Abstract

The thesis presents variable kinematic finite element (FE) formulations for the numerical simulation of laminated structures considering multi-field effects. In the weak-form governing equations, couplings among hygroscopic, thermal, electrical, and mechanical fields are accounted for. The development of refined beam, plate, and shell FE models in the framework of Carrera Unified Formulation (CUF) is presented. Various refined approximation theories (employing Taylor series, trigonometric series, exponential functions, Lagrange and Chebyshev polynomials) are implemented in either Equivalent-Single-Layer (ESL) or Layer-Wise (LW) approach and numerically assessed. Node-Dependent Kinematics (NDK), a versatile tool to construct FE models with variable nodal kinematic capabilities, is introduced. Adoption of hierarchical Legendre polynomial functions as beam cross-section functions and plate/shell shape functions is demonstrated.

Application of the proposed FE approach in pure mechanical and multi-field modeling is discussed through a variety of numerical examples. Construction of global-local beam, plate, and shell FE models with NDK is demonstrated. FE solutions for angle-ply laminates, which can be used as new benchmarks, are proposed. An evaluation of membrane and shear locking phenomena in hierarchical shell elements in the analysis of multi-layered structures is presented, and it is concluded that the p-refinement can effectively alleviate the locking effects. The solution of thermo-mechanical, hygro-mechanical, and electro-mechanical problems with refined FE models is discussed through numerical cases.

The used FE approaches lead to results agreeing well with the available reference solutions. Three-dimensional accuracy can be achieved with high numerical efficiency. It is demonstrated that CUF provides a powerful framework for the development of advanced FE approaches.

Keywords: *finite elements, composite laminates, beam models, plate models, shell models, Carrera Unified Formulation, node-dependent kinematics, global-local analysis, thermal stress, hygroscopic stress, piezo-electric components.*