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DEBONDING-INDUCED FATIGUE LIFE OF A CARBON-NANOTUBE SUPERCAPACITOR

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Summary. *The progressive debonding between aligned carbon nanotubes and the hosting matrix in the direction normal to the CNTs axis is described by a mechanical model with evolutionary damage [1,2,3]. The Eshelby-Mori-Tanaka theory is used to describe the mechanical response of the nanocomposite for a given volume fraction of the different phases (i.e., perfectly bonded CNTs and debonded CNTs). The Weibull statistics reduced in a differential form amenable to a dynamic formulation describes the cumulative progression of debonding. This approach is applied to a CNT-based supercapacitor (supercap) which comprises two layers made of forests of vertically aligned CNTs (immersed in an elastic isotropic matrix) separated by a spacer (see Fig. 1 left). This hybrid multi-layer structure is simulated over different loading histories leading to an assessment of the fatigue life.*

1. PROBLEM FORMULATION

Double layer capacitors called supercaps are used for lightweight power source applications such as in UAV vehicles. Supercaps offer high power density, high energy density and long cycle life. Various studies have investigated CNTs as electrodes in supercaps since they are characterized by a very high surface area, high conductivity, high temperature stability, percolated pore structure. CNTs-based supercapacitors do not yet outperform the best existing supercaps because of the limited adsorption sites available to ions in CNTs structures. High-denisity forests of vertically aligned CNTs were fabricated in a prototype supercap as part of a recent research project. When the forests of CNTs are immersed in a solid matrix hosting the electrolyte, a potential problem is the initiation of debonding between CNTs and matrix and its progressive growth over time in applications where the devices are subject to several repeated vibrational cycles as is the case of UAVs (due to take off manuevers, gusts, turbulence, unbalances, etc.). The drawback is that the supercap performance is degraded by the changes in charge distribution. The device can reach its (mechanical) fatigue life after several hours of operation. The major consequence is that CNTs-based supercaps possess very long cycle life (in principle, unlimited unlike batteries), however, they exhibit a finite fatigue life.

2. METHOD of APPROACH

This work proposes a model to describe debonding between the vertically aligned CNTs and the matrix. The model, based on theories such as the Eshelby-Mori-Tanaka theory and the Weibull statistics for the progression of the debonding phenomenon, can yield a prediction of the fatigue life. The model implemented in COMSOL Multiphysics allows to predict the evolution of debonding and the number of cycles over which the stiffness reduction (see Fig. 1 right) is such that the device fatigue life is reached.

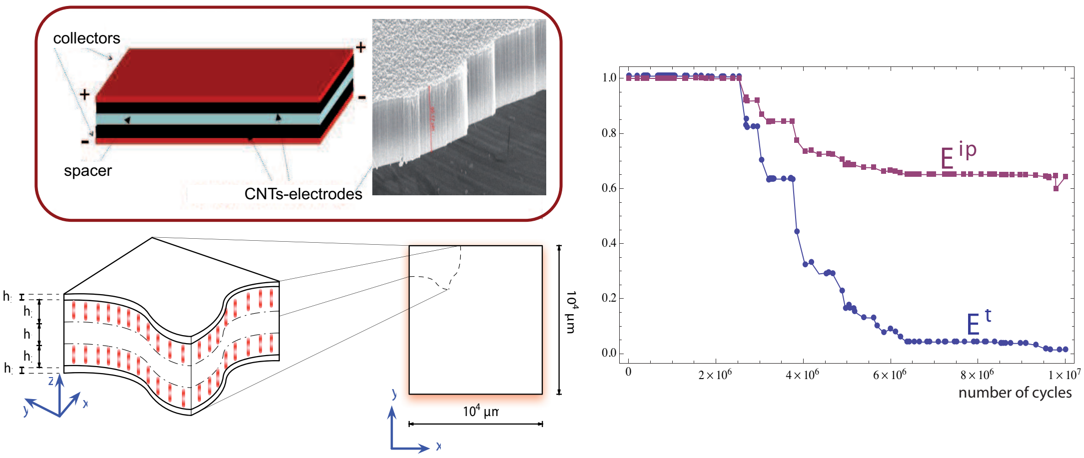

Figure 1. Supercapacitor scheme (left) and elastic moduli reduction vs. number of cycles.

References

[1] Ju J W, Lee H K. A micromechanical damage model for effective elastoplastic behavior of ductile matrix composites considering evolutionary complete particle debonding. *Comput. Methods Appl. Mech. Engrg.* 183 201–222, 2000.

[2] Ju J W, Ko Y F, Ruan H N, Effective Elastoplastic Damage Mechanics for Fiber-reinforced Composites with Evolutionary Complete Fiber Debonding. *Int. J. Damage Mechanics* 15: 237, 2006.

[3] Lee H K, Pyo S H, Multi-level modeling of effective elastic behavior and progressive weakened interface in particulate composites. *Compos. Sci. Tech.* 68 38797, 2008.