Aerospace Science and Technology 49 (2016) 276–288

Contents lists available at ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

Nonlinear free vibration analysis of laminated composite spherical shell panel under elevated hygrothermal environment: A micromechanical approach

Trupti R Mahapatra [a], Subrata K Panda [b,*]

[a] School of Mechanical Engineering, KIIT University, Bhubaneswar, India
[b] Department of Mechanical Engineering, National Institute of Technology, Rourkela, India

ARTICLE INFO

Article history:
Received 24 July 2015
Received in revised form 1 October 2015
Accepted 14 December 2015
Available online 17 December 2015

Keywords:
Composite shell panel
Hygrothermal loading
Micromechanics model
HSDT
Green–Lagrange nonlinearity
Nonlinear FEM

ABSTRACT

The nonlinear free vibration behaviour of laminated composite spherical shell panel under the elevated hygrothermal environment is investigated in this article. The composite material properties are considered to be the function of temperature and moisture concentration and the effective properties are evaluated using the micromechanics approach. The laminated shell panel model is developed mathematically using Green–Lagrange nonlinear kinematics in the framework of the higher-order shear deformation theory. The model is discretised using suitable finite element steps and solved numerically through a direct iterative method. The significance of the present nonlinear model is highlighted by solving the wide variety of numerical examples.

1. Introduction

Laminated composites are widely used in the past few decades in weight sensitive and high-performance engineering applications as structural components in aeronautical, naval, chemical, submarines, biomedical and other mechanical industries. The structural components made of laminated composites are well known for their tailor made stacking properties including the exceptional mechanical properties (high strength/stiffness to weight ratio), excellent corrosion resistance, good thermal properties. Laminated composites in the form of shells not only provide excellent aesthetic value but also bear the greater load as they possess higher membrane strength due to spatial curvature. In addition, laminated structural components pose a certain level of inherent thermal stresses owing to their manufacturing process. In general, the laminated components are distorted from their original geometries under the combined loading of action (hygral, thermal and/or hygrothermal load) in the course of the final fabrication and/or service period. It may lead to the degradation of composite properties and induction of residual stresses which may affect the final structural performances due to the variation in thermoelastic composite material properties. Therefore, the evaluation of mechanical responses (bending/vibration/buckling etc.) of laminated curved structure under high strain rate loading and hostile environment need to be assessed carefully. Thus, the numerical/analytical/experimental analysis of laminated composite shell under combined hygrothermal load is not only interesting but also challenging.

It is well known that the laminated structures are more susceptible to fail under shear in comparison to tension/fatigue. In addition, the number of unknowns increases as the number of layers increases and the total number of unknowns of the system will increase. This in turn makes the numerical/analytical computations of the laminated structure very tough due to the mathematical complexities. Finite element method (FEM) is proved to be a robust tool for the analysis of such complex structural problem due to its versatility under combined action of loading. Many attempts have already been made to compute the nonlinear vibration behaviour of laminated composites plates/shells under hygrothermal environment. The mathematical models are developed for laminated structures using various classical and shear deformation theories to obtain the vibration and buckling responses with less computational effort [1]. In order to assess the actual response of the structures, attempts are also modified to include the environmental effects on the composite material properties through the macro to micromechanics approaches. Some of the recent important contributions are discussed here to make this article self-standing. Doxsee [2] developed a higher order theory to investigate the hygrothermal behaviour of composite laminated sandwich shells with

* Corresponding author.
E-mail addresses: call2subrat@gmail.com, pandask@nitrkl.ac.in (S.K Panda).

http://dx.doi.org/10.1016/j.ast.2015.12.018
1270-9638/

and without the core in the hygrothermal environment. Sai Ram and Sinha [3] presented finite element (FE) solutions for the free vibration behaviour of laminated composite plates by taking hygrothermal dependent composite material properties. A quadratic isoparametric FE formulation based on the first order shear deformation theory (FSDT) is presented by Parhi et al. [4] to analyse the free vibration and the transient behaviour of multiple delaminated doubly curved composite shell panel under the hygrothermal environment. The static and dynamic responses of the thick laminated composite plate under hygrothermal environment is investigated numerically using FEM by Patel et al. [5] in the framework of the higher-order shear deformation theory (HSDT). Naidu and Sinha [6] presented nonlinear free vibration behaviour of laminated composite shells in the hygrothermal environment using nonlinear FEM. They have developed the mathematical model based on the FSDT and Green–Lagrange nonlinear kinematics. Wang et al. [7] investigated the nonlinear vibration and the bifurcation behaviour of circular cylinder shells under harmonic excitation using Galerkin's method. Biglari and Jafari [8] presented closed form solution of vibration responses of the doubly curved composite sandwich shell by developing the model in the framework of FSDT. The effective elastic properties of the sandwich composite are computed by Clifton et al. [9] using thermo–mechanical properties of the fabric through unit cell approach based on two-dimensional laminate theory. Nanda and Pradyumna [10] reported nonlinear free vibration and transient responses of the laminated composite shell (cylindrical and spherical) panel under hygrothermal environments. They have developed the theoretical model based on the FSDT and von-Kármán type nonlinearity. Zenkour [11] used a refined (sinusoidal) shear deformation theory to study the response of angle-ply laminated composite plates subjected to hygrothermal loads considering temperature and/or moisture-dependent material properties. The natural frequencies of woven fiber glass/epoxy delaminated composite plates are computed using both numerical (FEM) and the experimental methods by Panda et al. [12]. They have developed the theoretical model of laminated composite plate based on the FSDT mid-plane kinematics by incorporating the temperature and moisture dependent material properties. Masoumi et al. [13] presented multi-scale behaviour of viscoelastic–viscoplastic laminated composite plates using generalised differential quadrature method. The formulation is based on the FSDT and von-Kármán nonlinearity. Natarajan et al. [14] developed FSDT based to compute the free vibration and buckling behaviour of multilayered laminated composite plates with the central cutout using the extended FEM under hygrothermal environment. Parhi and Singh [15] reported free vibration responses of multilayered composite shell panel with uncertain material properties exposed to the hygrothermal environment using the HSDT type mid-plane kinematics and von-Kármán types' geometrical nonlinearity.

Limited number of studies is also reported on the bending [16–19], buckling [20,21] and free vibration [22–26] behaviour of laminated composite flat/curved panel under coupled (hygro-thermo–mechanical) loading effect by considering the hygrothermal dependent composite properties through the micromechanics model. However, it is also noted that in all the reported literature the mathematical model developed using HSDT mid-plane kinematics and von-Kármán type geometric nonlinear strains. Based on the authors' knowledge, no study have yet been reported on nonlinear free vibration behaviour of laminated composite shell panel under elevated hygrothermal environment based on the HSDT kinematics and Green–Lagrange nonlinearity by including the degraded composite properties through micromechanics approach. Recently, Panda and Mahapatra [27] developed a general nonlinear mathematical model to analyse thermal free vibration behaviour of laminated composite spherical shell panel using Green–Lagrange type geometric nonlinearity in the framework of HSDT mid-plane kinematics under uniform thermal load. However, the analysis is not focused on the corrugated composite material properties due to the elevated thermal environment.

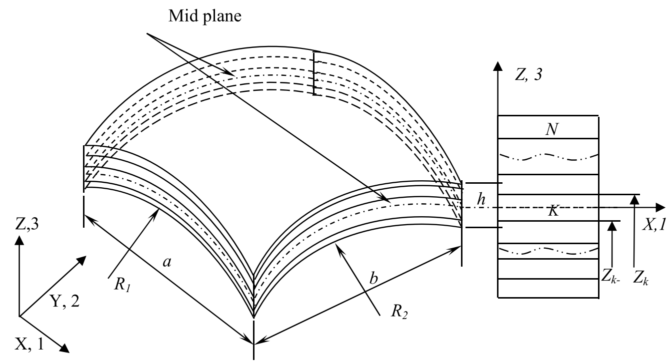

Fig. 1. Geometry and layup of laminated composite spherical shell panel.

Hence to overcome the knowledge gap between the earlier studies, the present investigation aims to analyse the nonlinear free vibration behaviour of laminated composite spherical shell panel under combined hygrothermal load. The effective stiffness of the laminated structure is evaluated using a micromechanical model including the corrugated composite properties under elevated environmental effect. The micromechanics model for the analysis is derived explicitly in term of the properties of fiber, matrix and the fiber volume fractions. Here, the mathematical model of the laminated composite panel has been developed using Green–Lagrange type nonlinear kinematics in the framework of the HSDT. Furthermore, all the nonlinear higher order terms arising in the strain displacement relation are included in the mathematical formulation to capture the original flexure of the structure. The nonlinear system governing equation is obtained using Hamilton's principle and discretised using suitable FEM steps. The nonlinear fundamental frequency of laminated panel under combined hygrothermal load is computed using a direct iterative method through a homemade computer code developed in MATLAB environment. The convergence behaviour of the developed model has been checked and validated by comparing the responses to various environmental conditions. The effectiveness of the proposed nonlinear model and the applicability have been revealed by computing the responses for various geometrical parameters through several numerical illustrations.

2. Theory and formulations

The geometry and layup of a typical laminated composite spherical shell panel with length a, width b, uniform thickness 'h' and consists of 'N' number of uniformly thick layers considered for the present analysis is shown in Fig. 1. Z_k and Z_{k-1} are the top and bottom faces of Z-coordinates of the kth lamina. Based on the spherical shell panel definition the present model is developed using the same principal radii of curvatures along x and y directions say, R_1 and R_2, respectively along the mid-plane or the reference surface ($z = 0$).

2.1. Displacement field

In this analysis, the HSDT type mid-plane kinematics is introduced to avoid shear correction factor as well as to maintain the parabolic shear stress behaviour through the thickness as in the case of general studies. The desired mid-plane and along x, y and z-directions corresponding to any point of time 't' are expressed as in [28]: