Abstract

Composite laminated and sandwich structures are extensively utilised as the load-bearing components in aircraft, automobile, civil and naval industries due to their high stiffness-to-weight and strength-to-weight ratios. Auxetic honeycomb cores having re-entrant cell geometry possess negative Poisson's ratio and lead to increased stiffness and density of the sandwich panel. Conventionally, laminated composites are reinforced with straight fibres which are aligned along a particular direction resulting in constant lamina properties and are known as constant stiffness composite laminates (CSCL). However, the recent advancement in manufacturing technologies like tow placement machines enables to fabricate structures with continuously varying fibre orientation, resulting in spatially varying stiffness. Such panels are named as variable stiffness composite laminates (VSCL). The use of curvilinear fibres in composite structures allows tailoring their response specific to the design requirement with additional weight reduction. The introduction of VSCL also improves the tensile and buckling response and enables an optimum control on the fundamental frequencies of the structure, and therefore, the present study explores the viability of the VSCL based auxetic sandwich panels.

This thesis presents finite element (FE) formulation based on zig-zag displacement fields to analyze linear and nonlinear static and dynamic response of variable stiffness laminated composite and auxetic honeycomb sandwich shell panels. The formulation considers third-order shear deformation theory incorporating zig-zag effects using Murakami zig-zag function and geometrical nonlinearity is included using von Kármán nonlinear strain–displacement relations. The variations of the in-plane and transverse displacements are considered according to global third- and second-order approximations along the thickness direction, respectively. A nine-noded C^0 isoparametric quadratic shell element with thirteen and eleven degrees of freedom per node is employed to study the structural response of VSCL panels. Hamilton's variational principle is used to derive the governing equations for nonlinear static and dynamic analyses. The governing equations for nonlinear static analysis are solved using the Newton-Raphson method to obtain the displacements and stress distribution curves of VSCL panels. The governing equations are further solved for eigenvalue solutions to obtain natural frequencies, and by using Newmark's time integration method for forced vibrational analysis.

The present work establishes the accuracy of the formulation by comparing the results obtained from the present structural models with those from the three-dimensional and two-dimensional benchmark FE solutions available in the literature. The numerical results are

obtained based on an appropriate mesh size determined using convergence studies. A thorough numerical study is presented in this thesis including the effects of curvilinear fibre path angles, lamination configuration, thickness ratio, curvature ratio, geometrical parameters of the honeycomb unit cell, and boundary conditions on the linear and nonlinear static and dynamic response of variable stiffness composite and auxetic honeycomb sandwich panels. New results are presented for the nonlinear static as well as free and forced vibration response of VSCL panels and auxetic structures.

The thesis also presents a finite element (FE) model based on a homogenization procedure and unit cell method to calculate the effective elastic properties of auxetic honeycomb core made up of composite CFRP material. In the absence of analytical expressions for the effective elastic properties of honeycomb core made up of composite material in the literature, the present FE model can prove to be quite useful. Using the obtained properties, the nonlinear static and dynamic behaviour of the sandwich shell panels with VSCL facesheets and CFRP auxetic core is studied. The present thesis also demonstrates the effect of curvilinear fibre angle and geometric parameters of the core on the linear and nonlinear behaviour of the VSCL panels with composite honeycomb core.