Carbon/epoxy composites are being utilized in primary aircraft structures to improve performance and saving weight. However, the brittle nature of carbon/epoxy shifts the critical damage type from fatigue cracking, found in metallic structures, to delamination. Currently, fasteners are employed en masse throughout the structure to address this type of damage by stopping the propagation of cracks as they reach the fastener, providing fail-safety by limiting the extent of the damage. The current research is aimed at optimizing the design of these delamination arrest features through both computational and experimental analysis.

The model consists of two carbon/epoxy split beams joined together by two titanium fasteners in series. The system is modeled in ABAQUS using the 2-D 4-node quadrilateral plane strain elements with each fastener modeled as two independent spring representing the axial and shear stiffnesses. Preload and clearance are modeled using a non-linear spring. The virtual crack closure technique (VCCT) is used to determine the mixed-mode crack propagation behavior.

The first fastener effectively shuts down Mode I propagation but the crack tip passes both fasteners under Mode II, indicating a need for multiple fasteners. Past the first fastener, the elastic resistance of the fastener as well as the crack face friction resist Mode II propagation, delaying the crack propagation until another failure mode occurs. However, under cyclic loading, at sub critical loading, propagation through the entire length of the sample is observed in some cases. Current work is to evaluate the capabilities of arrest fasteners to suppress delaminations under fatigue loads.

In concert, delamination arrest experiments have been conducted to validate the analytical tools. Carbon/epoxy pre-preg tape with a quasi-isotropic layup, ((0/45/90/-45)3S/crack)S, has been tested. The specimens were tested in tension to failure, with the crack tip location tracked visually. Reasonable agreement was accomplished between the experiments and analysis, with failure consistently occurring at the first fastener in quasi-static loading and delamination growth under cyclic loading.

The split-beam FEA model, in conjunction with the experimental testing, has shown that the presence of a fastener is highly effective in arresting the propagation of a crack by two primary mechanisms 1) its ability to restrict crack propagation to Mode II and 2), its elastic influence on the structure. The fastener is extremely effective in eliminating $G_I$ by preventing the opening displacement around the crack tip, forcing the crack into pure Mode II propagation. The subsequent increase in propagation load achieves the desired effect of crack arrestment, shifting the final failure mode away from delamination.
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