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Dynamic Stability and interlaminar Stress Analysis of Cylindrical Shells subjected to Elevated Thermal Field

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Abstract

Three-dimensional thermo-mechanical stress analyses of cylindrical shell structures made with laminated Fibre Reinforced Polymer (FRP) composites have been carried out. Brick 8-node 185 layered solid elements have been used in the present finite element simulation. Due to curved geometry and interaction of different coupling modes at the ply-interfaces, stress concentration effects have been realized throughout the domain of the laminated shell structure. Appropriate finite element mesh size obtained through convergence study has been adopted to capture these stress concentration effects. Thermal field induced out-of-plane interlaminar stresses (σ_{rr}, $\tau_{\theta r}$, τ_{zr}) responsible for delamination damage initiations have been analyzed in details. Effect of different stacking sequences on thermo-mechanical dynamic stability of shell structures has also been studied. It has been observed that, structural dynamics of composite shell structures get significantly affected under elevated thermal field.

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Keywords: Cylindrical shell structure; Dynamic stability; Finite Element Analysis; Interlaminar stresses; Laminated FRP composites

1. Introduction

Thin cylindrical shell structures made with laminated FRP composites find tremendous applications in aerospace, automobile, defense, civil engineering etc. due to their superior specific properties such as high specific strength and stiffness ratios, improved corrosion, and environmental resistance. These structures frequently come across elevated thermal field environments leading to prolific chances of various interply damages like delamination, debonding, matrix shear failure etc. Interlaminar stress distribution has been found to be significantly affecting the performance

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of composite laminates hence investigated by many authors. A relatively recent review paper of Kant and Swaminathan [1] discusses about advancement in theories regarding appropriate prediction of interlaminar stresses in laminated composite plates. Moreover it is found that interlaminar stresses in composite laminated plates are mostly at free-edges due to mismatch in elastic properties between plies. Thus in this region near the free edges, the stress state is three-dimensional in nature and not predictable accurately by Classical Lamination Theory (CLT) as suggested by Dong et al. [2]. In thermal environment like curing or when subjected to temperature changes, each layer tends to contract or expand in the transverse direction much more than in the fiber direction. However, this transverse contraction is constrained by the adjacent layer, and this produces in-plane thermal residual stresses in the laminate. Bogetti [3] suggested that the mechanics and performance of laminates are strongly dependent on curing history. Analytical methods were used by Senel et al. [4] to perform residual stress analysis of laminated composite plates under thermal loads. Shabana and Noda [5] have used finite element method to investigate elasto-plastic thermal stresses in rectangular plate composite functionally graded materials. Although these research discuss the planner stress distribution but, a complete three dimensional state of stress still needs to be understood properly which have been presented in the present research. Apart from stress, stability of the structures (in sense of deformation) is also very important performance characterization parameter. A review in recent development of the finite element analysis for laminated composite plates has been presented by Zhanga et al. [6]. Although literature is available for thermo-mechanical analysis of laminated plates but very little work is available for laminated curved panels. Thangaratnam et al. [7] have performed a FEM analysis on post buckling behavior of laminated cylindrical shells. Dynamic stability and interlaminar stress analysis of cylindrical shell structures subjected to mechanical loading has been carried out by Das et al. [8]. However, the coupling effect of thermal fields affecting structural integrity and dynamic stability still requires proper investigation and has been addressed in the present research.

2. Specimen geometry and boundary conditions

Graphite / Epoxy (Gr/E) laminated FRP composite having all the plies oriented along the axial direction of the shell structure (z-axis), $[90]_8$ have been considered in the present analysis. The composite cylindrical shell is symmetrical with respect to dimensions (*l*ength (*a*) = breadth (b) = 5000mm, *a*/b = 1). The thickness h = 50 mm, and radius of curvatures R = 10,000 mm. The dimensions have been adopted from the work of Qatu and Leissa [9]. The composite cylindrical shell has been subjected to cantilevered boundary conditions at one of the curved faces such that; $r = \theta = z = 0$. The present analysis has been carried out in cylindrical co-ordinate system with its origin lying on axis of cylinder towards cantilevered edge. The shell structure has been subjected to uniform elevated thermal field which is maintained at the temperature difference of $\Delta T=15^0C$ over room temperature of 25^0C. Specimen geometry and boundary conditions along with the different ply-interfaces have been shown in details in Fig. 1(a).

Materials properties for the orthotropic FRP composite used for the cylindrical shell have been given in Table 1. These material properties have been adopted from the work of Aditi et al. [10].

Table 1.Material properties (Aditi et al. [10]) of Gr/E laminated FRP composite used for the cylindrical shell.

Material composition	Material constants
Graphite/ Epoxy laminated FRP composite material properties	E_{zz} = 144.23GPa, E_{rr} = 9.65GPa, $E_{\theta\theta}$ = 9.65GPa, $\nu_{r\theta}= \nu_{\theta z}= \nu_{rz}=0.3$ $G_{r\theta}$ = 3.45GPa, $G_{\theta z}$= 4.14GPa, G_{rz}= 4.14GPa $\alpha_{zz}= 1.1\text{x}10^{-6}\ /^0C$ $\alpha_{\theta\theta}= 25.2\text{x}10^{-6}\ /^0C$

3. Finite element analysis

For cylindrical shell laminates, layered Brick 8-node SOLID 185 elements have been used to discretize the domain as shown in Fig. 1 (a). Each ply has been modeled separately with one element per ply in through the thickness direction. The element has been defined through eight nodes having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, stress stiffening, large deflection, and large strain capabilities. The default element coordinate system is along global directions. An appropriate mesh size has been selected through convergence study for out of plane interlaminar normal peel stresses (σ_{rr}). The