Critical stiffness damage envelopes for multidirectional laminated structures under multiaxial loading conditions

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Abstract

Load-bearing laminated structures undergo complex crack evolution processes and consequent stiffness degradation, which leads to a decline in their overall performance. Thus, consideration of damage evolution is important for stiffness critical applications. In this study, a multi-scale damage model combining synergistic damage mechanics (SDM) with an energy-based damage evolution model is developed for multidirectional laminated structures. The SDM approach combines computational finite element-based micromechanics with continuum damage mechanics, enabling the evaluation of the laminate stiffness. The damage model predicts evolution of sub-critical matrix cracks in different plies under multiaxial loading. Model predictions, which include ply crack density evolution and laminate stiffness degradation, correlate well with available experimental data, while model results for various CFRP and GFRP multidirectional laminates demonstrate its robustness. Additionally, damage envelopes corresponding to pre-selected critical stiffness degradation levels are developed to serve as an alternative to current approaches of final failure envelopes, and are regarded as a useful design tool for stiffness critical composite structures in practical applications.

Keywords: Failure prediction; stiffness degradation; multiaxial loading; damage mechanics; critical stiffness damage envelopes; multidirectional laminates.

1. Introduction