University of BRISTOL

Challenges in Composite Mechanics

Michael R. Wisnom

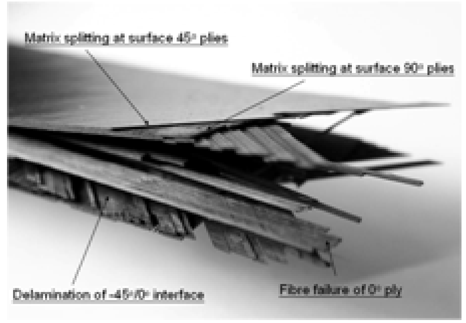
Director, ACCIS

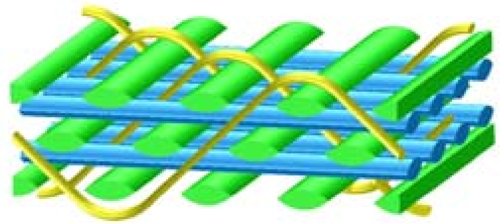
www.bris.ac.uk/composites

ADVANCED COMPOSITES CENTRE FOR INNOVATION & SCIENCE

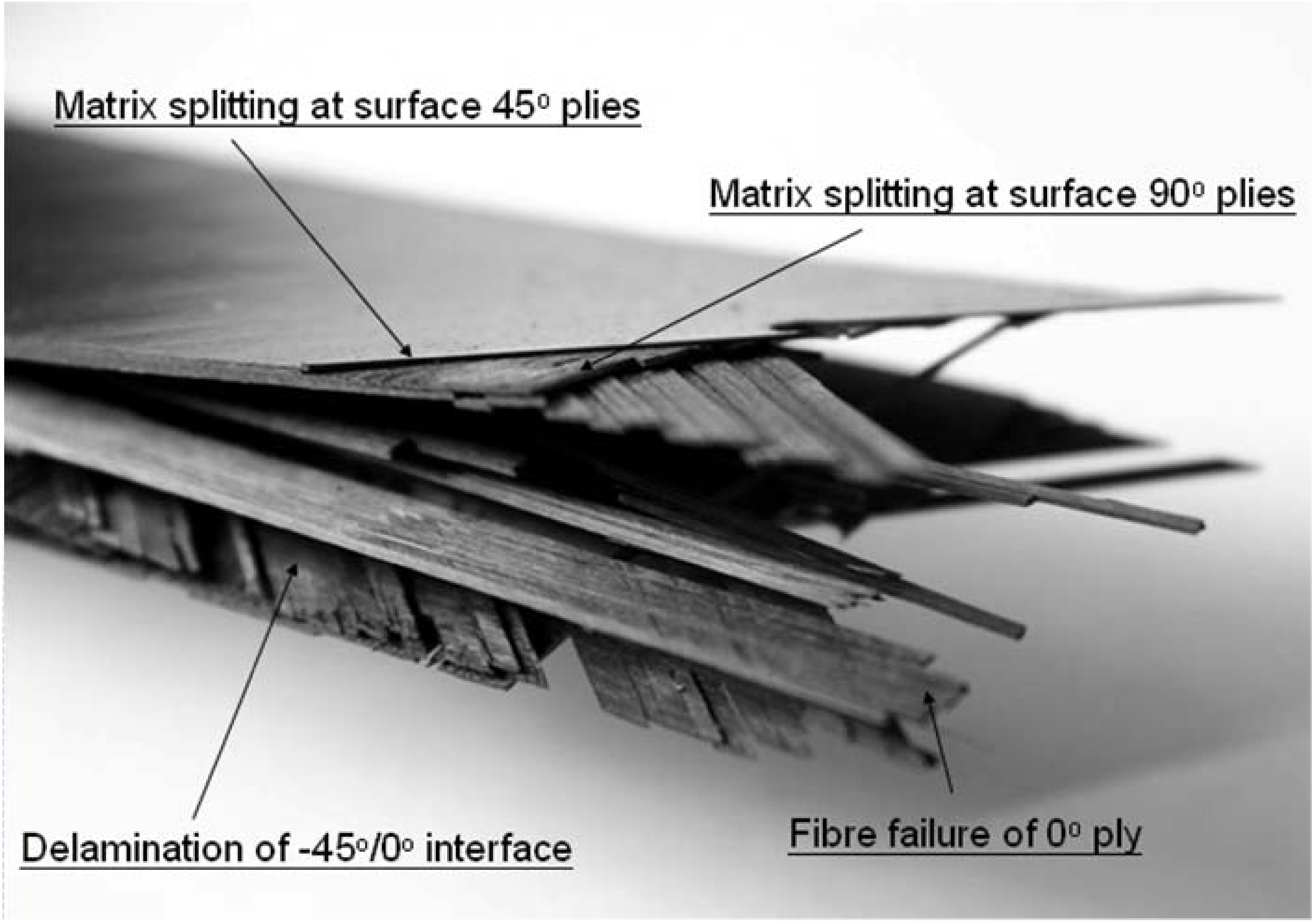
Challenges

- Complexity of behaviour
  - Models must be based on sound understanding
  - Requires good experimental techniques
- Failure determined at small length scales
  - Details are key e.g. ply drops, free edges
  - Defects can be very important
- Scaling up from micro to macro
- Many different architectures available
  - 3D weaving, braiding, through-thickness reinforcement
  - Tow placement
- Fatigue, impact, crash, fire behaviour…





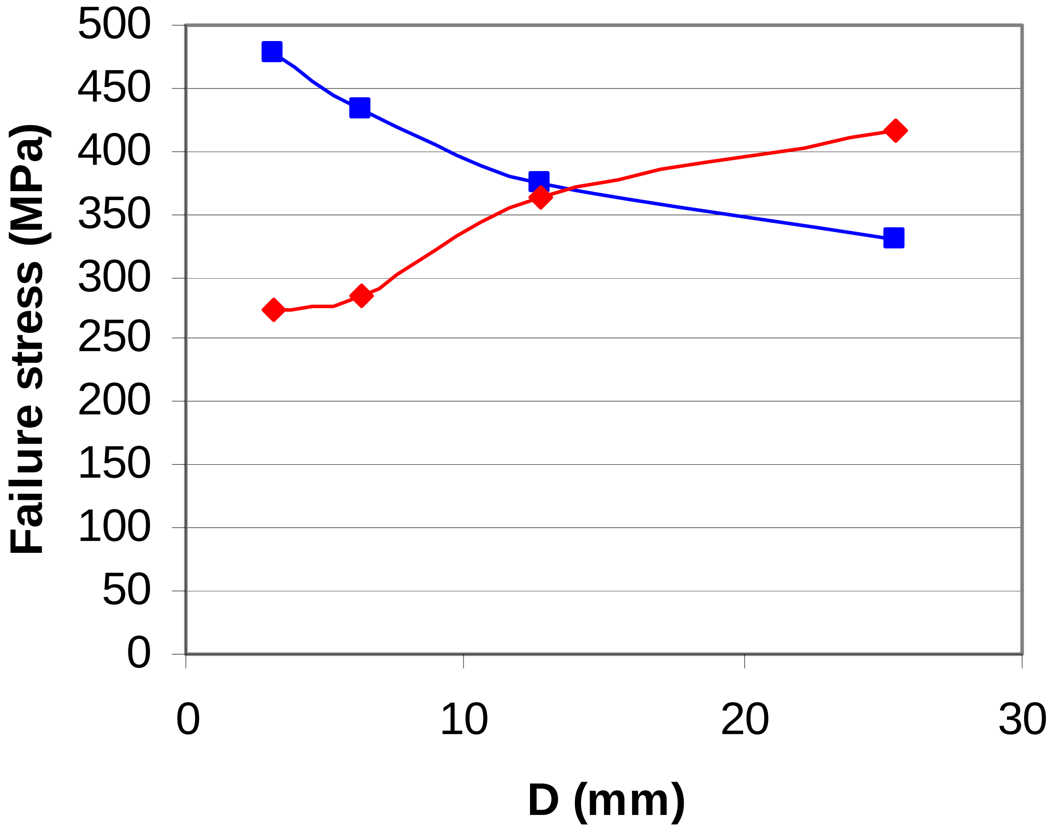
Complexity of behaviour



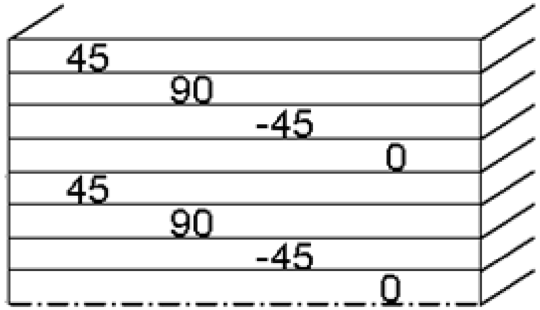
Multiple failure mechanisms that may interact

Open hole tensile strength

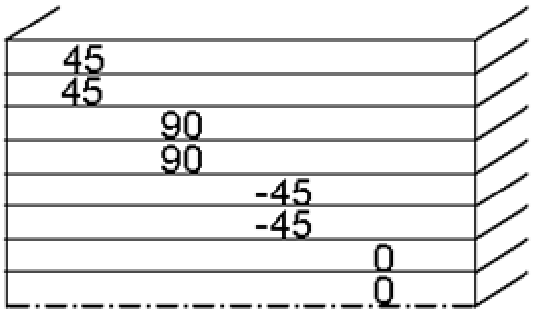
- In-plane scaled tests
- IM7/8552
- All specimens t = 4 mm
- All quasi-isotropic
- All with same w/d = 5
- Very different responses



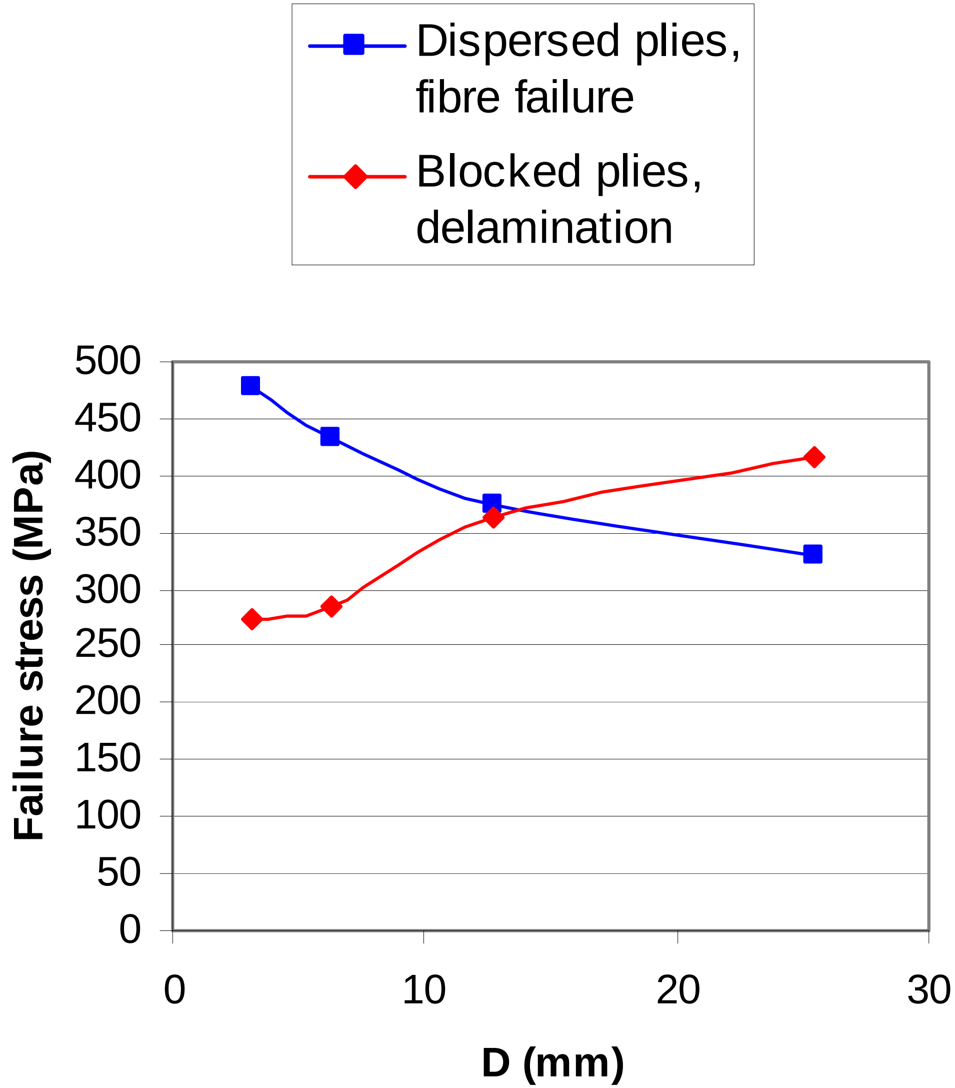
Effect of ply block thickness



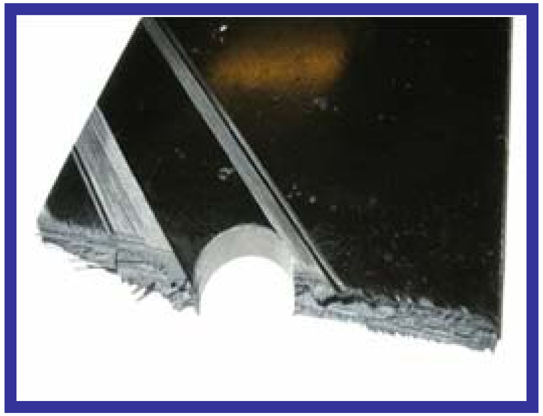
Dispersed plies



Blocked plies

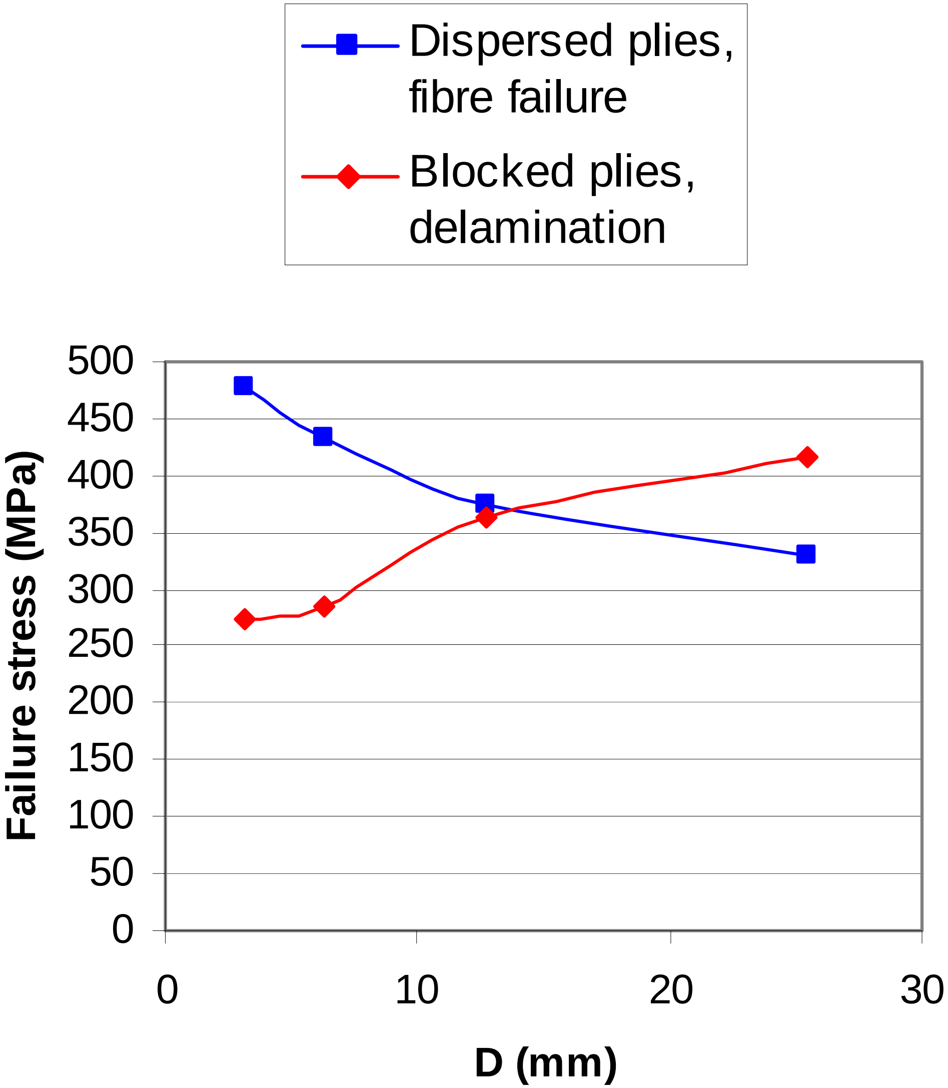


Change of failure mode



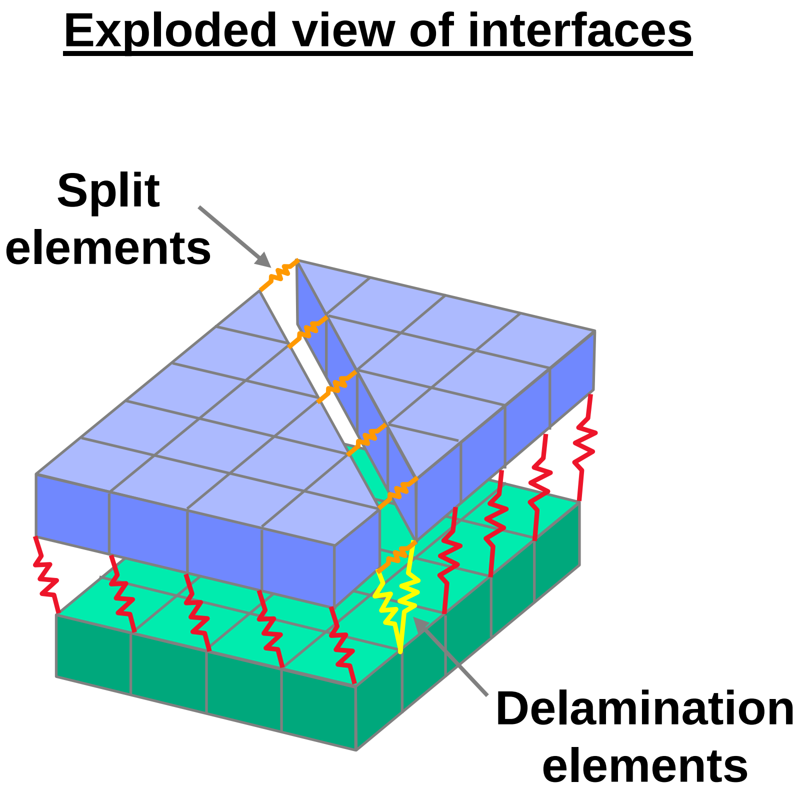
0.125 mm ply blocks: Brittle, fibre dominated

0.5 mm ply blocks: Delamination



Experimental techniques such as X-ray tomography are providing new insight into failure processes

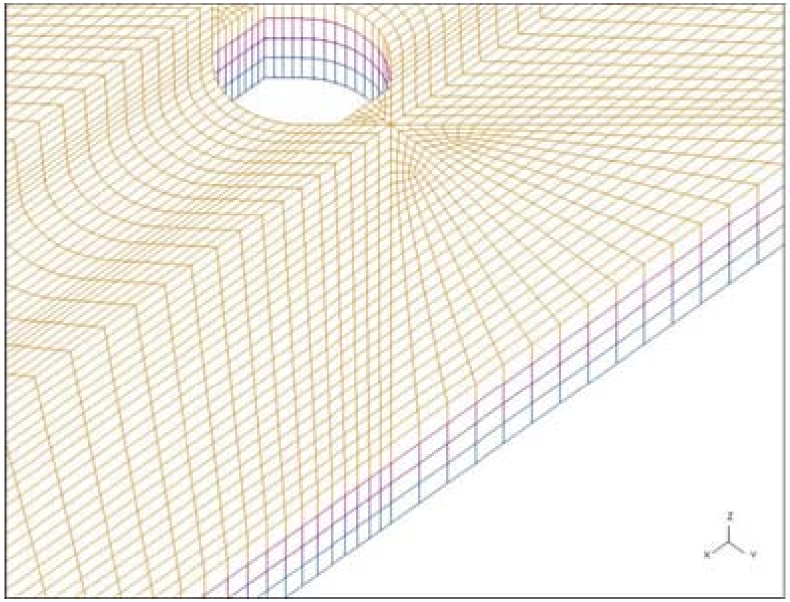
Interface element modelling



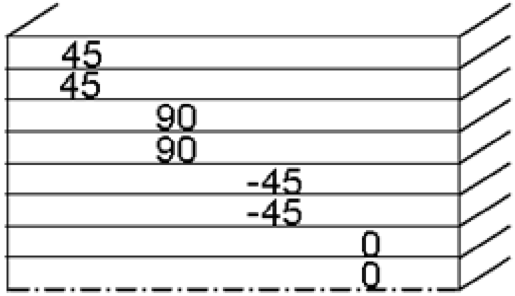
- Cohesive zone interface elements offer a powerful method for modelling discrete failures that occur in composites
- Can be thought of as non-linear springs with both stress and fracture energy failure criteria
- Interface elements used for delamination between plies
- Splits can also be also modelled with interface elements between coincident nodes in-plane

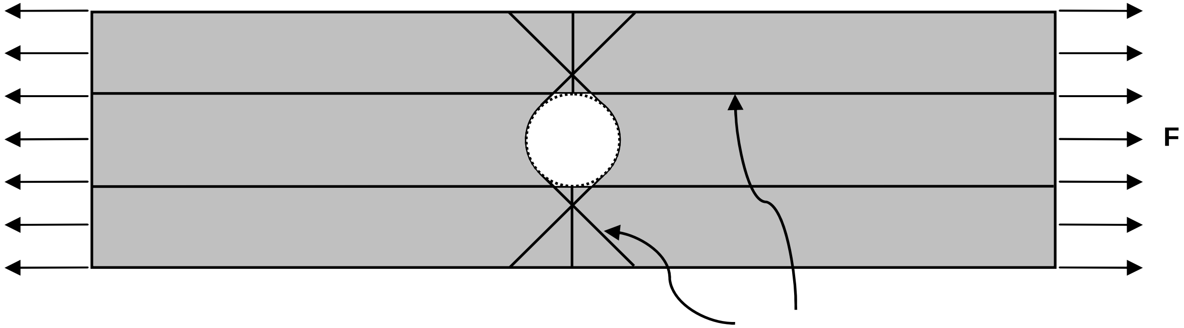
Wisnom, Composites Part A, 2010

Modelling open hole tension tests



- Half model through thickness
- Quasi-isotropic IM7/8552
- Weibull criterion for fibre failure

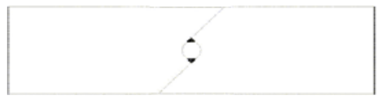
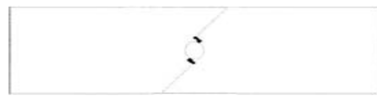
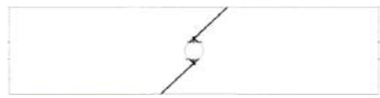
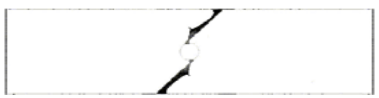
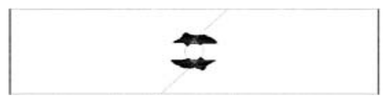
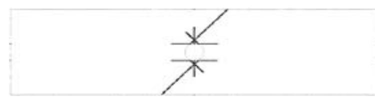
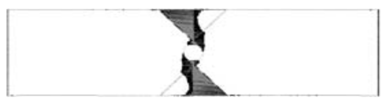
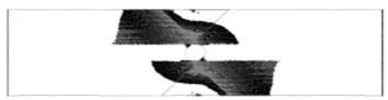
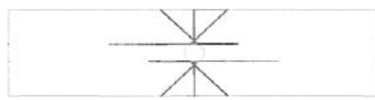
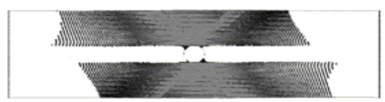
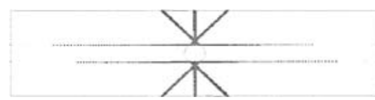
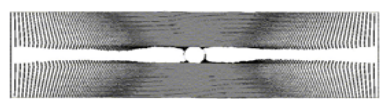
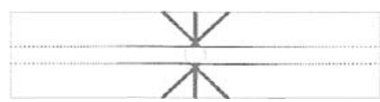




Hallett et al, Composites Part A, 2009

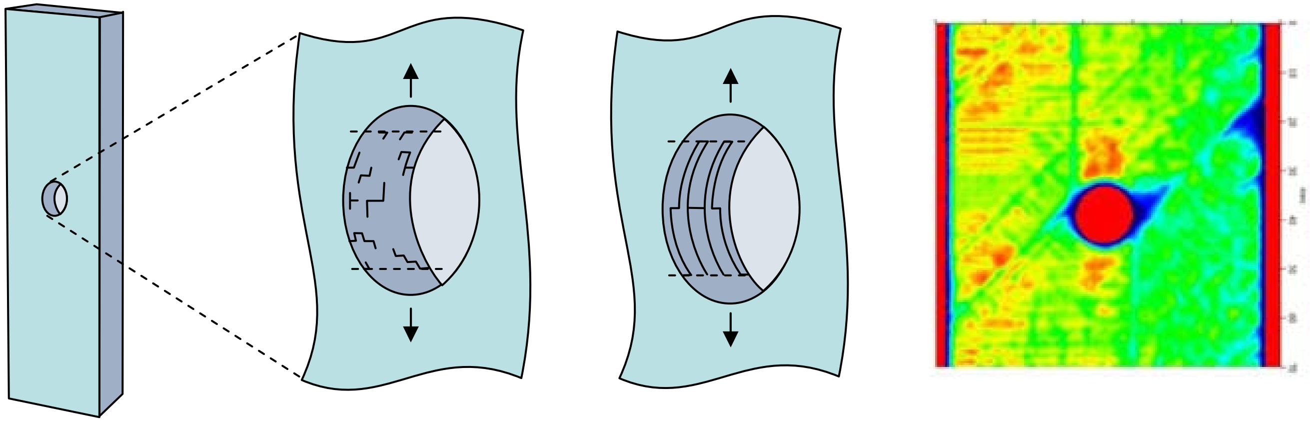
Lines show the locations of potential splits introduced in the FE model

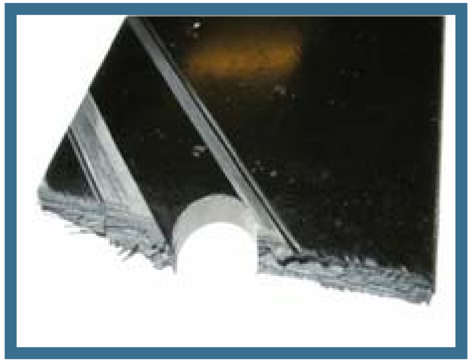
Predicted damage development

Stress level (MPa)	Location of interlaminar interface			Location of splitting within plies
	45°/90°	90°/-45°	-45°/0°	All layers (superimposed)
152				
184				
423				
372				
296				
278				

Interface modelling captures mechanisms

- Development of sub-critical damage is crucial
- Final failure depends on damage when fibres break



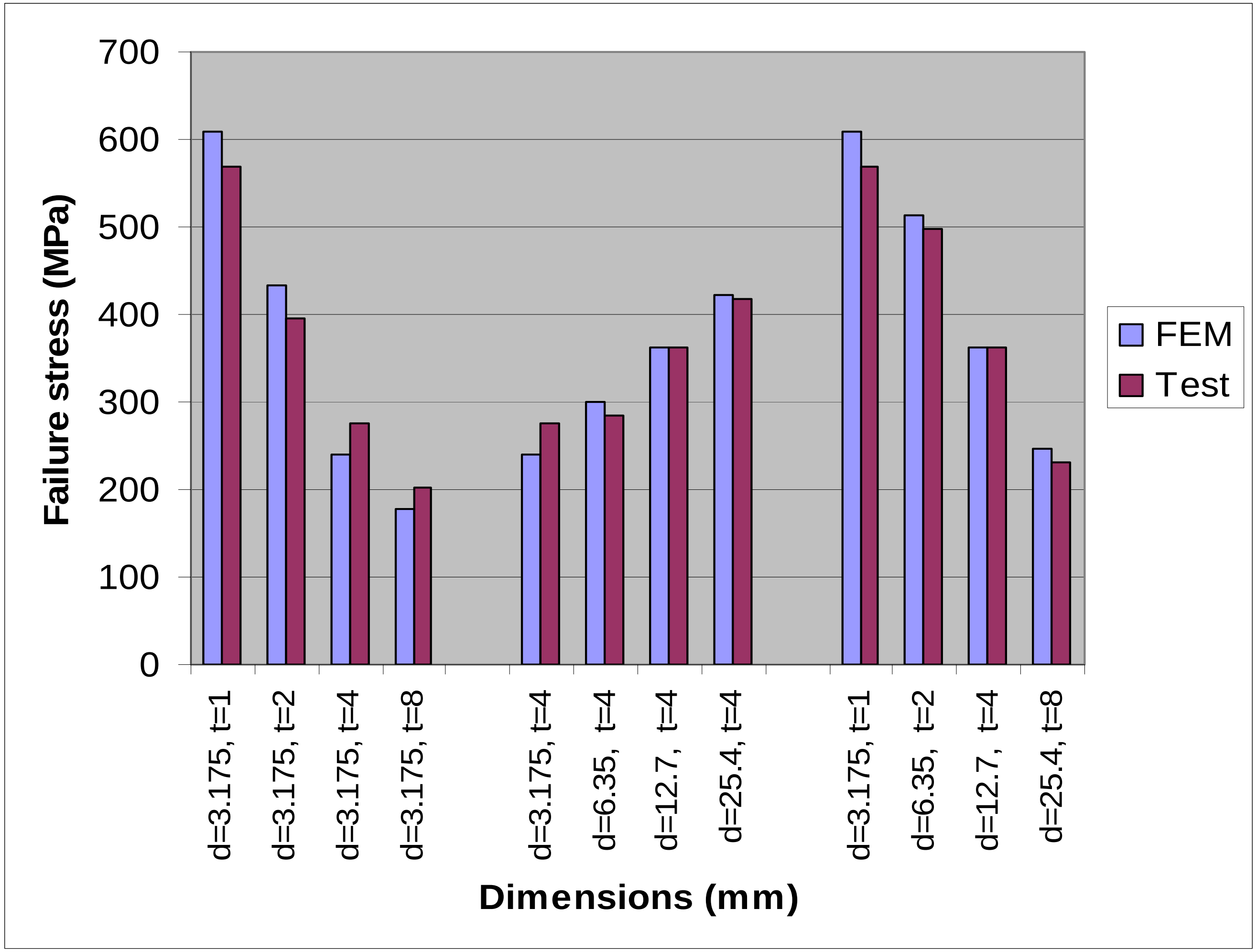


Brittle

Pull-out

Delamination

Correlation for different hole size and thickness

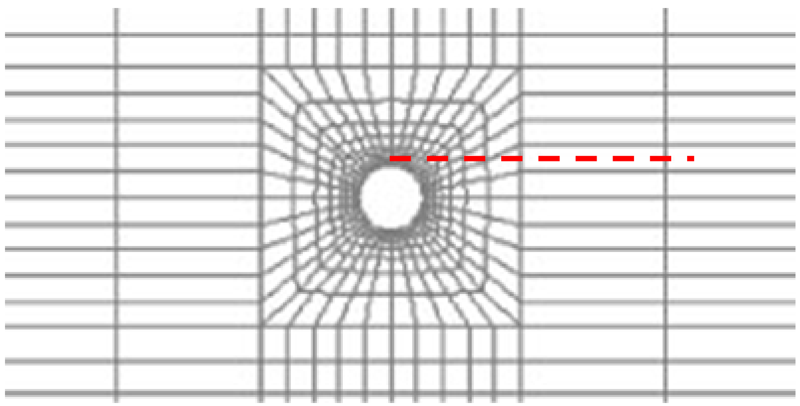


- Constant w/d=5
- Properties from independent tests
- Same input data for all models
- Simple stress analysis gives same strengths for all cases

(45m/90m/-45m/0m)s IM7/8552

Challenges

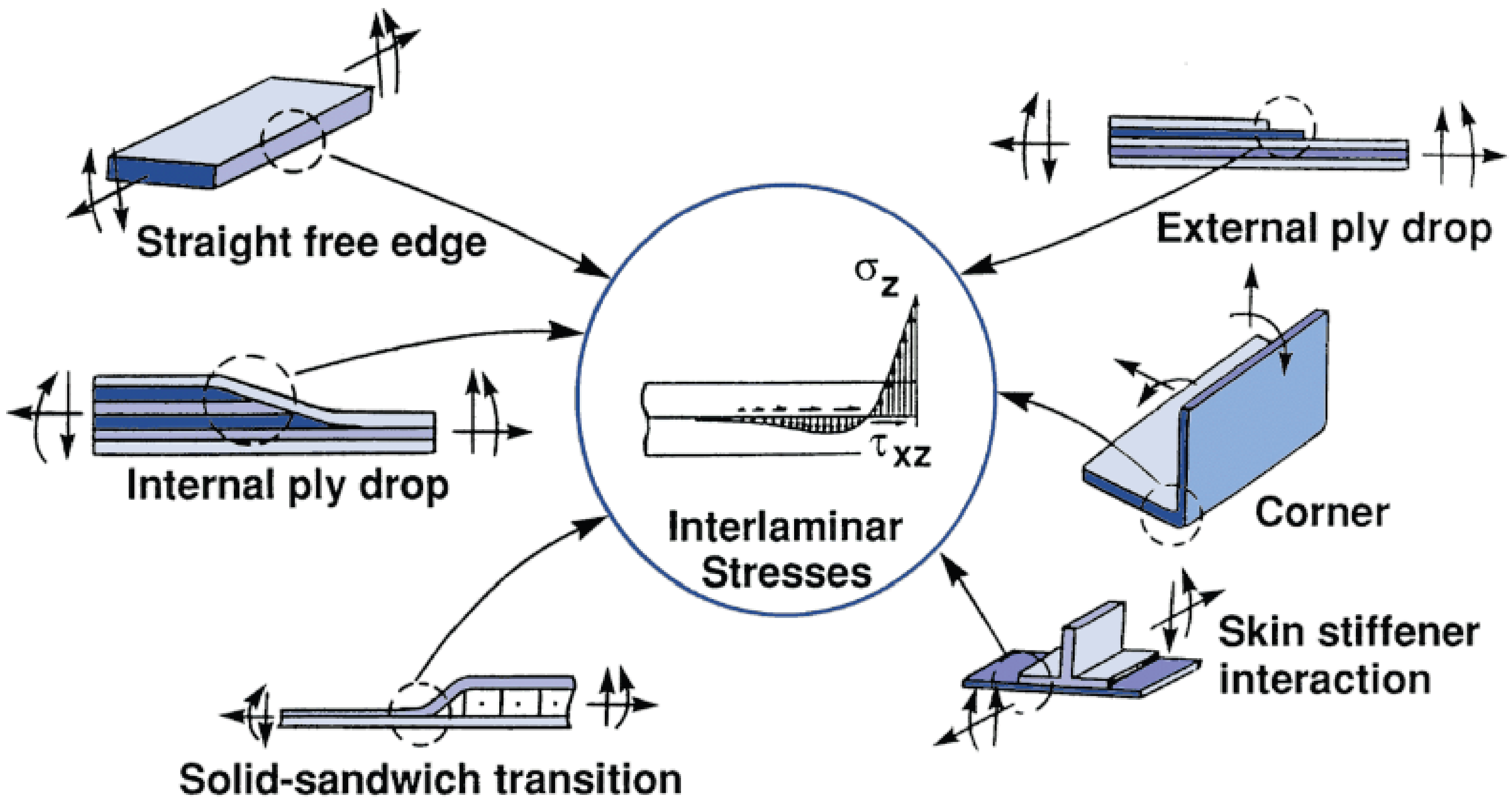
- Need good understanding of mechanisms
- Many experimental challenges
- Detailed models require large run times
- Automated ways of modelling key features required – XFEM



Effect of features at small length scales

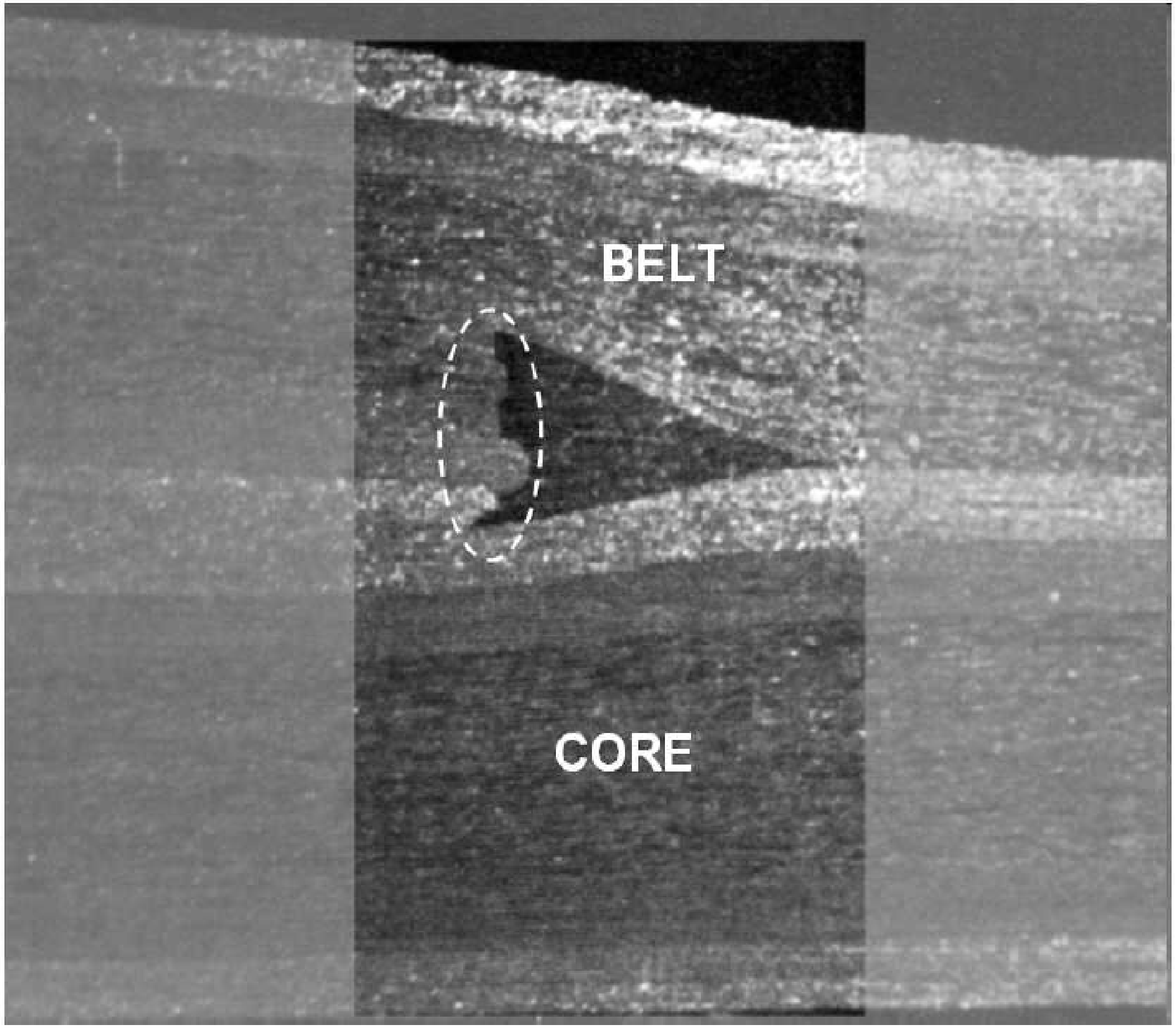
Local details may cause failure, especially delamination

Usually difficult to determine where failure has initiated



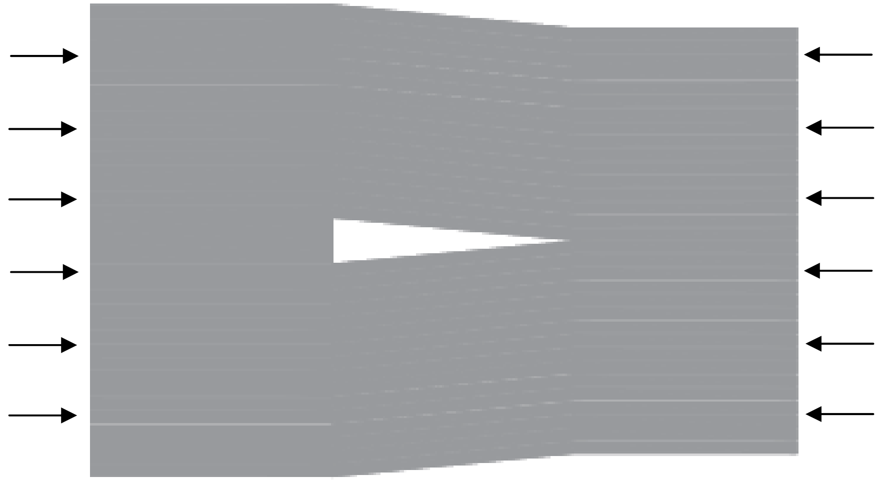
O'Brien T.K., Fatigue Life Prediction Methodology for Composite Delamination using Fracture Mechanics
http://www.esm.vt.edu/ESM100_Presentations/ESM100_OBrien.pdf

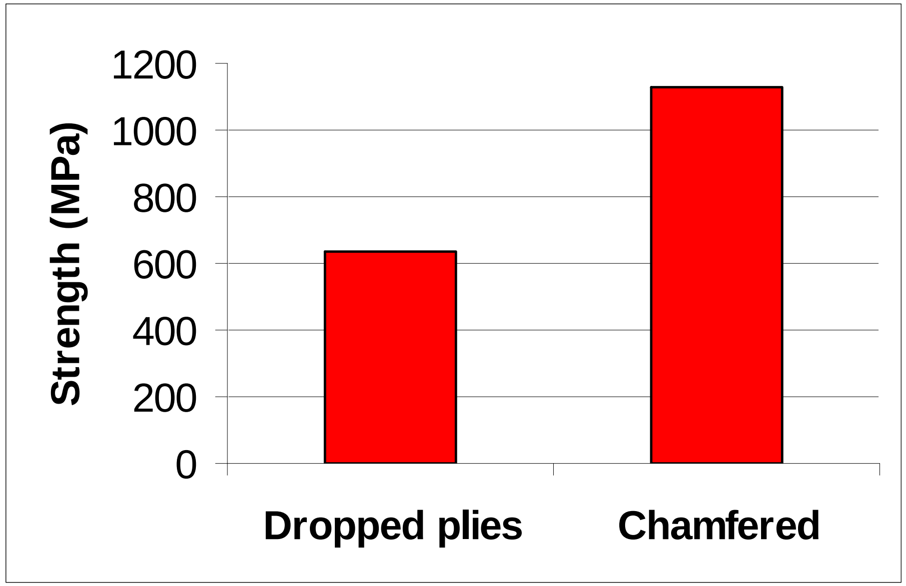
Geometry at ply drop



Failure at ply drops

- Unidirectional E-glass/913
- Tapered from 36 to 32 plies
- Loaded in compression
- 0.5 mm discontinuity
- Specimens made with chamfered plies to eliminate discontinuity
- 78% increase in strength
- Fibre failure instead of delamination

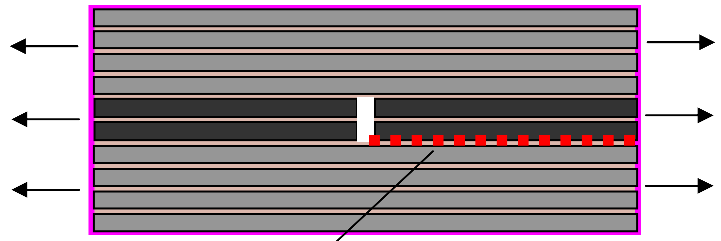


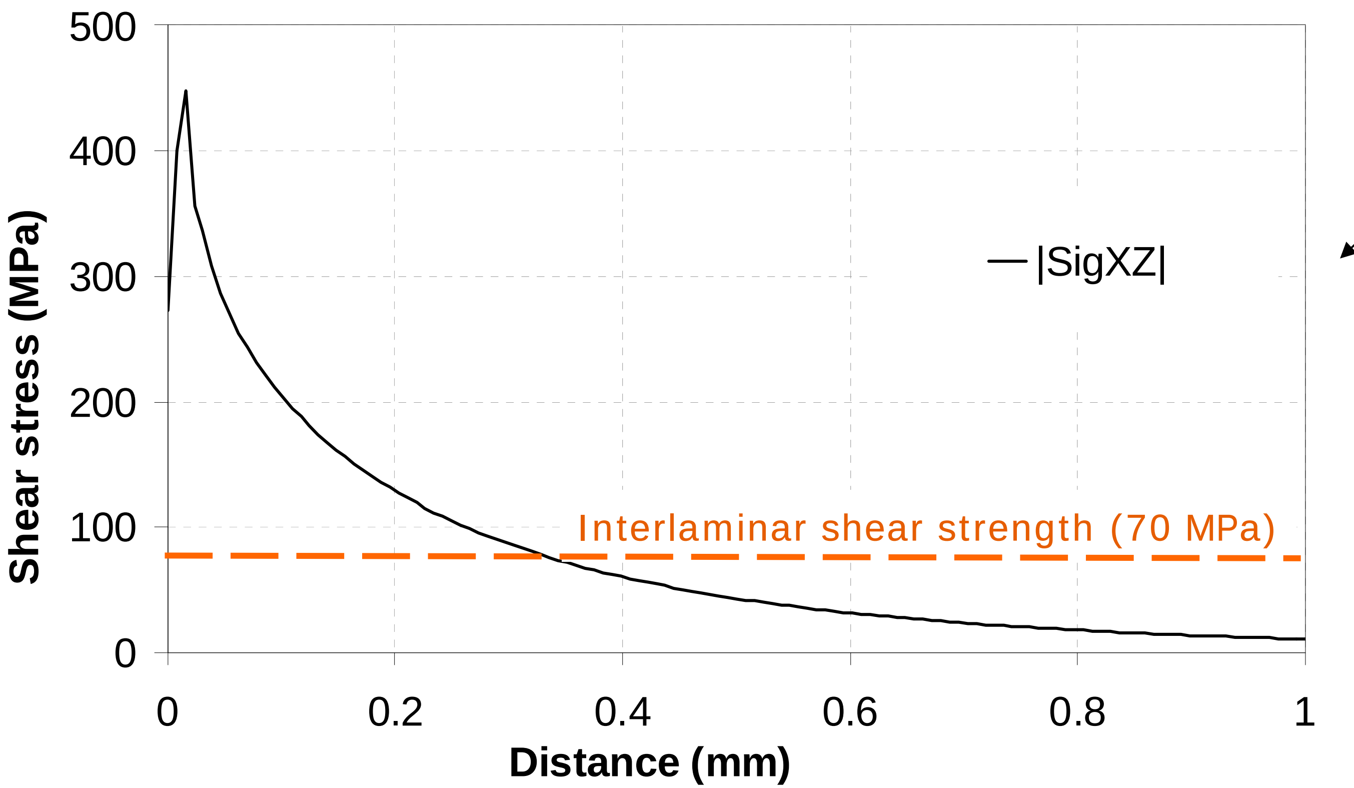


Khan et al, Journal of Composite Materials, 2006

Highly localised stresses causing failure

- Interlaminar shear stresses at a cut ply
- Stresses exceed strength only over 0.3 mm distance
- Require very detailed models to capture

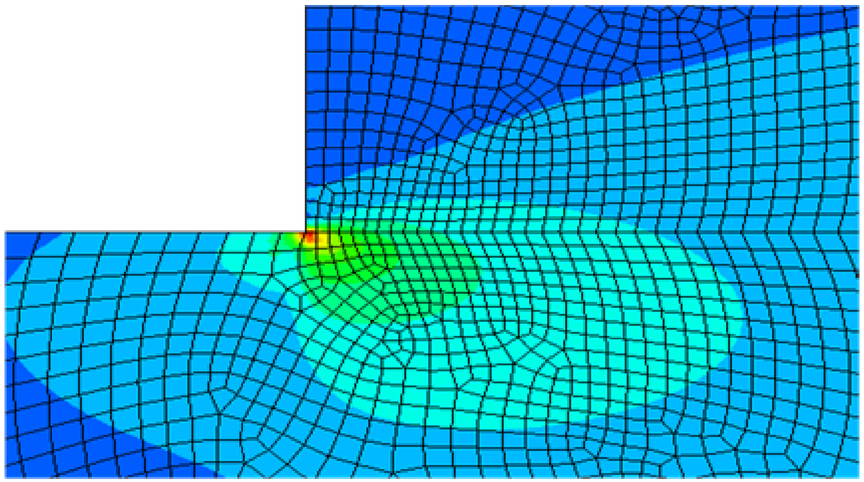




Linear elastic FE results at experimental failure load

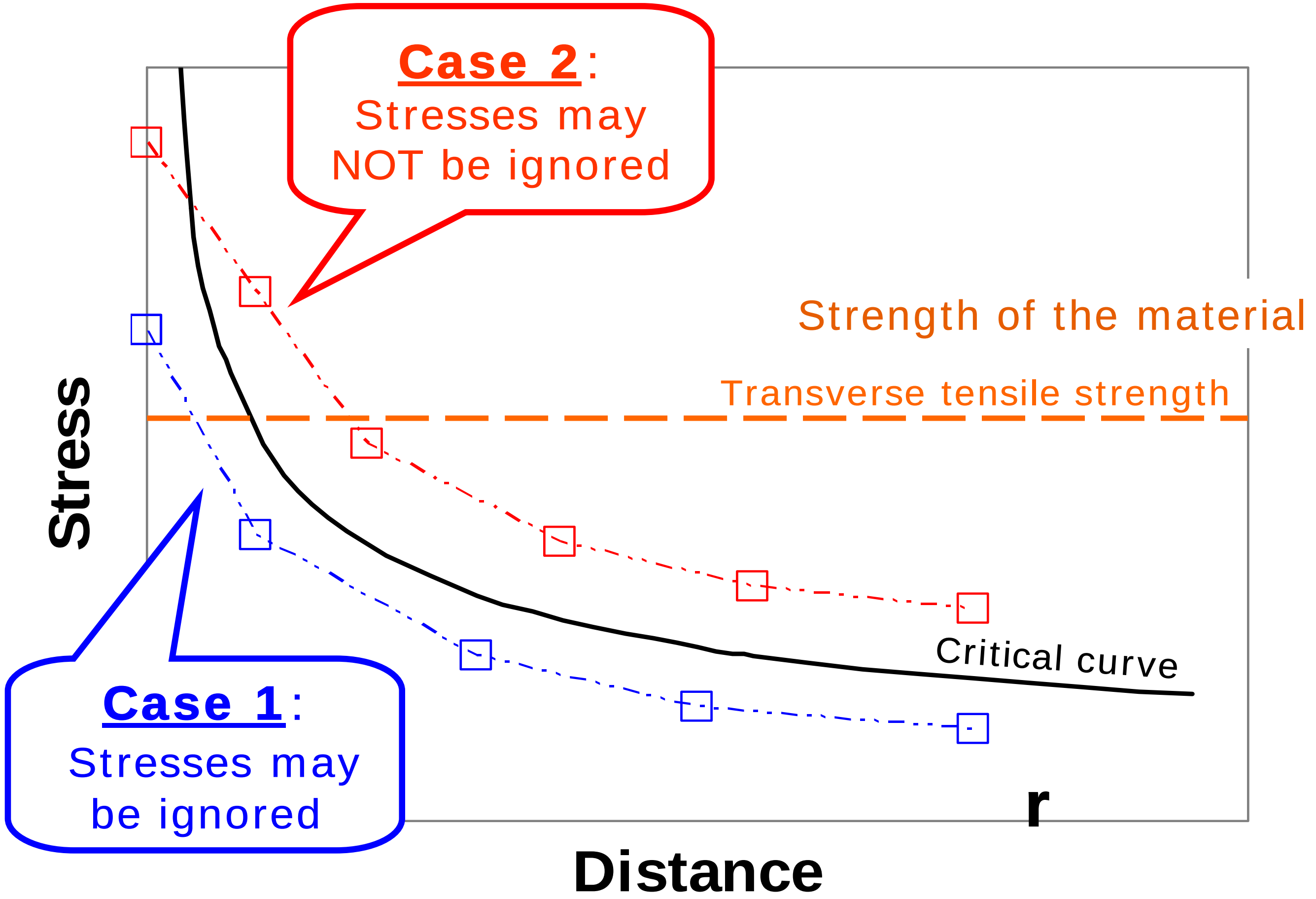
Highly localised stresses not causing failure

- Coarse meshes may miss high stresses causing failure
- But refined meshes may give high stresses that are very localised and may not cause failure
- Could be artifacts of the modelling
  - Poorly shaped elements
  - Discontinuities in material axes
- How to assess if these stresses may be safely ignored?



High stress concentration method

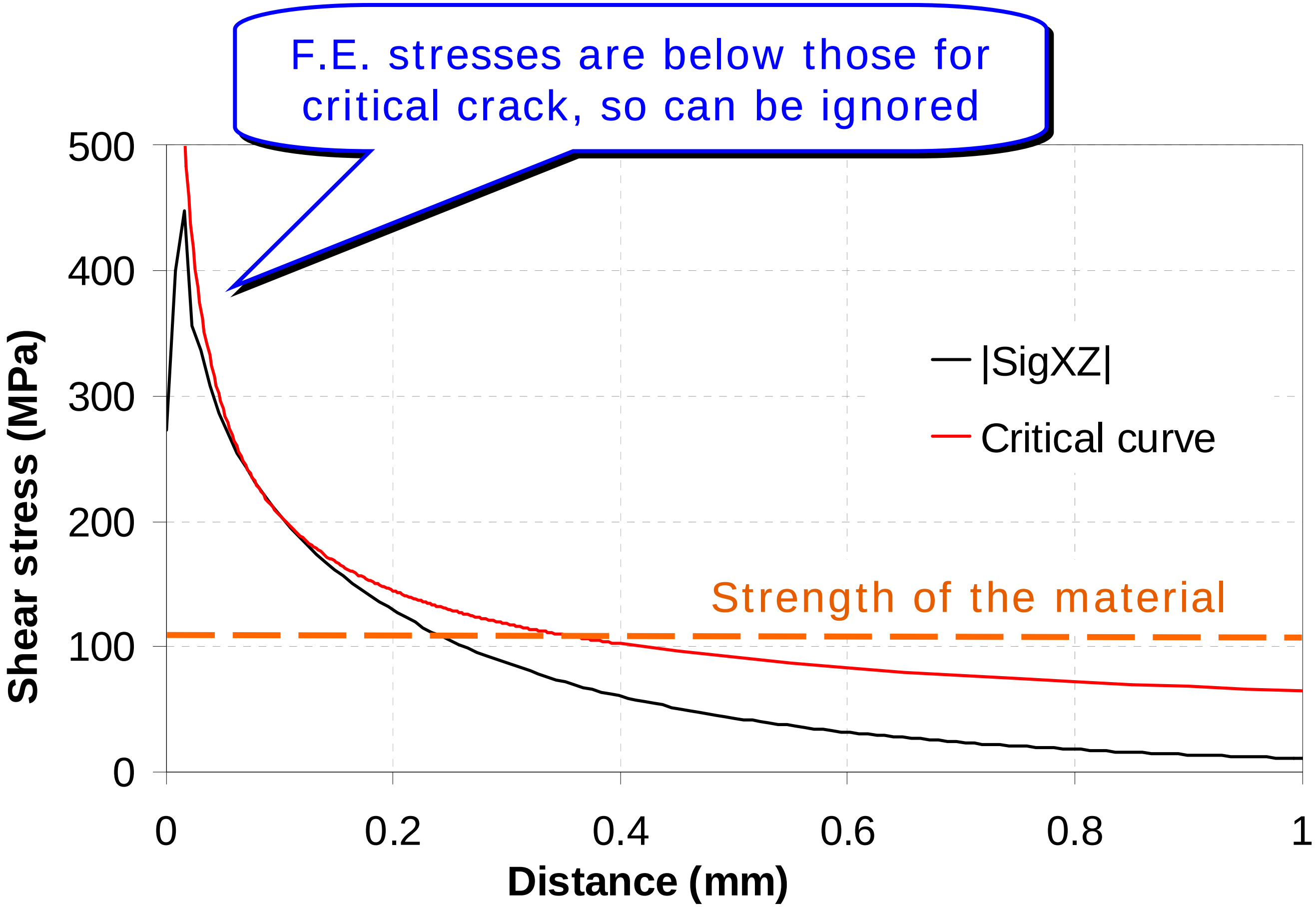
- Assume a crack just on the point of propagating
- Work out critical stresses at crack tip
- Stresses below the critical curve can be ignored

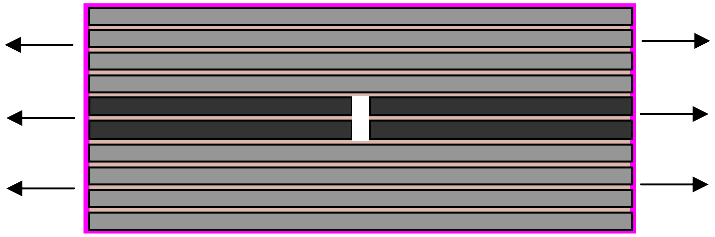


Helenon et al,
ICCM-17 2009

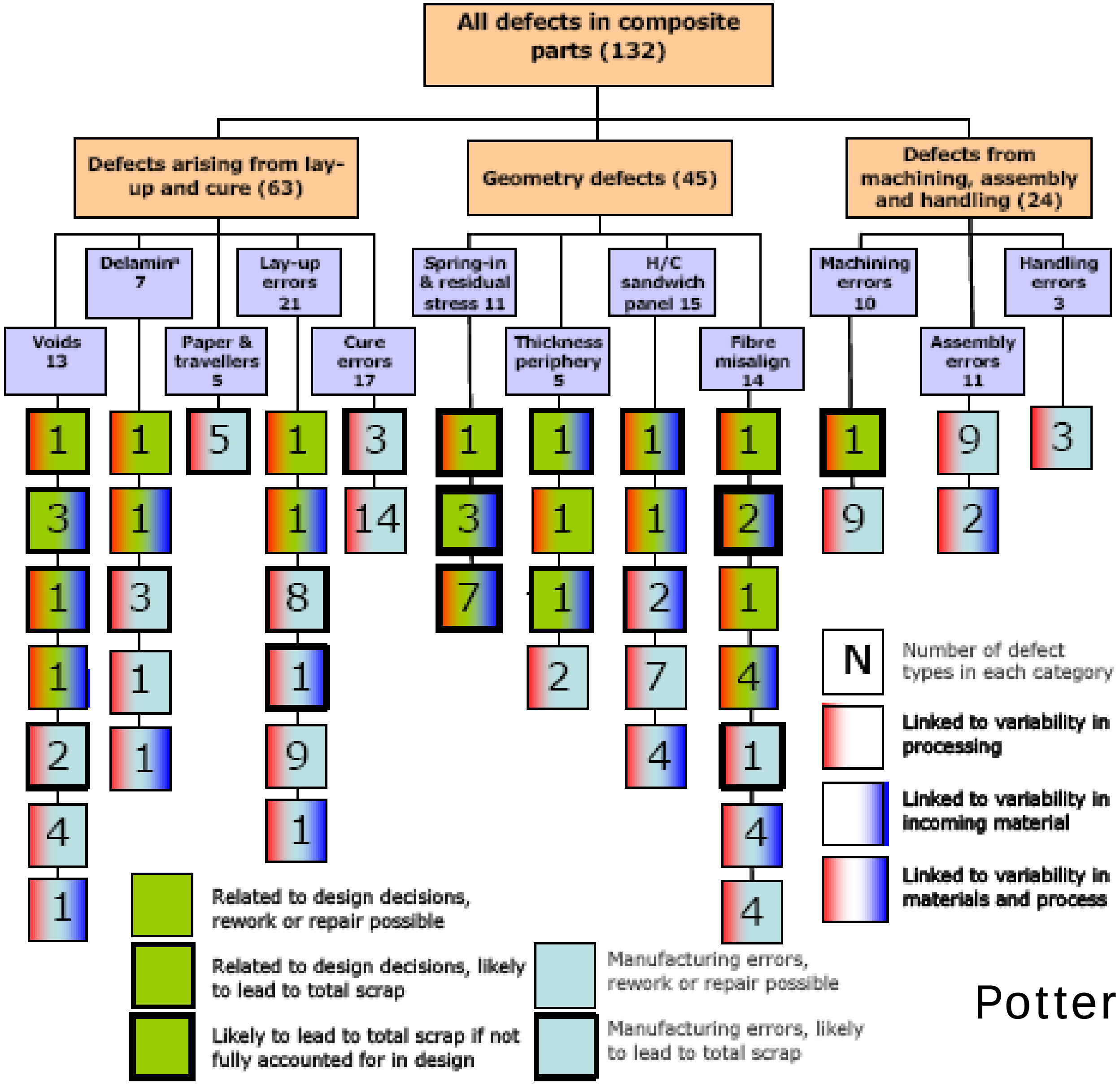
Validation on cut ply case

FE stresses at failure load are just below critical curve





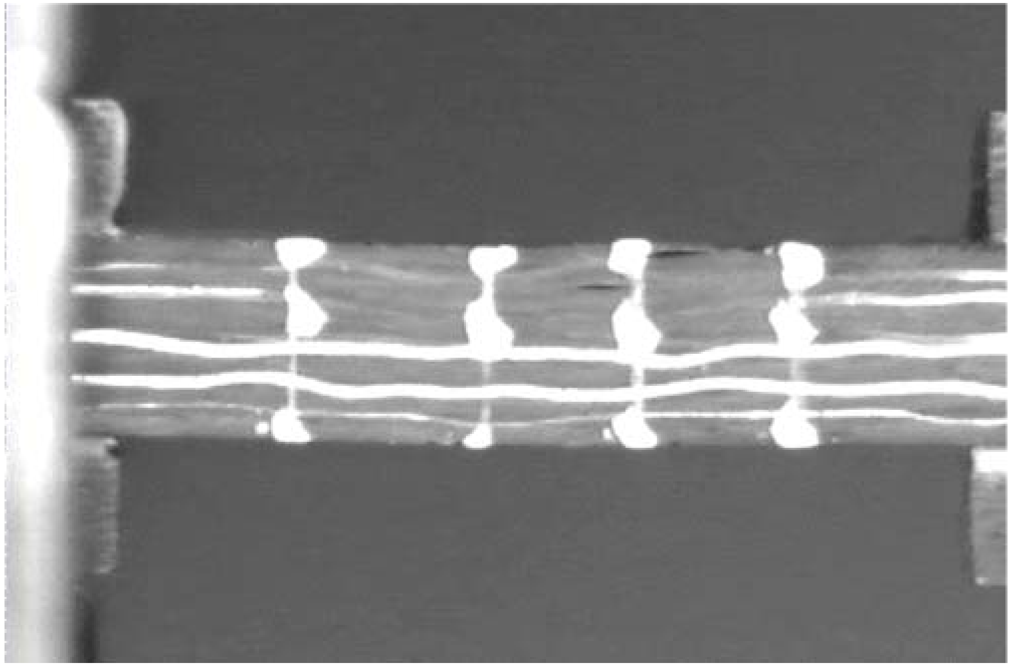
Taxonomy of defects



Potter, ICCM-17, 2009

Fibre waviness defects

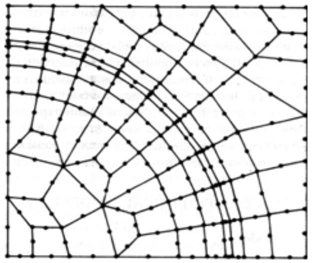
- Fibre waviness is critical in compression
- E.g. quasi-isotropic woven carbon-epoxy laminates
- 0.6 mm amplitude ply waviness gave 35% reduction in compressive strength
- Need to be able to detect defects and model their effect

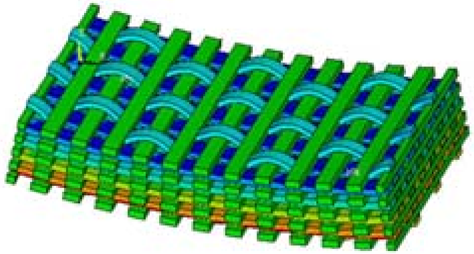


Khan et al, FPCM8, 2006

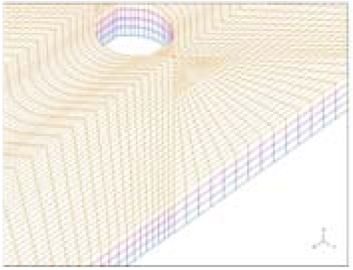
Scaling up – from micro to macro

- Micromechanical models at fibre-matrix level





- Mesomechanical level e.g. 3D woven composites

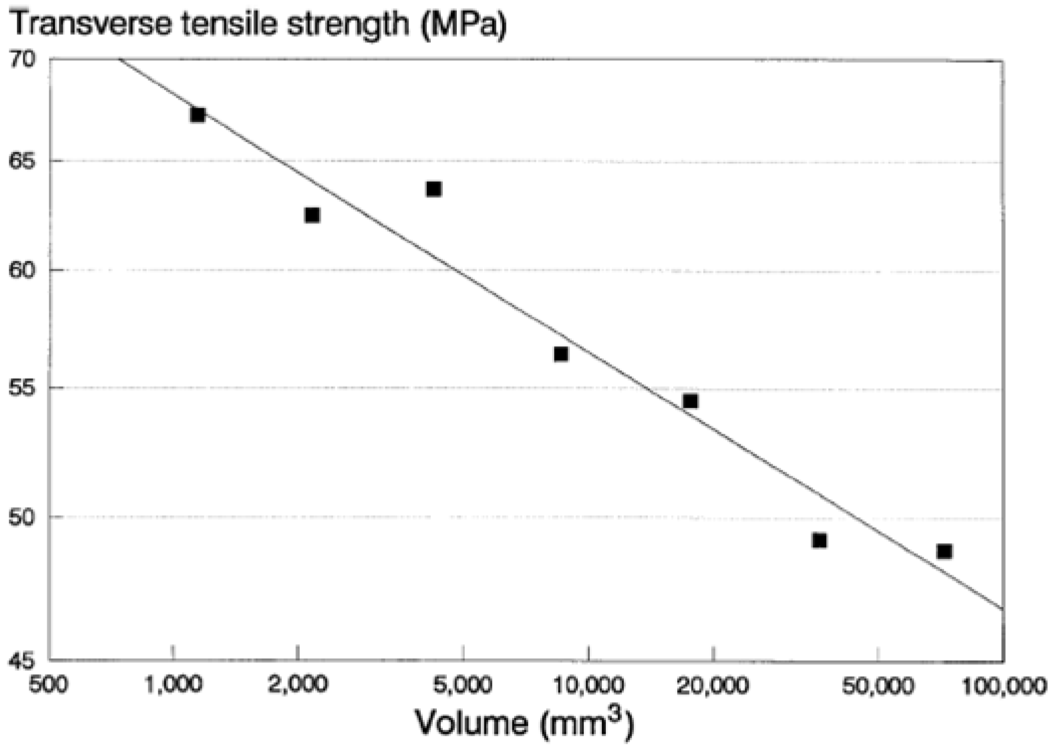


- Structural element level

- Large scale global structures
- Need to bridge the length scales

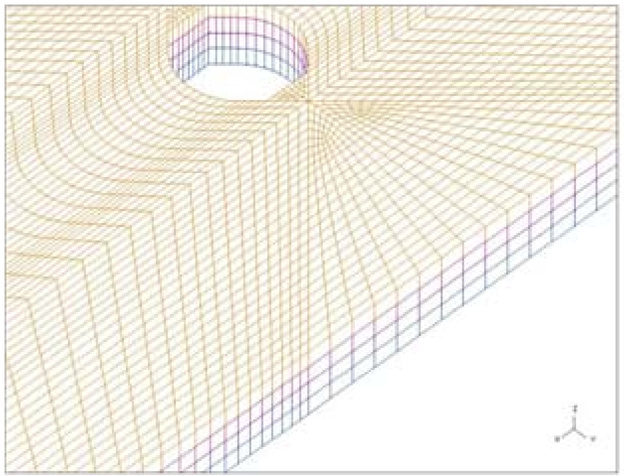
Challenges in scaling up

- Size effects – strength decreases with scale
- Large scale testing is expensive
- Very little data available for large specimens
- Need detailed observations to understand mechanisms



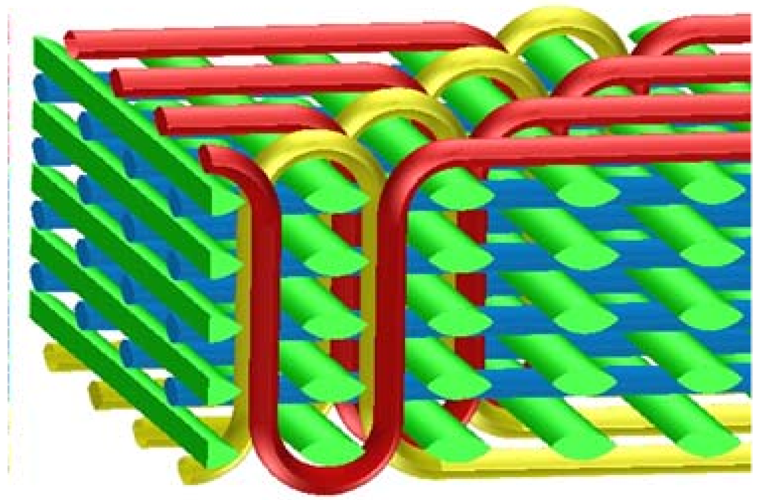
Multi-scale modelling

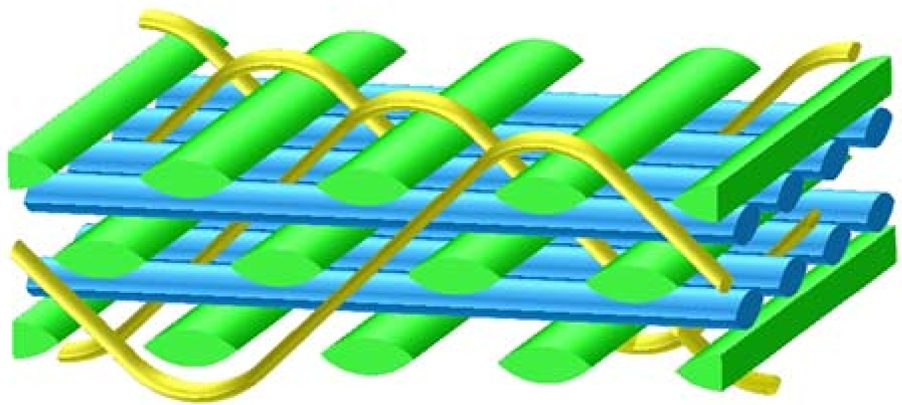
- Detailed model of large aircraft with elements at the scale of the ply thickness could require 10^{11} elements
- Need multi-scale modelling
  - E.g. using a homogeneous model and taking strains at ply drop locations into a local delamination model
  - Virtual testing of open hole tension strength
  - Must be careful not to model out key features



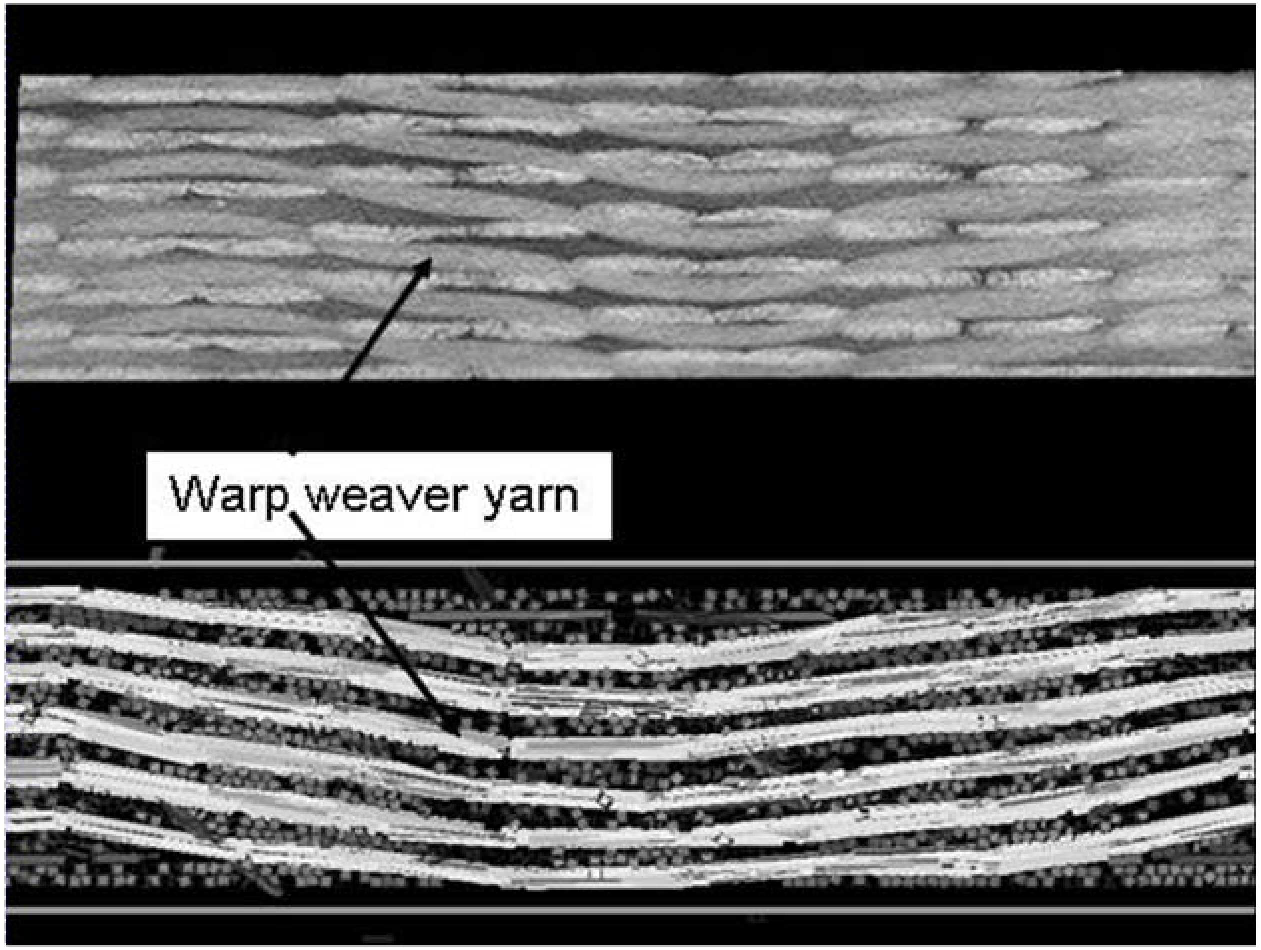
Wide range of composite architectures

- E.g. 3D woven composites
- Large variation in possible weave structures
- Complex behaviour not well characterised or understood
- Manufacturing process can significantly affect geometry
- Not practical to test all possibilities
- Need for effective approaches to analyse and compare architectures





Modelling fabric compaction



X-ray CT scan

FE simulation

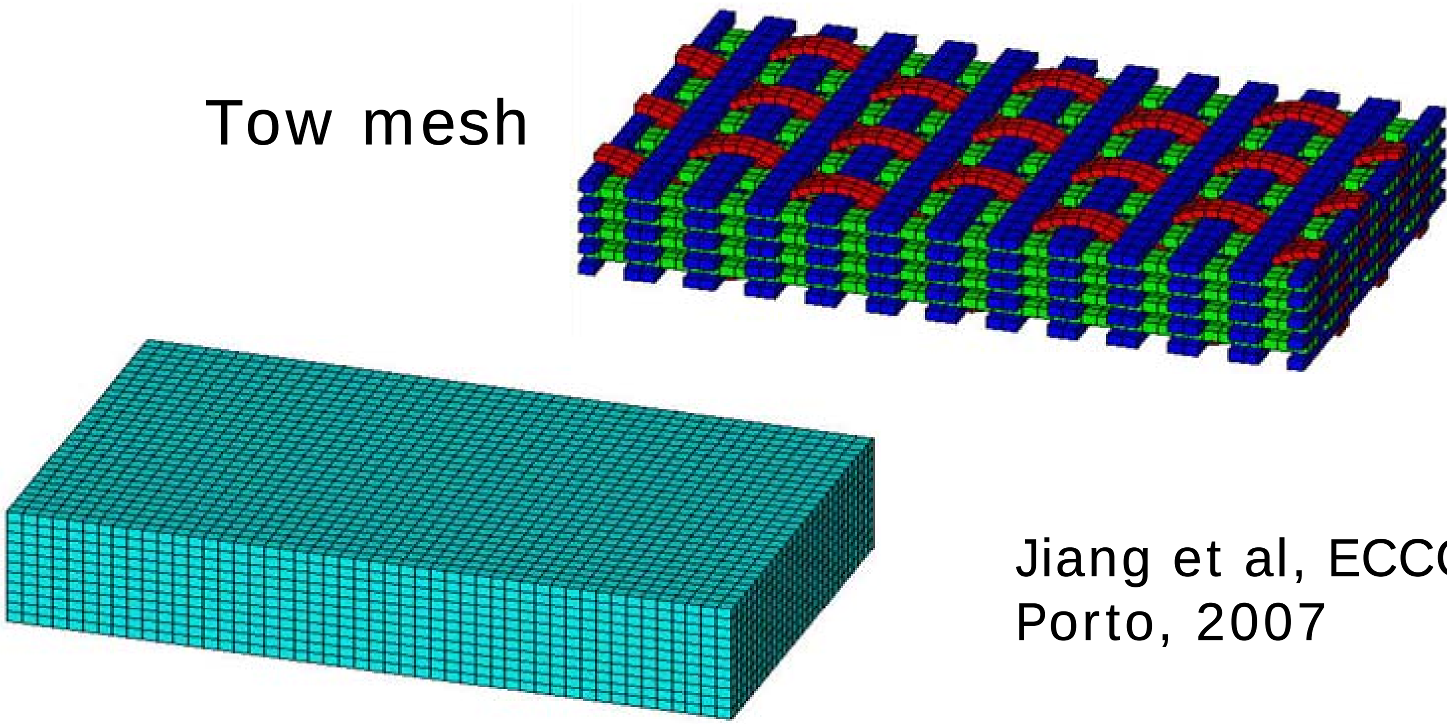
Mahadik and Hallett, TexComp 9, 2008

Domain Superposition Technique

- Resin not modelled separately
- Tow mesh constrained directly to global mesh
- Avoids meshing problems
- Excellent results with relatively coarse models

Tow mesh

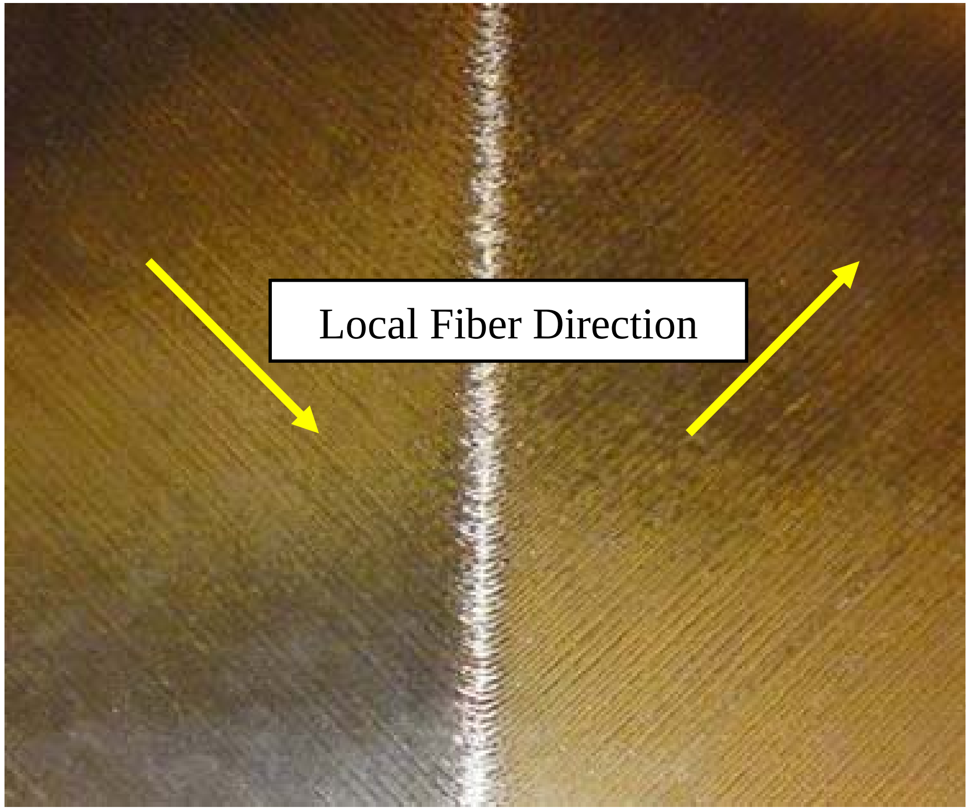
Global mesh



Jiang et al, ECCOMAS, Porto, 2007

Tow steered composites

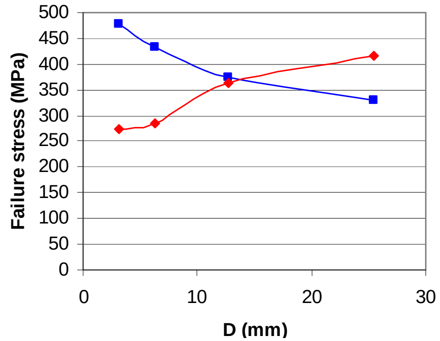
- Tow steering allows arbitrary orientation of fibres
- Greatly increases design degrees of freedom
- Produces materials that are continuously varying

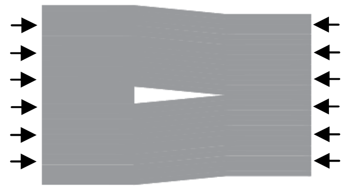


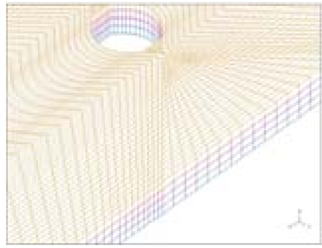
Panesar & Weaver,
ICAST, 2009

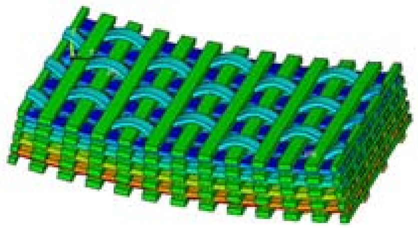
Challenges

- Complexity of behaviour
  - Need to understand failure mechanisms
  - Models must be based on sound understanding
- Failure determined at small length scales
  - Details are key e.g. ply drops
  - Defects can be very important
- Scaling up from micro to macro
  - Multi-scale modelling
  - Virtual testing
- Many different architectures available
  - 3D weaving, braiding, t-t reinforcement
  - Tow placement
- Fatigue, impact, crash, fire behaviour…





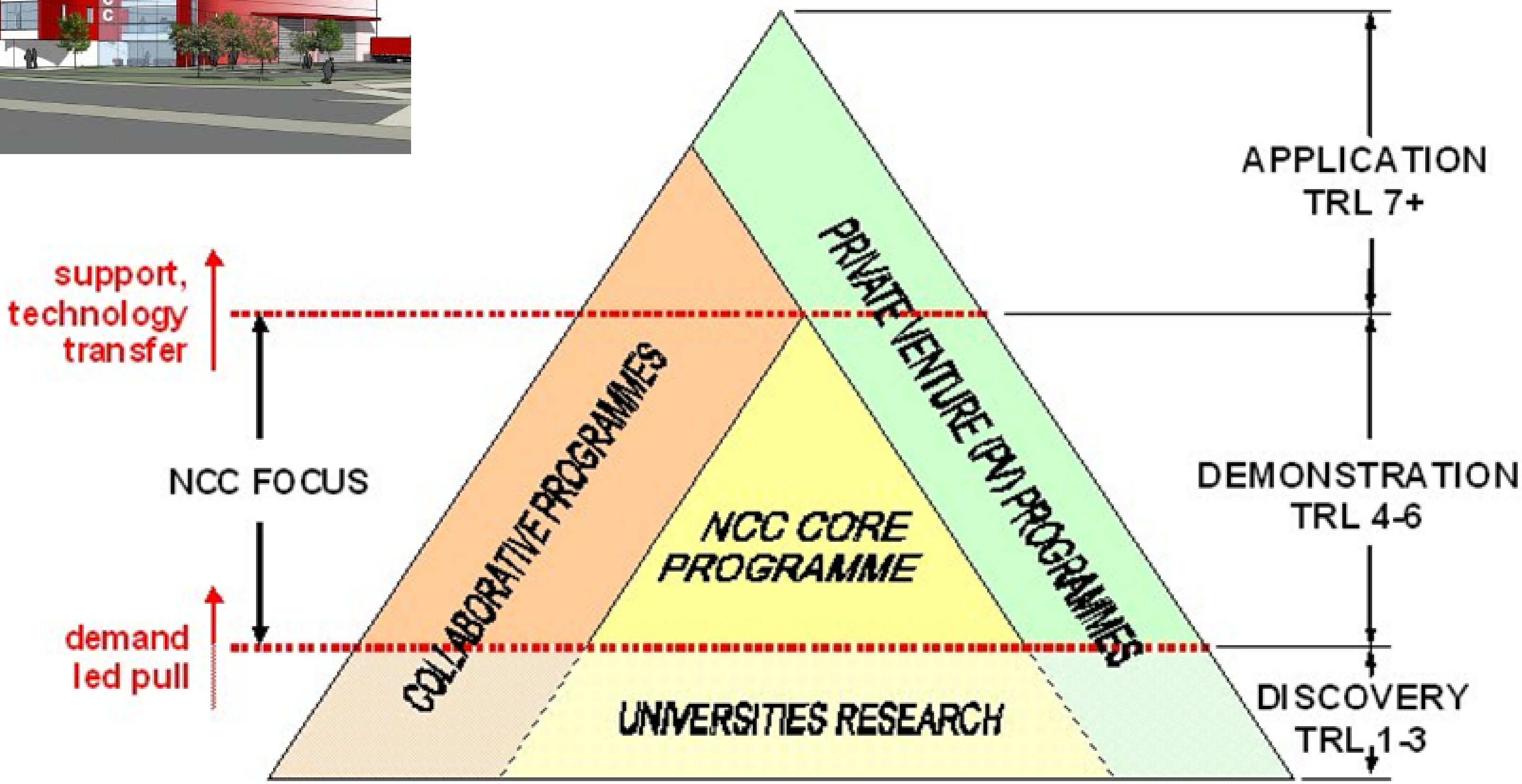




References

- Wisnom, M R. Size effects in the testing of fibre-composite materials, Composites Science and Technology 59, pp 1937-1957 (1999)
- Wisnom, M R. Modelling Discrete Failures in Composites with Interface Elements, Composites Part A, available on-line (2010)
- Hallett S R, Green B, Jiang W-G, Wisnom M R. An experimental and numerical investigation into the damage mechanisms in notched composites. Composites Part A 40 pp 613–624 (2009)
- Khan, B, Potter K and Wisnom M R. Suppression of Delamination at Ply Drops in Tapered Composites by Ply Chamfering, J. Composite Materials 40, pp 157-174 (2006)
- Hélénon F, Wisnom M R, Hallett S R, Allegri G. An approach for dealing with high local stresses in finite element analyses. ICCM17, Edinburgh, UK (July 2009)
- Khan B, Potter K, Wisnom M R. Simulation of Process Induced Defects in Resin Transfer Moulded Woven Carbon Fibre Laminates and their Effect on Mechanical Behaviour, FPCM8, Douai, France. (July 2006)
- Mahadik Y, Hallett S R. Finite Element Modelling of Tow Geometry in 3D Woven Fabrics. 9th Int. Conf. on Textile Composites (TexComp9), Univ Delaware (October 2008)
- Jiang W-G, Hallett S R, Wisnom M R. Development of Domain Superposition Technique for the Modelling of Woven Fabric Composites. ECCOMAS Thematic Conference on Mechanical Response of Composites. Camanho P P et al (eds), Porto, Portugal. (September 2007)
- Panesar, A S, Weaver P M. Thermally Induced Bi-stable Morphing Composites Using Tow-Steering. 20th International Conference on Adaptive Structures and Technologies, Hong Kong. (October 2009).

National Composites Centre



Launch event on 17th March: www.bristol.ac.uk/composites