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Thermal buckling and elastic vibration of third-order shear deformable functionally graded beams

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An improved third order shear deformation theory is employed to investigate thermal buckling and vibration of the functionally graded beams. A power law distribution is used to describe the variation of volume fraction of material compositions. The functionally graded material properties are assumed to vary smoothly and continuously across the thickness of the beams. The Ritz method is adopted to solve the eigenvalue problems that are associated with thermal buckling and vibration in various types of immovable boundary conditions. The parametric study covered in this paper includes the effects of material composition, temperature-dependent material properties, and slenderness ratio.

1. Introduction

Functionally graded materials (FGMs) are known as the excellent materials in mechanical properties, thermal and corrosive resistants. Unlike fibre-matrix laminated composites, FGMs do not have the problems of de-bonding and de-lamination resulting from large inter-laminar and thermal stresses. The idea of FGMs was initially introduced by Japanese scientists in the mid-1980s, as ultrahigh temperature resistant materials for various engineering applications such as aircraft, space vehicles, engine combustion chamber and fusion reactors. FGMs are microscopically inhomogeneous and spatial composite materials, which are usually composed of two different materials such as a pair of ceramic–metal. The composition of the material changes gradually throughout the thickness direction in which the mechanical properties are assumed to vary continuously and smoothly from top to the bottom surface. Due to excellent characteristics of ceramics in heat and corrosive resistances combined with the toughness of metals, the advantages of this combination lead to obtaining FGM structures which can withstand in large mechanical loadings under high temperature environment. The trend of use of FGMs for engineering structures has increased significantly in the last decade. Hence, the understanding of the behaviour of structures made of FGMs subjected to a variety of mechanical loadings under high temperature environment is important for design.

Miyamoto et al. [1] discussed the methods of FGM fabrication and general information about FGMs including microstructure analysis of the graded materials. Crack propagation of FGM made by ceramic-polymer, which has large disparity in elastic properties, was studied by Tilbrook et al. [2]. Chakraborty and Gopalakrishnan [3] presented wave propagation analysis in beams made of FGM by using the spectral finite element method. Sankar [4] investigated an elasticity solution for bending of functionally graded beams (FG beams) based on Euler–Bernoulli beam theory. Poisson's ratio was set to be constant, while Young's modulus was assumed to vary as an exponential function. Zhong and Yu [5] provided an analytical solution for cantilever beams subjected to various types of mechanical loadings using the Airy stress function. Bending analysis of FG beams based on higher order shear deformation under ambient temperature was investigated by Kadoli et al. [6]. Static and dynamic response of layered functionally graded beams was studied by using third order zigzag theory. Deflection and natural frequency obtained from the zigzag theoretical models were validated by comparison with experiments [7]. Xiang and Yang [8] used Timoshenko beam theory to study the free and forced vibration of laminated FG beams under heat conduction using the differential quadrature method (DQM). An analytical solution for free vibration analysis based on the first order shear deformation theory (FSDT) of FG beams was presented by Sina et al. [9]. Free vibration and buckling analysis of FG beams, which have an open crack at their edge, were considered by using Euler–Bernoulli beam theory and the rotational spring model [10]. The Timoshenko beam theory was employed to study post-buckling and nonlinear vibration of edge cracked FG beams without thermal effects [11,12]. Simsek [13] used the Lagrange multiplier method to solve

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