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NURBS-based isogeometric formulation for linear and nonlinear buckling analysis of laminated composite plates using constrained and unconstrained TSDTs

Surendra Verma [a,*], Abha Gupta [b], Rabindra Prasad [c], Donatus Oguamanam [a]

[a] Department of Mechanical, Industrial, and Mechatronics Engineering, Toronto Metropolitan University, Toronto, Ontario M5B 2K3, Canada
[b] Department of Aerospace Engineering, Punjab Engineering College (DU), Chandigarh 160012, India
[c] Mechanical Engineering Department, Indian Institute of Information Technology Design & Manufacturing Jabalpur, Jabalpur, Madhya Pradesh 482005, India

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ABSTRACT

Two isogeometric plate models employing Reddy's third-order shear deformation theory (TSDT) and unconstrained third-order shear deformation theory (UTSDT) are presented and compared for linear and nonlinear buckling analysis of laminated composite plates with and without imperfection and subjected to different in-plane loads. Cubic non-uniform rational B-spline (NURBS) basis functions that easily satisfy C^1 continuity of the IGA-TSDT model are employed. The total Lagrangian approach in conjunction with the principle of virtual work is used to derive the governing equations. The primary and secondary solutions are traced using a tangent based arc-length method with a simple branch switching technique. The performance of the models is evaluated by validation and comparison with solutions obtained using ANSYS, Navier method (for linear analysis only), and those in the literature. The buckling response is significantly affected by pre-buckling boundary conditions and strain-displacement relations. The nonlinear buckling approach, among other approaches, is observed to be the most accurate methodology for an arbitrarily laminated composite plate. Further, IGA-UTSDT with nine DOF gives marginal improvement over IGA-TSDT with five DOF at the cost of computation. The IGA-TSDT is observed to be superior to FEM-TSDT in terms of computation demand and performance.

1. Introduction

Composite materials are increasing used in various industries, including aerospace, automotive, defense, railways, shipbuilding, and polymeric electronics, due to their high specific strength and stiffness characteristics. In aerospace engineering specifically, laminated composites structures are widely used in the form of beams, plates, and panels, finding use in wing spars, wing skins, fuselage, bulkheads, control surfaces, flaps, spoilers, gusset plates, and airframes.

In a previous paper [1], a penalty based C^0 finite element model with seven degrees of freedom (DOF) is proposed for a C^1 high-order shear deformation theory (HSDT), particularly Reddy's third-order shear deformation theory (TSDT), for linear and nonlinear buckling analysis of laminated composite plates. The limitation of C^0 continuous Lagrange elements not only introduced approximation to the solution but also increased the computational cost because of the penalty approach. The present study is an attempt to improve the model using isogeometric analysis (IGA).

IGA technique, proposed by Hughes et al. [2], ensures C^1 requirement of HSDT and requires less computation power due to the use of non-uniform rational B-splines (NURBS). In addition, IGA provides a seamless integration of computer-aided design (CAD) and computer-aided engineering (CAE) and allows the analysis to be implemented on the geometry with higher continuity, instead of the conventional finite element mesh with C^0 continuity.

Many linear studies [3–11] predict the buckling strength of composite plates under inplane mechanical loads. Most of these studies [1,3–6,10,11] use the finite element method, and it is worth noticing that [1,3,7–9] found that the use of Green-Lagrange strain yields accurate prediction of buckling strength. Refs. [12–18] employ the IGA technique. Specifically, the IGA is combined with first-order shear deformation theory (FSDT)

* Corresponding author.
E-mail addresses: suri@torontomu.ca, surendraverma2501@gmail.com (S. Verma), abha.gupta91@gmail.com (A. Gupta), rabindrap@iiitdmj.ac.in (R. Prasad), doguaman@torontomu.ca (D. Oguamanam).

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