Dispersion of Dilatation Wave Propagation in Single-Wall Carbon Nanotubes Under Initial Stress Using Nonlocal Scale Effects

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In this paper we extend our previous work to show that there is an effect of initial stress on the dilatation wave propagation in single-wall carbon nanotubes. The nanotube structures are treated within the multilayer thin shell approximation with the elastic properties taken to be those of the graphene sheet. The equation of motion of the dilatation wave is obtained using the nonlocal elastic theory. The phase velocity and the group velocity are derived, respectively. The dispersion relation is analyzed with different wave numbers, scale coefficients and initial stress parameter. It can be observed from the results that the dispersion properties of the dilatation wave are induced by small scale effects, which will disappear in local continuous models. The dispersion degree can be strengthened by increasing the scale coefficient and the wave number. In particular, the group velocity of dilatation wave are sensitive to initial compression stress for higher frequencies and insensitive for lower frequencies. The investigation presented may be helpful in the application of CNTs, such as ultrahigh-frequency resonators, electron emission devices, high-frequency oscillators and mechanical sensors.

Keywords: Carbon Nanotubes Dilatation Wave, Nonlocal Shell Model, Initial Stress.

1. INTRODUCTION

Carbon nanotubes (CNTs) are regarded as potential nanostructural materials. In addition to experimental endeavors, CNT modeling is classified into two main categories. The first is atomic modeling, which includes such techniques as classical molecular dynamics (MD) and tight-binding MD and the density functional model. Li and Chou reported an atomistic simulation of single-walled carbon nanotube (SWCNT) subjected to harmonic waves. Atomic modeling is limited to systems with a small number of molecules and atoms and is therefore confined to small-scale modeling. The second category is continuum modeling, which includes classical (or local) beam and shell theories that are practical for analyzing CNTs for large-scale systems. Successful work has been conducted with continuum modeling, such as buckling analysis, dynamics studies, and mechanical property investigations of CNTs.

Recently, solid mechanics with elastic continuum model have been regarded as an effective method and widely used for studying the mechanical and physical properties of CNTs. The nanostructures length scales are often sufficiently small, and hence for the applicability of classical continuum models, we need to consider the small length scales such as lattice spacing between individual atoms, grain size, etc. The conventional continuum models cannot handle scale effects. Hence the best alternative is to use those methods which provides the simplicity of continuum models and at the same time incorporate the effects of scale in such chosen continuum models.

The Eringen’s nonlocal elasticity theory is a useful tool in treating phenomena whose origins lie in the regimes smaller than the classical continuum models. In this theory, the internal size or scale could be represented in the constitutive equations simply as material parameters. Such a nonlocal continuum mechanics has been widely accepted and has been applied to many problems including wave propagation, dislocation, crack problems, etc. Recently, there has been great interest in the application of nonlocal continuum mechanics for modeling and analysis of nanostructures such as CNTs, graphene sheets and nanoplates. On the other hand, CNTs often suffer from initial stresses due to residual stress, thermal effect, surface...