International Journal of Engineering Science 120 (2017) 82–99

Contents lists available at ScienceDirect

International Journal of Engineering Science

journal homepage: www.elsevier.com/locate/ijengsci

Vibration analysis of porous functionally graded nanoplates

Hossein Shahverdi*, Mohammad Reza Barati

Aerospace Engineering Department & Center of Excellence in Computational Aerospace, AmirKabir University of Technology, Tehran 15875-4413, Iran

ARTICLE INFO

Article history:
Received 19 March 2017
Revised 30 May 2017
Accepted 3 June 2017

Keywords:
Nanoporous nanoplate
Hygro-thermal environment
Nonlocal strain gradient theory
Four-variable plate theory

ABSTRACT

In this paper, a general nonlocal strain-gradient (NSG) elasticity model is developed for vibration analysis of porous nano-scale plates on an elastic substrate. The present model incorporates two scale coefficients to examine the vibration characteristics much accurately. The application of present nanoplate model as nano-mechanical mass sensors is also investigated. Porosity-dependent material properties of the nanoplate are defined via a modified power-law function and Mori–Tanaka model. Based on Hamilton's principle, the governing equations of the nanoplate on the elastic substrate under hygro-thermal loading are obtained. These equations are solved for hinged nanoplates via Galerkin's method. It is demonstrated that nano-pores, temperature change, humidity change, nonlocal-strain gradient parameters, gradient index and attached nanoparticle have a remarkable influence on vibration frequencies of nanoscale plates.

© 2017 Elsevier Ltd. All rights reserved.

1. Introduction

Fast growing developments in materials engineering led to microscopically inhomogeneous spatial composite materials named Functionally graded materials (FGMs) which have extensive applications for various systems and devices, such as aerospace, aircraft, automobile and defense structures and most recently the electronic devices. According to the fact that FG materials have been placed in the category of composite materials, the volume fractions of two or more material constituents such as a pair of ceramic–metal are supposed to change continuously throughout the gradient directions (Akgöz and Civalek, 2014; Kiani, 2016; Lee & Kim, 2013; Zidi, Tounsi, Houari, & Bég, 2014). The FGM materials are made to take advantage of desirable features of its constituent phases, for example, in a thermal protection system, the ceramic constituents are capable of withstanding extreme temperature environments due to their better thermal resistance characteristics, while the metal constituents provide stronger mechanical performance and diminish the possibility of catastrophic fracture (Barati & Shahverdi, 2016a, Khalfi, Houari, & Tounsi, 2014; Matsunaga, 2009; Sobhy, 2016). Hence, possessing novel mechanical properties, FGMs have gained its applicability in several engineering fields, such as biomedical engineering, nuclear engineering and mechanical engineering.

Furthermore, noticeable development in the application of structural elements such as FG beams and FG plates with micro or nano length scale in micro/nano electro-mechanical systems (MEMS/ NEMS), due to their outstanding chemical,

* Corresponding author.
E-mail addresses: h_shahverdi@aut.ac.ir (H. Shahverdi), mrb.barati@ymail.com, mrb.barati@aut.ac.ir (M.R. Barati).

http://dx.doi.org/10.1016/j.ijengsci.2017.06.008
0020-7225/© 2017 Elsevier Ltd. All rights reserved.

mechanical, and electrical properties, led to a provocation in modeling of micro/nano scale structures (Apppendix A, 2012; Lee et al., 2006; Lü, Chen, & Lim, 2009; Mao et al., 2016; Salehipour, Shahidi, & Nahvi, 2015; Sedighi, Daneshmand, & Abadyan, 2015; Zalesak et al., 2016). The problem in using the classical theory is that the classical continuum mechanics theory does not take into account the size effects in micro/nano scale structures. The classical continuum mechanics over predicts the responses of micro/nano structures. Eringen's nonlocal elasticity theory (Eringen, 1983; Eringen & Edelen, 1972) is the most commonly used continuum mechanics theory that includes small scale effects with good accuracy to model micro/nano scale devices and systems (Arani & Jalaei, 2016; Barati & Shahverdi, 2016b, Ebrahimi & Barati, 2016a, b, 2017a; Khajeansari, Baradaran, & Yvonnet, 2012; Lei, Adhikari, & Friswell, 2013; Naderi & Saidi, 2014; Nejad & Hadi, 2016a, b; Nejad, Hadi, & Rastgoo, 2016; Pavlović, Karličić, Pavlović, Janevski, & Ćirić, 2016; Rahmani & Pedram, 2014; Roque, Ferreira, & Reddy, 2011; Shafiei, Kazemi, Safi, & Ghadiri, 2016; Thai, 2012; Thai & Vo, 2012). The nonlocal elasticity theory assumes that the stress state at a reference point is a function of the strain at all neighbor points of the body. Hence, this theory could take into consideration the effects of small scales.

Finite element vibration analysis of FG nanosize plates based on classical plate theory (CPT) is conducted by Natarajan, Chakraborty, Thangavel, Bordas, and Rabczuk (2012). Based on the third order plate theory, Daneshmehr and Rajabpoor (2014) examined buckling behavior of nonlocal graded nanoplates under different boundary conditions. Analysis of resonance frequencies of FG micro and nanoplates according to nonlocal elasticity and strain gradient theory is performed by Nami and Janghorban (2014). They used nonlocal and strain-gradient theories separately, and concluded that these theories have different mechanisms in the analysis of nanoplates. Application of three-dimensional nonlocal elasticity theory in static and vibration analysis of FG nanoplate is investigated by Ansari, Shojaei, Shahabodini, and Bazdid-Vahdati (2015) based on classical plate model. Based on the generalized differential quadrature method (GDQM), Daneshmehr, Rajabpoor, and Hadi (2015) analyzed the vibrational behavior of higher-order FG nanoplates using nonlocal stress field theory. Application of four-variable plate theory in vibration analysis of FG nanoplates is examined by Belkorissat, Houari, Tounsi, Bedia, and Mahmoud (2015). They stated that presented plate model have fewer field variables compared with first-order and third-order plate theories. Based on four-variable plate theory, shear deformation effect is captured, while the governing equations are very similar to the classical plate theory. Barati, Zenkour, and Shahverdi (2016) proposed a refined four-variable plate model for thermal buckling analysis of FG nanoplates. Wave propagation, buckling and vibration analyses of smart FG nanoplates under various physical fields are carried out by Ebrahimi and Barati (2016c, d) and Ebrahimi, Dabbagh, and Barati (2016) using different plate theories. A comprehensive investigation of bending, buckling and vibrational behaviors of FG nanoplates on an elastic medium is conducted by Sobhy (2015a). Also, Khorshidi and Fallah (2016) performed buckling analysis of FG nanoplates via a general nonlocal exponential shear deformation plate model. Sobhy and Radwan (2017) presented a new quasi 3D nonlocal plate theory for vibration and buckling of FGM Nanoplates.

It is noticeable that all of the aforementioned studies on FG nanoplates have been reported a stiffness-softening mechanism due to the nonlocality. Although nonlocal elasticity theory (NET) of Eringen is a suitable theory for modeling of a nanostructure, it has some shortcomings due to neglecting stiffness-hardening mechanism reported in experimental works and strain gradient elasticity (Lam, Yang, Chong, Wang, & Tong, 2003). By using nonlocal strain gradient theory (NSGT), Lim, Zhang, and Reddy (2015) matched the dispersion curves of nanobeams with those of experimental data. They concluded that NSGT is more accurate for modeling and analysis of nanostructures by considering both stiffness reduction and enhancement effects. Application of NSGT in wave dispersion analysis of FG nanobeams is examined by Li, Hu, and Ling (2015). Also, some investigations are performed using NSGT on vibration and buckling of nanorods, nanotubes and nanobeams (Ebrahimi & Barati, 2016e, 2017b; Li & Hu, 2017; Li, Li, & Hu, 2016; Şimşek, 2016). Also, Farajpour, Yazdi, Rastgoo, and Mohammadi (2016) presented buckling analysis of nanoplates via a nonlocal strain gradient plate model employing exact and differential quadrature methods. In another work, Farajpour, Rastgoo, Farajpour, and Mohammadi (2016) presented nonlocal strain gradient modeling of nano-mechanical vibrating piezoelectric mass sensors. Also, Ebrahimi, Barati, and Dabbagh (2016) applied NSGT for wave propagation analysis of FG nanoplates under thermal loading. Therefore, it is of great importance to analyze the vibration behavior of FG nanoplates via NSGT for the first time. Nanoplates are usually subjected to hygro-thermal environments during their construction or operational life (Alzahrani, Zenkour, & Sobhy, 2013; Sobhy, 2015b). Although the significance, there is no study on hygro-thermal effects on vibration behavior of FG nanoplates supported by an elastic medium. Generally speaking, it is crucial to consider simultaneously moisture and temperature changes for more accurate analysis and design of nanostructures.

This paper makes the first attempt to model a compositionally graded nanoporous nanoplate according to the nonlocal strain gradient theory (NSGT). The proposed modeling of nanoplates incorporates a nonlocal stress field parameter as well as a length scale parameter related to strain gradient. Thus, stiffness enhancement or reduction observed in nanostructures are considered. Porosity-dependent material properties of nanoplate are described via a new power-law function. Non-classical boundary conditions related to NSG theory as well as governing equations are obtained using Hamilton's principle. By solving the governing equations using Galerkin's method, natural frequencies of the nanoplate are obtained. The results show that vibrational behavior of the nanoplate is significantly influenced by the nonlocality, strain gradient parameter, hygro-thermal loading, material composition, elastic medium and geometrical parameters. Obtained frequencies can be used as benchmark results in the analysis of nanoplates modeled by nonlocal and microstructure-dependent strain-gradient theories.

Download English Version:

https://daneshyari.com/en/article/5022640

Download Persian Version:

https://daneshyari.com/article/5022640

Daneshyari.com