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Postbuckling of FGM cylindrical shells under combined axial and radial mechanical loads in thermal environments

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Abstract

A postbuckling analysis is presented for a shear deformable functionally graded cylindrical shell of finite length subjected to combined axial and radial loads in thermal environments. Heat conduction and temperature-dependent material properties are both taken into account. The temperature field considered is assumed to be a uniform distribution over the shell surface and varied in the thickness direction only. Material properties are assumed to be temperature-dependent, and graded in the thickness direction according to a simple power law distribution in terms of the volume fractions of the constituents. The formulations are based on a higher order shear deformation shell theory with von Kármán–Donnell-type of kinematic nonlinearity. A boundary layer theory of shell buckling, which includes the effects of nonlinear prebuckling deformations, large deflections in the postbuckling range, and initial geometric imperfections of the shell, is extended to the case of functionally graded cylindrical shells. A singular perturbation technique is employed to determine the interactive buckling loads and postbuckling equilibrium paths. The numerical illustrations concern the postbuckling response of perfect and imperfect cylindrical shells with two constituent materials subjected to combined axial and radial mechanical loads and under different sets of thermal environments. The results reveal that the temperature field and volume fraction distribution have a significant effect on the postbuckling behavior, but they have a small effect on the imperfection sensitivity of the functionally graded shell.

Keywords: Functionally graded material; Heat conduction; Temperature-dependent properties; Cylindrical shell; Postbuckling; Combined loading

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1. Introduction

Recently, a new class of composite materials known as functionally graded materials (FGMs) has drawn considerable attention. Typically, FGMs are made from a mixture of metals and ceramics and are further characterized by a smooth and continuous change of the mechanical properties from one surface to another. It has been reported that the weakness of the fiber reinforced laminated composite materials, such as debonding, huge residual stress, locally largely plastic deformations, etc., can be avoided or reduced in FGMs (Noda, 1991; Tanigawa, 1995). Hence, FGMs are possessed of an enormous application potential, especially for working in the high temperature environments. With the increased usage of these materials, it is important to understand the buckling and postbuckling behaviors of FGM cylindrical shells subjected to mechanical loads in thermal environments.

Many initial postbuckling or fully nonlinear postbuckling studies of isotropic and composite laminated cylindrical shells have been performed by the classical and/or shear deformation shell theory. However, investigations on the buckling and postbuckling analysis of FGM cylindrical shells under thermal or mechanical loading are limited in number. Shahsiah and Eslami (2003a,b) presented the buckling temperature of simply supported FGM cylindrical shells under two cases of thermal loading, i.e. uniform temperature rise, linear and nonlinear gradient through the thickness, based on the first order shear deformation shell theory. In their analysis the material properties were considered to be independent of temperature. Shen (2002, 2003) studied the buckling and postbuckling of FGM cylindrical thin shells subjected to axial compression or lateral pressure in thermal environments. In the above studies, the material properties were considered to be temperature-dependent and the effect of temperature rise on the postbuckling behavior was reported. Recently, Shen (2004) gave a thermal postbuckling analysis of FGM cylindrical thin shells subjected to a uniform temperature rise. It should be noted that in the above studies the shells are considered as being relatively thin and therefore the transverse shear deformation is usually not accounted for. On the other hand, ceramics and the metals used in FGM do store different amounts of heat. This leads to a non-uniform distribution of temperature through the plate thickness, especially when the plate is thick. Hence the heat conduction usually occurs (Tanigawa et al., 1996; Kim and Noda, 2002), but it is not accounted for in the above studies. This is because when the material properties are assumed to be functions of temperature and position, and the temperature is also assumed to be a function of position, the problem becomes very difficult.

The present work attempts to solve this problem, that is, to provide analytical solution for the postbuckling of FGM cylindrical shell of finite length subjected to combined axial and radial loads in thermal environments. Heat conduction and temperature-dependent material properties are both taken into account. The temperature field considered is assumed to be a uniform distribution over the shell surface and varied in the thickness direction only. Material properties are assumed to be temperature-dependent, and graded in the thickness direction according to a simple power law distribution in terms of the volume fractions of the constituents. The formulations are based on Reddy's higher order shear deformation shell theory with von Kármán–Donnell-type of kinematic nonlinearity and including thermal effects. The boundary layer theory suggested by Shen and Chen (1988, 1990) is extended to the case of FGM cylindrical shells of finite length. A singular perturbation technique is employed to determine the interactive buckling loads and postbuckling equilibrium paths. The nonlinear prebuckling deformations and initial geometric imperfections of the shell are both taken into account but, for simplicity, the form of initial geometric imperfection is assumed to be the same as the initial buckling mode of the shell. The numerical illustrations show the full nonlinear postbuckling response of FGM cylindrical shells subjected to combined axial and radial mechanical loads and under different sets of environmental conditions.