Abstract

Currently, the usage of composite materials has almost covered every engineering sector ranging from the deep ocean to high in the sky. High strength-to-weight ratio, high stiffness-to-weight ratio, and ply optimization are some of the main reasons for its wide applicability in structural engineering. Most of the time, composite materials are used in the form of plates and shell structures. In order to utilize the full potential of the composite material in the plate or shell structures, various plate/shell theories are proposed in the literature to model the behavior of composite plate/shell in both dry and wet environments. As composite materials are weak in transverse shear, it necessitates the use of higher-order shear deformation theories (HSDTs) to take into account the transverse deformation in the structural analysis. These HSDTs can be grouped as polynomial shear deformation theories (PSDTs) and nonpolynomial shear deformation theories (NPSDTs). In comparison to PSDT, NPSDT gives better modeling flexibility, which can be seen by the number of NPSDTs developed in the open literature.

Despite the development of various NPSDTs with five degrees of freedom, there have not been considerable studies on geometrically nonlinear analysis of plate and panel structures. Most of the studies related to nonpolynomial theories are limited to linear bending analysis of multilayered composites plates. Further, a considerable amount of work has been done on buckling analysis of laminated composite plates using Navier type analytical model. However, bending and buckling analysis of panels under dry and hygrothermal environments is limited to first-order shear deformation theory (FSDT). In general, composite structures are thin and exhibits nonlinear behavior under high mechanical and thermal load. Although the panel has high buckling strength than the plate structure, their post-buckling response shows softening-hardening behavior. Hence, from the design and analysis point of view, an accurate, reliable, and robust analysis is needed for better utilization of composite material in the panel structures.

In this study, a reliable and accurate finite element model is formulated for linear and nonlinear bending and buckling analysis of multilayered composite plate and panel structures under both dry and hygrothermal environments. For the incorporation of nonlinearity, both von Kármán as well as Green-Lagrange strain-displacement relations are considered. A nonpolynomial shear deformation kinematics is considered, which assumes nonlinear variation of displacements over the thickness and predicts better response. In buckling analysis, both post-buckling and nonlinear buckling with imperfection is carried out to show the difference and sensitivity of imperfection. A detailed mathematical formulation is derived from the energy principle using the variational approach.

A tangent-based arc-length method is applied to solve the nonlinear bending and buckling problems, and a direct iterative method is employed to obtain the post-buckling response. A Navier-type analytical methodology is also developed for linear bending and buckling analysis of panels to assess the accuracy and efficiency of the present FEM model. The accuracy, performance, and applicability of the present FEM model are examined through various benchmark problems. Through this study, it has been shown that the present FEM model is efficient and can be conveniently implemented for both linear and nonlinear structural analysis of laminated and sandwich composite plates and panels.
Keywords: Composite panel; Higher-order shear deformation theory; Green-Lagrange nonlinearity; Bending and buckling analysis; Hygrothermal environment; Finite element analysis.