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Numerical study on the free vibration and thermal buckling behavior of moderately thick functionally graded structures in thermal environments

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Abstract

This paper is aimed at studying the free vibration and thermal buckling behavior of moderately thick functionally graded material (FGM) structures including plates, cylindrical panels and shells under thermal environments. A numerical investigation is performed by applying the finite element method (FEM). A formulation based on the first-order shear deformation theory (FSDT) is proposed for the purpose, which considers the effects of the transverse shear strain and rotary inertia. A graded concept is employed to allow the material property to vary gradually inside the elements. The proposed FGM structures are characterized by two constituents (ceramic and metal) whose material properties are dependent on the temperature and vary continuously throughout the thickness according to a power law distribution proportional to the volume fraction of the constituents. Two different sets of power law distribution are used to describe the volume fraction of the constituents, based on a single, or four parameters. Based on a parametric analysis, we demonstrate the potentials of the proposed method through its comparison with results available from the literature and by means of a convergence study. Several numerical examples are further presented to investigate the effects of material compositions, geometrical parameters, specified thermal loading and boundary conditions on the free vibration and thermal buckling behavior of these structures. The effect of initial thermal stresses on the vibration behavior is also investigated for plate and shell structures.

Keywords: Vibration, Thermal buckling, FGM, FSDT, FEM

1. Introduction

Structural elements such as plates, cylindrical panels and shells are widely used in civil, marine and offshore engineering. In addition to the respect to fatigue requirements, these structures also need to satisfy the dynamic and stability requirements [1]. The application of coatings in marine and offshore engineering is becoming even more popular in order to protect structures against thermal environments, which can significantly influence the mechanical properties of the materials and structures. Because of severe service conditions and greater expectations on the life time, thermal stability and durability of these structures are the major concern for the industry [2]. Thus, it is crucial to understand the vibration and thermal buckling characteristics in designing these structures [3]. Due to such adverse operating conditions, the marine and offshore structures should have, in good balance, enough thermo-mechanical strength to accommodate both thermal induced loadings and general mechanical forces. Materials of these structures should ideally exhibit low density, high strength, good thermal and corrosion resistance and high toughness, etc. Hence, new materials such as functionally graded materials (FGMs) are being designed to meet such demands. The basic physics behind the FGM concept is that the functionality of a particular material system can be tailored by appropriately combining two or more materials [4]. One example is represented by a ceramic-metal FGM which can combine the optimum properties of ceramics and metals, resulting in a desired property gradation in spatial directions [5]. The ceramic provides the high thermal resistance due to its low thermal conductivity [6], while the ductile metal constituent minimizes fracture due to its greater toughness. Thus, FGM structures are able to maintain the structural integrity while reducing thermal stresses, residual stresses and stress concentrations. For the thermal buckling analysis of FGM plates, Javaheri and Eslami [7]-[9] investigated the buckling of FGM plates subjected to uniform in-plane compressive and thermal loads using a variational approach based on the classical plate theory. Later on, the same authors employed some equilibrium and stability relationships to study the thermal buckling behavior of simply supported FGM plates using a higher-order shear deformation theory (HSDT) [10]. In order to take into account the complete effects of higher-order deformations, various higher-order plate theories have been presented in the literature [11]-[16]. Apart from higher-order theories, some researchers have analyzed thermal buckling characteristics of FGM structures by different numerical approaches. For

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