Abstract

Matrix cracking is the first and most dominant mode of damage in polymer matrix composite (PMC) laminates resulting in significant stiffness degradation under static and fatigue loading. Matrix crack evolution and its effect on stiffness degradation in cross-ply laminates under static loading have been studied extensively in the past three decades. Various analytical framework based on energy and strength-based approaches have been used to predict the matrix cracking in composite laminates. However, there have been limited studies on multi-directional (MD) symmetric laminates.

In the present study, in the first part of the work, an analytical framework for matrix crack evolution for an MD symmetric laminate under static loading has been proposed using oblique coordinate-based shear-lag analysis coupled with probabilistic strength approach and Weibull distribution. The statistical parameters have been estimated from an experimentally observed matrix crack evolution data termed as master laminate.

A methodology has been proposed to account the in-situ transverse strength variation due to varying thickness and constraint due to neighbouring plies. The ply-by-ply crack density evolution has been simulated. The models have also been verified under bi-axial loading conditions.

The approach developed for static analysis has been extended to estimate the stresses in a cracked laminate under fatigue loading. Smith Watson Topper (SWT) parameter has been used to model the number of cycles to initiate the first matrix crack, along with log-normal probability distribution to handle the scatter in the crack initiation life.

The matrix crack growth rate has been modelled using Paris law based on mixed mode effective stress intensity factor. Employing the crack initiation curve and strength degradation based on Palmgren-Miner damage rule, further formation of new crack initiation has been simulated. The crack density evolution has been simulated for cross-ply and MD-laminates under various constant amplitude in-plane fatigue stress levels. The crack density evolution and associated stiffness degradation predictions under both static and fatigue loading have been compared with the existing experimental values. Good correlation was found to exist between the experimental data and the simulation predictions.

In the present work, it has been shown that, the statistical strength-based approaches can be used successfully, to predict the matrix crack evolution under static and fatigue loading in an MD laminates. The methodology proposed based on the semi-analytical approach, can be easily used by the designer, as a first stage design tool to compare different laminate stacking sequence/material system to choose better matrix crack tolerant laminate.