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Free Vibration Analysis of Nanocomposite Plates Reinforced by Graded Carbon Nanotubes Based on First-Order Shear Deformation Plate Theory

S. Jafari Mehrabadi[1,*], B. Sobhaniaragh[2] and V. Pourdonya[1]

[1] *Department of Mechanical Engineering, Arak Branch, Islamic Azad University, Arak, Iran*
[2] *Young Researchers Club, Arak Branch, Islamic Azad University, Arak, Iran*

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Abstract. Based on the Mindlin's first-order shear deformation plate theory this paper focuses on the free vibration behavior of functionally graded nanocomposite plates reinforced by aligned and straight single-walled carbon nanotubes (SWCNTs). The material properties of simply supported functionally graded carbon nanotube-reinforced (FGCNTR) plates are assumed to be graded in the thickness direction. The effective material properties at a point are estimated by either the Eshelby-Mori-Tanaka approach or the extended rule of mixture. Two types of symmetric carbon nanotubes (CNTs) volume fraction profiles are presented in this paper. The equations of motion and related boundary conditions are derived using the Hamilton's principle. A semi-analytical solution composed of generalized differential quadrature (GDQ) method, as an efficient and accurate numerical method, and series solution is adopted to solve the equations of motions. The primary contribution of the present work is to provide a comparative study of the natural frequencies obtained by extended rule of mixture and Eshelby-Mori-Tanaka method. The detailed parametric studies are carried out to study the influences various types of the CNTs volume fraction profiles, geometrical parameters and CNTs volume fraction on the free vibration characteristics of FGCNTR plates. The results reveal that the prediction methods of effective material properties have an insignificant influence of the variation of the frequency parameters with the plate aspect ratio and the CNTs volume fraction.

AMS subject classifications: 35G05, 37N15, 74S30

Key words: Carbon nanotube-reinforced, functionally graded, Hamilton's principle, Eshelby-Mori-Tanaka, symmetric profiles, extended rule of mixture.

*Corresponding author.
Email: s-jafari@iau-arak.ac.ir (S. Jafari Mehrabadi)

1 Introduction

In recent years, nanotechnology has sparked a major breakthrough in materials science leading to the next industrial revolution to begin. Nanostructured materials such as graphene sheets (GSs), fullerenes and carbon nanotubes (CNTs) are fundamental building blocks of nanotechnology with wide potential applications in the emerging field of nanoelectromechanical systems. Carbon nanotubes (CNTs) have attracted much attention because of their superior mechanical, optical, thermal and electrical properties and potential applications of novel nanostructures [1–3]. Further development of CNT-based devices requires a good understanding of their mechanical behavior. Basic mechanical properties such as Young's modulus, shear modulus, Poisson's ratio and maximum tensile and compressive strengths have been studied rigorously, a review of which is given by Qian et al. [4]. Polymer composites consisting of polymers reinforced with various additives such as carbon fibers, graphite fibers, glass fibers, or Kevlar fibers and carbon black are increasingly being used in defense, aerospace, automobile, sports and electronics sectors as light-weight, high strength and high electrical and thermal conducting materials [5–8]. However, the addition of nano-sized fibers or nanofillers, such as CNTs, can further increase the merits of such composite materials. These nanocomposites, easily processed due to the small diameter of the carbon nanotubes (CNTs), exhibit unique properties [9, 10], such as enhanced modulus and tensile strength, high thermal stability and good environmental resistance. This behavior, combined with their low density makes them suitable for a broad range of technological sectors such as telecommunications, electronics [11] and transport industries, especially for aeronautic and aerospace applications where the reduction of weight is crucial in order to reduce the fuel consumption. For example, Qian et al. [12] showed that the addition of 1wt.% (i.e., 1% by weight) multiwall carbon nanotube to polystyrene resulted in 36-42% and $\sim$25% increases in the elastic modulus and the break stress of the nanocomposite properties, respectively.

Motivated by the concept of functionally graded materials (FGMs), Shen [13] suggested that for CNT-reinforced composite structures the distributions of CNTs within an isotropic matrix were designed purposefully to grade with certain rules along desired directions for the improvement of the mechanical properties of the structures and the nonlinear bending behaviors of the resulting functionally graded CNT reinforced composite (FG-CNTRC) plates in thermal environments were presented. With the knowledge that load transfer between the nanotube and polymeric phases is less than perfect (e.g., the surface effects, strain gradients effects, intermolecular coupled stress effects, etc), Shen introduced the CNT efficiency parameters to account load transfer between the nanotube and polymeric phases and other effects on the material properties of CNTRCs. They determined CNT efficiency parameters by matching the elastic modulus of CNTRCs observed from the MD simulation results with the numerical results obtained from the extended rule of mixture. Wang and Shen [14] investigated the large amplitude vibration of nanocomposite sandwich plates reinforced by SWCNTs resting on an elastic foundation in thermal environments. The effect of CNT volume fraction on the com-