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A Structural Analysis of Carbon Nanotubes

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***Abstract*-The anti-ballistic protective fabrics are currently made of multiple layers of lamina in order to stop bullets with spreading its kinetic energy. In order to solve stability and collapse phenomena, single-walled carbon nanotubes (CNTs) are treated as equivalent thin-walled continuum cylindrical structures with comparison molecular dynamics solution. The effective mechanical properties on multiple material scale of the protective lamina is determined by stochastic model of planar fibre network. Another form of personal protection material, e.g. CNT/polymer system is also commented.**

Keywords—Carbon nanotube; Impact; Anti-ballistic protective fabric

I. INTRODUCTION

Most anti-ballistic materials, like bullet-proof jackets and explosion-proof blankets, are currently made of multiple layers of lamina which stop bullets from penetrating by spreading the bullet's kinetics energy. Today designed jackets can stop bullets, but the users can still be severely wounded by the strength of the impact. The nanotech-based jackets not only stop the bullets, but they repel them, thus avoiding 'blunt force trauma', The scientists have found a way to use the elastic capacity of carbon nanotubes (CNTs) to not only stop bullets penetrating material but actually rebound their force. CNTs energy absorption mechanism are very different from the today used materials and therefore have great potential applications in making anti-ballistic protective garment. In the future, new functional and reduced-scale materials that are currently in the forefront of research will be hybridized into designer products that can perform dramatic "tailorable" functions in protective engineered systems. By the elasticity capacity of CNTs the blunt force trauma may be avoided and that's why we have undertaken these computational experiments to find the optimal microstructure for the most effective bullet-bouncing gear. The protective system is comprised of three parts: advanced fibers organized in tows and woven, a polymer matrix, and dense aligned CNTs organized within the polymer matrix [1]. The most critical factor is the production cost and CNT grown in situ. It is evident that good protection comes from hierarchically organized CNT structures which fabrication is supplied with many unpredictable phenomena [2], [3]. The purpose of this paper is to investigate the impact dynamic characteristics of composites containing single-walled CNTs, with a focus on analyzing the interfacial interaction between the CNT and the surrounding materials [4].

II. MULTIFUNCTIONAL MATERIAL SYSTEMS

A multifunctional material is typically a hybrid system of several distinct material phases, in which each phase performs a different but necessary function, such as structure, transport, logic, or energy storage. Each phase of the structure performs an essential function. Multifunctional material is much more efficient and flexible than traditional multicomponent systems. Multifunctionality in a material can be integrated on several material scales with increasing interconnectivity between phases. Multifunctional materials are designed for improved overall system performance therefore their performance metrics are different from their single component phases. A multifunctional material requires a new design methodology and optimizing methods that are not commonly used in material science. Advances have been made in the development of optimization tools for designing integrated multifunctional materials. Sigmund and Torquato [1] have done extensive work on topological optimization methods to determine the best morphological materials architectures to optimize performance from a highly integrated material embedding of very dissimilar physical mechanisms. Many functional combinations, more then three phases, have been simulated and validated by the similarity of the optimized topological solutions over multiple material scales found in biological systems. However, truly smart materials systems, analogous to biological systems, will require a combination of several functions, including logic, sensing, energy storage, structure, and actuation. Biological systems have perfected multifunction on a wide range of material scales. With the design of a priori multiple functions into a materials system, these concepts will be extended into large-scale engineering structures. The complexities of these higher order systems will require a sophisticated understanding of how basic physical mechanisms can be manipulated to create new, potentially less singly optimal means of achieving function and multivariable optimization tools [3], [4].

III. CNT BALLISTIC PROPERTIES

The dissipating forces can cause non-penetrating injuries which is known as blunt force trauma, resulting damage critical organs. Therefore, the best material for body amour should have a high energy absorption capacity (Fig. 1). The ballistic resistance capacity of CNTs has been reported in the work [5], [6]. Impact phenomena single CNT analysed by molecular dynamics. A piece of diamond was used as a bullet, with adequate dimensions that mimics the real bullet. There are discrepancies between result from molecular simulation and continuum mechanics for CNT/polymer systems, under presence large deformation and high strain rate phenomena.

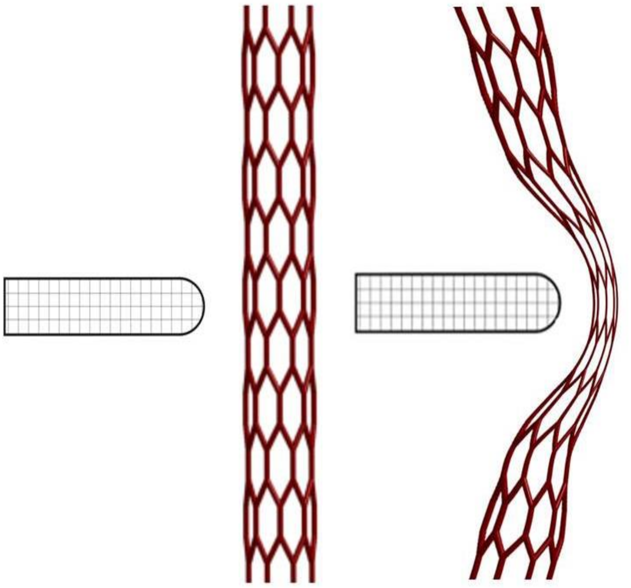

Fig. 1. CNT-Projectile impact test

The forms of elastic stability of CNT have great influence on elastic storage energy. In order to solve stability and collapse phenomena, single-walled carbon nanotubes are treated as an equivalent thin-walled continuum as cylindrical structures with extensional, torsional, and bending rigidities [7].

On Fig. 2. are shown effect of CNT geometry on stability forms under critical buckling load. Problem solved analytically and numerically with comparison molecular dynamic solution [8], [9], [10]. The analytical solution (Euler's formula) is simple method valid for small strain theory. The most elegant method is finite element method applied to the large displacement/strain shell theory. For small CNT length torsion is dominant mode of the lost stability, but for longer tube length bending prevails. The next step is CNTs bundle behaviour and overall stability phenomena of CNT network on microscopic scale [7], [11].

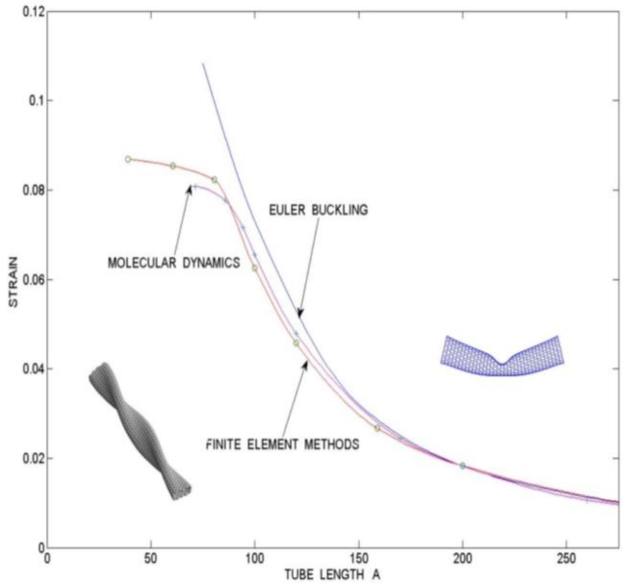

Fig. 2. Comparison solution methods in CNT buckling

Alignment, dispersion and adhesion of CNTs in polymer matrices are vital for structural applications. Stress transfer on CNT-matrix interface together with energy dispersion is a measure of overall behaviour. The ratio between maximum normal stress $\sigma_{\max}$ and maximum shear stress $\tau_{\max}$, $\delta = \sigma_{max}/\tau_{max}$, is of great importance among many others. This parameter δ characterizes the efficiency of transferring shear stress into tensile stress through a tube-matrix interface. Fig. 3. shows the variation of δ with the tube aspect ratio ℓ / a and nanotube volume fraction R/a. The large δ allows a high tensile stress to be obtained at a relatively low shear stress level, to reduce the possibility of matrix failure.

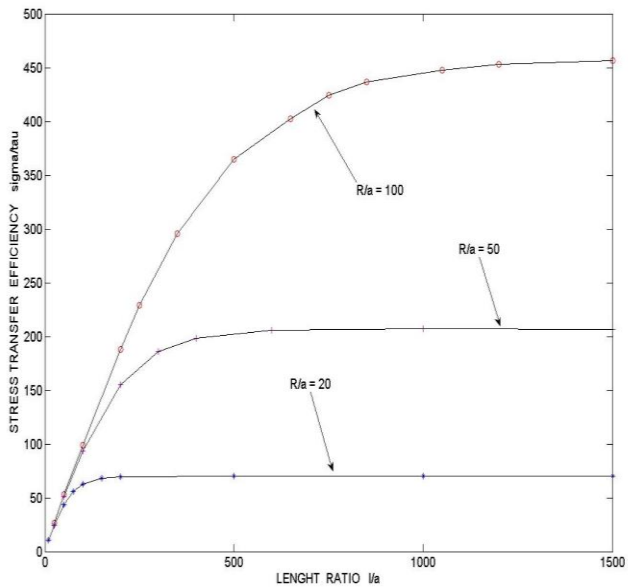

Fig. 3. The stress transfer efficiency

IV. CNT NANOCOMPOSITE

CNT in polymer matrix as nanocomposites come as one possible replacement for conventional armour fabric. Impact dynamical characteristics depend on composite processing condition, CNT dispersion and interface phenomena between CNTs and the matrix. There are many micromechanical models for determination of effective properties of these nanocomposites. One idea for the production of protective lamina is electrospun CNTs fibrous network. In our previous work [12], [13], [14] the effective mechanical properties on multiple material scale of the lamina were determined by stochastic model of planar fibre network. Dynamic macroscopic response of nanocomposite fabric structure in common finite element procedure is described by system of ordinary differential equations in matrix notation as follow presented

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=\{F\}$$
(1)

where $[M]$, $[C]$ and $[K]$ are mass, damping and stiffness matrix, respectively. The vectors $\{u\}$ and $\{F\}$ are displacement and force vectors. The matrix $[C]$ and $[K]$ constructed on the basis of an effective continuum/finite element (FE) approach for modelling the structural dynamics of CNTs fabrics. The effective property depends on representative volume element V and its orientation in structure ϑ

$$[K]=\frac{1}{V}\int_V dV\int_\vartheta [k_E(V,\vartheta)]\,d\vartheta$$
(2)

where $[k_E]$ is the stiffness matrix of the microelement. Individual CNTs in representative volume element can be modelled using shell-like or beam elements. The interactions effects in multi-wall CNTs, or in tube/tube, are simulated by the construction of special interface elements [15], [16]. The concept of interfacial “stick-slip” frictional motion between the CNT and the matrix can be proposed in order to model structural damping. The presence of CNT in polymer matrix reduces damping and dissipation of kinetic energy, Figure 4. Damping is the dissipation of vibrational energy under cyclic loading. Inducing damping in a structure would essentially improve the fatigue life of the system. For PMMA-CNT system, $Tan\,\delta$ (loss modulus) dependence on temperature and CNT concentration are described. It is evident that CNT content drastically reduces energy dissipation with improve of strength. The reinforcement of polymer matrix with CNTs needs optimization procedure, but no more than one material scale. The processing parameters directly influence the effective properties of the polymer matrix. Now, the polymer matrix becomes stronger anisotropic media with functionally graded properties depended on skeletal microstructure. The loss modulus, Figure 4., is effective modulus experimentally determined and doesn’t depend on the temperature but on the microstructure morphology parameters (not evident in Fig. 4.).

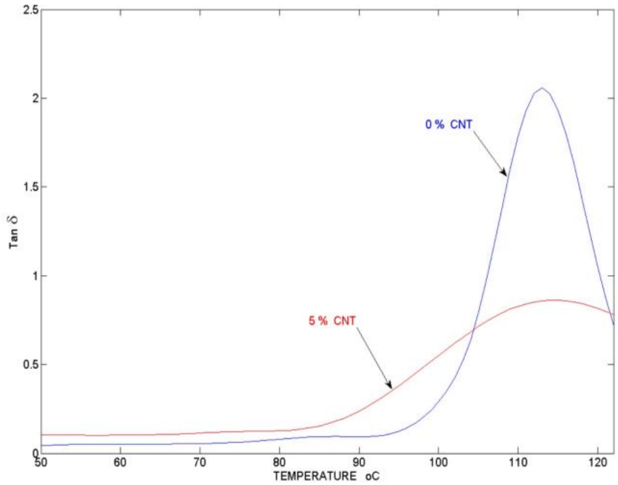

Fig. 4. Tan δ dependence on temperature and CNT concentration

Optimal damping mechanism is another primary requirement in future product design procedure. The nature of dissipation energy does not have viscous behaviour only, but structural damping, induced on nanoscale. Interlaminate shear strength is measure of the effectiveness of the CNTs reinforcement on macroscale. The complex experimental work, including microscale structural characterization, is necessary in order to validate the proposed numerical multiscale models. Optimal CNTs distribution directly depends on laminate fabrication. The achieved in situ growth CNTs from the surface of the microstructure is new manufacturing method (chemical vapour deposition) with more than one obstacle [7]. A cohesive law for CNT-polymer interfaces are established directly from the van der Waals force. In order to study interface phenomena on continuum level. Another future improvement is the use of Cauchy-Born theory of high order applied to CNT structures.

V. CONCLUSION

CNTs nanocomposites are promising materials for future ballistic protective structures. Our predicted findings are also verified by available molecular dynamics simulations. Based on our multiscale computational findings, six layers of woven nanotube yarn, about 500 μm thick may protect the wearer from a small bullet, so that it bounces off. Significant modelling and experimentation are required to determine characteristics of CNTs for this multifunctional architecture such as CNT geometry, configuration and interface interaction. Design of environment responsive structures requires multifunctional innovative thinking among others.

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