High fidelity finite element analysis of tapered laminates with dropped plies

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Introduction

- Finite element analysis is now an integral part of the design process.
- Efficient, accurate models are necessary to predict failure.
- Virtual Testing is more than stress analysis.
- Important to prediction of the onset of damage and the evolution of material properties as damage increases.
- Such models allow engineers to assess the suitability of the materials for use in components.
- The large number of layup and configuration options for composites means that testing is not always feasible.
Virtual Testing

**Current**
Test backed up by Analysis

**Future**
Analysis backed up by Test

Components
Sub-components
Specific features
Generic features
Coupons

Test | Analysis
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Test backed up by Analysis

Analysis backed up by Test
Modelling Approach

- University of Bristol Approach has been to include discrete failure mechanisms in finite element models
  - Matrix cracks
  - Delaminations
  - Fibre failure

- Previous work has shown accurate simulations for coupon tests
  - Straight sided specimens
  - Fracture specimens

- Generic Features
  - Open Hole Tension

- Now extended the work to generic tapered specimens and more complex “representative” tapered specimen
Generic Tapered Laminates

- High fidelity models built of tapered laminates
- Individual plies included in the models
- Cohesive interface elements between plies
- Failure dominated by delamination
- Finite element analysis used to down select layup to test
Testing Configurations

• Two configurations manufactured
• Symmetric and asymmetric – give different bending/tension ratios
• Testing by MERL Ltd in iComposites programme – static and fatigue

Defects (embedded delaminations) were inserted at selected locations – chosen by analysis
Model-Test Correlation: Asymmetric

![Graph showing thin section stress vs cycles with labels: pristine, defect, delamination from ply drop.](image-url)
Model-Test Correlation: Symmetric

- **pristine**
- **defect**

- delamination from release film
- delamination from ply drop

**Cycles** vs. **Thin Section Stress [MPa]**

- **FE, pristine**
- **Exp, pristine**
- **Exp, defect**
Representative Tapered Specimen

- More complex than simplified tapered specimen
- Made up from a large number of pre-preg plies dropped off to create thickness change
- Tested in a dovetail type fixture
- Designed and manufactured at the University of Bristol
- To be representative of aerospace component features
- Modelled using the same analysis tools
- To inform and validate high fidelity modelling
Manufacture

- Custom tool developed and built
- Layup into tool with integrated bagging
- Specimens cut from finished plate
- Quality monitored by surface scans and CT X-ray

**Key Requirement:** Accurate, reproducible positioning of ply drops
Test/Model Correlation: Load-Displacement

- Force-displacement curves for (2D) slice and 3D models
Test/Model Correlation: Failure Location

- FE results were used to **predict** the site of delamination initiation
- **5 out of 6 specimens** delaminated within 1-2 millimetres from predicted location
Conclusions

- Composite failure usually initiates from highly localised features (or defects)
- High fidelity simulations have been necessary to capture influence of local features for accurate predictions of failure
- Static and fatigue simulations are now possible and taking account of the effect of defects at generic and representative feature level
- Good correlation has been obtained using only basic input parameters with no fitting
- Along with high fidelity analysis, high quality experimental data is required to develop understanding of failure and to validate models
Future Challenges

- How to model a full component when a feature model takes >500,000 elements?
  - Homogenised models
  - Shell elements

- Bridging the length scales
  - Micro-meso
  - Meso-macro
  - Multi-scale models

- Modelling the as manufactured condition
  - Effect of defects
  - Statistical variance

- New materials and manufacturing processes
  - 3D woven textiles
  - Fibre placement

- Computational resource
  - Very large numbers of CPU
  - Used efficiently

- Advanced Numerical Methods
  - XFEM
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