Abstract

The present work deals with the development of shear deformation theories for modeling and analysis of laminated composite and sandwich plates. New plate theories, in the framework of displacement based axiomatic approaches, are developed by means of expressing the shear deformation effects in terms of non-polynomial shear strain functions. These functions are inverse hyperbolic, secant function and an inverse cotangent functions. Based upon the functions employed, the theories are termed as inverse hyperbolic shear deformation theory (IHSDT), secant function based shear deformation theory (SFSDT) and inverse trigonometric shear deformation theory (ITSDT). The developed theories inherently satisfy the zero transverse shear stress conditions on top and bottom surfaces of the plate and do not require a shear correction factor. The laminated composite and sandwich plates are modeled using the developed theories and their structural and aeroelastic responses are examined in deterministic and random environment. The validity of the theories is ascertained by presenting the Navier type closed form solution for structural responses (static, buckling and free vibration) of simply supported laminated composite and sandwich plates. The validity of the proposed theories is demonstrated successfully by comparing the results with the exact solution and other existing methodologies. Further, a computationally efficient C^0 finite element methodology is developed in the framework of proposed theories in order to enhance their range of applicability. The developed finite element methodology is applied to examine the deterministic static, buckling and free vibration behavior of laminated composites and sandwich plates. The developed C^0 finite element model is then implemented to examine the flutter characteristics of laminated composite and sandwich plates subjected to yawed supersonic flow. The linear piston theory is employed to consider the aerodynamic load. The influences of the stiffness characteristics (fiber orientation, stacking sequence, and material anisotropy ratio), geometric characteristics (boundary conditions), and flow characteristics on the flutter boundary are investigated and it is concluded that the flutter boundaries (critical dynamic pressure and flutter frequency) are greatly influenced by the boundary conditions, lamination sequences, flow angle, and the material anisotropy ratio. Further, in order to consider the variability in the material properties, a stochastic finite element approach is developed with the aid of a mean-centered first order perturbation technique. In order to ensure the validity of the resulting stochastic finite element approach, Monte Carlo Simulation is employed in conjunction with developed finite element model. The variability in the material properties of composites are characterized employing the stochastic approach and their propagation on the structural and aeroelastic behavior is quantified. The effects of the randomness in the material properties are examined by calculating the second order statistics i.e., mean and variance of the response. The stochastic finite element analysis is performed for static, buckling, free vibration and flutter behavior. The results are compared with those of existing results and independently developed MCS results. The characterization of uncertainties on the structural and aeroelastic responses provides useful insight into the manner by which material uncertainties propagate.

Overall, the range of applicability of the developed non-polynomial shear deformation theories is demonstrated successfully for structural and aeroelastic responses of laminated composite and sandwich plates with and without random material properties by solving plate problems having different span-thickness ratios, boundary conditions, lamination sequences and other relevant parameters. Moreover, the formulation is presented in a generalized approach which enables its implementation to all existing shear strain function based shear deformation theories in a single computer algorithm thereby making it practically more significant.

Keywords: Laminated composite, sandwich plate, shear deformation theory, non-polynomial shear strain function, static, buckling, free vibration, flutter, uncertainty quantification, Navier solution, finite element method, perturbation technique, Monte Carlo simulation