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Abstract. A high order theory for functionally graded (FG) beams based on expansion of the two dimensional (2-D) equations of elasticity for functionally graded materials (FGMs) into Legendre's polynomials series has been developed. The 2-D equations of elasticity have been expanded into Legendre's polynomials series in terms of a thickness coordinate. In the same way functions that describe functionally graded relations also has been expanded. Thereby all equations of elasticity including Hook's law have been transformed to corresponding equations for coefficients of Legendre's polynomials expansion. Then system of differential equations in term of displacements and boundary conditions for the coefficients of Legendre's polynomials expansion coefficients has been obtained. Cases of the first and second approximations have been considered in more detail. For the obtained boundary-value problems solution, a finite element method (FEM) has been used and numerical calculations have been done with MATHEMATICA, MATLAB and COMSOL Multiphysics software. Numerical results are presented and discussed.

Key words: beam, FEM, FGM, exponential law, material graduation, Legendre polynomial.

1 Introduction

A FGMs with material properties varying continuously, possess remarkable advantages over classical laminated composites in maintaining the integrity of the structure subjected to the action of thermo-mechanical loads, due to the absence of distinct interfaces. The FGMs are heterogeneous materials in which the elastic properties change from one surface to the other, gradually and continuously to achieve a required function [29]. They have been presented as an alternative to laminated composite materials that show a mismatch in properties at material interfaces. This material discontinuity in laminated composite materials leads to large interlaminar stresses and the possibility of initiation and propagation of cracks [24]. This problem is reduced in FGM because of the gradual change in mechanical properties as a function of position through the composite laminate.

The FG thin-walled structures, such as beams, rods, plates and shells, have numerous applications in sciences and engineering, especially in micro- and nanotechnology [2, 15]. At the micro- and nano-scale surface effects may have a significant effect on the physical properties and behavior of material and structures [12, 28]. The study of the stress-strain state of FG beams is an important aspect in the successful applications of them as structural elements [1, 5, 6, 22, 24, 29]. Stability and vibration analysis is very important to ensure the safe operation of thin-walled structures. For FG beams, plates and shells such analysis has been presented, for example in [9, 13, 17-20, 27]. Various theoretical models of FG beams, plates and shells have been developed in the last decades [3, 4, 7, 8, 10, 11, 16, 30-34, 36- 38]. Most of the proposed models of FG beams are based on the Euler–Bernoulli, Timoshenko [3, 11, 13, 23, 27, 37] hypotheses or have used more complicated high order theories such as the third-order shear deformation plate theory [10, 11, 16,