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An investigation into size-dependent vibration damping characteristics of functionally graded viscoelastically damped sandwich microbeams

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ABSTRACT

The size-dependent mathematical formulation of a functionally graded viscoelastically damped sandwich microbeam is developed on the basis of a modified couple stress theory called symmetric–deviatoric couple stress theory. All the physical and mechanical properties of the functionally graded layers are assumed to vary continuously through thickness according to a power law and also the sandwich core is modeled with a complex modulus. The newly developed model contains five material length scale parameters to interpret the size-dependent vibration damping characteristics of the sandwich microbeam. The natural frequency and loss factor of a functionally graded damped sandwich microbeam with sliding simply supported boundary conditions are analytically determined by using Navier solution procedure. Finally, the influence of size effect and functionally graded layers on the vibration damping characteristics of the damped sandwich microbeam is investigated.

1. Introduction

Owing to structures in order of micron and sub-micron are size dependent (Lam, Yang, Chong, Wang, & Tong, 2003; Liu et al., 2013; Motz, Schöberl, & Pippan, 2005; Son, Jeong, & Kwon, 2003), classical continuum theories are incapable of predicting mechanical behavior of such structures. Hence, different nonclassical continuum theories have been developed to interpret size effect in micro scale (Eringen, 1965; Hadjesfandiari & Dargush, 2011; Lam et al., 2003; Mindlin, 1965; Mindlin & Eshel, 1968; Mindlin & Tiersten, 1962; Yang, Chong, Lam, & Tong, 2002). Recently, Yang et al. (2002) proposed a modified couple stress theory by incorporating an additional equilibrium relation to govern the behavior of the couples. The newly developed theory called symmetric–deviatoric couple stress theory includes only one material length scale parameter to capture size effect in microstructure.

Symmetric–deviatoric couple stress theory has been widely utilized by many researchers to investigate size effect in microstructures. Some of these works can be outlined as: a Euler–Bernoulli beam model for static bending analysis and comparison with experimental data by Park and Gao (2006), a nonlinear Euler–Bernoulli beam model for static bending, free

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oscillation and post buckling analyses by Xia, Wang, and Yin (2010), functionally graded Euler–Bernoulli and Timoshenko beam models for static and free vibration analyses by Asghari, Ahmadian, Kahrobaiyan, and Rahaeifard (2010) and Asghari, Rahaeifard, Kahrobaiyan, and Ahmadian (2011), respectively, buckling analysis of axially loaded micro-scaled beams by Akgöz and Civalek (2011), dynamic stability analysis of functionally graded microbeams by Ke and Wang (2011), free vibration analysis for single-layered graphene sheets in an elastic matrix by Akgöz and Civalek (2012), composite laminated Kirchhoff, Mindlin and Reddy plate models by Chen, Xu, and Li (2012), wave propagation characteristics of a twisted micro scale beam by Mustapha and Zhong (2012a), spectral element analysis of a spinning micro beam embedded in an elastic medium by Mustapha and Zhong (2012b), a functionally graded Reddy plate model for bending and free vibration analyses by Thai and Kim (2013), nonlinear free oscillation analysis of functionally graded microbeams by Ke, Wang, Yang, and Kitipornchai (2012), three-dimensional nonlinear size-dependent behavior of Timoshenko microbeams by Ghayesh, Amabili, and Farokhi (2013), static and dynamic stability analysis of a capacitive functionally graded microbeam by Abbasnejad, Rezazadeh, and Shabani (2013), free vibration analysis of axially functionally graded tapered Euler–Bernoulli microbeams by Akgöz and Civalek (2013), axisymmetric nonlinear free vibration of size-dependent functionally graded annular microplates by Ke, Yang, Kitipornchai, Bradford, and Wang (2013), functionally graded Kirchhoff and Mindlin plate models by Thai and Choi (2013), a Mindlin plate finite element for static bending, buckling and dynamic analyses by Zhang, He, Liu, Gan, and Shen (2013), dynamic stability analysis of functionally graded higher-order shear deformable microshells by Sahmani, Ansari, Gholami, and Darvizeh (2013), a unified higher order beam theory for buckling of a functionally graded microbeam embedded in elastic medium by Şimşek and Reddy (2013), modeling of a functionally graded micro-ring segment for the analysis of coupled extensional–flexural waves by Mustapha (2014), buckling analysis of microbeams based on different beam theories with general boundary conditions by Mohammad-Abadi and Daneshmehr (2014a), a comparison study between constitutive and Euler–Bernoulli beam models by Dehrouyeh-Semnani (2014), nonlinear static and free vibration analyses of microbeams resting on the nonlinear elastic foundation by Şimşek (2014), thermo-mechanical buckling behavior of functionally graded microbeams embedded in elastic medium by Akgöz and Civalek (2014), in-plane and out-of-plane motion characteristics of microbeams with modal interactions by Ghayesh, Farokhi, and Amabili (2014), axisymmetric postbuckling analysis of size-dependent functionally graded annular microplates using the physical neutral plane by Ke, Yang, Kitipornchai, and Wang (2014), three-dimensional vibration analysis of curved microbeams under fluid force induced by external flow by Tang, Ni, Wang, Luo, and Wang (2014b), nonlinear modeling and vibration analysis of curved microtubes conveying fluid by Tang, Ni, Wang, Luo, and Wang (2014a), a thin conical shell model by Zeighampour and Tadi Beni (2014), a Timoshenko beam element for static and dynamics analysis of microbeams by Kahrobaiyan, Asghari, and Ahmadian (2014), triangular composite plate elements based on different plate theories by Chen, Shengqi, and Xiaopeng (2014), nonlinear-electrostatic analysis of micro-actuated beams incorporating surface elasticity by Shaat and Mohamed (2014), simulation of fluid–solid interaction in a microchannel using a combination of Lattice-Boltzmann method and finite element method by Esfahanian, Dehdashti and Dehrouyeh-Semnani (2014a, 2014b), nonlinear vibrations of functionally graded Mindlin microplates by Ansari, Faghih Shojaei, Mohammadi, Gholami, and Darabi (2014), static, dynamic and buckling analysis of orthotropic Kirchhoff-type skew microplates by Tsiatas and Yiotis (2014), nonlinear thermal stability and vibration of pre/post-buckled temperature- and microstructure-dependent functionally graded beams resting on elastic foundation by Komijani, Esfahani, Reddy, Liu, and Eslami (2014), penalty finite element approaches for two dimensional and symmetric problems by Garg and Han (2013) and Garg and Han (2015), buckling and vibration analysis of microcomposite laminated using different beam theories by Mohammad-Abadi and Daneshmehr (2014b) and Mohammad-Abadi and Daneshmehr (2015), a discussion on evaluation of material length scale parameter based on micro-cantilever test by Dehrouyeh-Semnani and Nikkhah-Bahrami (2015a), nonlinear bending and postbuckling of functionally graded Mindlin rectangular microplates considering the physical neutral plane position by Ansari, Gholami, Faghih Shojaei, Mohammadi, and Darabi (2015), dynamics and instability of current-carrying microbeams in a longitudinal magnetic field by Wang, Liu, and Dai (2015), dependency of material length scale parameter on higher-order elasticity theory unlike Lame's constants by Dehrouyeh-Semnani (2015a), mechanical behavior of functionally graded sandwich microbeams by Thai, Vo, Nguyen, and Lee (2015), the influence of size-dependent shear deformation on static bending, buckling and free vibration behavior of microstructures-dependent beam using finite element method by Dehrouyeh-Semnani and Nikkhah-Bahrami (2015c), thermo-mechanical dynamics of perfect and imperfect Timoshenko microbeams by Farokhi and Ghayesh (2015b), thermal buckling analysis of microcomposite laminated based on Euler–Bernoulli, Timoshenko and Reddy beam theories by Mohammad-Abadi, Daneshmehr, and Homayounfard (2015), dependency of material length scale parameter on higher-order elasticity theory unlike Lame's constants by Dehrouyeh-Semnani and Nikkhah-Bahrami (2015b), coupled longitudinal-transverse-rotational behavior of shear deformable microbeams by Ghayesh and Farokhi (2015), free vibration analysis of shear deformable functionally graded cylindrical shell by Tadi Beni, Mehralian, and Razavi (2015), nonlinear motion characteristics of microarches under axial loads by Farokhi and Ghayesh (2015a) static and dynamic analyses of functionally graded annular and circular microplates by consideration of spatial variation of the length scale parameter by Eshraghi, Dag, and Soltani (2015), investigation of flapwise vibration behavior of a rotating microbeam at a constant angular speed using finite element method by Dehrouyeh-Semnani (2015b), nonlinear parametric vibration and stability of microbeams due totime-dependent longitudinal excitation load by Ghayesh, Farokhi, and Alici (2015), exact closed-form free vibration analysis for functionally graded microplates based on three-dimensional elasticity theory by Salehipour, Nahvi, and Shahidi (2015) and developing a nonlinear model for cantilevered microbeams and also exploring the nonlinear dynamics i.e., frequency–response curves, phase portraits and time histories by Dai, Wang, and