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EXACT AND NUMERICAL ELASTIC ANALYSIS FOR THE FGM THICK-WALLED CYLINDRICAL PRESSURE VESSELS WITH EXPONENTIALLY-VARYING PROPERTIES

Assuming exponential-varying properties in the radial direction and based on the elasticity theory, an exact closed-form analytical solution is obtained to elastic analysis of FGM thick-walled cylindrical pressure vessels in the plane strain condition. Following this, radial distribution of radial displacement, radial stress, and circumferential stress are plotted for different values of material inhomogeneity constant. The displacements and stresses distributions are compared with the solutions of the finite element method (FEM).

Keywords: cylindrical pressure vessel, thick-walled, Functionally Graded Material (FGM), Finite element method (FEM), exponential

1. Introduction

Functionally graded materials (FGMs) are a new type of materials with continuously varied microstructure, which lead to the continuous variation of physical and mechanical properties through the thickness. These materials are advanced, heat resisting, erosion and corrosion resistant, and have high fracture toughness. The thick cylindrical pressure vessels made of FG materials can be used in many engineering fields such as aerospace, mechanical, naval, nuclear energy, chemical plant, electronics, and biomaterials and so on.

Horgan and Chan [1] analyzed a pressurized hollow cylinder in the state of plane strain. Assuming that the material has a graded modulus of elasticity, while the Poisson's ratio is a constant, Tutuncu and Ozturk [2], investigated the stress distribution in the axisymmetric structures. They obtained the closed-form solutions for stresses and displacements in functionally graded cylindrical and spherical vessels under internal pressure. Shi et al. [3], studied two different kinds of heterogeneous elastic hollow cylinders. One was multi-layered, and the second had continuously graded properties. They found the exact solutions for an N-layered elastic hollow cylinder subjected to uniform pressures on the inner and outer surfaces. Given the assumption that the material is isotropic with constant Poisson's ratio and exponentially varying modulus of elasticity through the thickness, Naki Tutuncu [4], obtained power series solutions for stresses and displacements in functionally-graded cylindrical vessels subjected to internal pressure alone. In a recent study by Chen and Lin [5], assuming that the property of FGMs is exponential function form, they conducted the elastic analysis for both a thick cylinder and a spherical pressure vessel which were made of functionally graded materials. Assuming that the material properties vary nonlinearly in the radial direction and the Poisson's ratio is constant, Zamani Nejad and Rahimi [6], obtained closed form solutions for one-dimensional steady-state thermal stresses in a rotating functionally graded pressurized thick-walled hollow circular cylinder. A complete and consistent 3-D set of field equations has been developed by tensor analysis to characterize the behavior of FGM thick shells of revolution with arbitrary curvature and variable thickness along the meridional direction [7]. Ghannad and Zamani Nejad [8], obtained the elastic solution of clamped-clamped thick-walled cylindrical shells by an analytic method. Assuming that the material properties vary nonlinearly in the radial direction and the Poisson's ratio is constant, Zamani Nejad and Rahimi [9] obtained closed form solutions for stresses and displacements in a rotating functionally graded pressurized thick-walled hollow circular cylinder. Assuming the volume fractions of two phases of a FG material vary only with the radius, Nie et al. [10], obtained a technique to tailor materials for linear elastic hollow cylinders and spheres to attain through the thickness either a constant circumferential stress or a constant in-plane shear stress. Based on basic equations of elasticity and power series solution method (PSSM), a simple and efficient method is proposed to elastic analysis of rotating internally pressurized thick-walled cylindrical pressure vessels in plane strain and plane stress conditions by Gharibi and Zamani Nejad [11].

In this paper, using the infinitesimal theory of elasticity, a closed-form analytical solution for displacements and stresses of FGM thick cylindrical pressure vessels with exponential varying material properties are obtained. For the numerical solution, a commercial finite element program ANSYS 12 is used.

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5. Conclusion

In this work, using a mathematical method, an elastic analysis for FGM thick cylindrical pressure vessels with exponential varying material properties in the plane strain condition is presented. The method presented is very suitable for the purpose of calculation of radial displacement, radial stress, and circumferential stress. To show the effect of inhomogeneity on the stress distributions, different values were considered for material inhomogeneity parameter ζ. The presented results show that the material inhomogeneity has a significant influence on the mechanical behaviors of exponential FGM thick-walled cylindrical pressure vessels. In the present study, from ANSYS commercial finite elements analysis program, a numerical solution is also presented. Good agreement was found between the analytical solutions and the solutions carried out through the FEM. It is also possible to find an optimum value for the inhomogeneity parameter such that the variation of stresses along the radial direction is minimized, yielding optimum use of material.

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