

Damage Tolerant Composite Design Principals for Aircraft Components Under Fatigue Service Loading Using Multi-Scale Progressive Failure Analysis

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Abstract

Virtual testing has increased in order to try new materials in structures earlier in an applications timeline. Progressive failure analysis can be combined with available data to accurately predict structure/component safety based on the physics of micro/macro mechanics of materials, manufacturing processes, and service environments. The robust methodology is show cased using blind predictions of fatigue stiffness degradation and residual strength in tension and compression after fatigue compared with test data from Lockheed Martin Aeronautics (**LMA**) and Air Force Research Laboratory (**AFRL**). The Multi-Scale Progressive Failure Analysis (**MS-PFA**) methodology in the **GENOA** software considers uncertainties and defects evaluated the damage and fracture evolution of three IM7-977-3 laminated composite layups at room temperature. The onset and growth of composite damage was predicted and compared with X Ray CT. After blind predictions, recalibrations were performed with knowledge of the test data using the same set of inputs for all layups and simulations and noting the methods used before and after knowledge of test. Damage and fracture mechanism evolution/tracking throughout the cyclic loading is achieved by an integrated MS-PFA extended FEM solution: **a)** Damage tracking predicts % contributing translaminar and interlaminar failure type, initiation, propagation, crack growth path, and observed shift in failure modes, and **b)** Fracture mechanics (**VCCT, DCZM**) predicts crack growth (**Crack Tip Energy Release Rate vs. Crack Length**), and delamination. The predictive methodology is verified using a building block validation strategy that uses: **a)** Composite Material Characterization and Qualification (**MCQ**) software, and **b)** the GENOA MS-PFA fatigue life, stiffness degradation, and post-fatigue strength predictions for open-hole specimens under tension/compression at RTD. The unidirectional tension, compression and in-plane shear lamina properties (D3039, D638, D3518) supplied LMA/AFRL were used by MCQ to reverse engineer effective fiber and matrix static and fatigue properties for the IM7-977-3 material system. The use of constituent properties identified root cause problem for composite failure and enabled the detection of damage at the micro-scale of the material where damage is incepted. The blind predictions for fatigue stiffness degradation and residual strength for open-hole in tension/compression for cyclic loaded ($R=0.1$) coupons at RTD were evaluated using FE mesh where one shell elements represents all layers in the 3 layups [0/45/90/-45]2s, [+60, 0, -60]3s, and [+30, +60, 90, -60, -30]2s, and approximately 2k shell elements was used to mesh the openhole geometry. The results for all simulations correlated well with test including the micro-graphs of damage during the fatigue life.

Keyword: 1) Virtual Testing, 2) Fatigue, 3) Multi-Scale Progressive Failure Analysis, 4) Damage and Fracture Evolution, 5) ASTM Coupons, 6) Building Block Validation Strategy, 7) Open Hole