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Dynamic analysis of flat and folded laminated composite plates under hygrothermal environment using a nonpolynomial shear deformation theory

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ABSTRACT

In this paper, the effect of the hygrothermal environment on the dynamic analysis of one-fold and two-fold folded laminated composite plates using a nonpolynomial shear deformation theory (NPSDT) is investigated. A computationally efficient C^0 finite element method (FEM) is applied to examine the free vibration characteristic, transient behavior, and steady-state response of laminated composite plates. The formulation employs the total Lagrangian approach for analysis, and the initial stress generated due to hygrothermal load is taken into account through the Green–Lagrange strain displacement relation. The Newmark's method is employed to integrate the spatial–temporal partial differential governing equations. The effect of the thermal environment on the natural frequency of folded and flat composite plates has been illustrated through various examples. The transient displacement and stresses are plotted for various loads. Moreover, transient damped analysis under the thermal load is carried out by considering the Rayleigh damping model. Further, linear harmonic analysis under the hygrothermal environment has also been carried out, and the responses in the neighborhood of natural frequency are plotted. The present model has been compared and validated by the existing literature and the obtained ANSYS APDL solutions, and is found to be performing better for NPSDT.

1. Introduction

The advent of advanced composite materials has brought a paradigm shift in the structural design and manufacturing of aircraft, automobiles, ships, etc. Especially, aerospace and structural application are the biggest beneficiaries of this development. The reason can be attributed to the low density, high strength, and high stiffness of the composite structure. Further, for the holistic analysis of structural engineering, different types of structures like flat and folded plates are needed to be considered. As these types of structures are often used in aircraft fuselages, winglets, vehicle chassis, ship hulls, buildings, bridges, etc. Besides, the folded structures are observed in nature as well, such as palm leaves, seashells, etc. In addition, the composite structures used in these applications undergo large variations in the hygrothermal environment due to their manufacturing process and operation. Moreover, the hygrothermal environment profoundly affects the behavior of composite material due to the greater susceptibility of the matrix than the fiber under the elevated hygrothermal environment. Due to this, the transverse direction displacement is more in the matrix than the fiber, which seeks for the relative movement of a constituent, and the same is restricted due to different properties of the fiber and matrix. This leads to the development of induced hygrothermal residual stress. Often, these stresses induce large deformation and need to be considered for structural analysis. Also, it has been observed that the elastic modulus and the strength of composite laminates degrade at elevated temperatures. And hence, it is imperative to make a proper assessment of the thermal and moisture effect on the structure to have proper design and analysis to safeguard the structural life.

Further, the transverse shear deformation is an inherent characteristic found in the multilayered composite structure and therefore needs to be taken care of during the analysis. To incorporate this, several shear deformation theories have been proposed by various researchers as can be found in the review paper of Ghugal and Shimpi [1]. These theories can be classified as polynomial shear deformation theory (PSDT) and nonpolynomial shear deformation theory (NPSDT). The polynomial theories are obtained by considering few terms of Taylor's series for the kinematic equation, and the nonpolynomial theories take nonpolynomial functions to model the kinematic equation properly. It is observed that the polynomial shear deformation theories do not reg-

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