MIXED-MODE TRANSLAMINAR FRACTURE: EXPERIMENTAL RESULTS AND NUMERICAL MODELLING

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1 Introduction

Mode I translaminar, fibre-breaking, fracture (see Fig. 1) can be treated as a self-similar crack at the laminate level and can be quantitatively characterised as a fracture process in terms of fracture energies ($G_{Ic}$) \cite{1} or a traction-separation law \cite{2}. This laminate-level material property encompasses the energy dissipated by all microlevel damage mechanisms such as fibre-matrix debonding, fibre fracture and fibre pull-out.

Whilst the experimentally obtained $G_{Ic}$ has proved useful for numerically simulating translaminar failure \cite{3,4}, pure mode I loading represents a narrow portion of the design spectrum that an engineering component might see during its operational lifetime. A complete understanding of the translaminar fracture behaviour of composite laminates under a range of loading conditions is required for numerical design.

Thus far, relatively few studies have experimentally investigated the translaminar fracture behaviour of notched laminates under mixed-mode loading and, to the knowledge of the authors, none has explored the possible routes for numerically simulating this failure mode. This paper will present work that aims to address the questions that arise in both these areas.

2 Experimental

A mixed mode compact tension specimen and fixture have been developed \cite{5}, shown in Fig. 2, such that fracture tests can be performed on specimens under several mixed mode ratios by changing the loading angle $\theta$. An advantage of this new configuration over specimens that have been previously used in the literature is that the crack can be propagated in a stable manner under several mixed-mode loading ratios, therefore allowing for the detailed investigation of damage zone initiation and development.

A detailed fractographic analysis of failed specimens, identifying the mechanisms controlling mixed-mode failure will be presented. It will be shown through scanning electron microscopy (SEM) of the fracture surfaces of failed specimens, see Fig. 1, that increasing the component of mode II loading increases the amount of delamination and splitting. This amounts to an increase in fracture energy dissipation with increasing proportion of mode II loading.

It will be shown that while at low proportions of $G_{II}$, fracture can be characterised by a critical strain energy release rate (as has been done for the mode I), no single fracture property can be used to characterise failure as the proportion of shear loading increases and the damage becomes more diffuse.

3 Numerical simulation of mixed-mode failure

The fractographic and failure analysis of specimens form the basis for the development of an appropriate numerical modelling strategy.

We will present methodologies for numerical simulation of mixed-mode translaminar fracture designed to capture the relevant micro-mechanisms of failure. Results from simulations using commercially available modelling tools and from a newly developed damage model will be presented.
The model, implemented as a user material within Abaqus, is able to predict the response of the tested specimens and the features of the damage zone using a single layer of 2D elements alone, see Fig. 3. This new approach significantly reduces the analysis time by eliminating a considerable amount of model pre-processing and by increasing the computational efficiency of the analysis.

References


