University of BRISTOL

Modelling of defects and failure in composites

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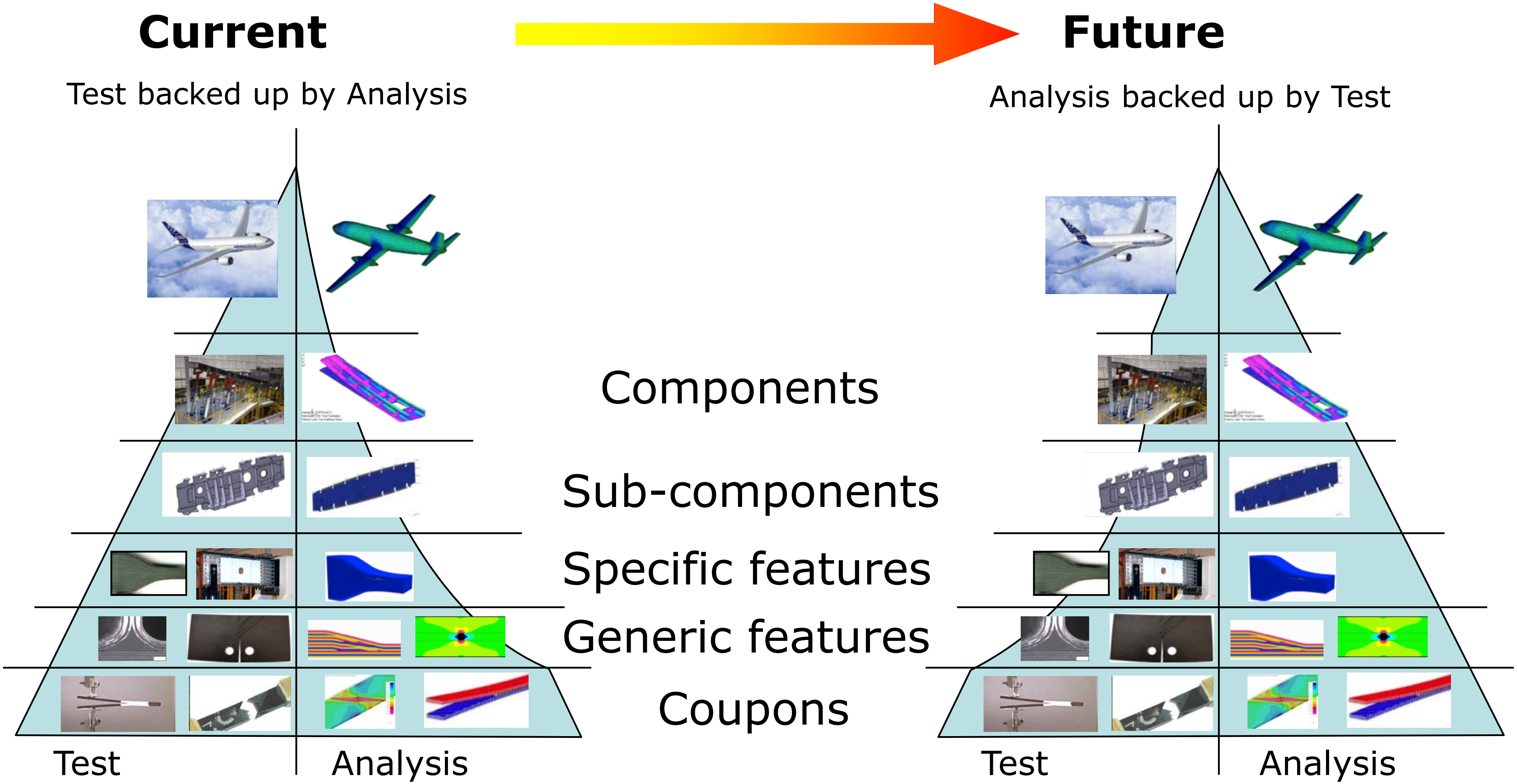
www.bris.ac.uk/composites

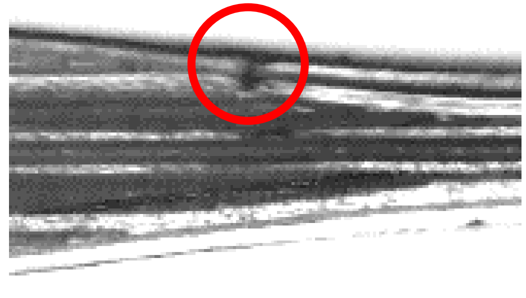
ADVANCED COMPOSITES CENTRE FOR INNOVATION & SCIENCE

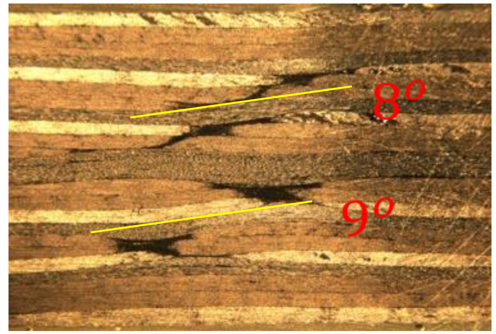
Virtual Testing

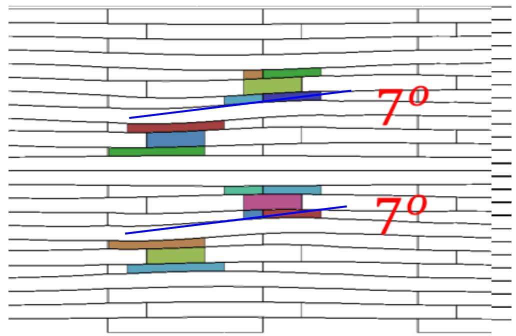


Defects and Features

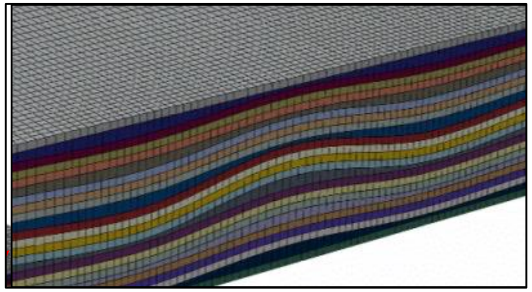
- Composites' structural properties are influenced by ply scale features in the geometry
- The as-manufactured component varies from the design intent
- Knowledge of the effect of defects is important for :
  - Certification
  - Design process to inform stress allowables
  - NDT and quality control for sentencing of defects
  - Test work to design representative specimens
- Large range of possible defects means testing of all cases is not possible – development of hi-fidelity modelling tools







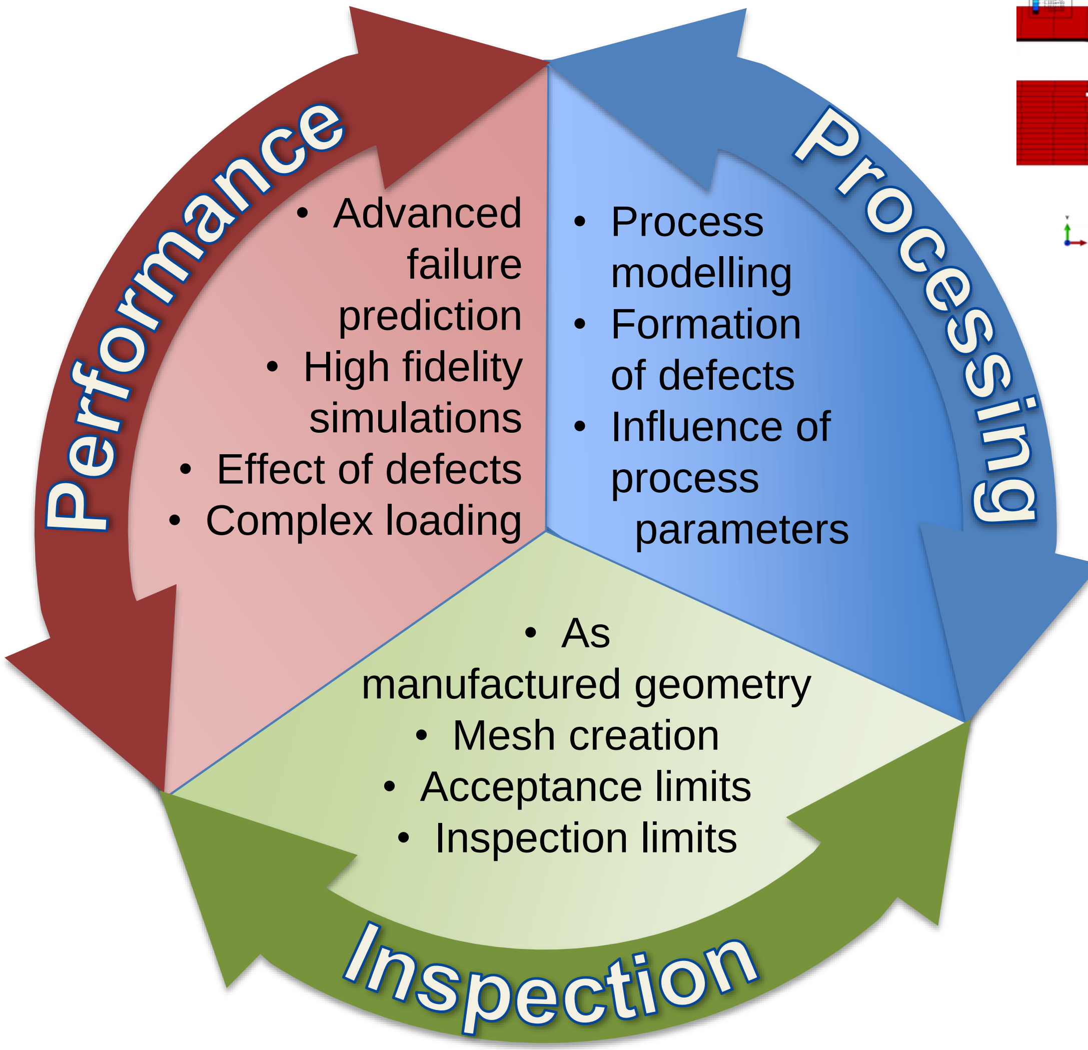
As-Manufactured Virtual Composites

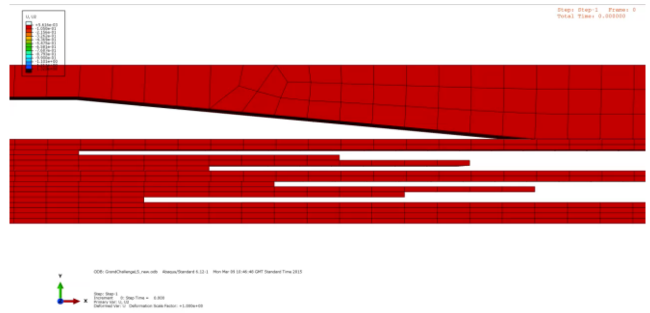


Effect of wrinkles

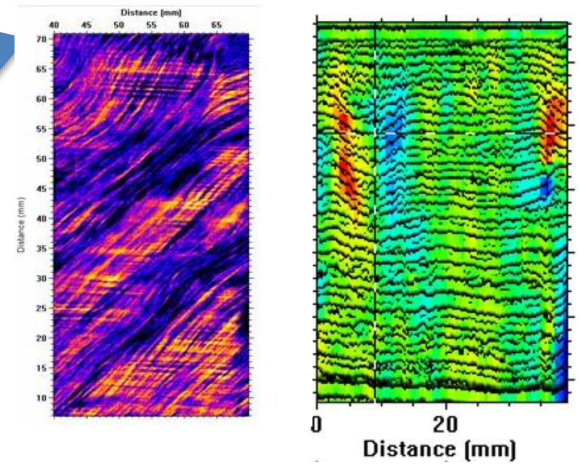
Ply drops and embedded delaminations

Textile composites





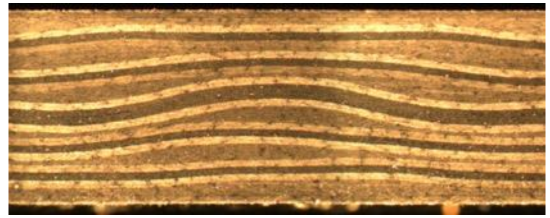
Process modelling

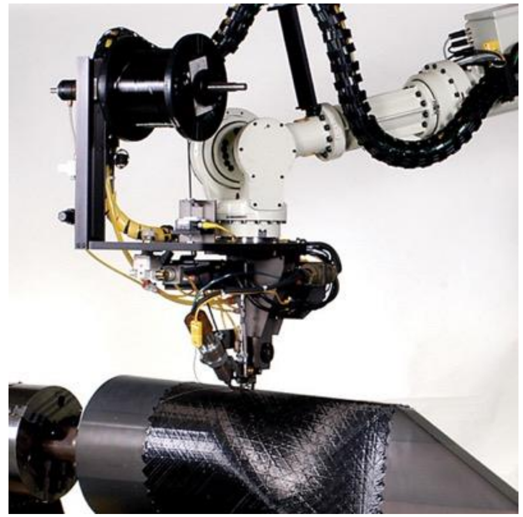


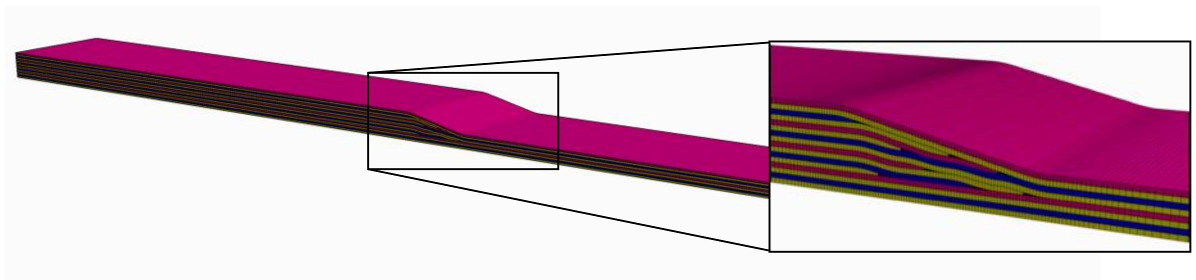
FE models from NDTdata

Defect Types

- Out of plane waviness
  - Critical defect in terms of reduction in compressive strength
- Gaps and overlaps
  - Caused by automated tape laying process
- Delamination defects
  - E.g. small inclusions or imperfections during layup
  - Simplified specimen used, combined with ply drops
  - Low velocity impact damage
- Voids and Porosity

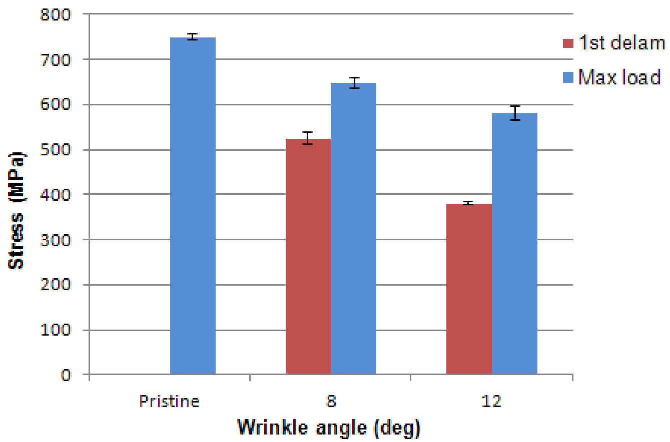


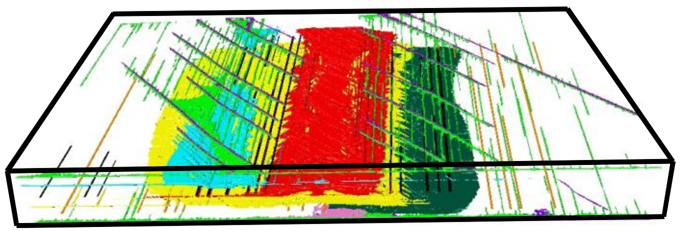


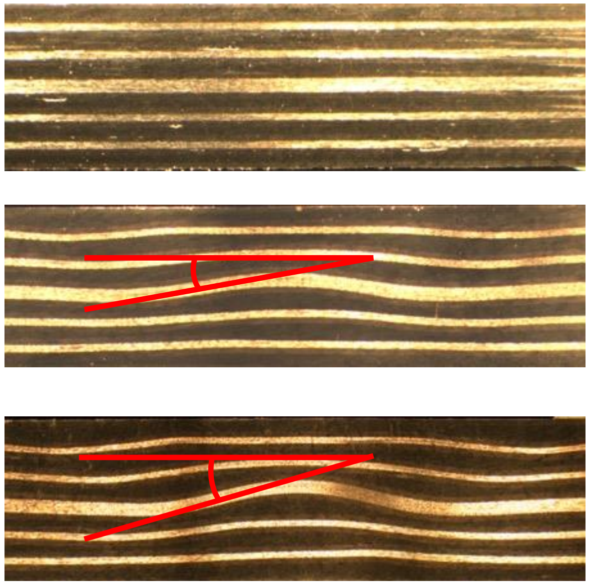


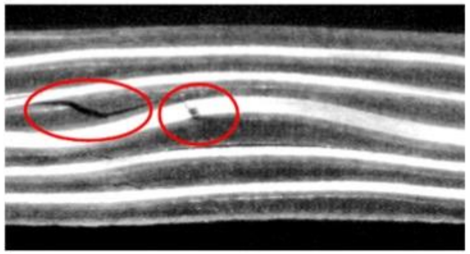
Wrinkle Experiments

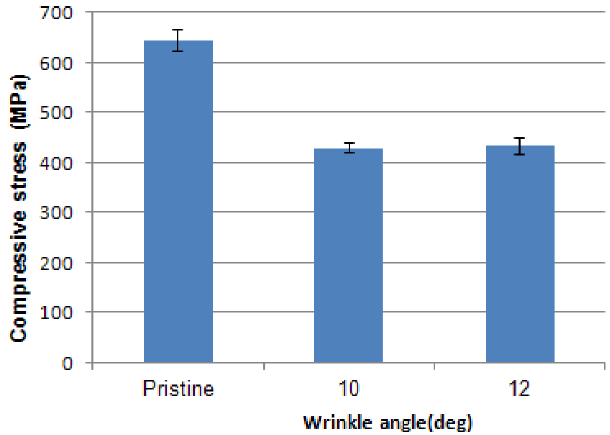
- Coupons with wrinkle angle θ (8° and 12° for tension, 10° and 12° for compression)
- Produced by varying the number of inserted 90° strips, together with pristine specimen for comparison.







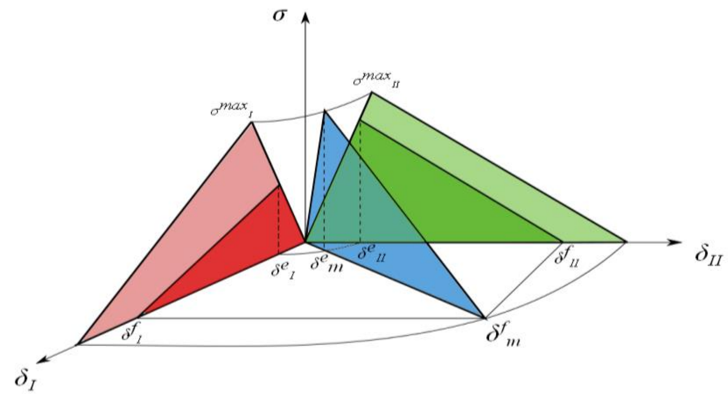


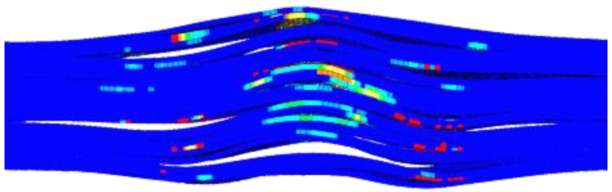


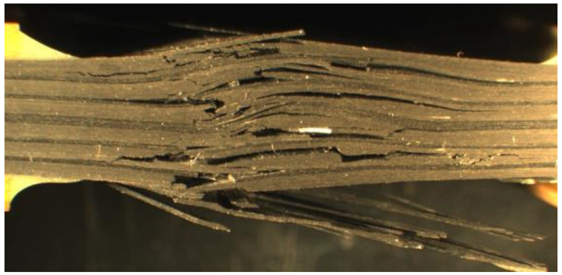
* Mukhopadhyay S., Jones M.I. & Hallett S.R. Composites 2013, Azores

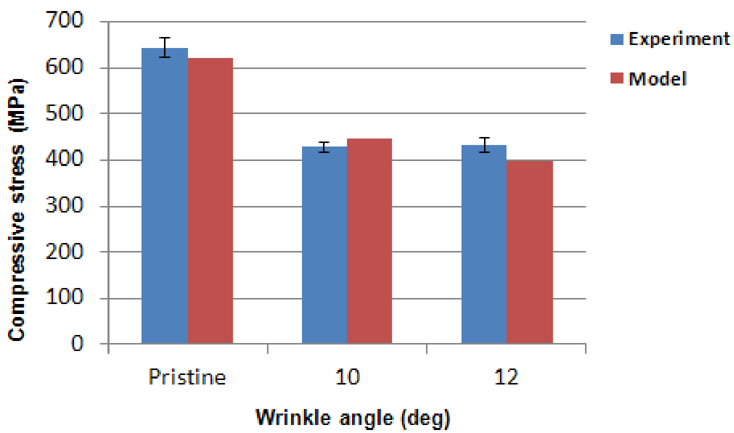
Wrinkle Modelling

- Modelled with ply-by-ply hi-fidelity analysis in Abaqus/explicit
- Cohesive interface elements for delamination
- In-plane damage models for matrix cracking and fibre failure

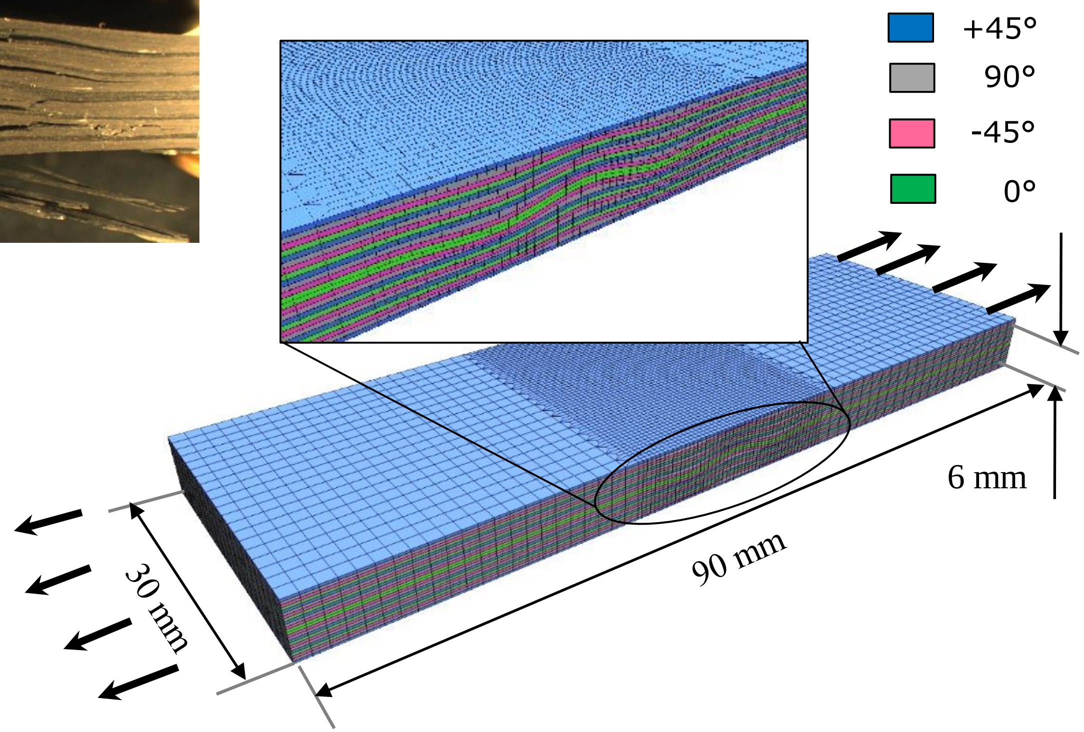








Compressive stress at final failure



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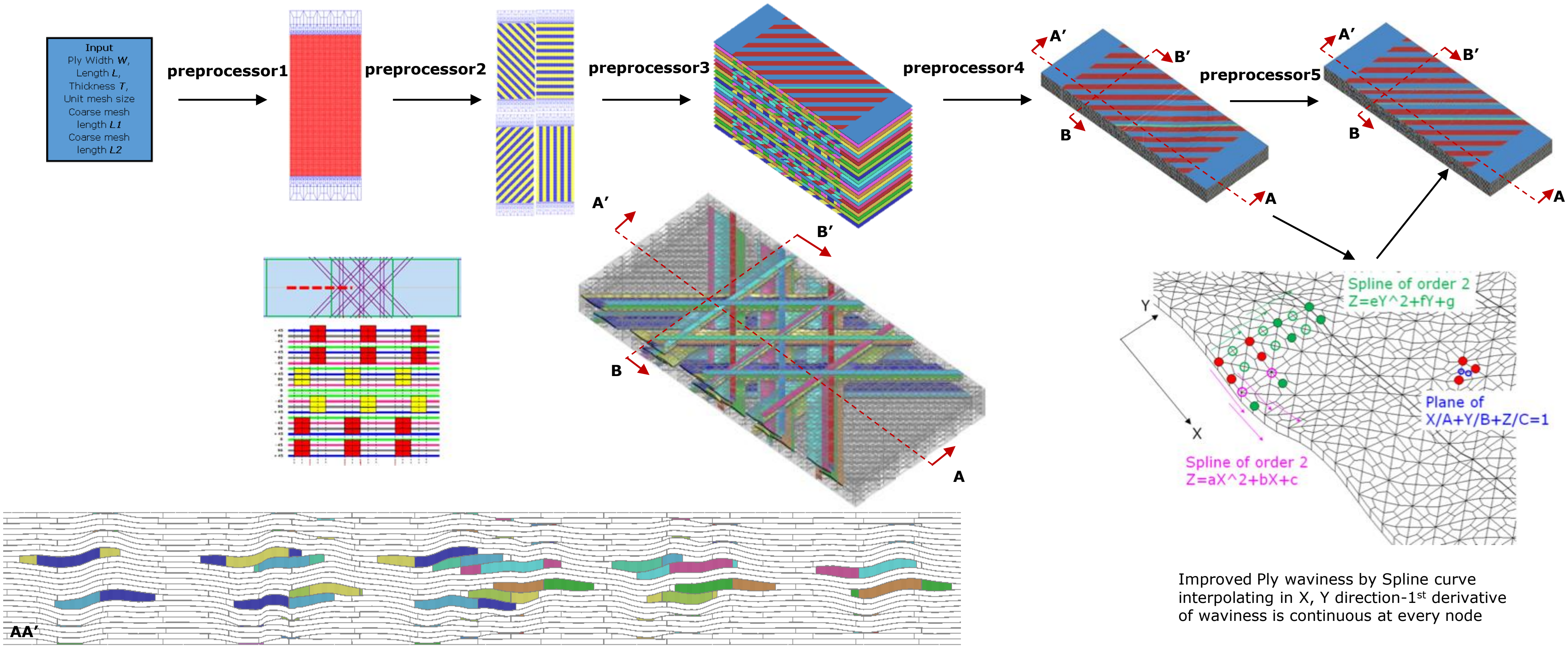
Hi-fidelity Gaps & Overlaps Modelling

- Internal geometry of plies and Gaps & Overlaps features is highly complex
- Requires custom tools for generating models with Gaps & Overlaps



Improved Ply waviness by Spline curve interpolating in X, Y direction-1st derivative of waviness is continuous at every node

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* Li X. et al, ICMAC, 2015, Bristol

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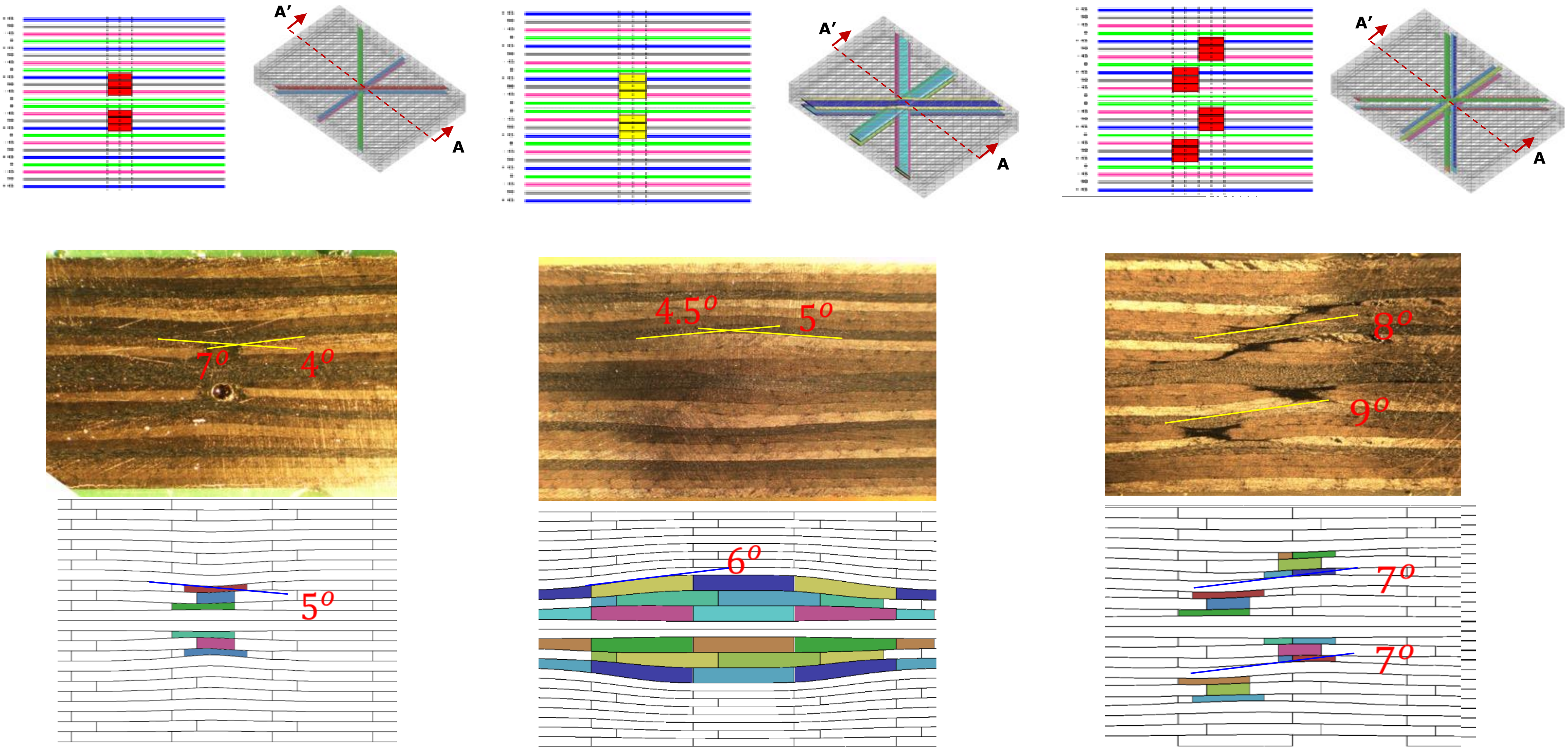
Gaps & Overlaps Models

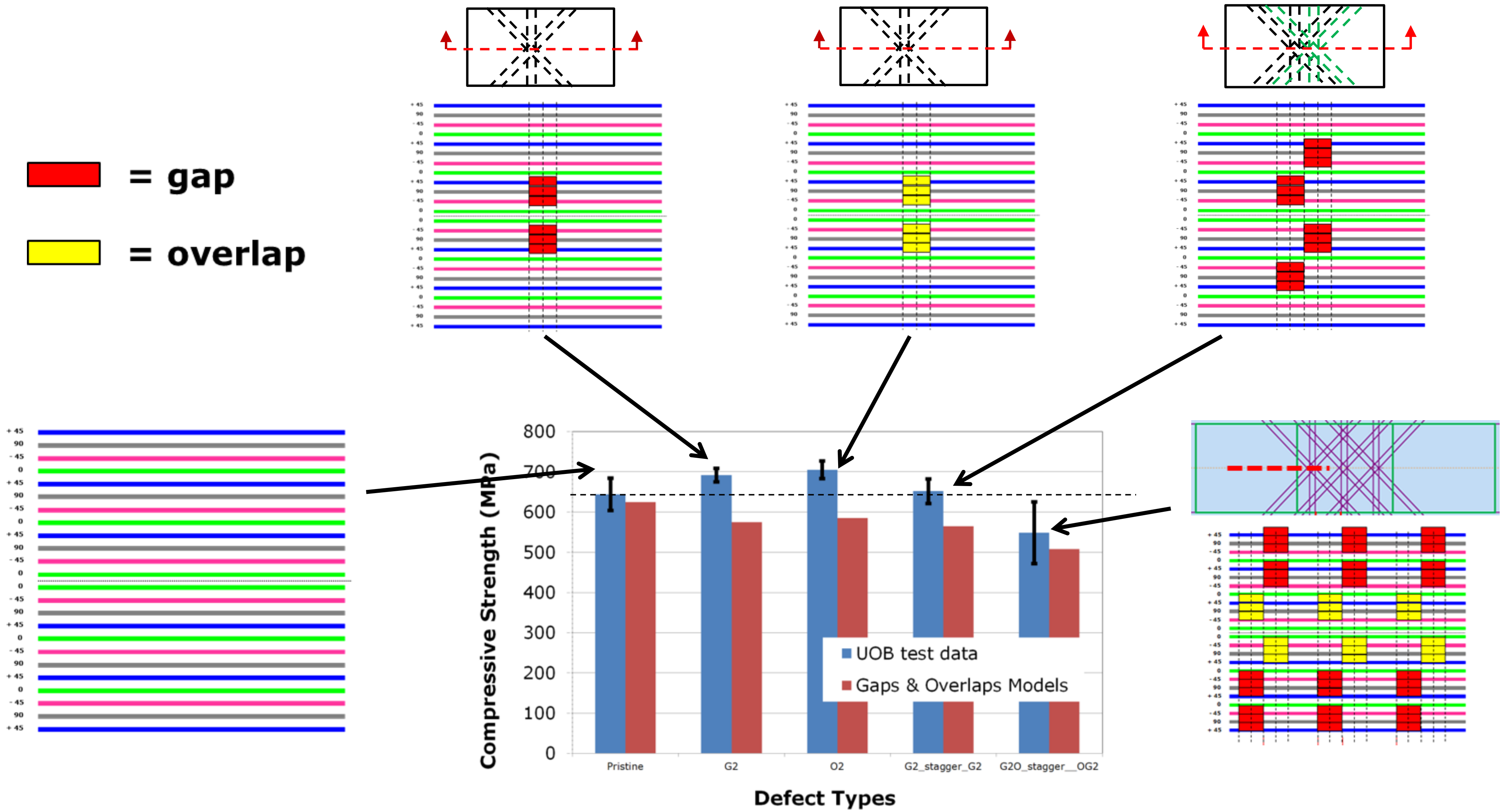
- Cross-section images

= gap   = overlap



* Li X. et al, ICMAC, 2015, Bristol

Compression Testing of Gaps and Overlaps



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* Li X. et al, ICMAC, 2015, Bristol

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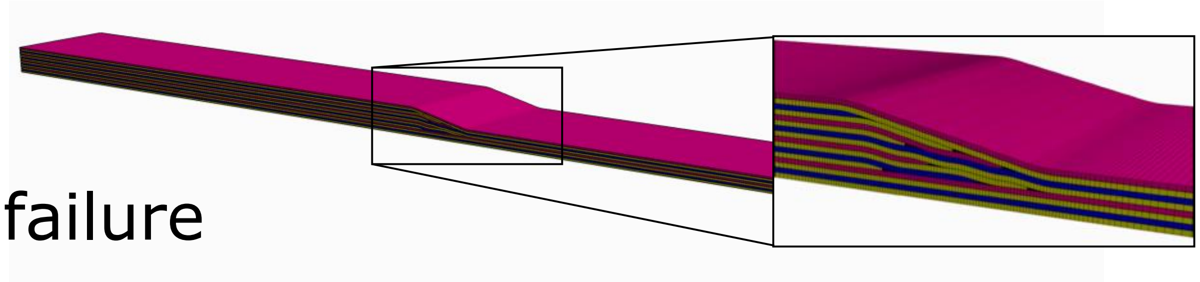
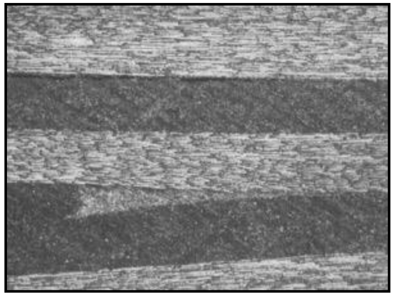
Delaminations and Ply-drops

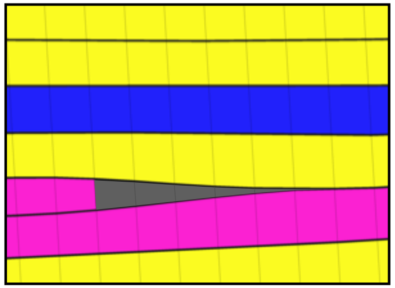
- Ply-drops are an unavoidable feature in variable thickness laminates



- Simplified specimen developed to examine failure
- Hi-fidelity modelling with cohesive elements used for assessment

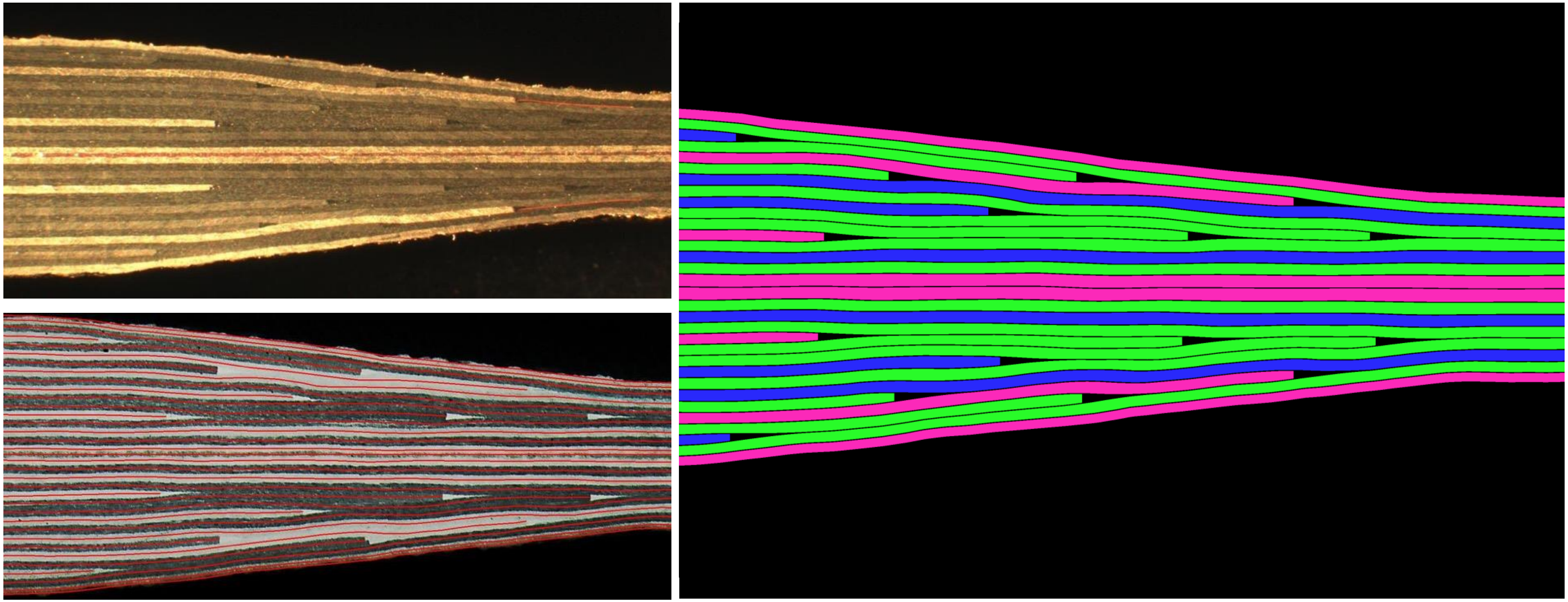


- Local geometry has a strong effect on strength
  - Ply waviness from layup
  - Shape of resin pocket at ply termination
  - Manufacturing defects leading to small delaminations at the end of ply terminations



Ply-Level Meshing Algorithms

- As-manufactured geometries and internal features captured initially by an image-based meshing technique
- Virtual testing can then be used to augment the building block approach – here considering a wide range of delamination defect locations



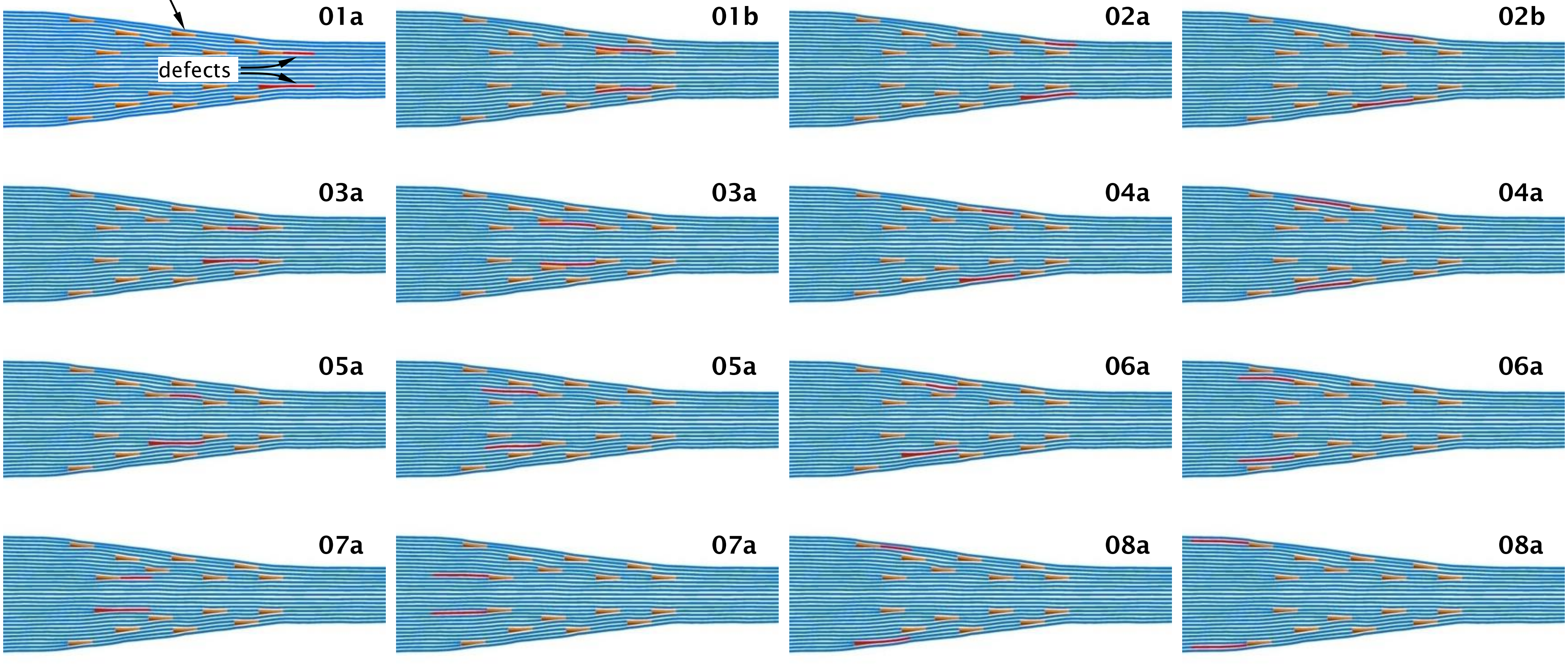
* Kawashita L et al, ICCM18, 2011, Jeju Island

Virtual Testing of Defects

- Example: 4mm long delaminations (NDT detection threshold) introduced near ply terminations
- Automatic mesh generation, job submission & post-processing in a Linux cluster; hundreds of runs completed overnight

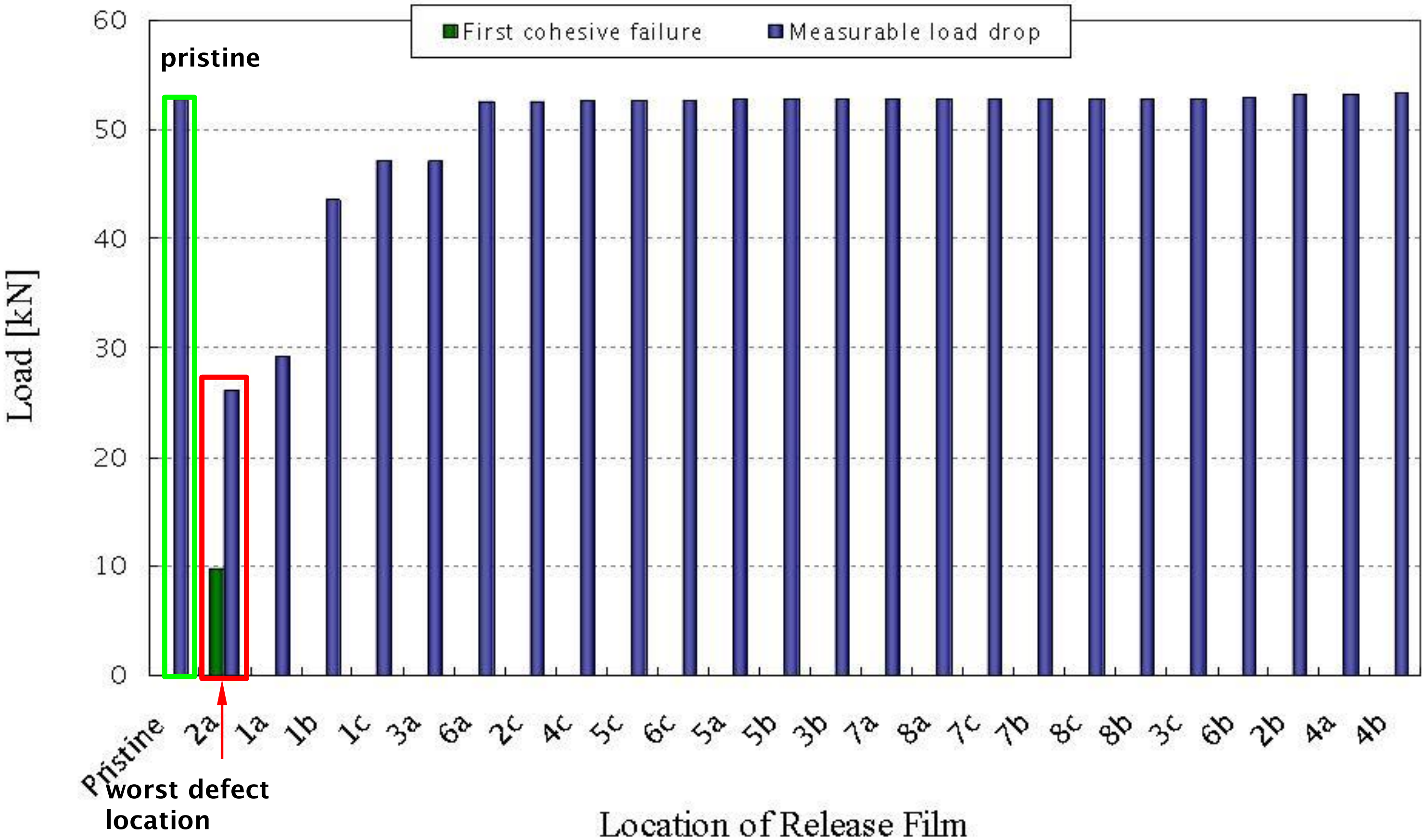
Runtime for each slice model:
<u>20-40 min*</u>

*previous generation 8-core HPC node

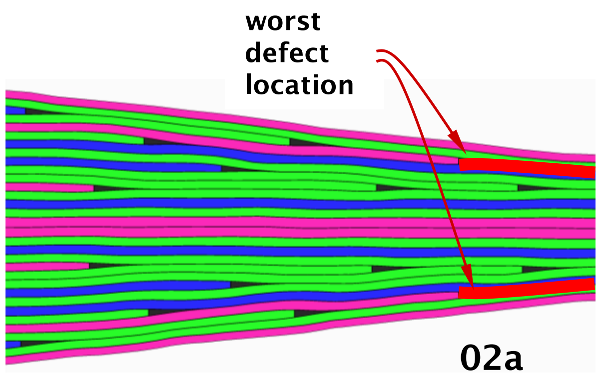


Virtual Testing of Defects: Static Strength

- Maximum strength knockdown, critical defect locations and respective delamination mode-mixities identified
- Methodology validated against experiments for various thickness and taper angles

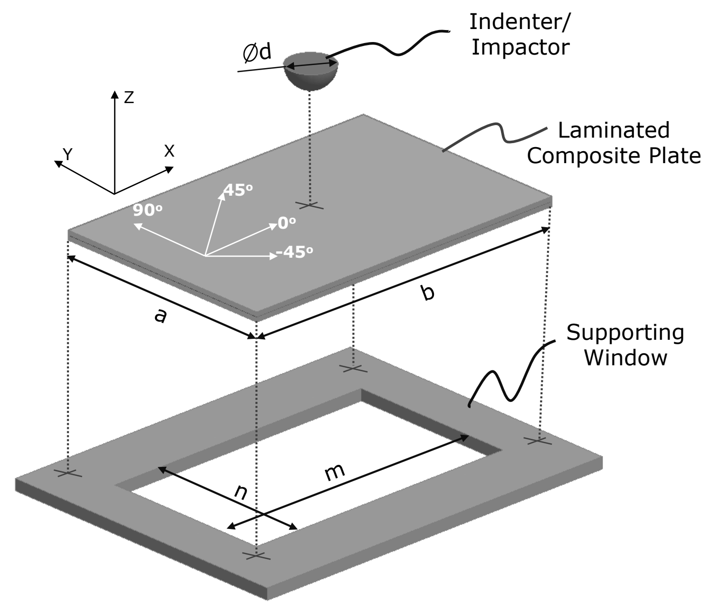


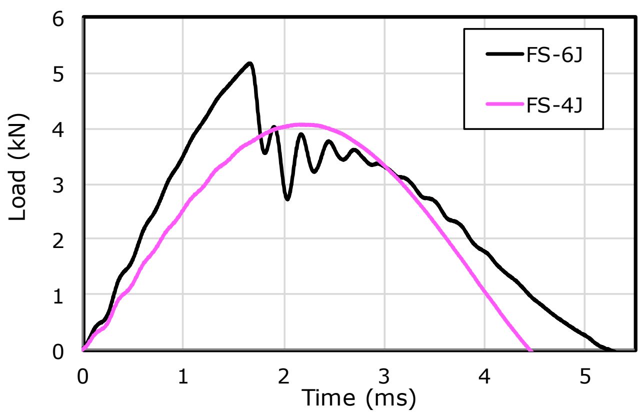
Symmetric specimens

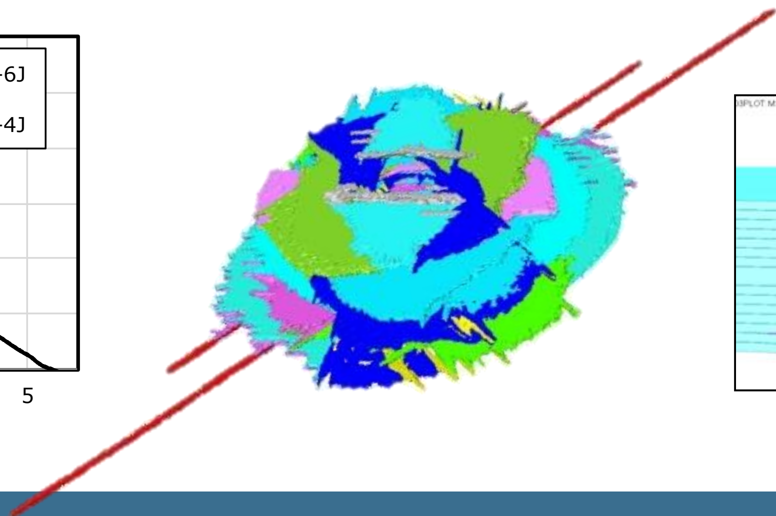


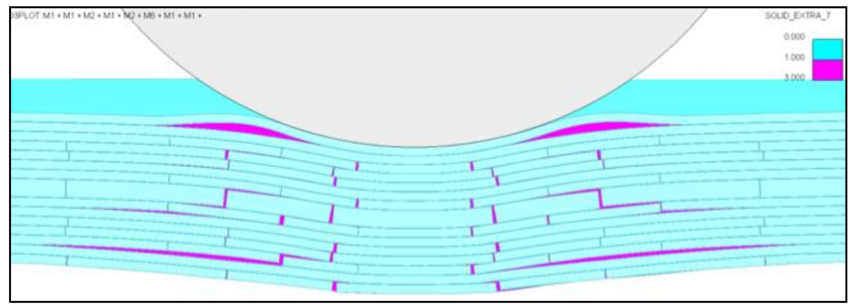
Impact Damage

- Low velocity impact is well known for introducing delamination damage (BVID)
- This dramatically reduces the Compression After Impact (CAI) strength
- Hi-fidelity models are able to accurately predict impact damage in the form of delamination, matrix cracks and fibre failure



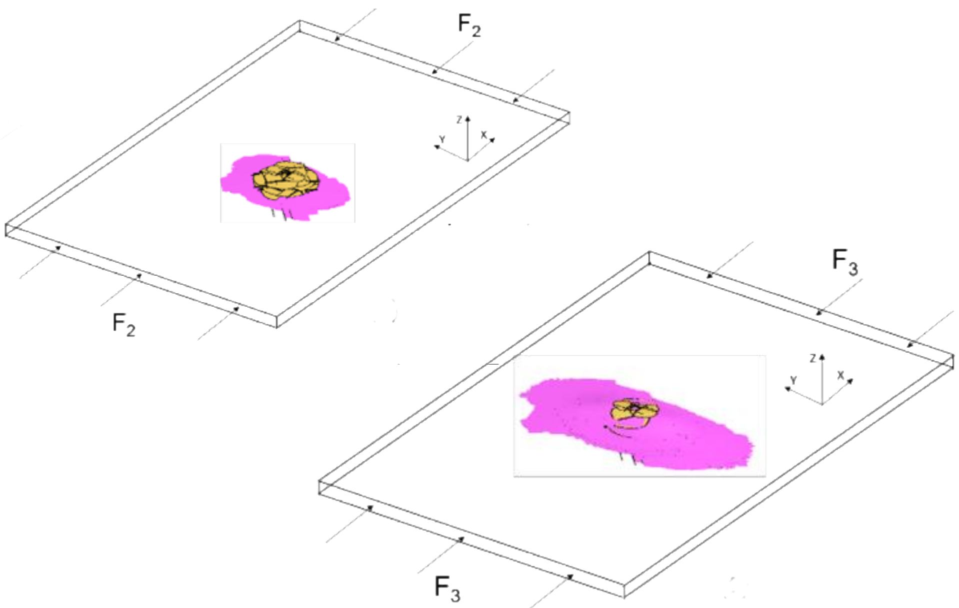


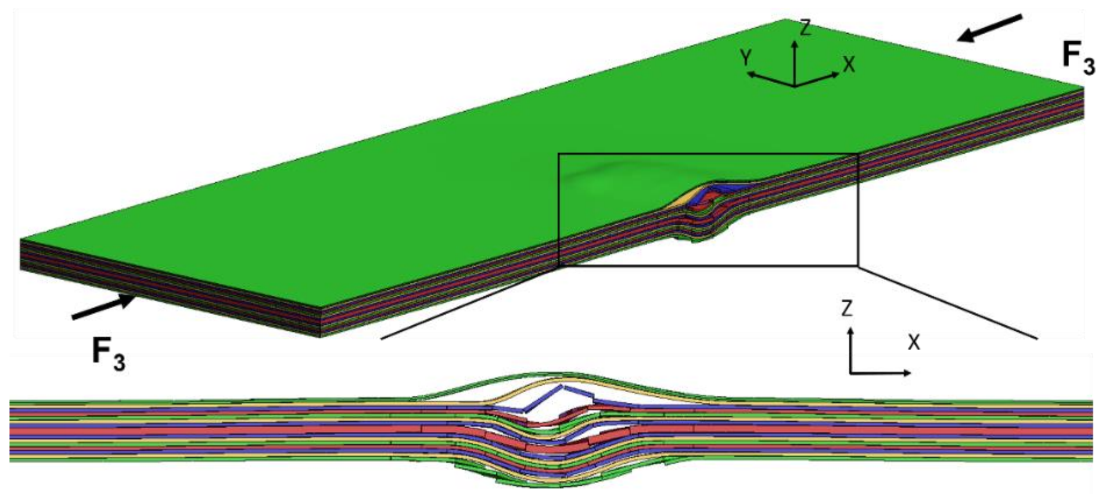




CAI Strength

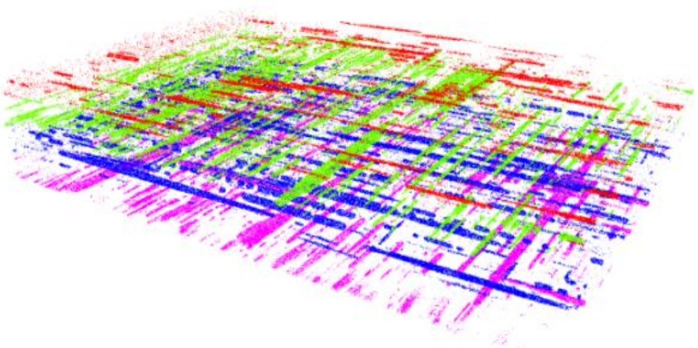
- Impact induced damage can be input into models either from simulation or test data
- In-plane loading of damaged panel caused growth of critical delaminations and ultimate failure
- Models can be used to predict failure and also study mechanisms in detail as well as effect of layup etc.

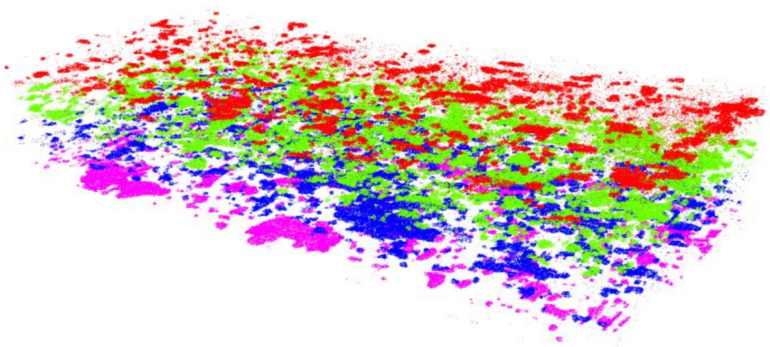


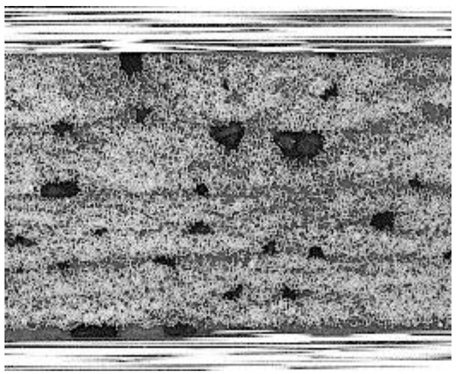


Voids

- Modelling of voids is not as well advanced as other defect types
- More challenging because the exact mechanism of failure from voids is not well understood
- Most work considers the knock-down due to global void volume fraction, but not local void morphology
- Current work is focussed on the detailed understanding of failure from voids to embed into future models

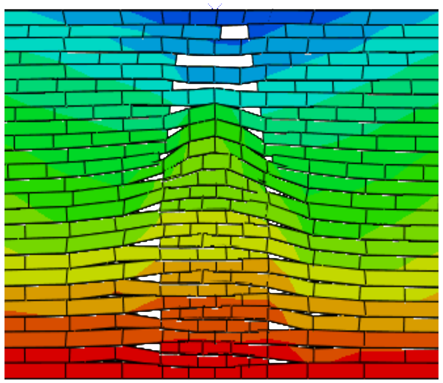


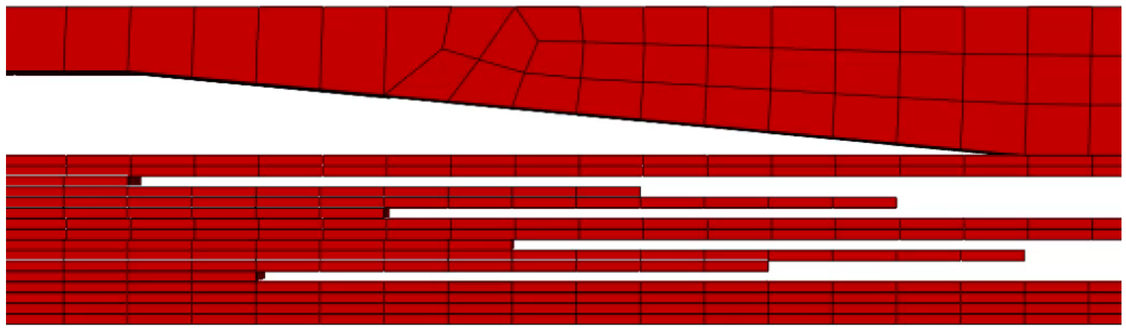




Process Modelling

- As well as failure behaviour, for design it is also important to understand the origin of defects
- Modelling can be used to predict the formation of defects, especially fibre waviness
- Compaction during processsing is a major driver of the excess length needed for creation of wrinkles
- FE models recently developed that can capture this behaviour





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
  - 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