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Short Communication

A discussion on incorporating the Poisson effect in microbeam models based on modified couple stress theory

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ABSTRACT

In this paper, an attempt is made to investigate the Poisson effect in modified couple stress microbeam models by use of available experimental data of an epoxy micro-cantilever. Euler–Bernoulli and Timoshenko microbeam models based on modified couple stress theory are employed to analyze static bending behavior of the epoxy micro-cantilever theoretically. It is indicated that incorporating the Poisson effect resulting in overestimation of bending rigidity of the epoxy micro-cantilever.

1. Introduction

Yang, Chong, Lam, and Tong (2002) presented modified couple stress theory based on strain gradient theory. They introduced an additional equilibrium relation to govern the behavior of couples. Based on this modification, they developed a linear elastic model for isotropic materials. Park and Gao (2006) developed an Euler–Bernoulli beam model based on modified couple stress theory and uniaxial stress–strain relationships. The new beam results agree fairly well with those obtained experimentally by Lam, Yang, Chong, Wang, and Tong (2003). Ma, Gao, and Reddy (2008) developed Euler–Bernoulli and Timoshenko beam models based on modified couple stress theory and three-dimensional stress–strain relationships. Due to using three-dimensional stress–strain relationships, the Poisson effect is incorporated in the modified couple stress microbeam models. The aforementioned approaches have been employed by researchers to derive governing equations of microbeams and analyze mechanical behavior of microstructures-dependent beams.

Some of the works associated with including the Poisson effect can be listed as: static and free vibration analysis of Timoshenko and Reddy–Levinson microbeam models, respectively, by Ma et al. (2008) and Ma, Gao and Reddy (2010), vibration and instability analysis of Timoshenko microtubes conveying non-viscous and incompressible fluid by Xia and Wang (2010), dynamic analysis of an embedded microbeam carrying a moving microparticle by Şimşek (2010), static and free vibration of Timoshenko curved microbeams by Liu and Reddy (2011), thermal effect on natural frequencies and critical buckling load of Timoshenko microbeams by Ke, Wang, and Wang (2011), dynamics stability of functionally graded Timoshenko microbeams by Ke and Wang (2011), free vibration and buckling analysis of microbeams by Dos Santos and Reddy (2012), buckling analysis of functionally graded microbeams using different beam theories by Nateghi, Salamat-Talab, Rezapour, and Daneshian (2012), static and dynamic analysis of third-order shear deformation functionally graded microbeams by Salamat-talab,

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Nateghi, and Torabi (2012), spectral element analysis of spinning microbeams embedded in an elastic medium by Mustapha and Zhong, (2012a), nonlinear free vibration analysis of functionally graded microbeams by Ke, Wang, Yang, and Kitipornchai (2012), wave propagation characteristics of a twisted micro scale beam by Mustapha and Zhong (2012b), thermal effect on static bending, free vibration and buckling of Reddy microbeams by Daneshmehr, Mohammad Abadi, and Rajabpoor, (2013), thermal effect on buckling and free vibration of Euler–Bernoulli and Timoshenko functionally graded microbeams by Nateghi and Salamat-talab (2013), static bending analysis of functionally graded Timoshenko microbeams by Şimşek, Kocatürk, and Akbaş (2013), static and vibration analysis of functionally graded microbeams using a new higher order beam theory by Şimşek and Reddy (2013a), nonlinear free vibration of Euler–Bernoulli microbeams by Wang, Lin, and Liu, (2013), Static and free vibration analyses of small-scale functionally graded beams possessing a variable length scale parameter using different beam theories by Aghazadeh, Cigeroglu, and Dag (2014), stability analysis of microbeams with general boundary conditions and higher order beam theories by Mohammad-Abadi and Daneshmehr (2014), thermo-mechanical buckling behavior of functionally graded microbeams embedded in elastic medium by Akgöz and Civalek (2014) and nonlinear bending and post-buckling analysis of extensible microscale beams by Wang, Lin and Liu (2014).

Some of the works associated with excluding the Poisson effect can be listed as: nonlinear static bending, free oscillation and post buckling analysis of Euler–Bernoulli microbeams by Xia, Wang, and Yin (2010), flexural sensitivity of atomic force microscope micro-cantilever by Kahrobaiyan, Asghari, Rahaeifard, and Ahmadian (2010), nonlinear static bending and free oscillation analysis of Timoshenko beam model by Asghari, Kahrobaiyan, and Ahmadian (2010b), static bending and free vibration analysis of functionally graded Euler–Bernoulli and Timoshenko beam models by Asghari, Ahmadian, Kahrobaiyan, and Rahaeifard (2010a) and Asghari, Rahaeifard, Kahrobaiyan, and Ahmadian (2011), buckling analysis of axially loaded microbeams by Akgöz and Civalek (2011), nonlinear formulation of Euler–Bernoulli and Timoshenko microbeam models and linear static bending, buckling and free vibration analysis by Reddy (2011), bending relationships between Timoshenko functionally graded microbeams and Euler–Bernoulli homogeneous microbeams by Reddy and Arbind (2012), generalized thermoelasticity model for Timoshenko microbeams by Taati, Najafabadi and Tabrizi (2013), energy release rate of Euler–Bernoulli and Timoshenko notched microbeams by Sherafatnia, Kahrobaiyan, and Farrahi (2013), free vibration analysis of axially functionally graded tapered Bernoulli–Euler microbeams by Akgöz and Civalek (2013), three-dimensional nonlinear forced vibration of Timoshenko microbeams by Ghayesh, Amabili, and Farokhi (2013), nonlinear geometrically imperfect microbeams by Farokhi, Ghayesh, and Amabili (2013), buckling analysis of nonlinear functionally graded piezoelectric microbeams embedded in elastic medium by Komijani, Reddy and Ferreira (2013), buckling analysis of functionally graded microbeams embedded in elastic medium using a unified higher order beam theory by Şimşek and Reddy (2013b), finite element models for nonlinear static and dynamics analysis of Euler–Bernoulli and Timoshenko functionally graded microbeams by Arbind and Reddy (2013), nonlinear free oscillation and divergence instability of microtubes conveying fluid by Yang, Ji, Yang, and Fang (2014), dynamic characteristics of Euler–Bernoulli microbeams considering micro-inertia effect by Fathalilou, Sadeghi, and Rezazadeh (2014), simulation of fluid–structure interaction in a microchannel by a coupled lattice Boltzmann-finite element approach by Esfahanian, Dehdashti, and Dehrouyeh-Semnani (2014), nonlinear three-dimensional modeling of curved microtubes conveying fluid for vibration analysis by Tang, Ni, Wang, Luo, and Wang (2014a), nonlinear static bending and free oscilation analysis of Euler–Bernoulli microbeams embedded in nonlinear elastic foundation by Şimşek (2014), nonlinear thermal stability and vibration of pre/post-buckled temperature- and microstructure-dependent functionally graded beams resting on nonlinear elastic foundation by Komijani, Esfahani, Reddy, Liu, and Eslami (2014) and three-dimensional vibration analysis of curved microbeams under fluid force induced by external flow by Tang, Ni, Wang, Luo, and Wang (2014b).

As reported in previous literature, the Poisson effect plays an important role in mechanical behavior of microstructures-dependent beams and neglecting this effect resulting in significant error. The experimental bending rigidity and static deflection of the epoxy micro-cantilever reported by Lam et al. (2003) are employed to investigate the Poisson effect in modified couple stress microbeam models.

2. Comparative study

The experimental results are extracted from the work conducted by Lam et al. (2003). They performed a bending test on an epoxy micro-cantilever with the following mechanical properties: the Young's modulus: $E = 1.44$ GPa and the Poisson's ratio: $\nu = 0.38$. In addition, in the aforementioned bending test, the geometrical properties of the micro-cantilever were as follows: the thickness: $h = 20$, 38, 75, 115 μm, the width: $b = 0.235$ mm and the ratio of the length to the thickness: $L/h = 10$. Lam et al. (2003) reported the higher-order bending parameter (b_h) of epoxy is equal to 24 μm. Park and Gao (2006) determined the modified couple stress material length scale parameter (ℓ) of epoxy to be 17.6 μm by using the analytical and the experimental results reported by Lam et al. (2003). The theoretical results are obtained based on modified couple stress Euler–Bernoulli and Timoshenko microbeam models developed by Ma et al. (2008). The closed-formed solutions of a micro-cantilever subjected to a point load at is free end based on modified couple stress Euler–Bernoulli and Timoshenko beam models are proposed in Appendix A. It is notable that the shear correction factor (k_s) in a Timoshenko microbeam model is taken to be $(5 + 5\nu)/(6 + 5\nu)$.

In Fig. 1 bending rigidity of the micro-cantilever obtained based on the different modified couple stress beam models, are compared to the experimental data reported by Lam et al. (2003). As seen in the figure, the Timoshenko microbeam results