CONSIDERATION OF A NEW KINEMATIC ASSUMPTION FOR FAILURE TRACKING IN LAMINATED STRUCTURES

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In recent work [1] the initiation and progression of delamination failure in composite, laminated shells has been modeled by use of a finite element approach wherein an irreversible constitutive law is used at the debonded interface. The approach has been successful but requires a large number of nodal degrees of freedom; thus the analysis is quite slow. The current paper describes part of the work that is ongoing to create a time savings over the finite element approach as currently implemented.

Typical finite element analyses of laminated structures use either an equivalent single layer (ESL) approach or a layerwise (LW) approach [2]. ESL approaches require only one element through the thickness of the laminate and use nodes only on the reference surface. A LW approach uses one set of elements for each layer of the laminate, requiring a relatively high number of nodal degrees of freedom. ESL analyses are relatively fast, but may lose accuracy as the number of layers increases. The LW approach tends to be much slower than ESL solutions, but is more forgiving of multiple layers.

For this work a new kinematic assumption [3] is used, which simultaneously holds down the required number of nodal unknowns and provides complete, appropriate, *a priori* satisfaction of interlaminar continuity of stresses, strains and displacements. The result is an ESL approach which promises speedy analysis without sacrifice of accuracy. The kinematic assumption is incorporated into an appropriate finite element, and may be useful within the context of shell theory. The parameters of the new kinematic assumption are: reference surface displacements, rotations about the Gaussian coordinate axes, and a thickness-direction stretching parameter.

The paper documents the rationale for the kinematic assumption made, demonstrates its various features, and provides investigation of the correctness of results obtained using this assumption. Correctness is argued by use of results from finite element analysis using a specially derived element, for axially symmetric geometry and load, and assumed axisymmetric response. Test cases include isotropic materials and laminates of orthotropic materials.

The paper also provides consideration of the mathematic complexities of incorporation of the new kinematic assumption into shell theory, and hoped-for benefits of a modified shell theory approach to analysis of laminated structures.

References

[1] Vinay K. Goyal, and others, "An Irreversible Constitutive Law for Modeling the Delamination Process Using Interface Elements," *43rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference*, April 2002, Denver, CO

[2] Erasmo Carerra, "Developments, Ideas, and Evaluations Based upon Reissner's Mixed Variational Theorem in the Modeling of Multilayered Plates and Shells," *ASME Applied Mechanics Reviews* **54**, pp. 301-328, 2001

[3] Scott E. Steinbrink, "On a Proposed New Kinematic Assumption for Analysis of Laminated, Fiber-Reinforced Composite Shells – Part 1," *ASME Pressure Vessels and Piping Conference,* July 2003, Cleveland OH.

Keywords: laminated structures, failure