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Multiphase nanocomposite viscoelastic laminated conical shells subjected to magneto-hygrothermal loads: Dynamic buckling analysis

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ABSTRACT

Dynamic buckling of viscoelastic sandwich truncated nanocomposite conical shell subjected to moisture, temperature and magnetic field is presented in this paper. This class of structures is of great interest due to its extensive use in aerospace applications. The layers of the structure are made from a multiphase nanocomposite consist of polymer-carbon nanotubes (CNT)-carbon fibers. The micromechanics and Halpin–Tsai equations in hierarchy are applied for calculating the effective material properties of the multiphase nanocomposite layers. The structural damping effects are considered based on Kelvin–Voigt theory. The surrounding medium is simulated using visco-Pasternak model. Utilizing the first order shear deformation theory (FSDT), energy method and Hamilton's principle, the motion equations are derived. Differential quadrature method (DQM) and Bolotin's method are applied for solution of the motion equations to obtain the dynamic instability region (DIR) of the structure. The effects of various parameters such as structural damping, viscoelastic medium, magnetic field, number of layers, volume fraction of CNTs, temperature and moisture changes as well as boundary conditions on the DIR of the structure are studied. The results reveal that by increasing the moisture and temperature changes, the DIR will be happened at lower excitation frequencies.

1. Introduction

In modern technologies, there are an intense interest in the laminated sandwich structures which can be used in various industries such as aerospace involving aircraft, helicopters, missiles, launchers, satellites and etc for their excellent properties. One type of such structures is laminated sandwich conical shells with wide range of engineering applications especially in aerospace, marine and structural engineering. In practice, such structures can be subjected to different types of loading. For improving the strength of these structures, carbon fiber reinforced-polymer layers are a good choice. Researchers show that the mechanical properties of composites can strongly increase by adding a few weight percent of CNTs [1]. Noted that the elastic modulus of CNTs is over 1 TPa which make them much stiffer than steel while being three to five times lighter [3]. However, mathematical modeling of such components and the dynamic buckling analysis of them are essential for the sound and reliable designs of this class of structural components.

Mathematical modeling and mechanical analysis of the laminated sandwich shells are studied by many researchers. Free vibration of conical or cylindrical shells with various boundary conditions was studied by Wilkins et al. [1] based on Galerkin's method. Free vibration of composite laminated conical shells was presented by Tong [2] based on FSDT. Free damped vibration of sandwich shells was investigated by Korjakin et al. [3] using numerical method. A higher-order theory for the analysis of cylindrical and conical sandwich shells with flexible core was presented by Zhong et al. [4]. The formulation was based on a three-layer sandwich model. Numerical investigation of nonlinear free vibration of thermally post-buckled laminated composite spherical shell panel embedded with shape memory alloy (SMA) fibre was studied by Panda and Singh [5]. The active vibration control of thin rotating laminated composite truncated conical shells using vertically and obliquely reinforced 1–3 piezoelectric composite (PZC) materials as the constraining layer of an active constrained layer damping (ACLD) treatment was presented by Kumar and Ray [6]. An accurate solution approach based on the FSDT was developed by Yang et al. [7] for the free vibration and damping analysis of thick sandwich cylindrical shells with a viscoelastic core under arbitrary boundary conditions. Kerboua et al. [8] investigated a numerical model to simulate the aerodynamic behavior of combined conical–cylindrical shells. Nonlinear buckling analysis of the conical and cylindrical shells using the SGL strain based reduced order model and the PHC method was presented by Liang and Ruess [9]. The nonlinear free vibration behaviour of laminated composite spherical shell panel

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under the elevated hygrothermal environment was investigated by Mahapatra and Panda [10].

With regards to the mechanical analysis of nanocomposite structure, the effect of agglomeration and distribution of CNT on the free vibration characteristics of a functionally graded nanocomposite beams reinforced by single-walled carbon nanotubes (SWCNTs) by employing an equivalent fiber based on the Eshelby–Mori–Tanaka approach was presented by Heshmat and Yas [11]. Linear thermal buckling of a composite conical shell made from a polymeric matrix and reinforced with CNT fibres was investigated by Mirzaei and Kiani [12].

Free vibration behavior of functionally graded CNT reinforced composite plate was investigated by Mehar et al. [13] under elevated thermal environment. An analytical formulation combined with a fractional-order time derivative damping model was developed by He et al. [14] to conduct a comprehensive study on the large amplitude free and forced vibration response of carbon nanotubes (CNTs)/fiber/polymer laminated multiscale composite beams. The CNT reinforced composite plate has been modeled mathematically using higher order shear deformation theory. The sandwich structures were manufactured by Khurram et al. [15] from E-glass fiber/epoxy composites filled with carbon nanomaterials and para-aramid honeycomb cores. An investigation on the nonlinear dynamic response and vibration of the imperfect laminated three-phase polymer nanocomposite panel resting on elastic foundations and subjected to hydrodynamic loads were presented by Dinh Duc et al. [16]. Ebrahimi and Habibi [17] studied nonlinear, eccentric, low-velocity impact response of a polymer-CNT-fiber multiscale nanocomposite plate on elastic foundations in hygrothermal conditions. Shen et al. [18] investigated the small- and large-amplitude vibrations of thermally postbuckled sandwich plates with CNT-reinforced composite (CNTRC) face sheets resting on elastic foundations. Kolahchi et al. [19] presented wave propagation of FG-CNT-reinforced sandwich plates integrated by piezoelectric layers based on refined zigzag theory. Static response and free vibration of functionally graded CNT reinforced composite (FG-CNTRC) rectangular plate resting on Winkler–Pasternak elastic foundations using an analytical approach were studied by Dinh Duc et al. [20].

To the best of our knowledge, the dynamic stability analysis of viscoelastic laminated sandwich truncated nanocomposite conical shells considering hygrothermal environments has not received enough attentions so far. This paper deals with the dynamic buckling of laminated sandwich truncated conical shells subjected to magnetic and hygrothermal loads. Each layer of the sandwich structure are made from a multiphase nanocomposite consist of carbon fiber/CNT/ polymer based on micromechanics and Halpin–Tsai equations in hierarchy. The structural damping effects are considered based on Kelvin–Voigt. The surrounding medium is simulated with visco-Pasternak model. DQM and Bolotin's method are employed to calculate the DIR of the sandwich structure. To confirm the validity of the present research, the results are compared with those reported in the literature. The effects of structural damping, viscoelastic medium, number of layers, boundary condition, volume fraction of CNTs, temperature and moisture changes as well as magnetic field on the DIR of the structure are shown.

2. CNT/fiber/polymer multiphase nanocomposite model

The equivalent material properties of each layers of lamina, the combination of Halpin–Tsai [21] and micromechanics approach scheme [22] are used in two steps. The orthotropic effective properties of the CNT-reinforced multi phase laminas can be written as

$$E_{11} = V_F E_{11}^F + V_{MNC} E^{MNC}, \tag{1}$$

$$\frac{1}{E_{22}} = \frac{1}{E_{22}^F} + \frac{V_{MNC}}{E^{MNC}} - V_F V_{MNC} - \frac{\frac{\nu_F E^{MNC}}{E_{22}^F} + \frac{\nu_{MNC}^2 E_{22}^F}{E^{MNC}} - 2\nu_F \nu_{MNC}}{V_F E_{22}^F + V_{MNC} E^{MNC}}, \tag{2}$$

$$\frac{1}{G_{12}} = \frac{V_F}{G_{12}^F} + \frac{V_{MNC}}{G^{MNC}}, \tag{3}$$

$$\rho = V_F \rho^F + V_{MNC} \rho^{MNC}, \tag{4}$$

$$\nu_{12} = V_F \nu^F + V_{MNC} \nu^{MNC}, \tag{5}$$

where *E, G*, ρ, *V* and ν are respectively, Young's modulus, shear modulus, mass density, volume fractions and Poisson's ratio. The superscript or subscript *F* and *MNC* are related to the fibers and matrix of nanocomposite, respectively. Based on the Halpin–Tsai model, the elastic modulus of nanocomposite can be expressed as

$$E^{MNC} = \frac{E^M}{8}\left[5\left(\frac{1 + 2\beta_{dd} V_{CN}}{1 - \beta_{dd} V_{CN}}\right) + 3\left(\frac{1 + 2(\ell^{CN}/d^{CN})\beta_{dl} V_{CN}}{1 - \beta_{dl} V_{CN}}\right)\right], \tag{6}$$

where

$$\beta_{dl} = \left(\frac{(E_{11}^{CN}/E^M) - (d^{CN}/4t^{CN})}{(E_{11}^{CN}/E^M) + (\ell^{CN}/2t^{CN})}\right), \tag{7}$$

$$\beta_{dd} = \left(\frac{(E_{11}^{CN}/E^M) - (d^{CN}/4t^{CN})}{(E_{11}^{CN}/E^M) + (d^{CN}/2t^{CN})}\right), \tag{8}$$

where E^M and V_M are Young's modulus and volume fraction of the matrix, respectively; E^{CN}, t^{CN}, d^{CN}, ℓ^{CN} and V_{CN} represent respectively, the Young's modulus, thickness, outer diameter, length and volume fraction of CNTs which can be defined as

$$V_{CN} = \frac{w_{CN}}{w_{CN} + (\rho^{CN}/\rho^m) - (\rho^{CN}/\rho^m) w_{CN}}, \tag{9}$$

where w_{CN}, ρ^m and ρ^{CN} are mass fraction of CNTs, density of matrix and CNTs, respectively. The Poisson's ratio and mass density of the *MNC* can be given as

$$\nu^{MNC} = \nu^M, \tag{10}$$

$$\rho^{MNC} = V_{CN} \rho^{CN} + V_M \rho^M, \tag{11}$$

$$G^{MNC} = \frac{E^{MNC}}{2(1 + \nu^{MNC})}, \tag{12}$$

where ν^M and ν^{MNC} are Poisson's ratio of the matrix and *MNC*, respectively. Noted that due to the small amount of CNTs, the Poisson's ratio of the matrix and *MNC* are considered equal [23]. The longitudinal and transverse thermal expansion coefficients can be expressed as

$$\alpha_x = \frac{V_F E_{11}^F \alpha_{11}^F + V_{MNC} E^{MNC} \alpha^{MNC}}{V_F E_{11}^F + V_{MNC} E^{MNC}}, \tag{13}$$

$$\alpha_\theta = (1 + \nu_{12}^F) V_F \alpha_{22}^F + (1 + \nu^{MNC}) V_{MNC} \alpha^{MNC} - \nu_{12} \alpha_x, \tag{14}$$

where α_{11}^F and α_{22}^F are the fiber thermal expansions and α^{MNC} is the thermal expansion of *MNC* which can be given as

$$\alpha^{MNC} = \frac{1}{2}\left\{\begin{aligned} &\left(\frac{V_{CN} E^{CN} \alpha^{CN} + V_M E^M \alpha^M}{V_{CN} E^{CN} + V_M E^M}\right)(1 - \nu^{MNC}) \\ &+ (1 + \nu^M)\alpha^M V_M + (1 + \nu^M)\alpha^{CN} V_{CN} \end{aligned}\right\}, \tag{15}$$

where α^{CN} and α^M are thermal expansion coefficients of CNTs and matrix, respectively. Since the matrix absorbs all the water content, the effect of moisture on the CNTs or fiber can be neglected [24,25]. However, the moisture coefficients of the nanocomposite may be stated as

$$\beta_x = \frac{V_F E_{11}^F + V_{MNC} E^{MNC} \beta^M}{V_F E_{11}^F + V_{MNC} E^{MNC}}, \tag{16}$$