Composites Part B 77 (2015) 349–362

Contents lists available at ScienceDirect

Composites Part B

journal homepage: www.elsevier.com/locate/compositesb

Influences of shear stresses on the dynamic instability of exponentially graded sandwich cylindrical shells

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ARTICLE INFO

Article history:
Received 30 December 2014
Received in revised form
4 March 2015
Accepted 8 March 2015
Available online 18 March 2015

Keywords:
A. Layered structures
B. Vibration
C. Analytical modelling
C. Numerical analysis

ABSTRACT

The aim of present study is to investigate the dynamic instability of exponentially graded (EG) sandwich cylindrical shells under static and time dependent periodic axial loadings using the shear deformation theory (SDT). The modified Donnell-type dynamic instability equations of EG sandwich cylindrical shells based on the SDT are deduced. Then are reduced to Mathieu-Hill equation and by solving the expressions for the boundaries of instability regions of EG sandwich cylindrical shells are obtained. The similar expressions for EG single-layer shell, ceramic-rich shell and metal coated sandwich cylindrical shell on the basis of SDT and classical shell theory (CST) are obtained in a special case. The numerical illustrations concern the influences of compositional profiles of coating layers, shear stresses and geometrical parameters of sandwich cylindrical shells on the boundaries of instability regions. As a check on the accuracy of the present study, the values of the lower and upper boundaries of instability regions are compared with those in the literature.

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1. Introduction

The dynamic instability of periodic axial loaded shells has received considerable attention over the years and related research progress has been presented by Sahu and Datta [1]. The investigation of dynamic instability of elastic systems was first studied by Bolotin [2], who found the boundaries of instability regions. Vijayaraghavan and Evan-Iwanowski [3] analytically and experimentally studied parametric instability of circular cylindrical shells subjected to in-plane longitudinal inertia loading arising from sinusoidal base excitation. Following these studies, have emerged series of publications related to the dynamic instability of cylindrical shells under time-dependent periodic loads. For example, Korval [4] studied the parametric instability of a cylindrical shell under pulsating axial load, wherein the internal axial stress resultant is computed on a dynamic basis with the shell acting as a longitudinal rod. Hsu [5] analyzed the parametric instability of a circular cylindrical shell under a uniform pressure load and an axial dynamic load, using Donnell shell theory. Radwan and Genin [6] investigated the stability of the steady state response of simply supported circular cylinders subjected to harmonic excitation by using variational equations reduced from “exact” modal equations. Nagai and Yamaki [7] investigated dynamic stability of circular cylindrical shells under periodic compressive forces under different boundary conditions, using Donnell shallow-shell theory. Bert and Birman [8] analyzed parametric instability of thick orthotropic circular cylindrical shells using the high-order shell theory. Argento and Scott [9] studied the dynamic instability of layered anisotropic circular cylindrical shells under periodic axial loading based on the CST. Ng et al. [10] reported the dynamic instability of cross-ply laminated composite cylindrical shells under combined static and periodical axial forces using Love's shell theory. Ganapathi and Balamurugan [11] studied the dynamic instability of laminated composite circular cylindrical shells subjected to a periodic load, using a C^o shear flexible two-node axi-symmetric shell element. Recently, Park and Kim [12] analyzed the dynamic stability of a completely free isotropic circular cylindrical shell under a follower force. Pellicano and Amabili [13] reported the instability and vibration analysis of empty and fluid-filled circular cylindrical shells under static and periodic axial loads. Liew et al. [14] investigated the dynamic instability of rotating cylindrical shells under static and periodic axial forces using a combination of the Ritz method and Bolotin's first approximation. Pellicano [15] studied dynamic instability of a circular cylindrical shell carrying a top mass under base excitation, theoretically and experimentally. Bespalova and Urusova [16] investigated dynamic instability of shells of revolution

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http://dx.doi.org/10.1016/j.compositesb.2015.03.040
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with alternating curvature under periodic loading. Han et al. [17] analyzed parametric instability of cylindrical thin shell with periodic rotating speeds based upon Bolotin's method.

Functionally graded materials (FGMs) are a new generation of composite materials first introduced by a group of Japanese scientists in 1984 (see, Ref. [18]). The study on design, manufacture, applications and techniques of FGMs can be found in the Refs. [19–21].

FGM shell structures are generally used as structural components in missiles engine, resistant coatings in space plans, atomic reactors, spacecraft thermal shields, intelligent electrical components, submarines, turbine components, sensors and others. A detailed review on the vibration and stability performance of FGM shell structures can be found in Shen [22]. Studies on the dynamic instability behavior of FG cylindrical shells under time dependent periodic axial loads are limited. Ng et al. [23] reported the dynamic instability of FG cylindrical shell subjected under periodic axial loading based on the CST. Yang and Shen [24] reported free vibration and parametric resonance of FG cylindrical panels based on the SDT. Oh et al. [25] investigated the vibration and instability of functionally graded circular cylindrical spinning thin-walled beams. Darabi et al. [26] studied the dynamic instability of FG cylindrical shells under an axial harmonic loading have been investigated applying the Donnell shell theory and using Galerkin's method and Bolotin's approximation in order to extract the unstable regions. Ansari and Darvizeh [27] presented a general analytical approach to investigate dynamic behavior of temperature-dependent FG shells under different boundary conditions. Ovesy and Fazilati [28] conducted dynamic stability analysis of moderately thick FG cylindrical panels by employing finite strip formulations. Lei et al. [29] analyzed dynamic instability of CNTR-FG cylindrical panels under static and periodic axial forces by using the mesh-free kp-Ritz method.

Sandwich structures are used in a variety of engineering applications including aircraft, construction, and transportation where strong, stiff, and light structures are required [30]. Among the various sandwich constructions, the sandwich plates and shells are commonly used in the aerospace vehicles, because of its outstanding bending rigidity, low specific weight, excellent dynamic characteristics and good fatigue properties. Due to the mismatch in stiffness properties between the coatings and core, sandwich shells are susceptible to delamination, caused by high interfacial stresses, especially under dynamic loadings. To increase the resistance of sandwich shells to this type of failure, the concept of FGMs is being actively explored in the design of sandwich shells. The composition and structure of FGMs continuously and gradually varied over volume, results in continuous and gradual changes in the properties of the material. This advantage eliminates interface problems of composite materials and thus the stress distribution becomes smooth. Used as coatings and interfacial zones, they can help to reduce mechanically and thermally induced stresses caused by the material property mismatch and to improve the bonding strength. One of the first attempts to the vibration and buckling behaviors of FGM sandwich structures has been realized by Zenkour [31]. Due to the practical importance, many researchers have been motivated to analyze the characteristics of FGM sandwich structures. From those available, Li et al. [32] reported free vibration of the sandwich with FGM face sheet and homogenous core, and the sandwich with homogenous face sheet and FGM core rectangular plates based on the three-dimensional linear elasticity theory. Zenkour and Sobhy [33] investigated the thermal buckling of FG coated sandwich plates using the SDT and CST. Neves et al. [34] investigated the free vibration and buckling analysis of isotropic and sandwich FG plates using high-order SDT and Meshless technique. Bessaim et al. [35] developed a new higher-order shear and normal deformation theory for the static and free vibration analysis of sandwich plates with FG isotropic face sheets. Sobhy [36] investigated the free vibration and buckling of EG sandwich plates in the surrounding medium under various boundary conditions based on SDT. Xiang et al. [37] analyzed the free vibration of sandwich plate with FG face and homogenous core using meshless global collocation method based on the thin plate spline radial basis function and nth-order shear deformation theory. Fazzolari and Carrera [38] presented free vibration analysis of sandwich plates with anisotropic face sheets in thermal environment by using the hierarchical trigonometric Ritz formulation. Alipour and Shariyat [39] investigated analytical zigzag-elasticity transient and forced dynamic stress and displacement response prediction of the annular FGM sandwich plates. Liu et al. [40] presented high-order free vibration analysis of sandwich plates with both FG face sheets and functionally graded flexible core. Nguyen et al. [41] presented analytical solutions of free vibration and buckling analysis of FG sandwich plates composed of FG face sheets and an isotropic homogenous core using a new inverse trigonometric shear deformation theory. Mashat et al. [42] studied free vibration of several FG layered structures under various boundary conditions by using the Finite Element method. Iurlaro et al. [43] presented bending and free vibration analysis of FG sandwich plates using the refined zigzag theory. Pandey and Pradyumna [44] studied free vibration of FG sandwich plates in thermal environment using a layer-wise theory. Liu et al. [45] presented high-order free vibration analysis of sandwich plates with both functionally graded face sheets and functionally graded flexible core. Mantari and Granados [46] examined thermoelastic analysis of advanced sandwich plates based on a new quasi-3D hybrid type HSDT with five unknowns. Although there are researches have reported on the overall sandwich structures, little has been done to examine the dynamic behavior of functionally graded or exponentially graded sandwich shells [47–57].

To the author's knowledge that the dynamic instability of EG sandwich cylindrical shells subjected static and time-dependent periodic axial loads has not yet been reported. The aim of this study is to solve this problem. A first order shear deformation shell theory is presented here for the study of the dynamic instability of EG sandwich shells. The theory does not require shear correction factors and the transverse shear stresses vary parabolically across the thickness satisfying shear stress free surface conditions. The influences of shear stresses, EG coatings and sandwich shell characteristics on the boundaries of instability regions of sandwich cylindrical shells are analyzed.

2. Formulation of the problem

Consider a sandwich cylindrical shell with EG coatings and ceramic-rich core, with the total thickness h, length L and mean radius of curvature R, referred to the coordinates (x,y,z), as shown in Fig. 1. The coordinate axes x, y and z in the axial, circumferential, and the inward normal directions (see, Fig. 1).

The sandwich cylindrical shell is composed of three elastic layers, i.e., the layers “1”, “2” and “3” from outer to inner surfaces of the shell, as shown in Fig. 2. Note that the kernel is symmetric ceramic-rich cylindrical shell, and the lower and upper surfaces of the cylindrical shell are metal-rich. The lower and upper coatings of the sandwich cylindrical shell are made of a heterogenous isotropic material with properties varying smoothly in the z (thickness) direction only. The thickness of each coating is h_{EG}, while the thickness of the ceramic core is h_c. Three types of sandwich cylindrical shells, namely, a) the sandwich cylindrical shell with EG coatings and ceramic-rich core (FG-C-FG), b) the sandwich cylindrical shell with metal-rich coatings and ceramic-rich core (M-C-M) and c) the

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