Higher-order Cohesive Segment Method for Dynamic Delamination Analysis in an Explicit Solver

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ABSTRACT

Cohesive zone models (CZM) have gained vast applications in the progressive failure analyses of composite structures. However, rapid design iteration of large composite structures is still infeasible due to the high computational costs of these models. Each cohesive zone must be discretised with several linear elements to yield sufficiently accurate and stable crack propagation, because of the poor bending and shear profile captured around the crack tip [1]. Interface elements are defined at potential crack planes to provide cohesive tractions. This approach becomes very labour intensive in the model setup, and computationally expensive for structures with many potential crack planes. To this end, discontinuities can be adaptively introduced into the bulk elements via remeshing [2] or enrichment functions [3]. In explicit dynamic analyses, spurious oscillations have been reported upon creation of new surfaces [4-5]. Some attempts to resolve the issue involved the use of ad-hoc damping coefficients [4], force correction methods [5] or resorting to static implicit analyses to eliminate all dynamic effects. In the present work, a higher-order cohesive segment method is proposed to address these challenges; here the bulk elements are split at arbitrary locations through the thickness where the delamination criterion is satisfied. This is followed by the application of uniquely shifted cohesive laws, where the cohesive tractions are introduced without using interface elements.

The split is created through adaptive local *h*-refinement in the thickness direction of the bulk element. A transition element has been formulated to connect the pristine and split elements to guarantee C0 continuity in displacements across the crack support nodes. An arbitrary number of split elements with only displacement degrees of freedom can be supported by the transition elements, hence a lumped mass matrix is easily obtained. The cohesive segment method is 'higher-order' in the sense that a bilinear cohesive law is used in conjunction with higher-order continuum elements. As a result, the relative displacement fields in the cohesive zones are captured more accurately, hence discretisation with larger element sizes are possible. To eliminate the spurious oscillations upon initiation of new cohesive segments, the cohesive law at each Gauss point is uniquely 'shifted', so that the interface stress states are the same before and after initiation. The approach is independent of the number of new surfaces created, loading conditions, mass-scaling and time-scaling of the model.

Using the developed methods, we studied several quasi-static benchmarks in modes I, II and mixed I/II; and dynamic fracture benchmarks in mode II using an explicit dynamic solver. Stable crack initiation and propagation were observed using only one element in the cohesive zone. With the use of higher-order bulk elements, off-angle or curved crack fronts can also be hosted in a single element. The number of degrees of freedom in the model is kept low initially and increase as elements split. Also, by utilising the artificial strength reduction technique [6], we observed stable delamination propagation using element sizes 4-5 times the cohesive zone length. Despite the higher computational cost per element, the overall computational cost is drastically reduced when the higher-order cohesive segment approach is used, due to the increased allowable element size, reduced model size and larger explicit time steps.

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