University of BRISTOL

High fidelity finite element analysis of tapered laminates with dropped plies

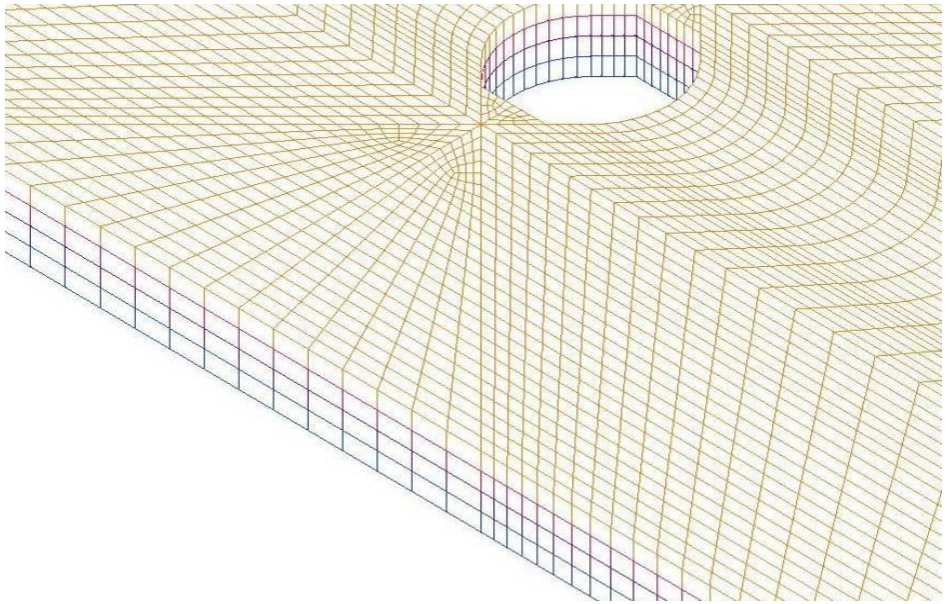
Stephen Hallett

www.bris.ac.uk/composites

ADVANCED COMPOSITES CENTRE FOR INNOVATION & SCIENCE

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

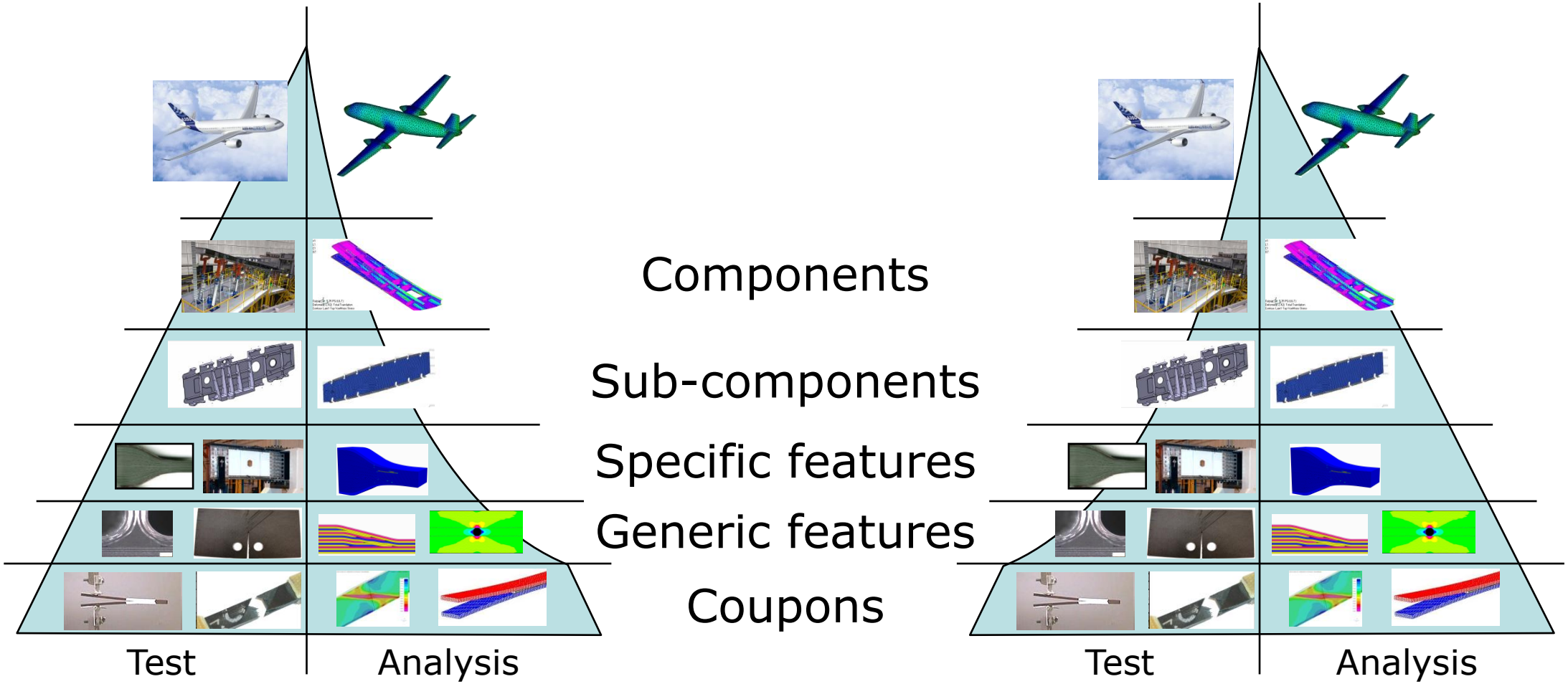
Virtual Testing

Current

Test backed up by Analysis

Future

Analysis backed up by Test

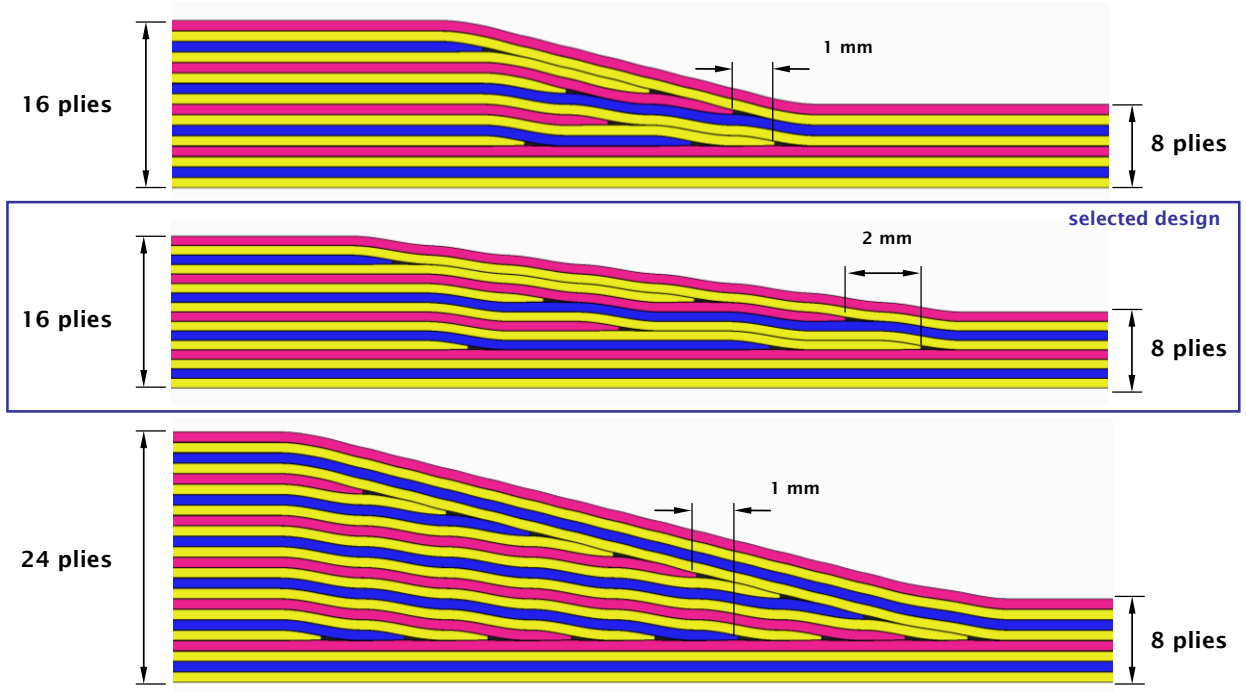


Modelling Approach

- 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

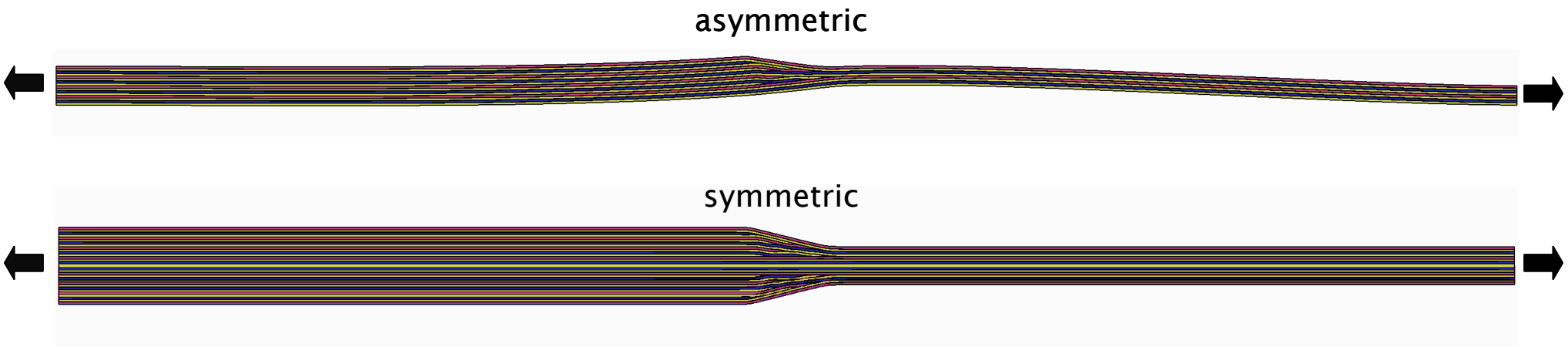
Generic Tapered Laminates

- 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



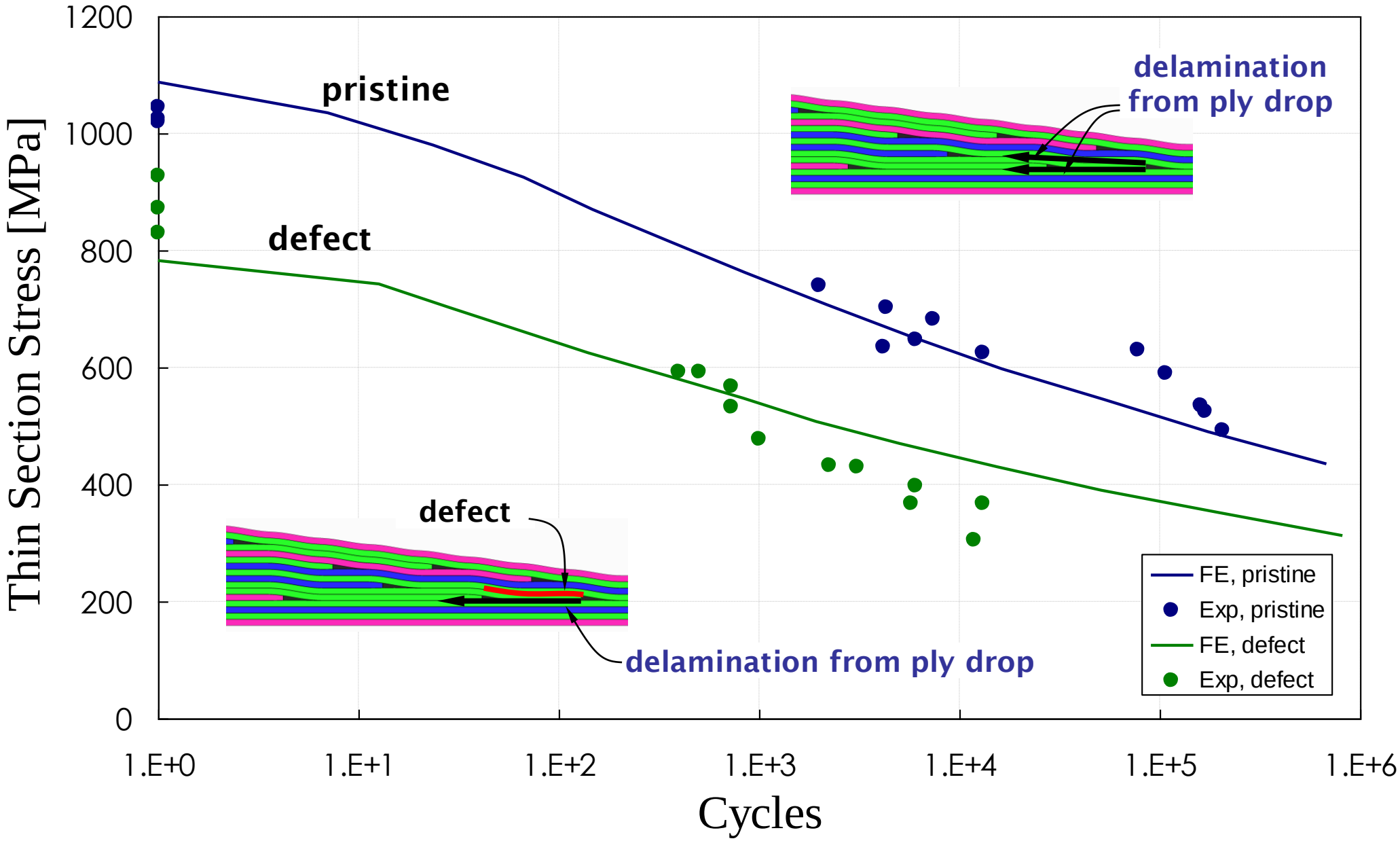
Testing Configurations

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

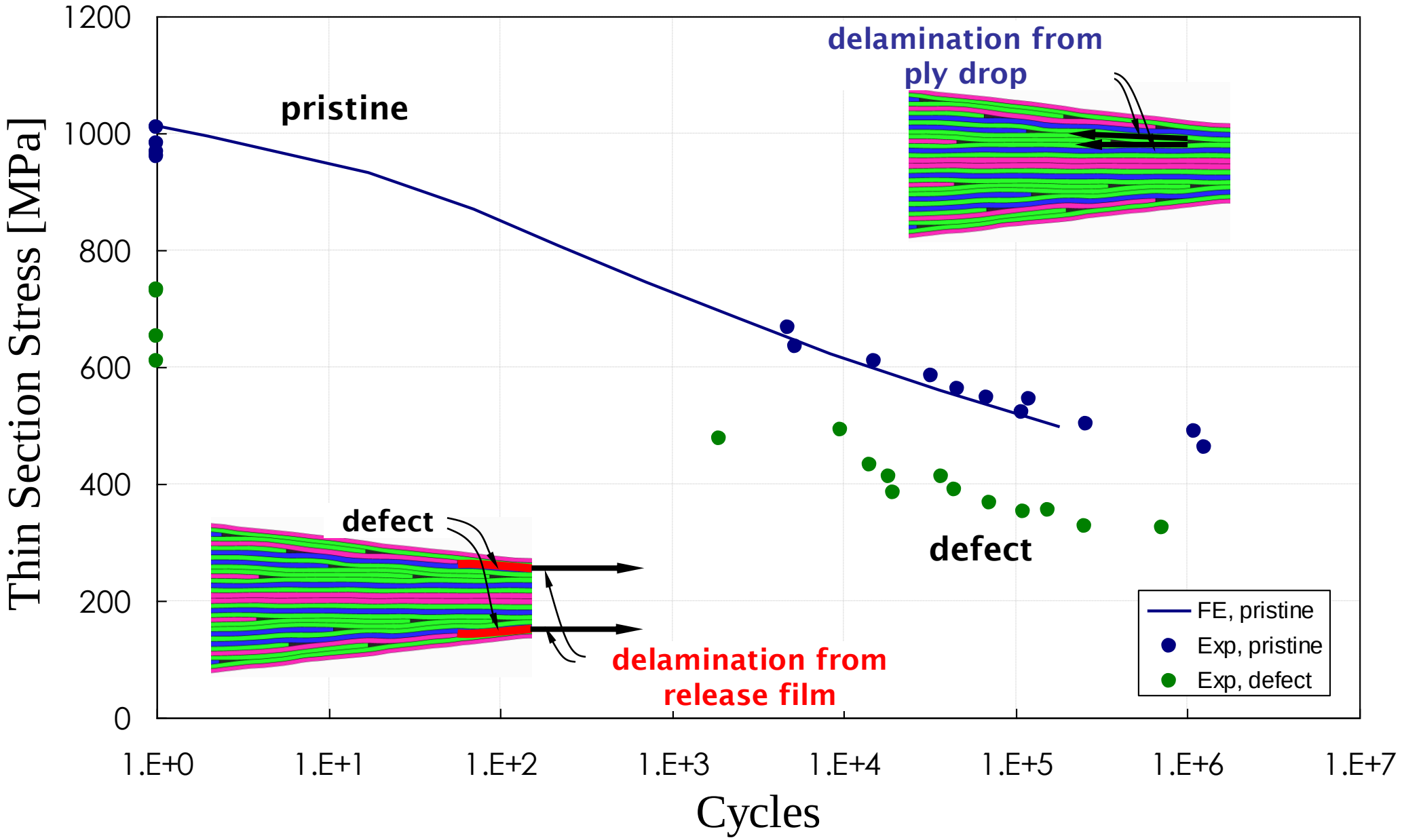


- Defects (embedded delaminations) were inserted at selected locations – chosen by analysis

Model-Test Correlation: Asymmetric

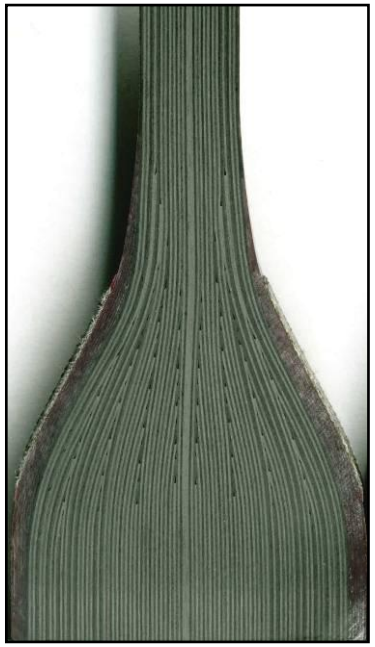


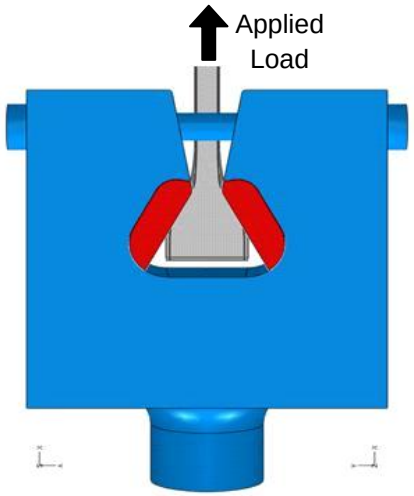
Model-Test Correlation: Symmetric



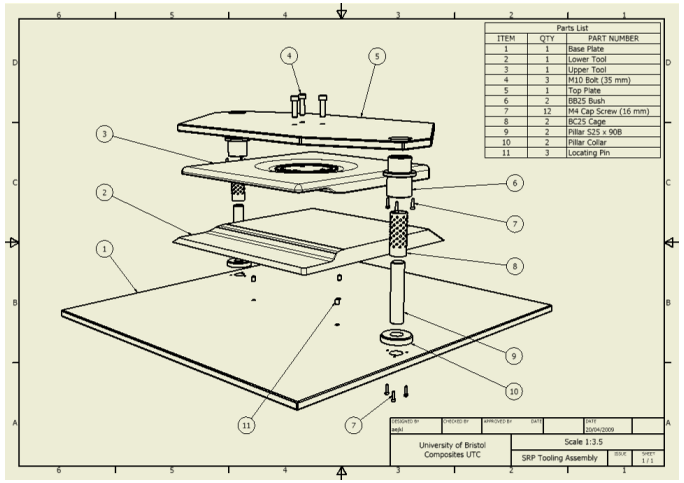
Representative Tapered Specimen

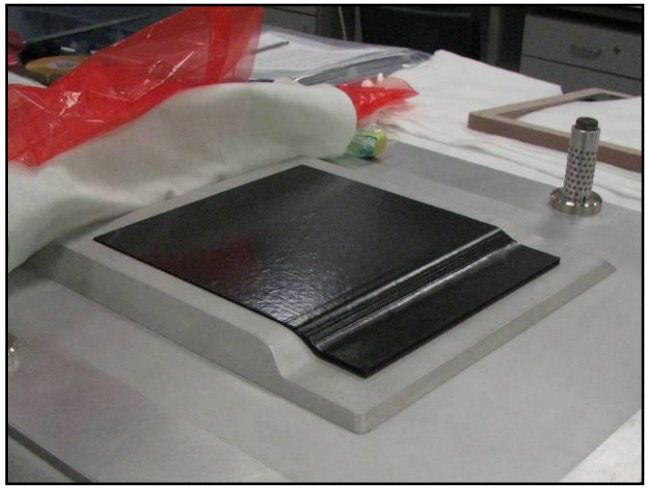
- More complex than simplified tapered specimen
- Made up from a large number of pre-preg plies dropped off to create thickness change
- Tested in a dovetail type fixture
- Designed and manufactured at the University of Bristol
- To be representative of aerospace component features
- Modelled using the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

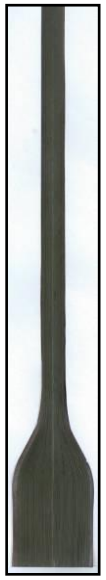




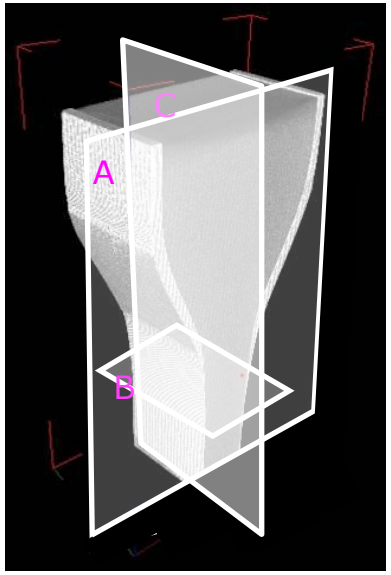
Manufacture







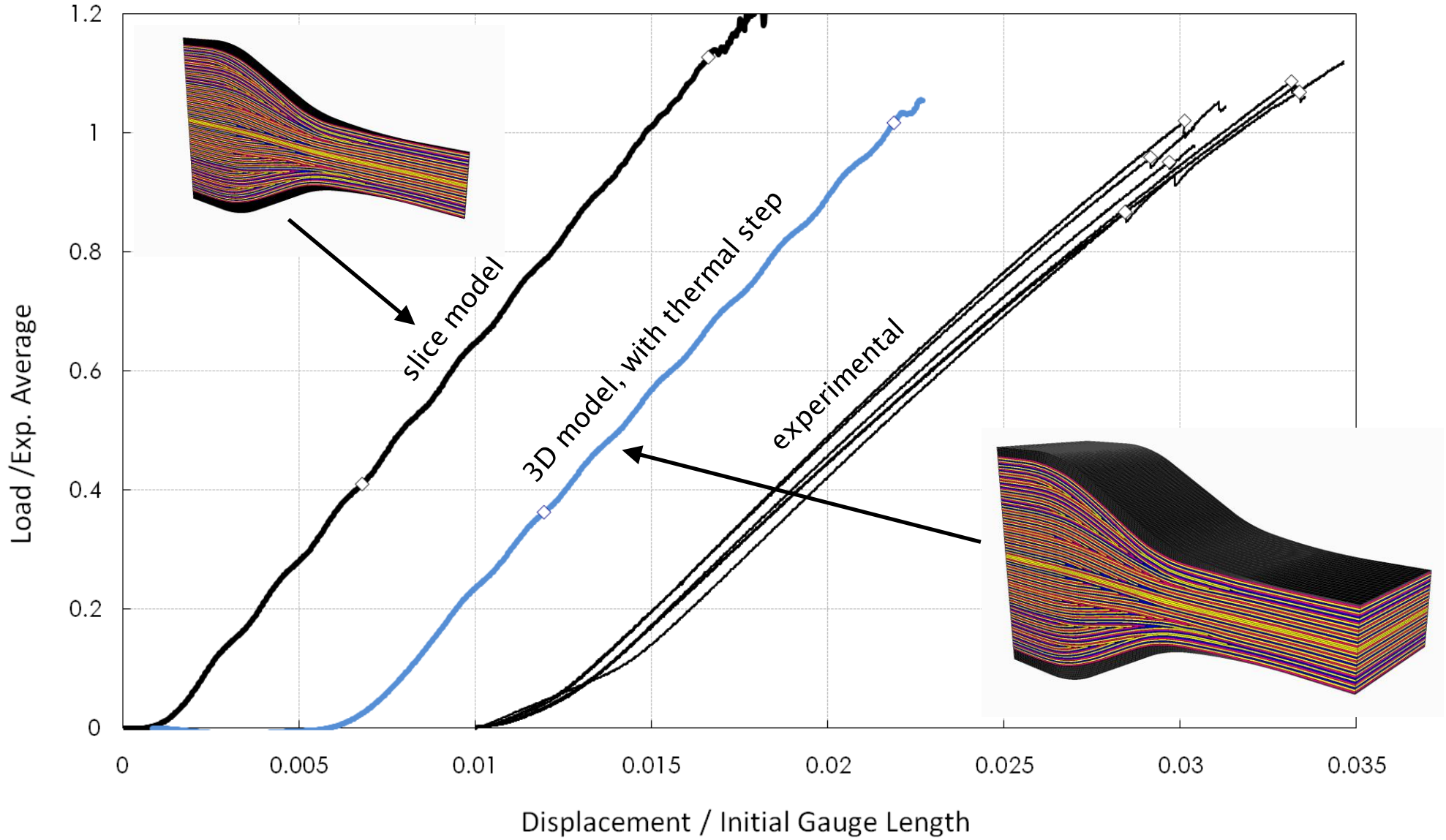
- Custom tool developed and built
- Layup into tool with integrated bagging
- Specimens cut from finished plate
- Quality monitored by surface scans and CT X-ray



<u>Key Requirement:</u> Accurate, reproducible positioning of ply drops

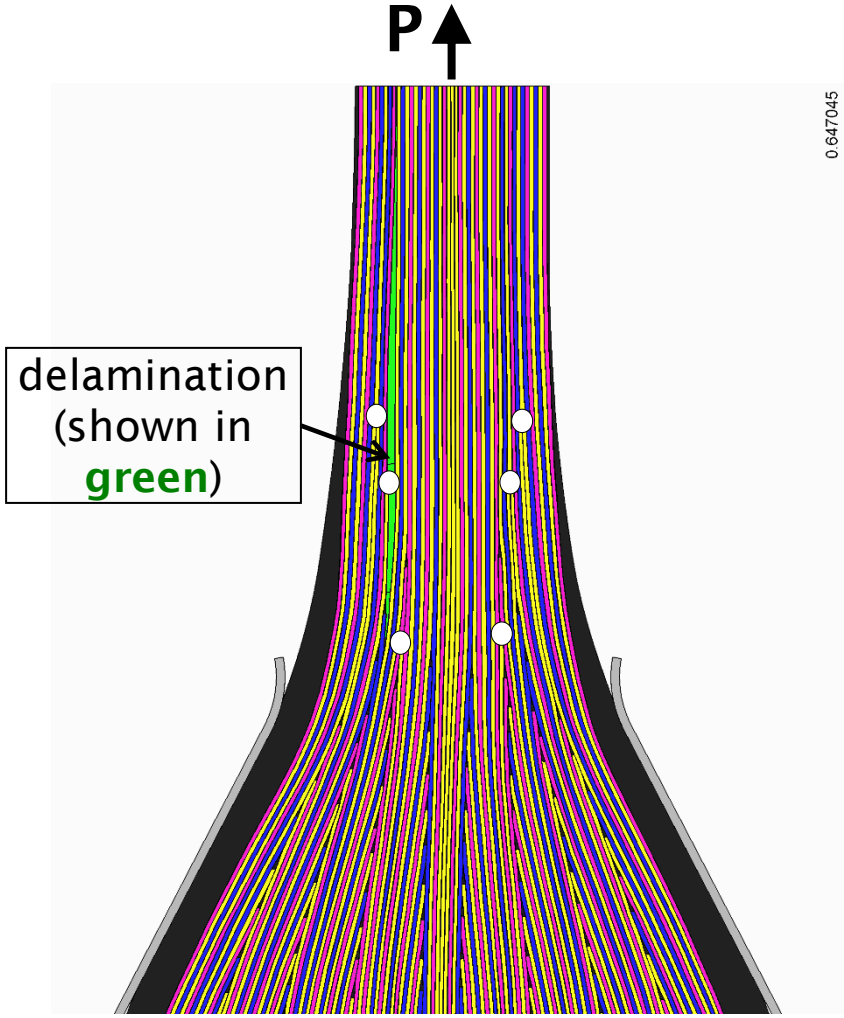
Test/Model Correlation: Load-Displacement

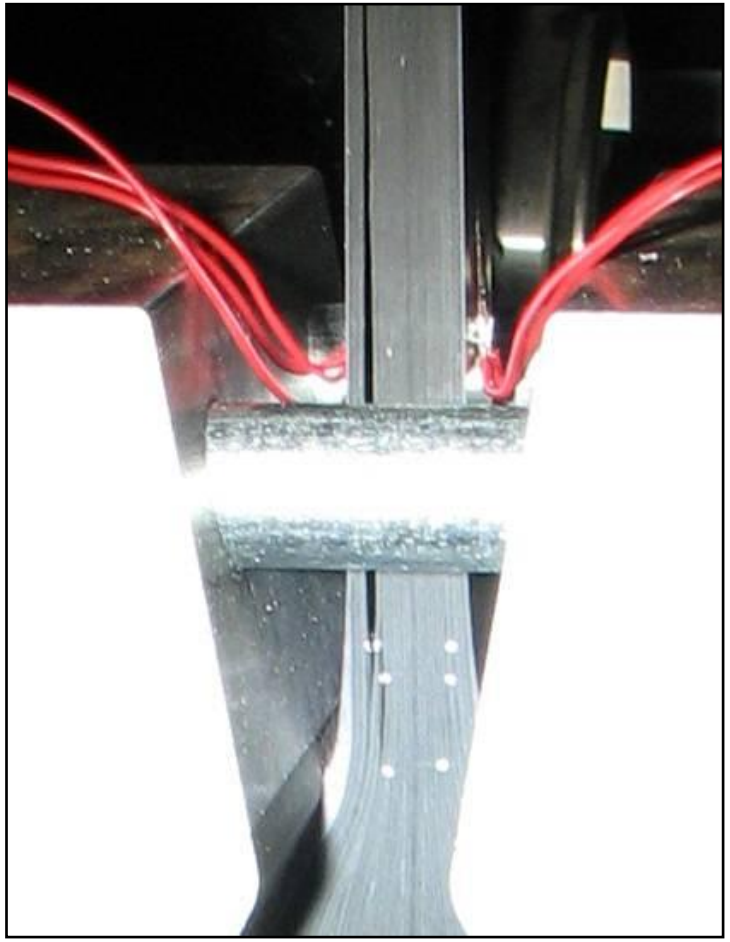
- Force-displacement curves for (2D) slice and 3D models



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

Acknowledgements

Research work on tapered laminates has been funded by Rolls-Royce plc through the Composites University Technology Centre at the University of Bristol

Colleagues who have contributed to the research work are:-

Luiz Kawashita, James Lander, Mike Jones, Giuliano Allegri and Michael Wisnom