A cohesive phase-field model for intra-laminar damage in fabric composite laminates

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ABSTRACT

The phase-field paradigm provides a robust damage modelling approach which is equipped with capabilities of automatically predicting initiation, propagation, branching and merging of complex curvilinear crack topologies. To this point, phase-field modelling has been widely applied to study brittle fractures based on Griffith's theory, with some extensions also to ductile and cohesive fractures. Despite its immense popularity, its application to complex high-performance materials, for e.g. composites, has been limited. This is because most composites are not brittle in the Griffith's sense. Rather, they display quasi-brittle fracture characteristics wherein a crack is driven by cohesive forces present within the fracture process zone, which spans over a domain sufficiently large in comparison to the overall structure. As a result, industrial applications of phase-field method for composites using commercial software has not been much widespread, also due to its requirements of finer discretization and associated high computational costs.

The present work discusses the use of a cohesive phase-field model for simulating intra-laminar damage response in fabric composite laminates, which are widely used in aerospace industries. The damage model uses a linear crack-surface density functional which retains a pure-elastic behaviour until damage onset, and a quasi-quadratic degradation function which can be used to calibrate experimental strain softening curves, thereby accurately predicting quasi-brittle damage response in fabric composites. The nonlinear phase-field evolution equation is solved using a staggered solution scheme, and an Augmented Lagrange method is incorporated to facilitate irreversible evolution of damage phase-field variable. The implementation is done in Abaqus using standard S4 shell elements, which are ideal for modelling thin laminate structures. Furthermore, a sub-modelling approach is employed to reduce the computational complexity of the entire phase-field solution procedure. The proposed model is validated using a set of benchmark numerical and experimental damage results.

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