Rate and Microstructure Effects

on the Dynamics of Carbon Nanotube Foams

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Dedicated, with admiration,

to Rajaratnam Shanthini and Kirthi Sarachchandra Walgama,

for their simple life.

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"The point is, to live everything. Live the questions now. Perhaps then, someday far in the future, you will gradually, without even noticing it, live your way into the answer. Perhaps you do carry within you the possibility of creating and forming, as an especially blessed and pure way of living."

-Rainer Maria Rilke (Letters to a Young Poet)

ABSTRACT

Soft hierarchical materials often present unique functional properties that are sensitive to the geometry and organization of their micro- and nano-structural features across different lengthscales. Carbon Nanotube (CNT) foams are hierarchical materials with fibrous morphology that are known for their remarkable physical, chemical and electrical properties. Their complex microstructure has led them to exhibit intriguing mechanical responses at different length-scales and in different loading regimes. Even though these materials have been studied for mechanical behavior over the past few years, their response at high-rate finite deformations and the influence of their microstructure on bulk mechanical behavior and energy dissipative characteristics remain elusive.

In this dissertation, we study the response of aligned CNT foams at the high strain-rate regime of 10^2 - 10^4 s^{-1}. We investigate their bulk dynamic response and the fundamental deformation mechanisms at different lengthscales, and correlate them to the microstructural characteristics of the foams. We develop an experimental platform, with which to study the mechanics of CNT foams in high-rate deformations, that includes direct measurements of the strain and transmitted forces, and allows for a full field visualization of the sample's deformation through high-speed microscopy.

We synthesize various CNT foams (e.g., vertically aligned CNT (VACNT) foams, helical CNT foams, micro-architectured VACNT foams and VACNT foams with microscale heterogeneities) and show that the bulk functional properties of these materials are highly tunable either by tailoring their microstructure during synthesis or by designing micro-architectures that exploit the principles of structural mechanics. We also develop numerical models to describe the bulk dynamic response using multiscale mass-spring models and identify the mechanical properties at length scales that are smaller than the sample height.

The ability to control the geometry of microstructural features, and their local interactions, allows the creation of novel hierarchical materials with desired functional properties. The fundamental understanding provided by this work on the key structure-function relations that govern the bulk response of CNT foams can be extended to other fibrous, soft and hierarchical materials. The findings can be used to design materials with tailored properties

for different engineering applications, like vibration damping, impact mitigation and packaging.

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