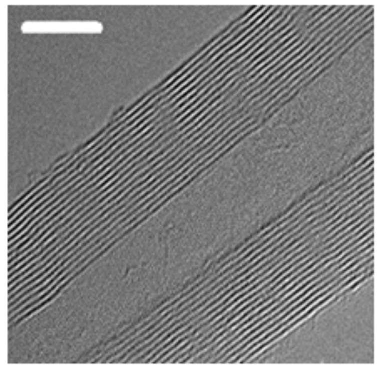
Venerdi 4 Novembre 2011- Friday November 5, 2011
3pm, Room 112 - Ore 15.00, Aula 112 del Dipartimento di Ingegneria Civile
Lecture 5) Multiscale modeling I
Lecture 6) Multiscale modeling II

Lecture abstracts follow:

Lecture 1) Synthesis and properties of CNTs

Abstract: Carbon nanotubes (CNTs) have been touted as a wonder-material in recent years, with the highest strength-to-weight ratio of any known material and high electrical and thermal conductivity. This lecture will explore the underlying basis from which these properties arise, and discuss various synthesis techniques. In particular, chemical vapor deposition approaches allow for large quantities of CNTs to be easily synthesized, and will therefore be emphasized.

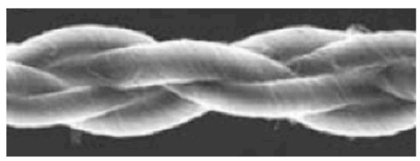


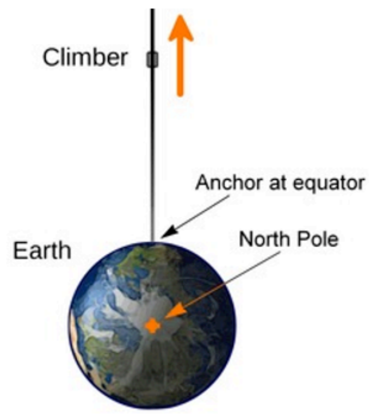


While there are a number of synthesis pathways to obtain carbon nanotubes, typical chemical vapor deposition techniques rely on transition metal catalysts such as Fe, which are observed to absorb carbon at high temperatures, and can excrete it in graphitic form (diagram on left); typical carbon nanotubes can consist of many concentric cylinders (right, 5 nm scale bar).

Lecture 2) Applications

Abstract: Much of the interest in CNTs stems from the fact they have remarkable mechanical, electrical, thermal, and multifunctional properties. This has led to proposals for their use in a wide variety of applications, from probe tips in atomic force microscopy to space elevators for cheaply putting objects in space. We will explore several of these proposed uses, focusing primarily on mechanical applications but discussing some others as well. Feasibility and associated challenges, such as nanotoxicity, will be discussed, as will the use of CNTs in structural materials relevant to civil engineering applications.

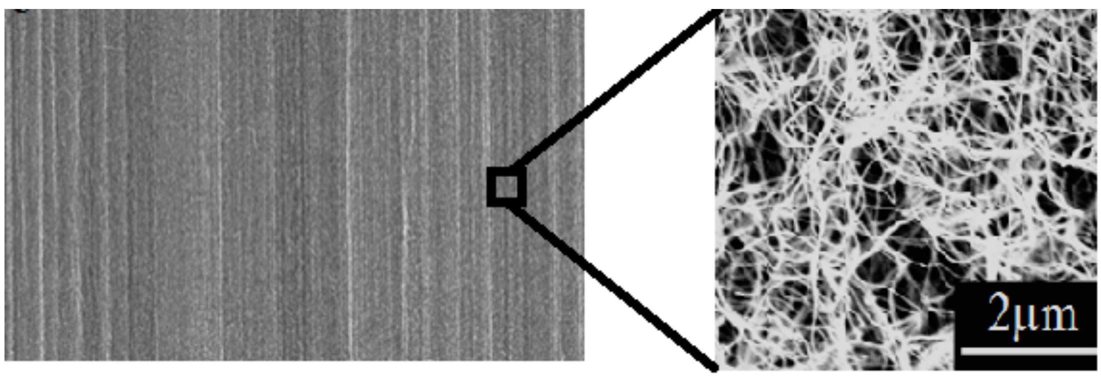




Due to their very high strength-to-weight ratio and excellent electrical and thermal properties, carbon nanotubes have been proposed for a variety of applications. This includes possible replacements for Kevlar protective vests (left) since carbon nanotubes can be spun into tough yarns (center); carbon nanotubes have even been proposed for the cable of a space elevator.

Lecture 3) CNT arrays

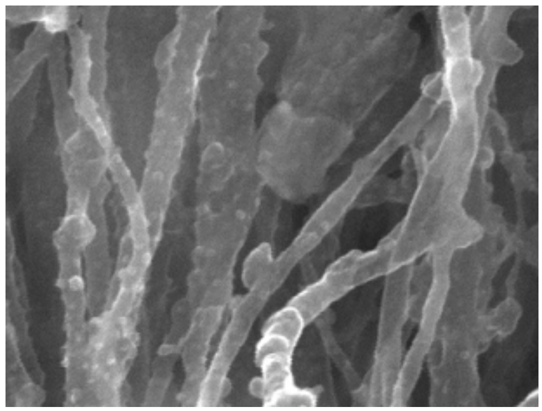
Abstract: As discussed in the previous lecture, despite the promising characteristics of CNTs, there are still many challenges to realizing benefits in macroscopic systems. Designing materials based on aligned arrays of CNTs is one approach for obtaining useful bulk materials for engineering applications that make use of nanostructures. In this lecture we will discuss the bulk properties of CNT arrays (emphasizing mechanics) and how they are synthesized. Their unique properties in compression will be discussed, such as their foam-like response, strain localization, and strain recovery.



Carbon nanotube arrays can be synthesized which have foam-like characteristics and display a hierarchical structural arrangement. At the mesoscale, the material appears very ordered, with well-aligned carbon nanotube bundles (left); but if one looks at a smaller length scale, the individual carbon nanotubes are observed to be highly laterally entangled (right).

Lecture 4) Modifying CNT arrays and creation of multilayer materials

Abstract: Depending on the application, one may desire to use CNT arrays of varying mechanical properties. In this lecture we will examine structure-property correlations that explain the bulk mechanical response in terms of nano-, micro-, and milli-meter structural features. Techniques for tuning the mechanical response will be discussed, as will the assembly of multilayer materials that hold promise for energy dissipation applications.

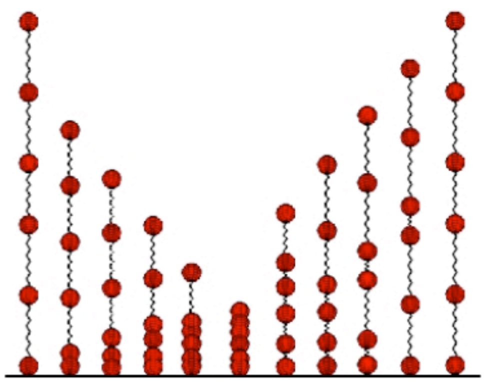


Carbon nanotube arrays can be customized both during and after synthesis. Pictured above are individual nanotubes (of approximately 50 nm diameter) which have been modified with MnO_2 particles on their surfaces. This modification could be useful both for increasing the compressive strength of the arrays and for electrochemical applications.

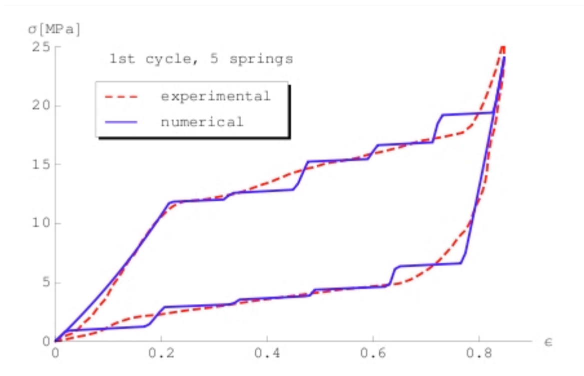
Lecture 5) Multiscale modeling I

Abstract: The hierarchical features of CNT arrays, which were explained from an experimental perspective in previous lectures, create challenges in developing a single modeling approach for encompassing the material. In this lecture we will discuss some of the past modeling efforts that have been used for CNTs and motivate the need for a multiscale model. We employ such a model based on bistable spring elements

Graphical abstract



Axial strain localization in a mesoscopic chain of five bistable springs. The spring collapse mimics the local kinking of compressed carbon nanotubes.

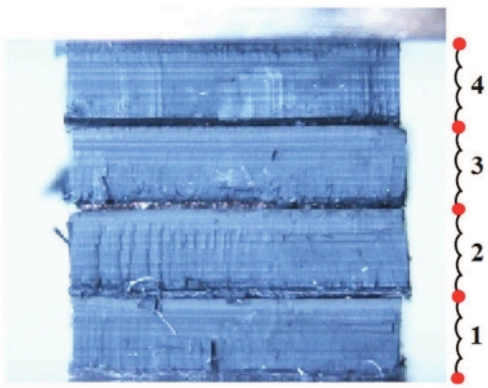


Predicted stress-strain response (solid line) at the macroscopic scale, reproducing the experimental behavior of a real CNT foam (dashed line).

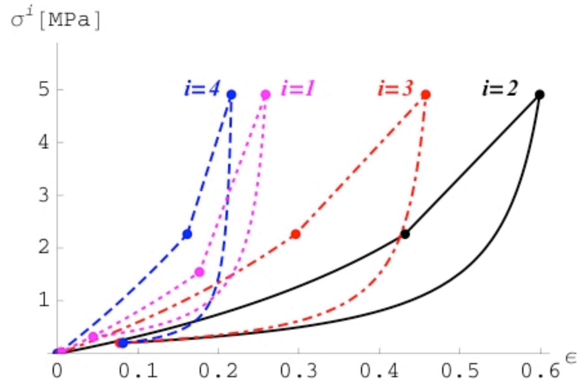
Lecture 6) Multiscale modeling II

Abstract: We present the mechanical modeling of multilayer composite structures composed of alternating layers of aligned carbon nanotubes and copper/polymeric interlayers under compression. We employ the model presented in Lecture 5 to capture the three-phase hysteretic response of the loading curve with excellent agreement. An *in situ* identification procedure is proposed to quantify the material parameters corresponding to the mesoscopic scale of the structure. We use a high resolution CCD camera to measure local strain while the structure is quasistatically compressed.

Graphical abstract



A multilayer structure of alternating layers of aligned carbon nanotubes and Cu foils. The mechanical behavior of this structure under compression can be modeled by a series of bistable springs.



The regions corresponding to the various springs undergo nonuniform collapse. This behavior is captured by experimentally observing and mathematically modeling the separate stress-strain behavior for each region.

References

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Biographical sketches of the lecturers

Jordan R. Raney is currently a recipient of a National Defense Science and Engineering Graduate Fellowship from the U.S. Department of Defense at the California Institute of Technology. Before coming to Caltech he was on staff at the Massachusetts Institute of Technology's Lincoln Laboratory, where he performed systems analysis on defense-related issues. He holds a M.S. in materials science from Caltech and B.S. degrees in physics and computer science from the University of Minnesota. His work focuses on the design of bulk hierarchical materials from nanostructural components and has been published in nanotechnology journals such as *Carbon* and *ACS Nano*.

Fernando Fraternali is an Associate Professor of Structural Mechanics in the Department of Civil Engineering of the University of Salerno, Italy. He received a M.S/B.S. in Civil Engineering from the University of Salerno and the PhD in Multiscale Mechanics from the King's College of London. He has been awarded a Fulbright Research Scholarship for the Academic Year 2005/2006 and has been Visiting Associate in Aeronautics at the Graduate Aerospace Laboratories of the California Institute of Technology from September 2005 through present (several periods). Most of his current and past research work has dealt with multiscale modeling and simulation of materials and structures; multiscale fracture mechanics; design, analysis and experimentation of innovative materials, such as environmentally compatible composite materials, nanomaterials and biomaterials; nonlinear dynamics of materials and structures; structural optimization; and mechanics of masonry structures.