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Vibration of composite cylindrical shallow shells subjected to hygrothermal loading-experimental and numerical results

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ABSTRACT

Hygrothermal effects on free vibration of woven fiber glass/epoxy laminated composite cylindrical shallow shells are investigated both numerically and experimentally. In the present finite element analysis a composite doubly curved shell model based on first order shear deformation theory (FSDT) is used for free vibration of cylindrical shell panels in hygrothermal environment. B&K FFT analyzer is used to determine the natural frequencies of vibration experimentally by conducting non-destructive testing. The effects of curvature ratios, lamination sequences and boundary conditions on natural frequencies of vibration under hygrothermal loading are investigated. The frequency of vibration decreases with increase of temperature and moisture.

1. Introduction

Due to lightweight, high strength to weight ratio, tailorability in challenging applications, excellent thermal characteristics and simplicity in fabrication laminated composite shells are more and more used in various engineering applications such as fuselage panels of aeroplane, turbine blades, automobile body panels, deep submersible vehicles and many more. A significant temperature gradient is observed during fight and landing conditions of aircraft. Moisture variations are observed for naval, sailboat and other applications. These structures are also subjected to dynamic loads due to wind, water pressure etc. The vibration behaviour of laminated composite shell structures are significantly affected by the varying environmental conditions due to moisture absorption and temperature. However, these materials are irreversibly damaged by high stresses due to the formation and propagation of cracks. Regardless of the application, once cracks have formed within polymeric materials, the integrity of structure is significantly compromised. Microcracking induced by environment is a long-standing problem in polymer composites. Cracking leads to mechanical degradation of fiber polymer composites [1]. Both reversible and irreversible changes in mechanical properties of thermoset polymers are known to occur as a result of water absorption [2]. Therefore the vibration characteristics of laminated composite shells subjected to hygrothermal loading are of great practical significance in the prediction of structural behaviour of these types of structures.

Plenty of literature are available on the free vibration of laminated composite shells without considering the effects of temperature and moisture absorption. The literature on vibration of laminated composite curved panels is reviewed by Liew et al. [3] Qatu [4], and Qatu et al. [5]. Reddy [6] presented an exact solution for vibration of doubly curved shells using first order shear deformation theory (FSDT). Closed form solutions on buckling and initial postbuckling behaviour of symmetrically laminated, thin cross ply cylindrical panels under axial compression were investigated by Hui [7]. Free vibrations of anisotropic laminated doubly curved shells were investigated by Chandrasekhara [8] using an isoparametric doubly curved quadrilateral shear flexible element. An analytical method for free vibration and stability problems of cross-ply laminated circular cylindrical shells was illustrated by Nosier and Reddy [9] using Donnell shear deformation theory and Donnell's classical theory. Free vibration analysis of cross-ply laminated cylindrical shells was done by Narita et al. [10] using finite element method (FEM). Qatu [11] analyzed vibrations of doubly cantilevered laminated composite thin shallow shells using Ritz method. Chakravorty et al. [12] analyzed the free vibration of doubly curved laminated composite shells utilizing FEM. Free

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vibrations of laminated composite cylindrical shells were investigated by Shu and Du [13] using generalized differential quadrature (GDQ). Lam and Qian [14] studied the vibrations of thick symmetric angle-ply laminated composite cylindrical shells analytically using FSDT. Timarci and Soldatos [15] presented the vibrations of angle-ply laminated circular cylindrical shells subjected to different boundary conditions. Zhang [16] used wave propagation approach to investigate the natural frequencies of cross-ply laminated composite cylindrical shells. The fundamental frequencies of composite hypar shallow shells with various edge supports were determined by Sahoo and Chakravorty [17] using FEM. Toorani and Lakis [18] studied the free vibrations of non-uniform composite cylindrical shells using finite element analysis. Non-linear higher-order shear deformation theory was used by Amabili and Reddy [19] for large-amplitude vibrations of laminated doubly curved shells. Natural frequency of laminated shells with different boundary conditions and resting on the Pasternak type elastic foundation were determined by Sofiyey and Kuruoglu [20] applying Galerkin methods. Free vibration of thick laminated cylindrical shells with different boundary conditions was investigated by Asadi and Qatu [21] using general differential quadrature (GDQ) method. Free vibration analysis of orthotropic doubly-curved shallow shells was done by Ghavanloo and Fazelzadeh [22] using gradient elasticity theory. Frequencies of free vibration of completely doubly curved laminated shells were determined by Viola et al. [23] using higher order shear deformation theory (HSDT). Vibration analysis of laminated composite conical shells was done by Civalek [24] using method of discrete singular convolution based on the shear deformation theory. The effects of shear deformation, rotary inertia and heterogeneity on the frequencies of cross-ply laminated orthotropic cylindrical shells were investigated by Sofiyey and Kuruoglu [25] using Donnell shell theory. The non-linear vibration of laminated non-homogenous orthotropic truncated conical shell was studied by Sofiyey [26] using the large deformation theory. Tornabene et al. [27,28] presented the dynamic analysis of doubly-curved shell structures using the generalized displacement field of the Carrera Unified Formulation (CUF). Fazzolari [29] presented a refined dynamic stiffness element for free vibration analysis of cross-ply laminated composite cylindrical and spherical shallow shells. Najafov et al. [30] presented non-linear dynamic analysis of symmetric and antisymmetric cross-ply laminated orthotropic thin shells using theory of large deformations. Day et al. [31] presented Kriging model approach for stochastic free vibration analysis of composite shallow doubly curved shells. Huang and Hui [32,33] solved the modified-Duffing ordinary differential equation for large-amplitude vibration of imperfect angle-ply laminated rectangular composite plate with viscous damping. Natural frequencies of free vibration of laminated curved panels were determined by Mohazzab and Dozio [34] using spectral collocation method. Free vibrations of composite oval and elliptic cylinders were studied by Tornabene et al. [35] employing generalized differential quadrature (GDQ) method. Numerical and exact models for free vibration analysis of cylindrical and spherical shell panels were presented by Tornabene et al. [36].

The effect of Carbon Nanotube (CNT) agglomeration on the free vibrations of laminated composite doubly-curved shells was investigated by Tornabene et al. [37] using HSDT.

Study on the free vibration of laminated composite shells subjected to hygrothermal environment is much less in the literature. Vibrations of thermally induced cross-ply laminated shallow shells were investigated by Khdeir [38] using classical theory. Parhi et al. [39] studied the effect of moisture and temperature on the dynamic behaviour of composite plates and shells with or without delaminations using FEM. Nonlinear free vibrations of composite shells in hygrothermal environments were investigated by Naidu and Sinha [40] using FEM. Nonlinear vibrations of laminated cylindrical shallow shells under thermomechanical loading were analyzed by Ribeiro and Jansen [41] using FEM. Nonlinear static and dynamic behaviour of laminated composite shell panels under hygrothermal conditions were studied by Kundu and Han [42] using geometrically nonlinear finite element method. The nonlinear free vibration analysis of shells considering post buckling for a uniform temperature field was carried out by Panda and Singh [43]. Nanda and Pradyumna [44] presented the results of free vibration frequencies of laminated shells with geometric imperfections in hygrothermal environments. Wous et al. [45] studied hygrothermal effects on the dynamic compressive properties of graphite/epoxy composite material using Split Hopkinson Pressure Bar apparatus. Non-linear bending analysis of laminated conical panels under various thermomechanical loadings and boundary conditions was presented by Maleki and Tahani [46] using generalized differential quadrature (GDQ) method. The linear static thermal stress analysis of composite structures was done by Cinefra et al. [47] utilizing a shell finite element.

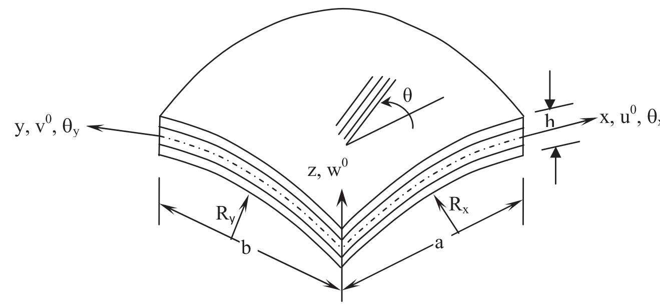

Fig. 1. Laminated doubly curved composite shell.

A critical review of literature on vibration of shells indicate that many studies are appeared in the literature on vibration of laminated shells in ambient temperature and moisture conditions using various analytical and numerical approaches. The studies on the free vibration of unidirectional laminated composite shells subjected to hygrothermal environment are limited in the literature. To the best of the author's knowledge, no experimental work is reported in literature on the free vibration of woven fabric laminated composite cylindrical shallow shells subjected to variations of temperature and moisture. Experimental studies give the real picture about behaviour of the structure under these conditions. In the present study, the authors utilise for the first time, the advanced vibration measurement system for the industry-driven woven fiber Glass/Epoxy composite cylindrical shell panels to study its free vibration behaviour in hygrothermal environment experimentally. The authors also developed a code in MATLAB environment for comparing the experimental results using finite element method (FEM).

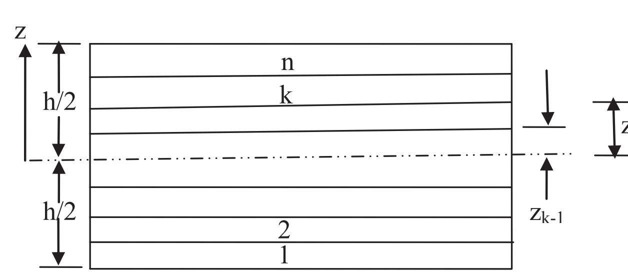

Fig. 2. Details of layer.