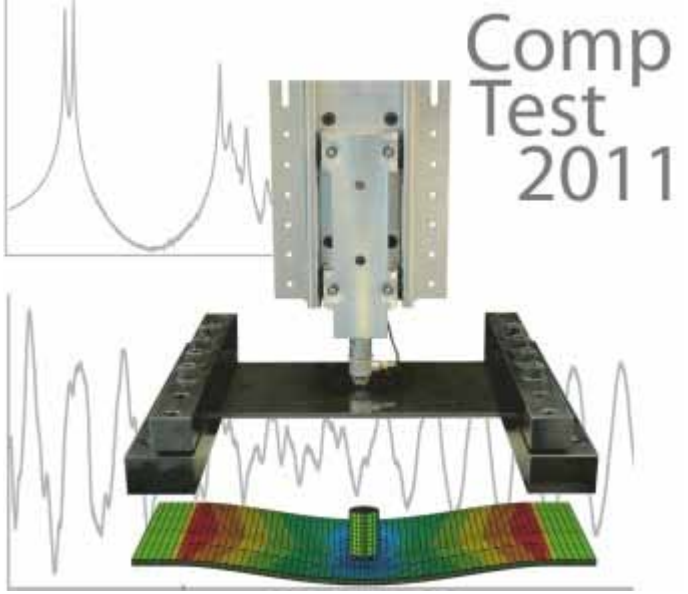
University of BRISTOL




# Testing and Modelling of a Severely Tapered Composite Specimen

***Stephen Hallett***, *James Lander,*
*Mike Jones, Luiz Kawashita*
*and Michael Wisnom*

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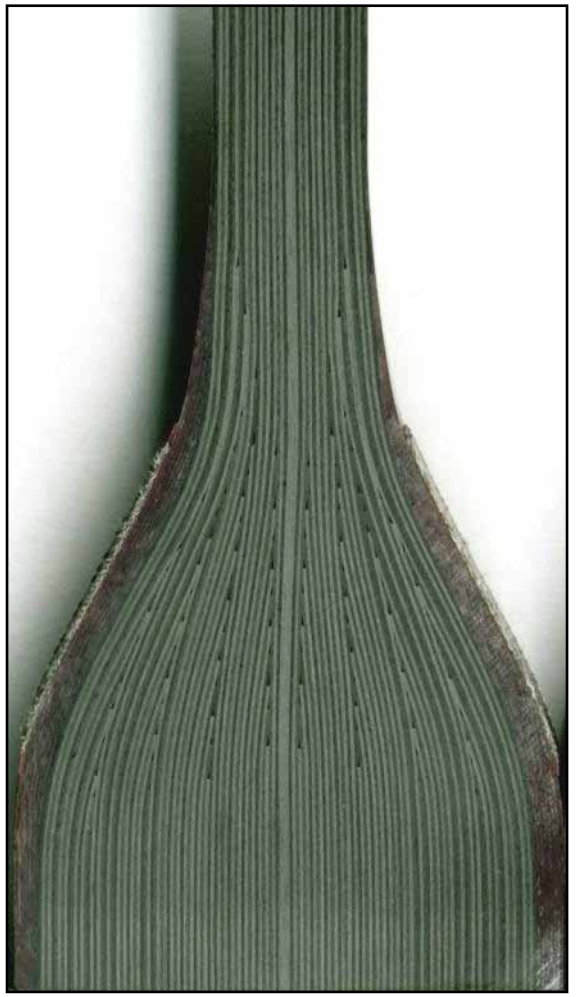
# Introduction

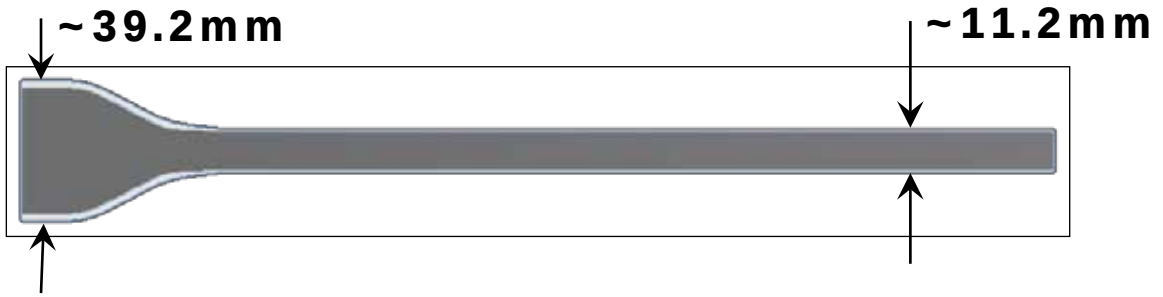
- A severely tapered specimen has been designed and manufactured at the University of Bristol
- Purpose is to be representative of aerospace component features
- Made up from a large number of pre-preg plies dropped off to create thickness change
- Tested in a dovetail type fixture
- Purpose if to inform and validate high fidelity modelling of situations where failure is governed by delamination from ply drops



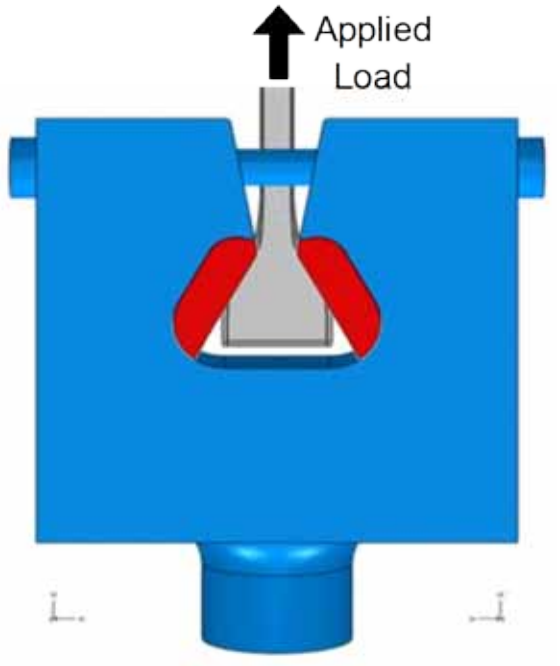
# Summary

- Overall specimen configuration:-

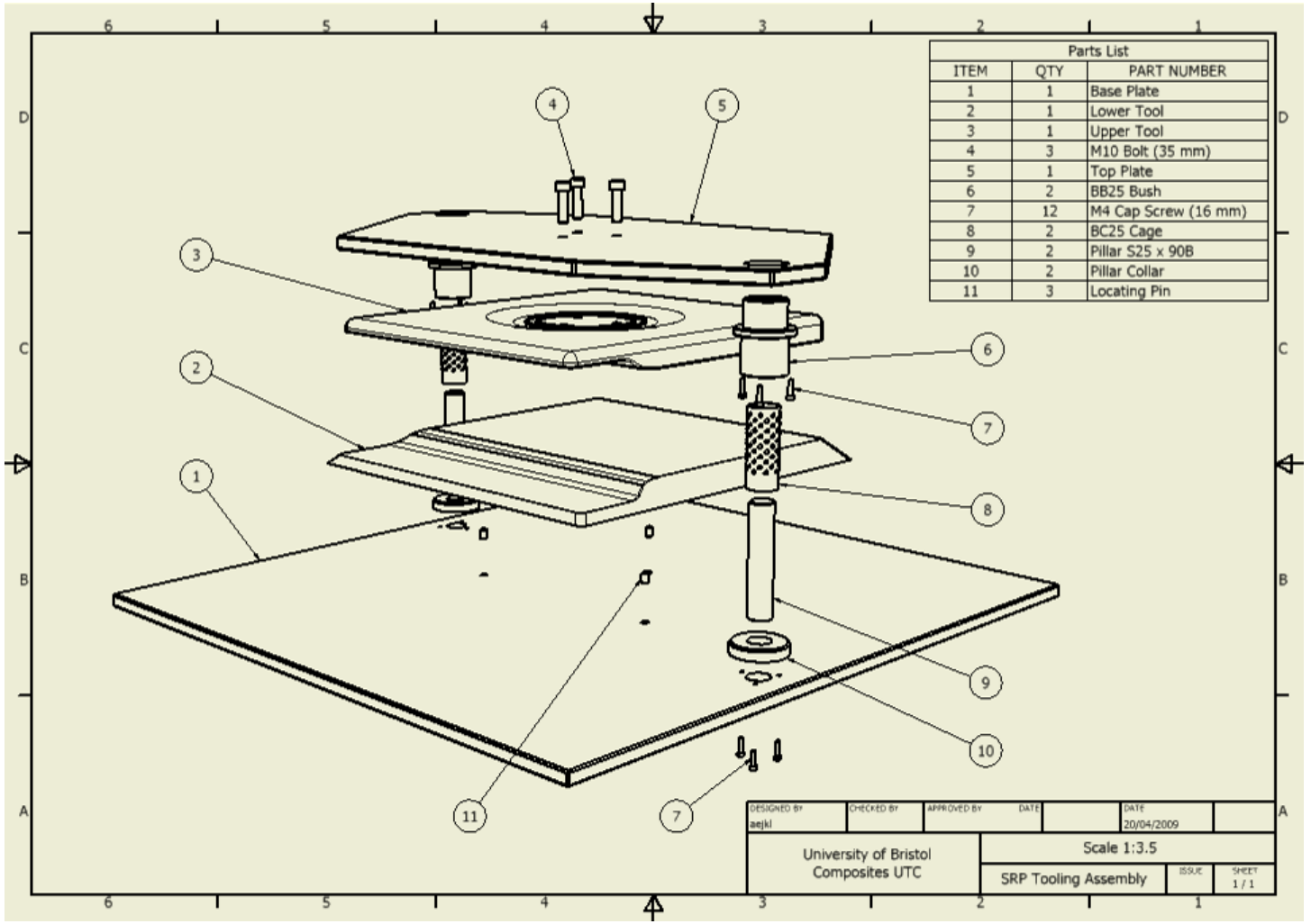
**Overall Length = 310 mm**
**Gripped length = ~140 mm**
**Width =20mm**




- Specimen manufacture
- Static Test Results
  - Failure load/location
  - High speed photography
  - DIC
  - CT Imagery
- Modelling



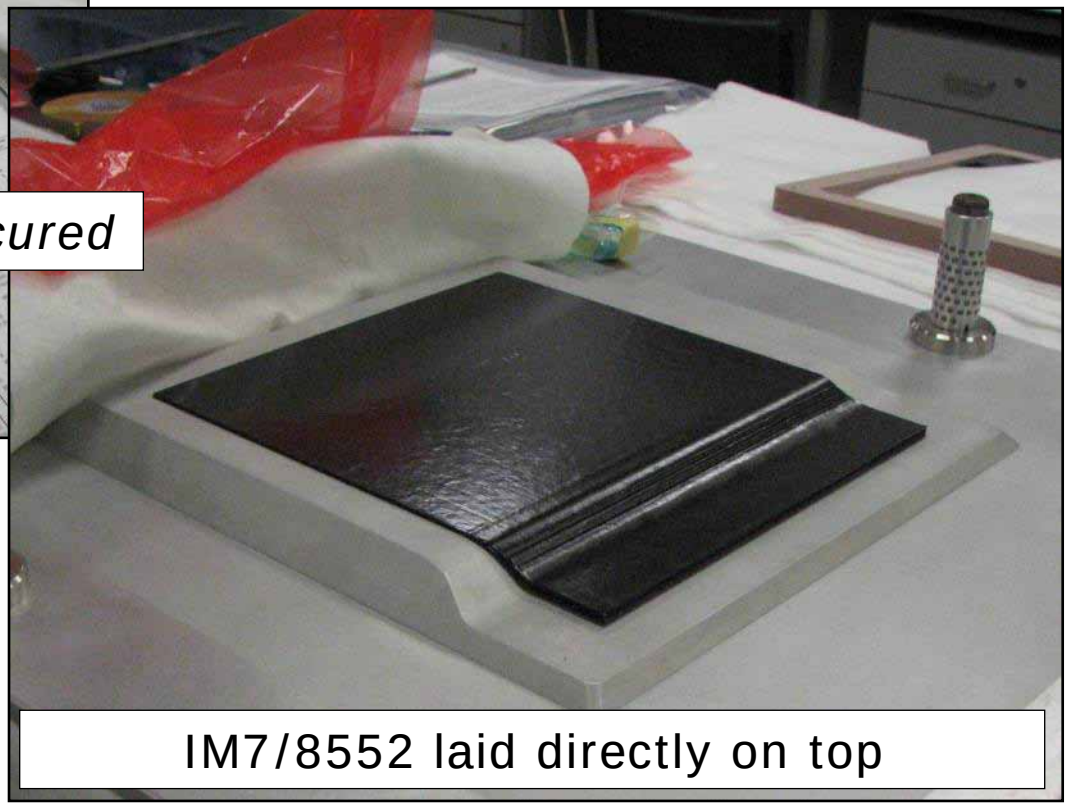
# Manufacture



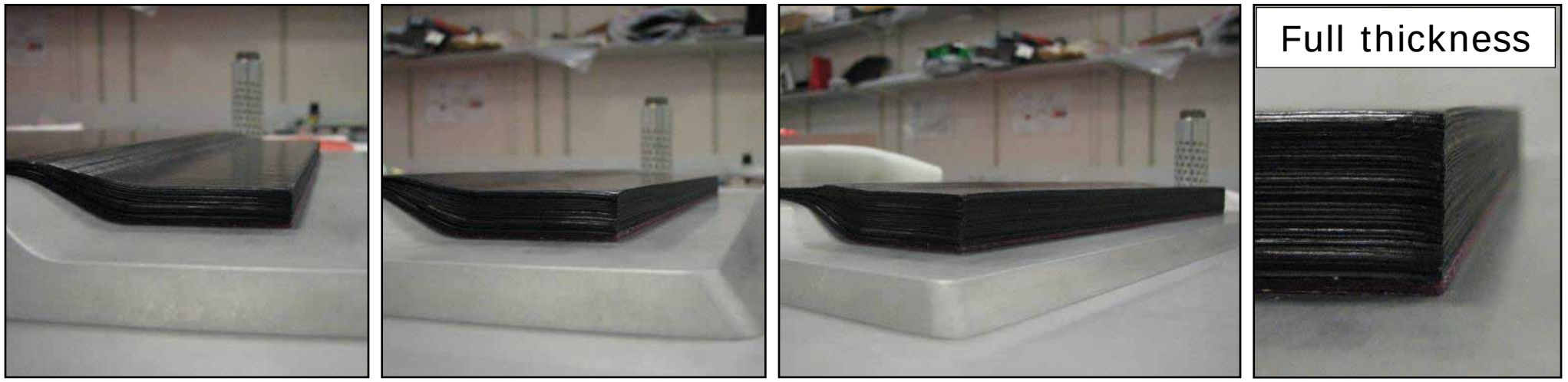

Key Requirement: Accurate, reproducible positioning of ply drops

# Laying Up

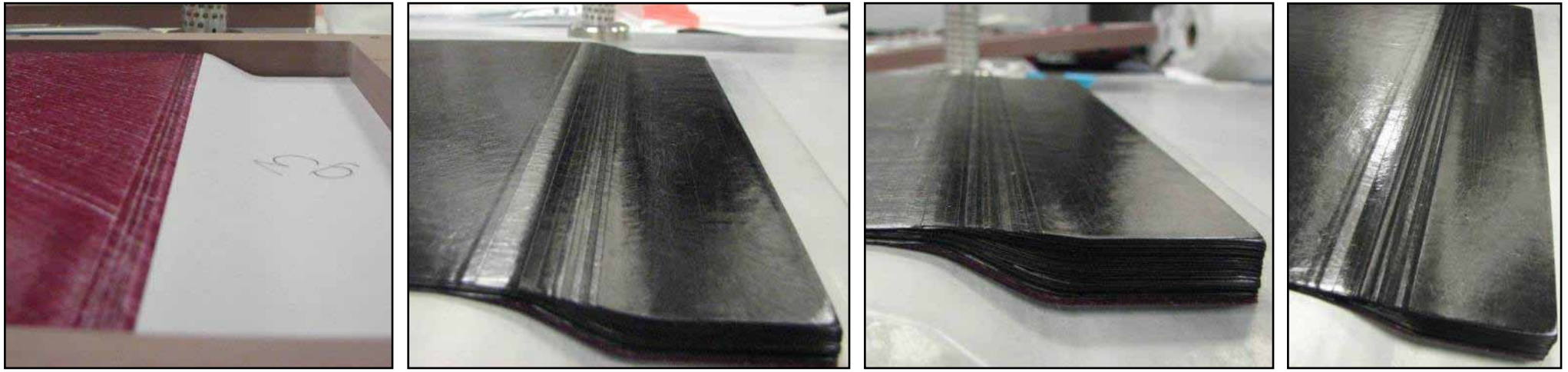

*Co-cured*



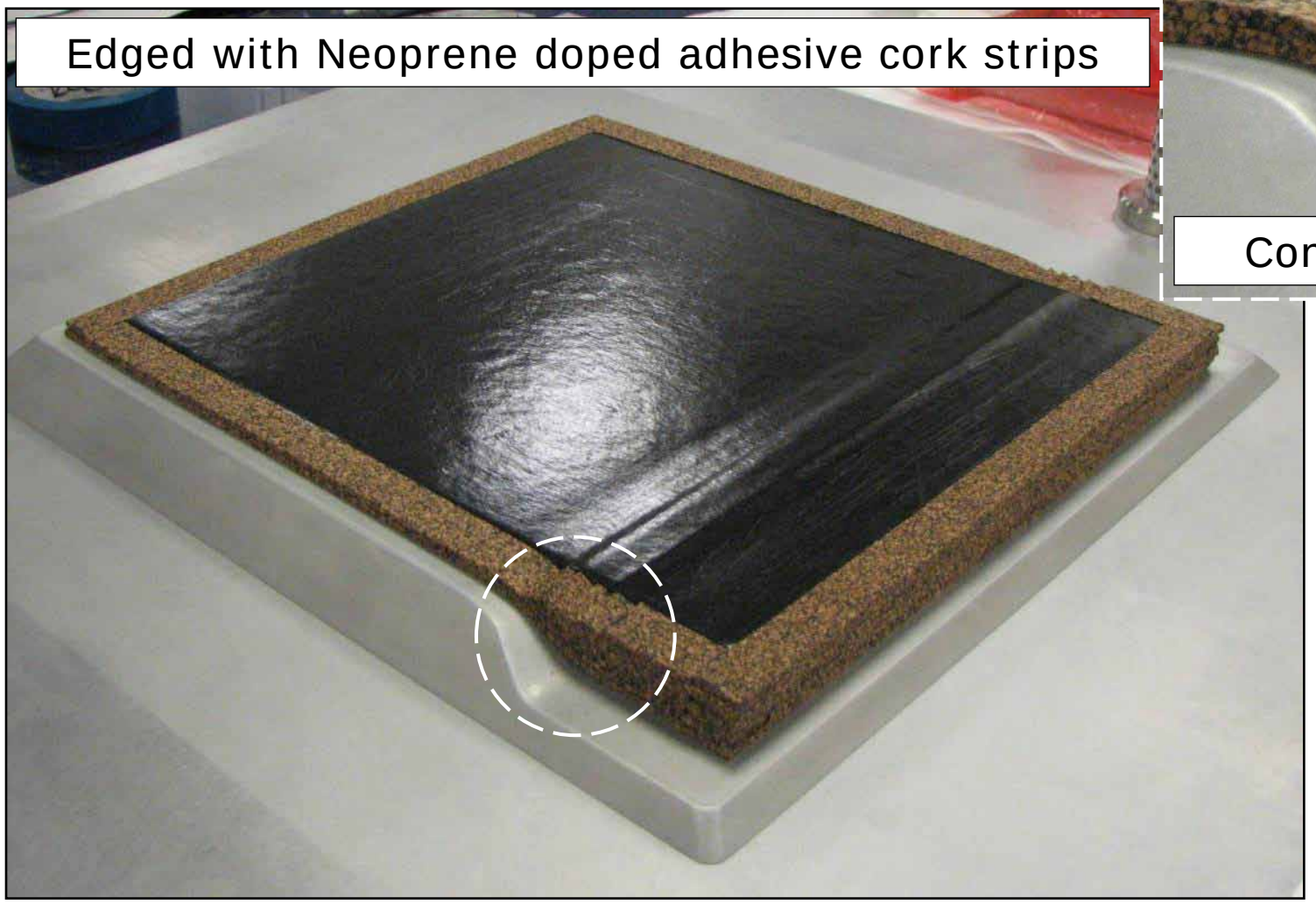
# Continuous Visual Accuracy Assessment




Increasing thickness

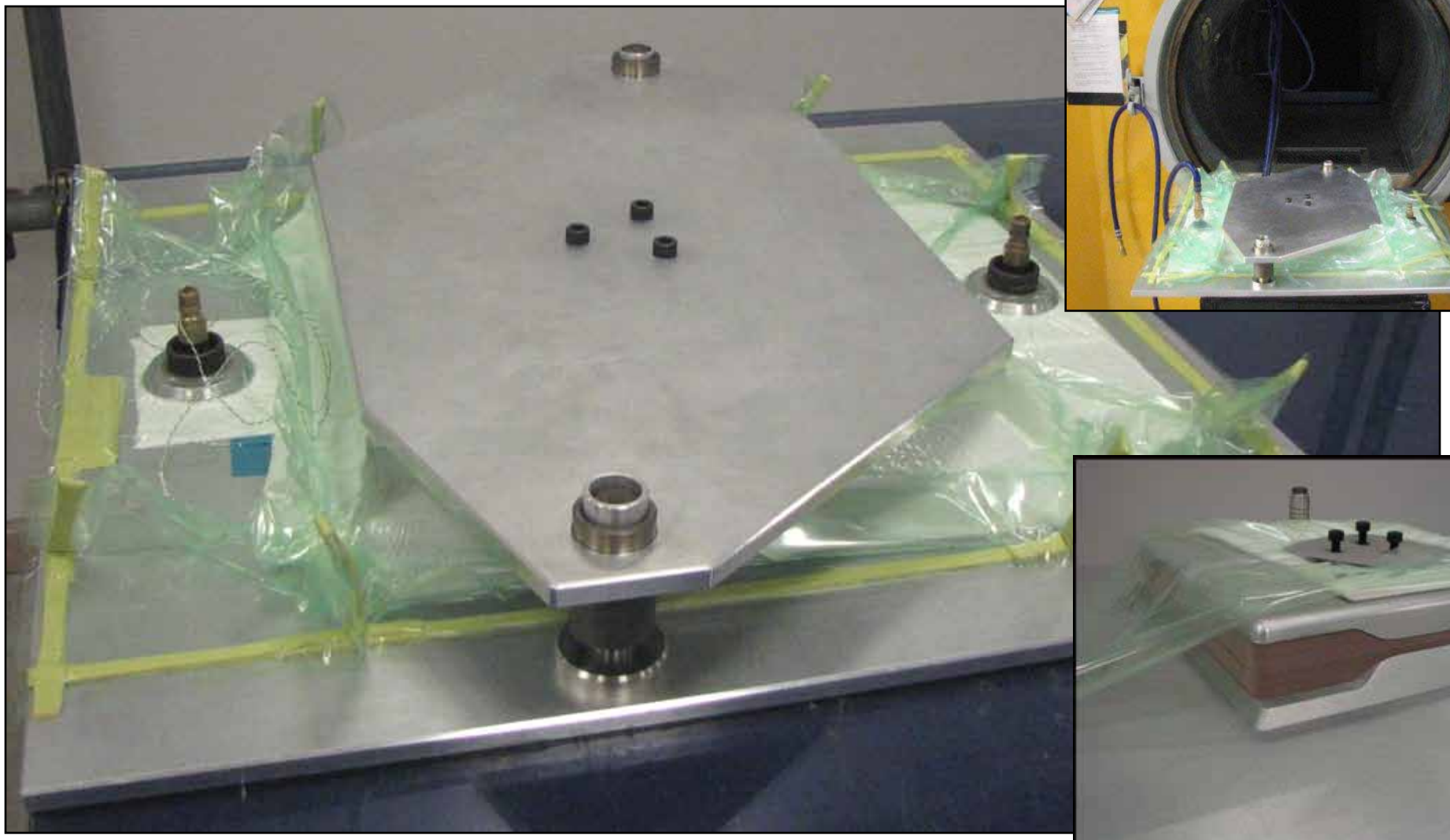


# Edging

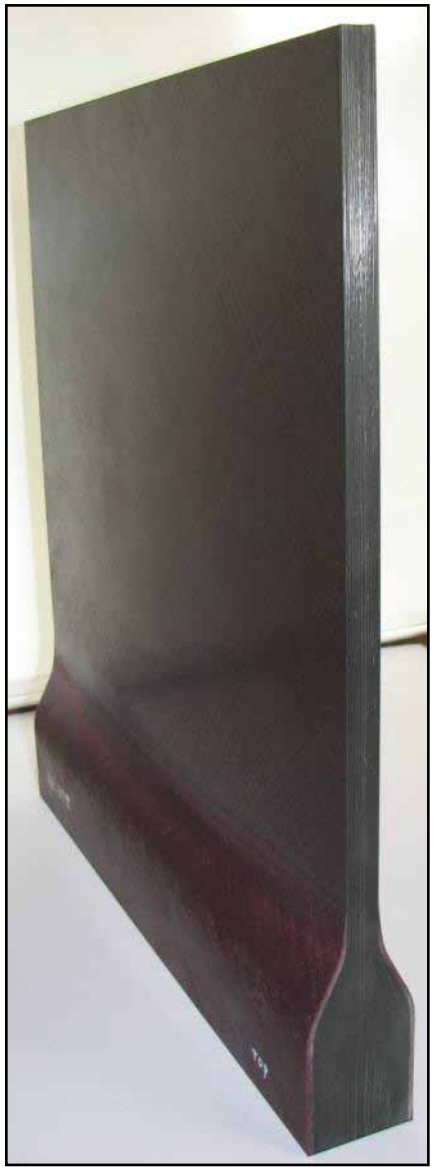

Edged with Neoprene doped adhesive cork strips

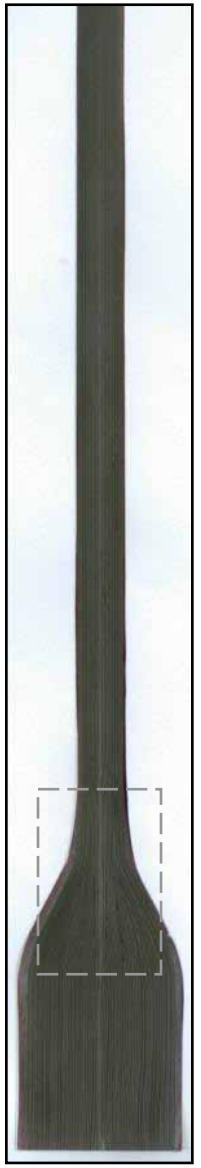

Contour edging detail

# Autoclave cure

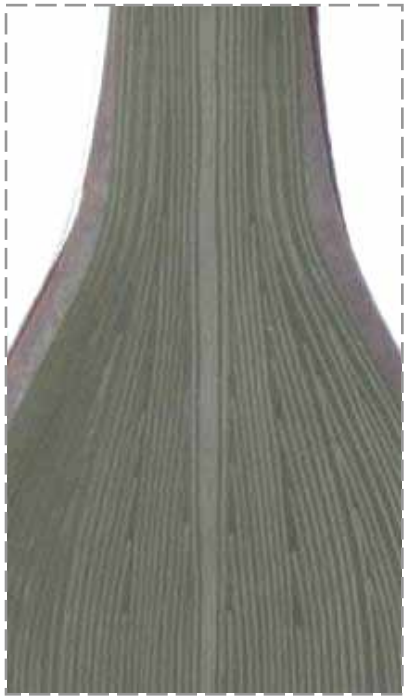


# Finished Part





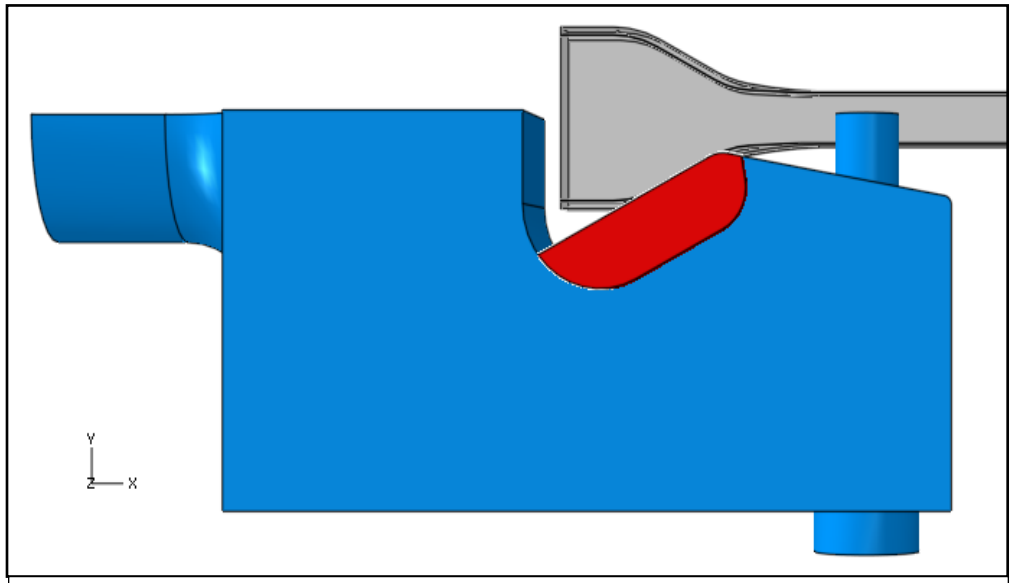
- Specimens were cut from cured plate
- Each was 20mm wide



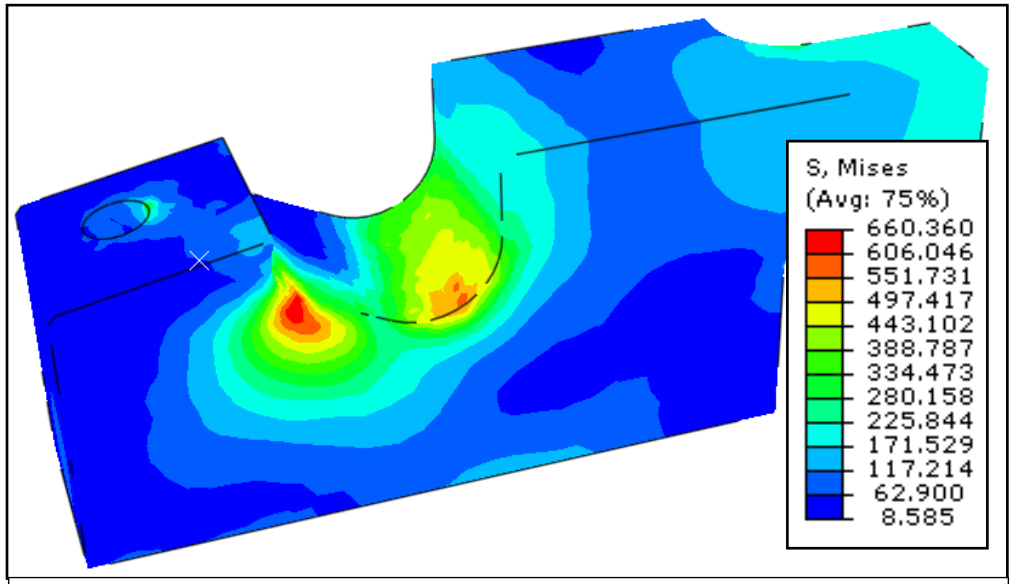
- Surface scan shows well placed plies with good consolidation

# Test Fixture

- For static (tensile) and fatigue (tension-tension) testing
- Quarter fixture FE analysis performed

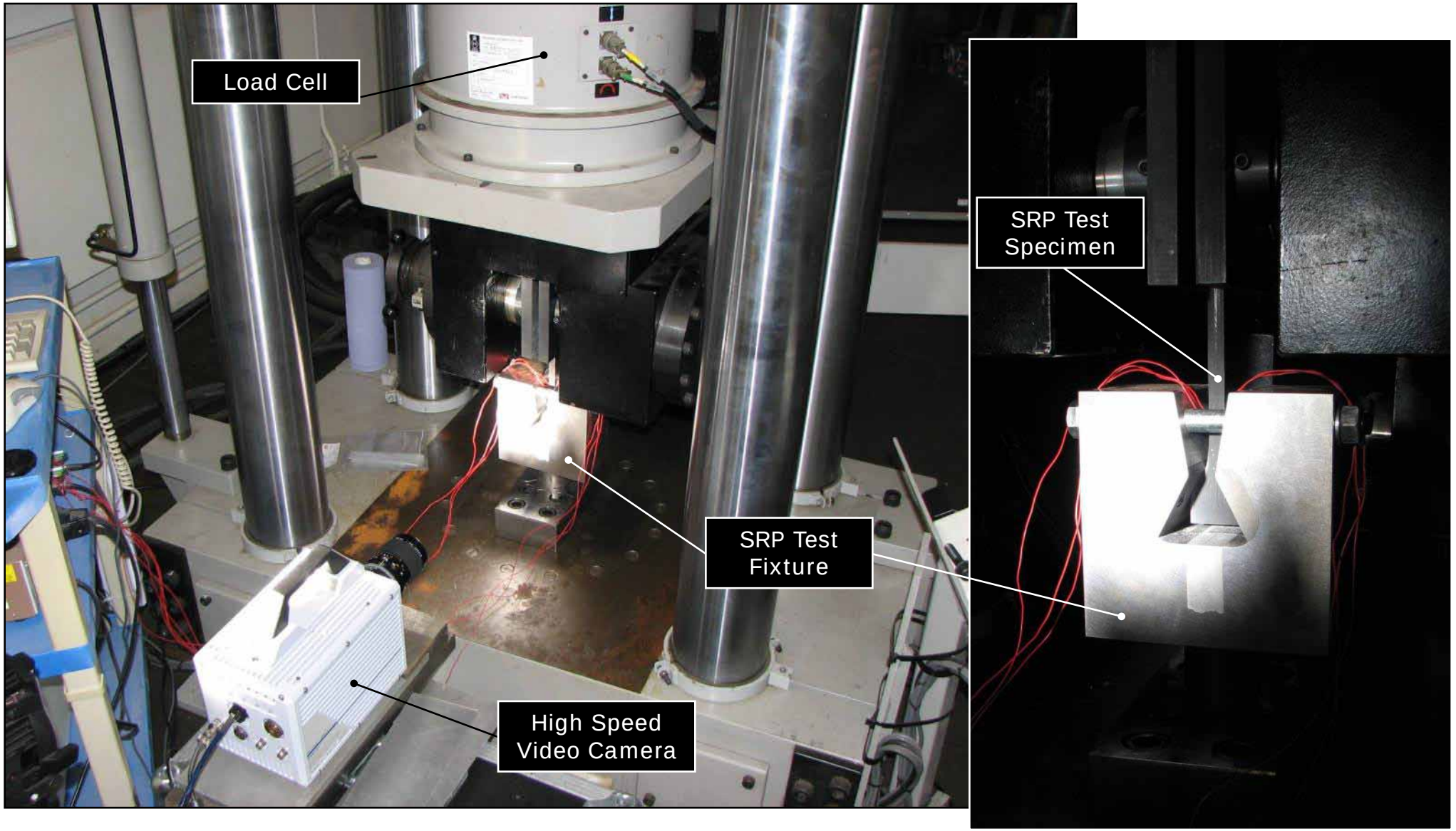


- Steel fixture
- Titanium inserts

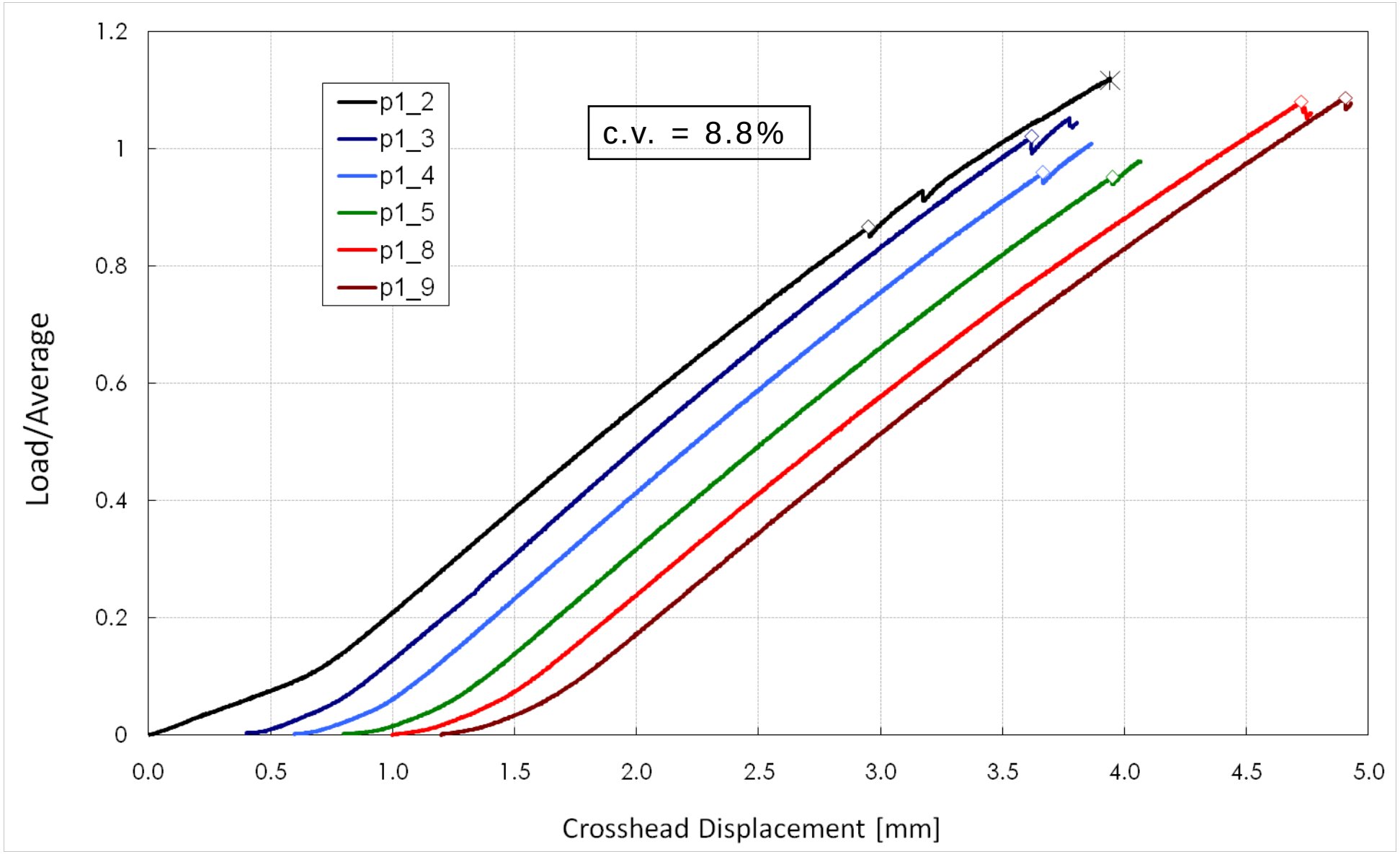



- Abaqus generated von Mises stress plot

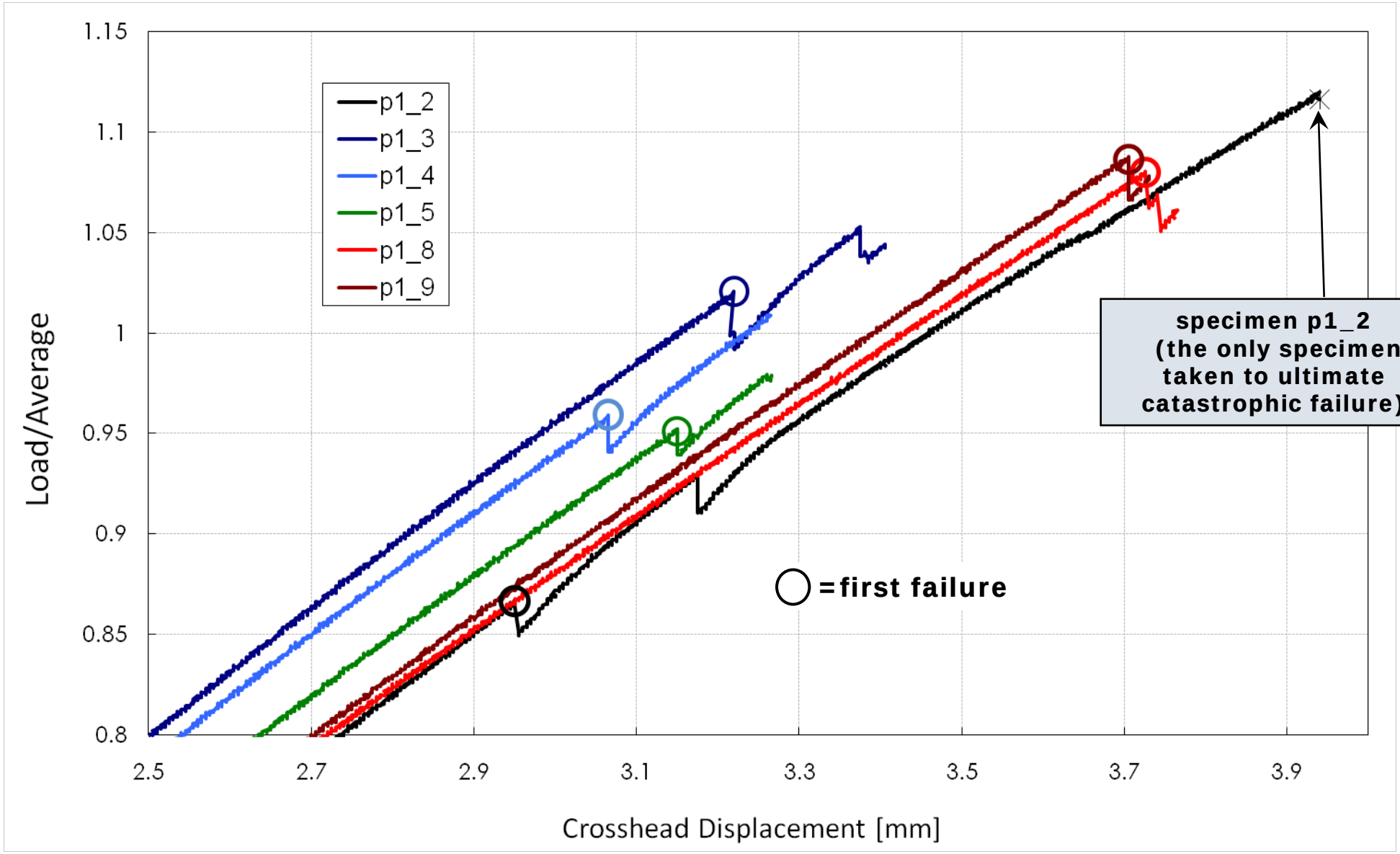
# SRP Static Tensile Testing Setup



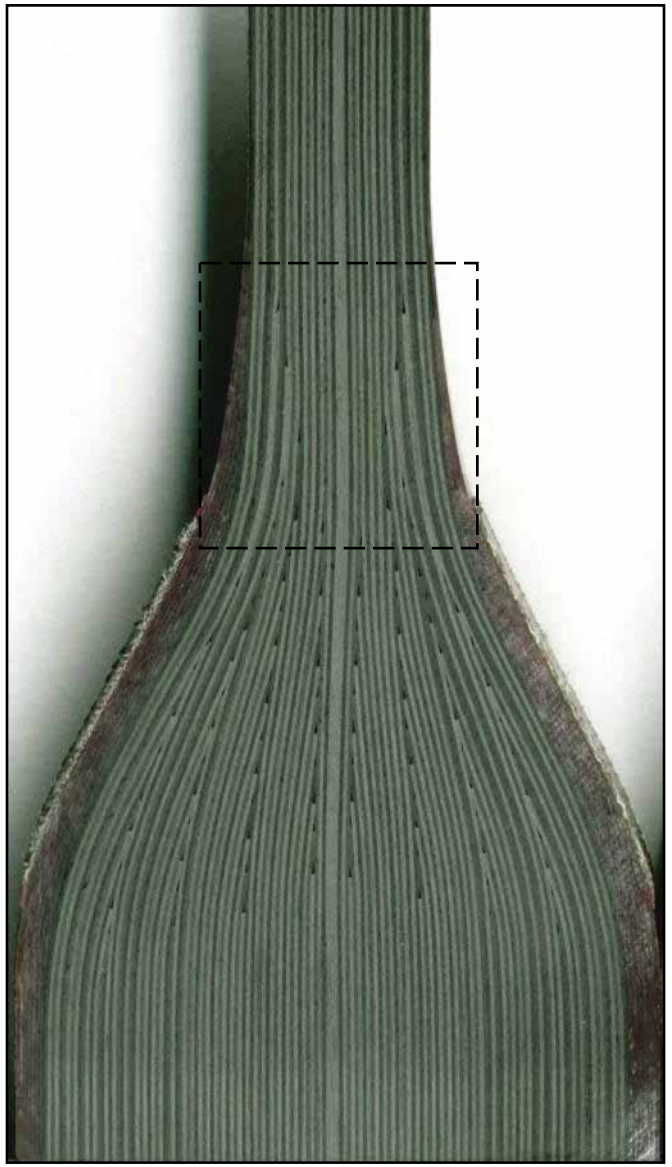
# Test Curves - Load vs. Displacement

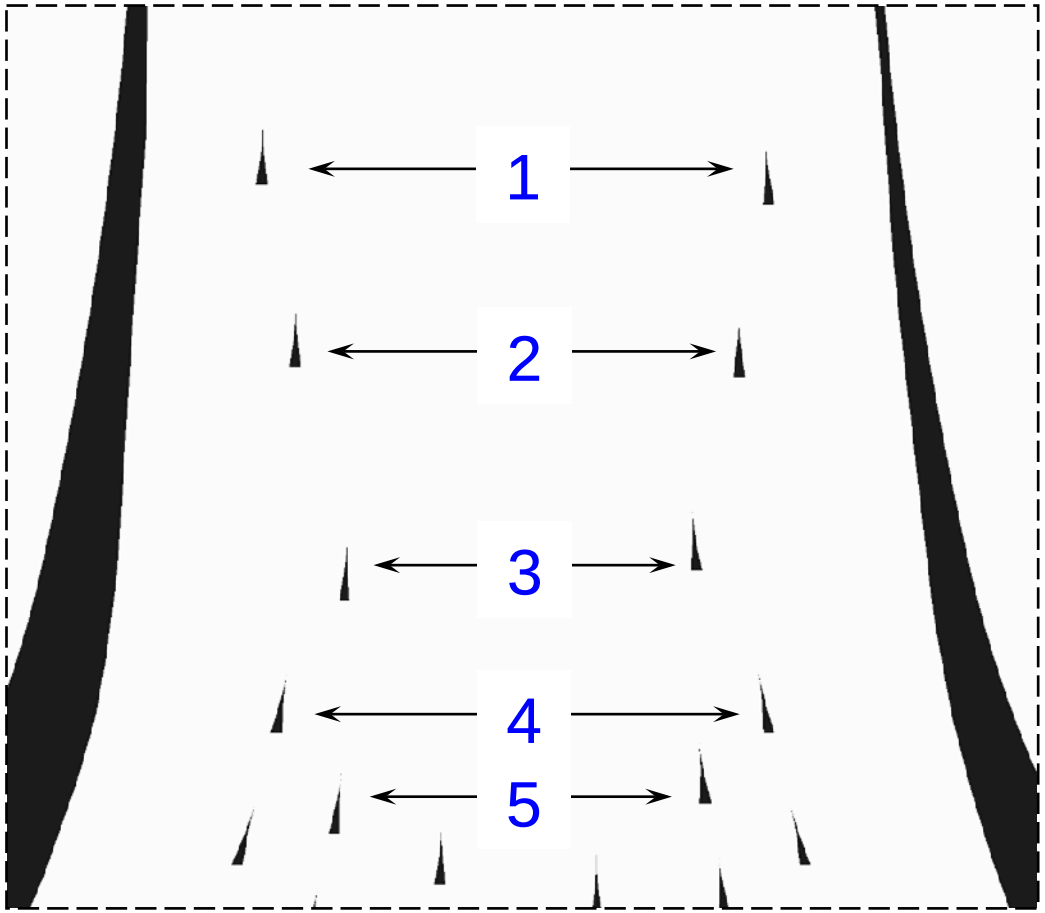


# Test Curves - Close-up of failure region

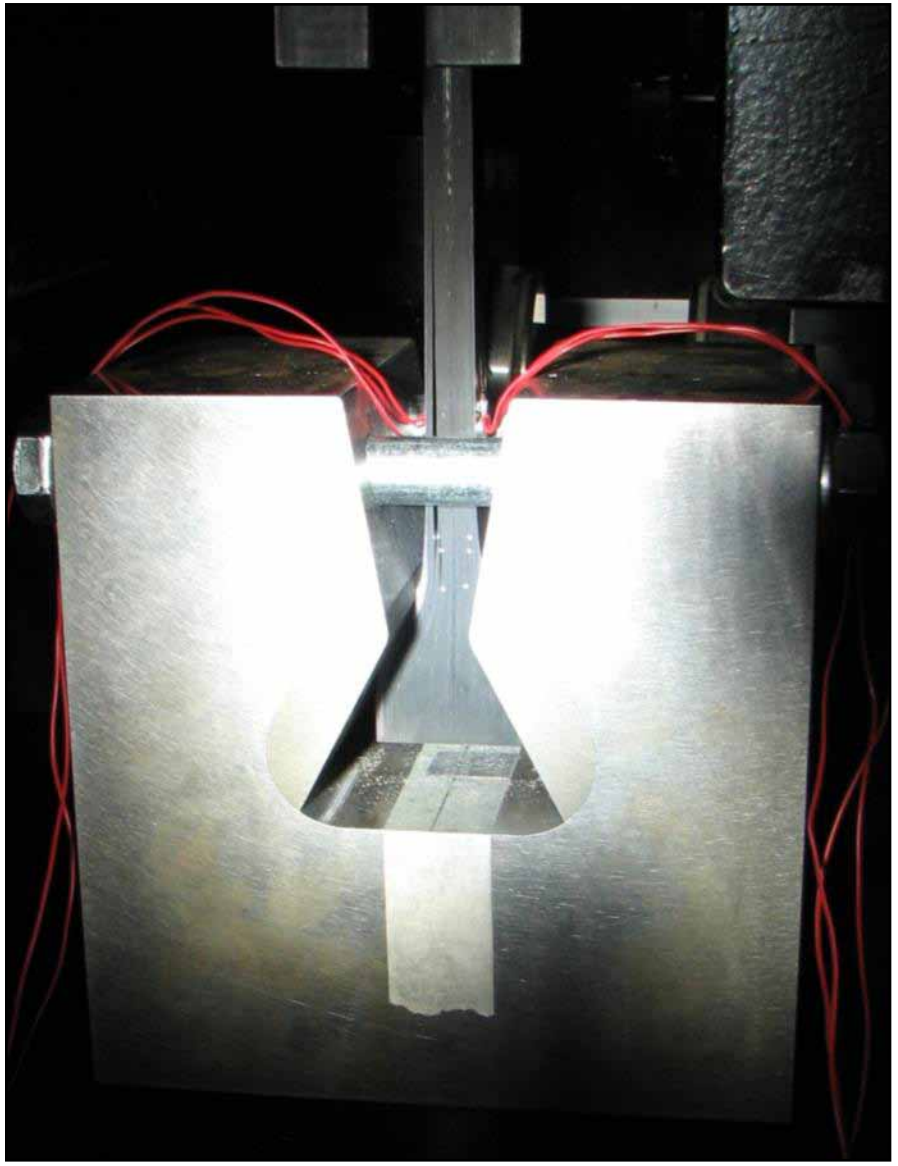


# Ply Drop Map

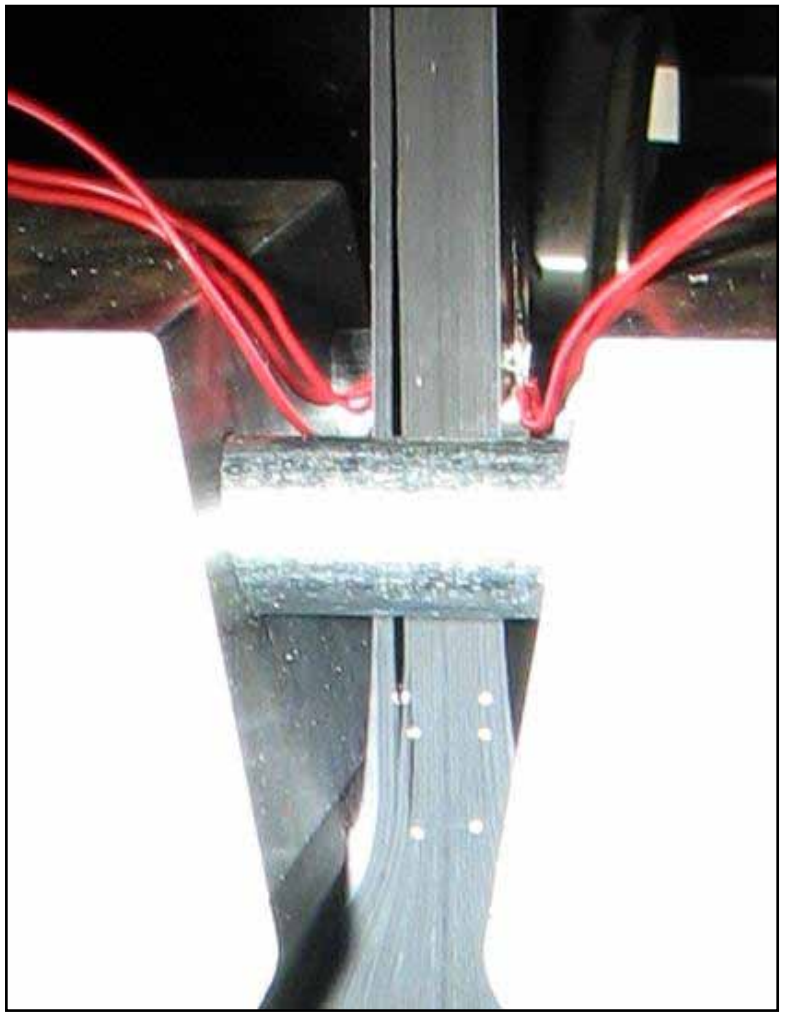




# Failure Location

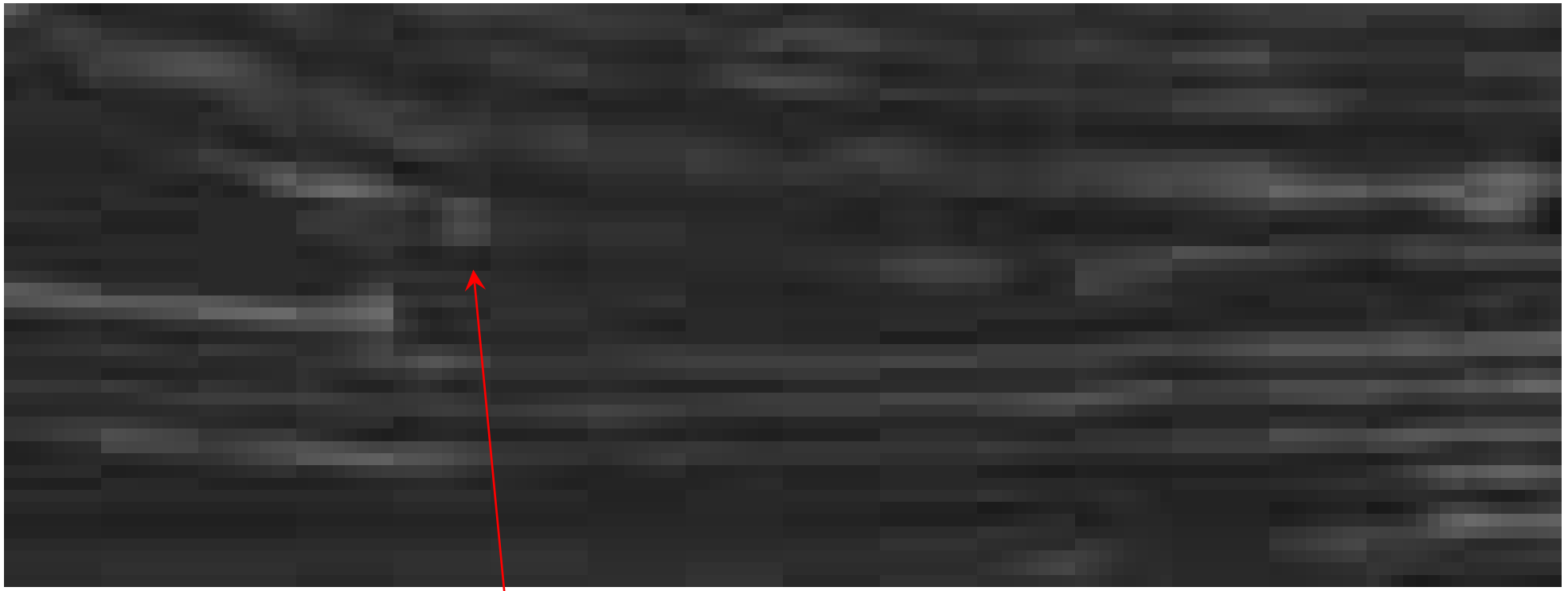


White markers indicate PD 1, PD 2 and PD 5

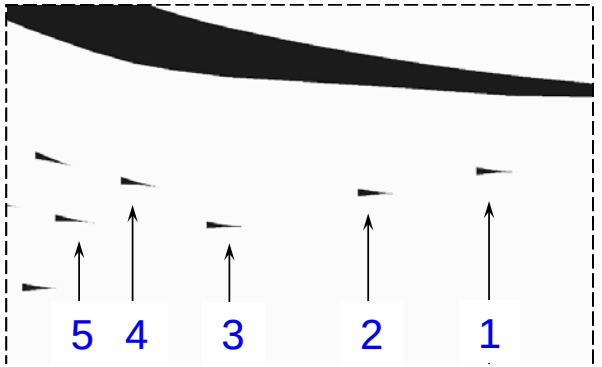


Initiation occurs above PD 5

# High Speed Camera Video – specimen p1_8

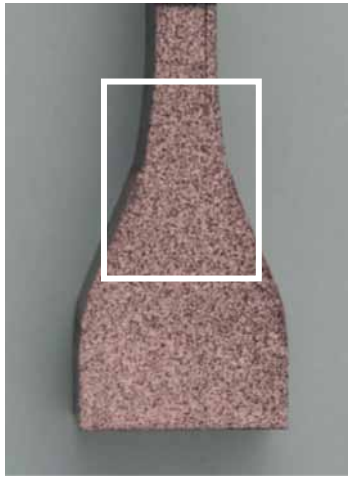


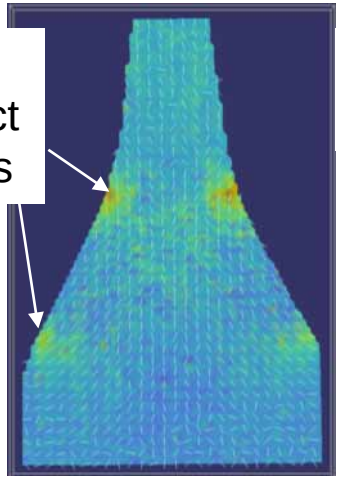

Frame rate: 360,000 fps



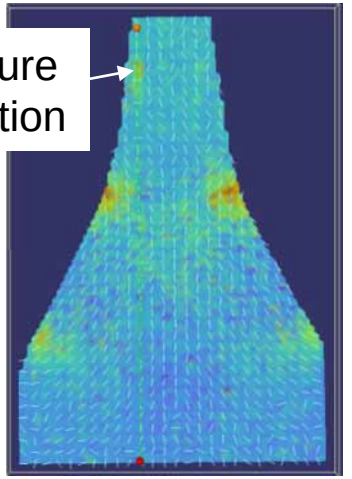
# Digital Image Correlation

- Random black on white speckle pattern applied to specimen using spray paints






96.3%
Failure load

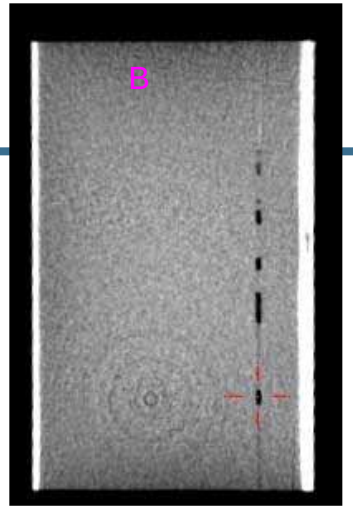


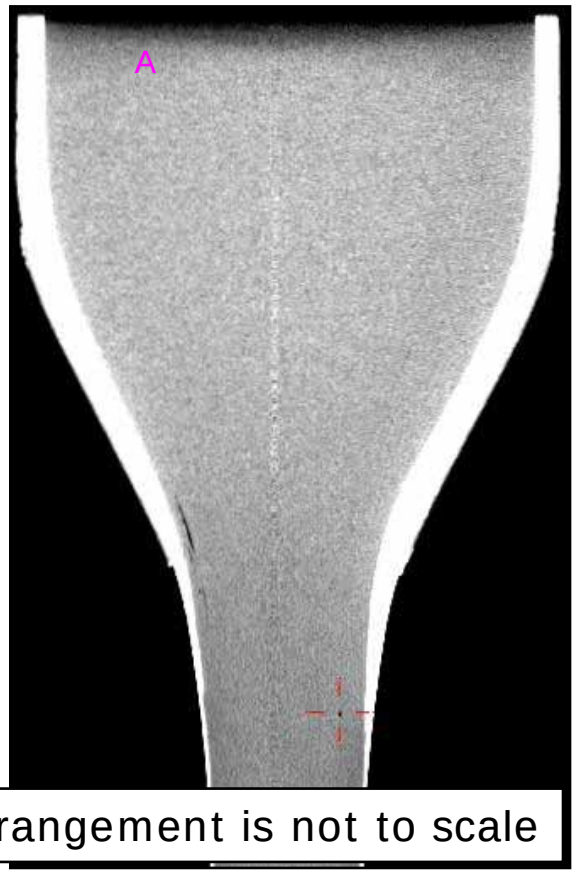

99.8%
Failure load

- 2D system used as no significant out-of-plane deformation expected
- Images captured at 2 sec intervals throughout test (i.e. approx 450-500 images per test)
- Images processed post-test using Dantec Istra 4D software

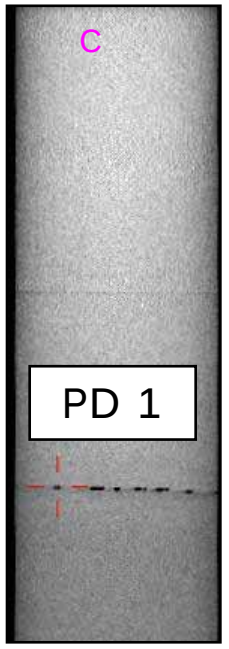
# CT Scans

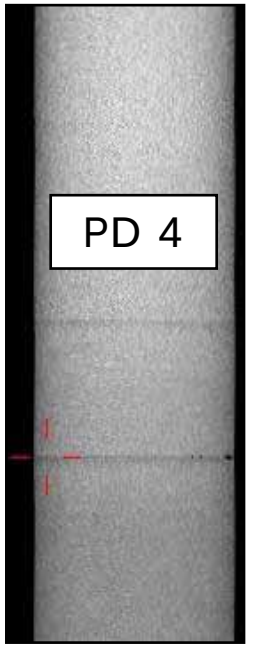
- CT scan was taken of representative sample
- Shows voids at some critical ply drop locations

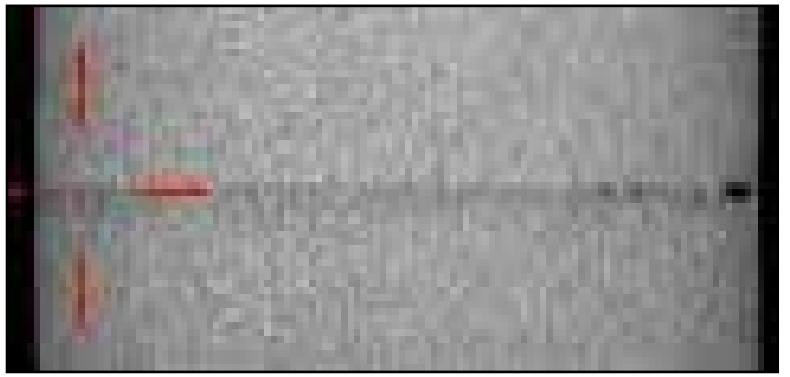


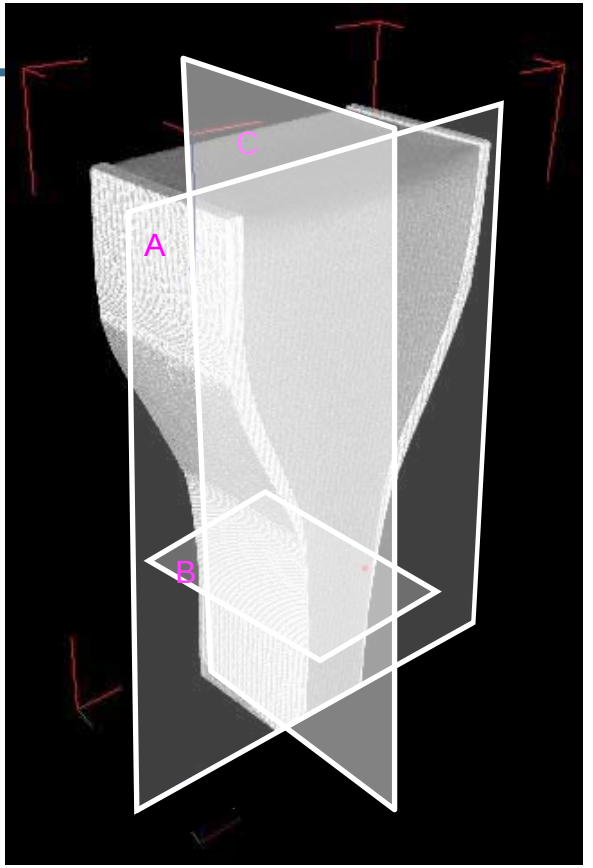




Arrangement is not to scale



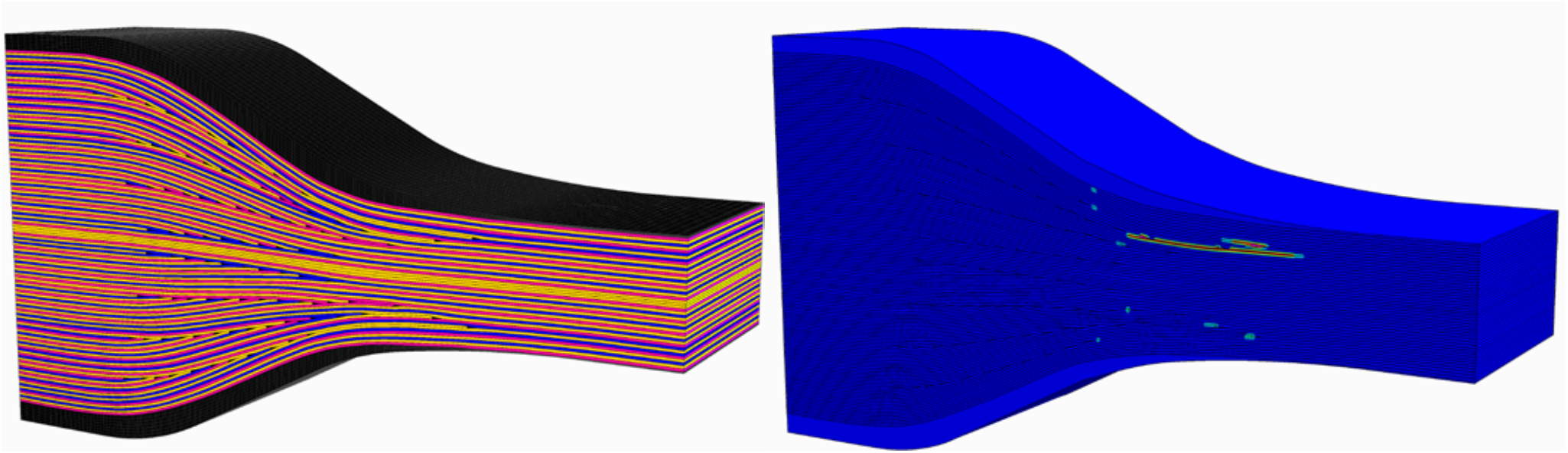





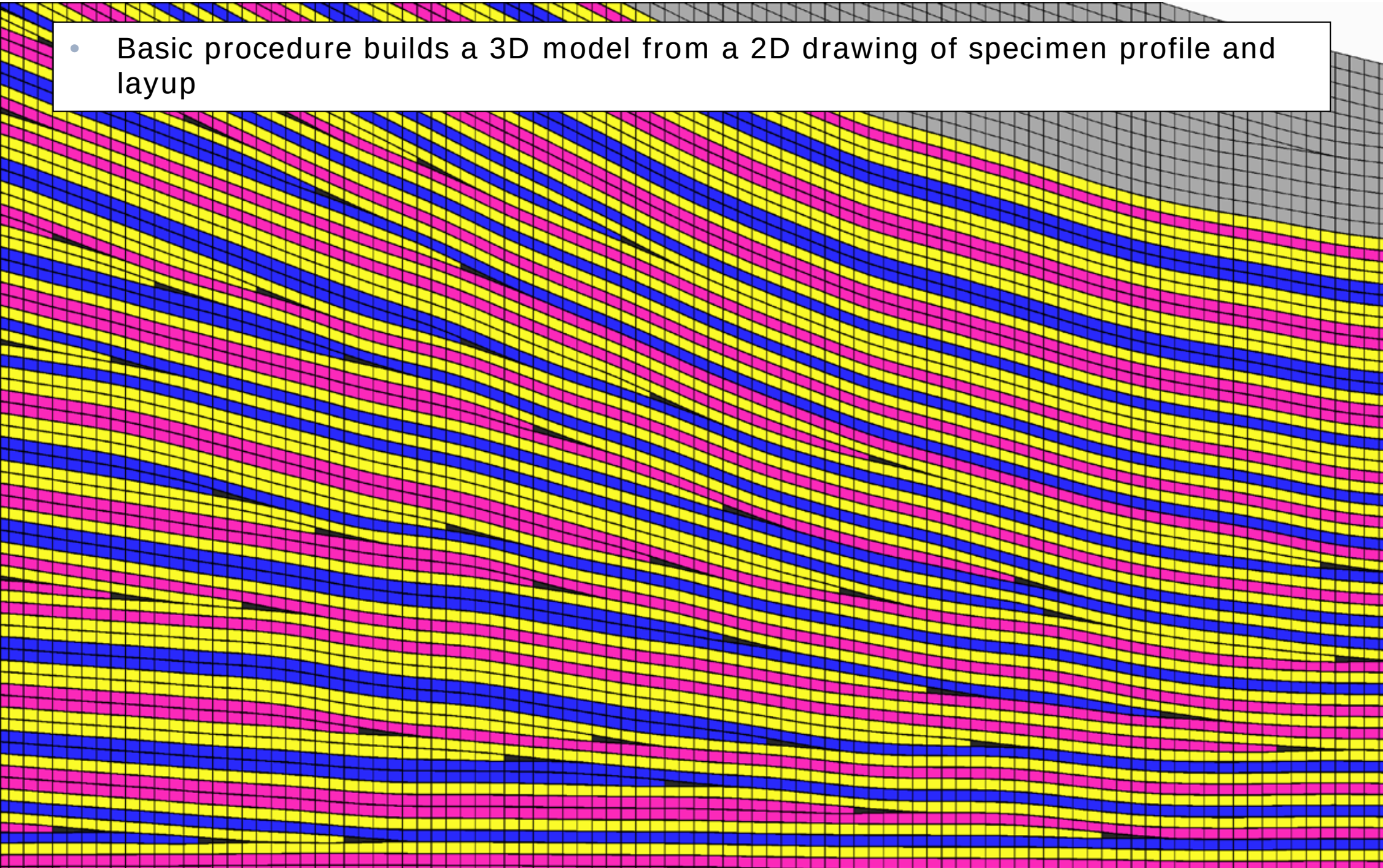
# High-Fidelity FE Modelling

- Methodology based on the use of custom (user-defined) cohesive elements for modelling delamination in the presence of high through-thickness compressive stresses
- Cohesive interfaces defined between every ply, as well as around resin pockets and glass pads
- Required the development of automated meshing software to tackle the complexity of such models
- Meshing tools used to provide realistic specimen and ply drop geometries



# High-Fidelity FE Modelling

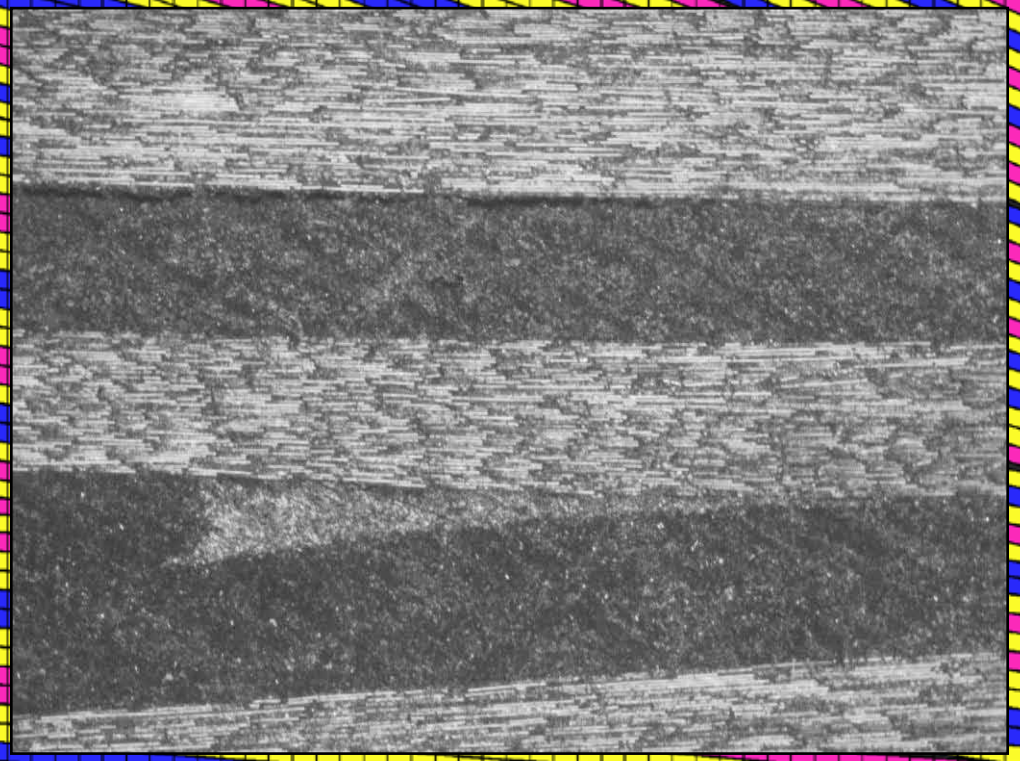
- Basic procedure builds a 3D model from a 2D drawing of specimen profile and layup

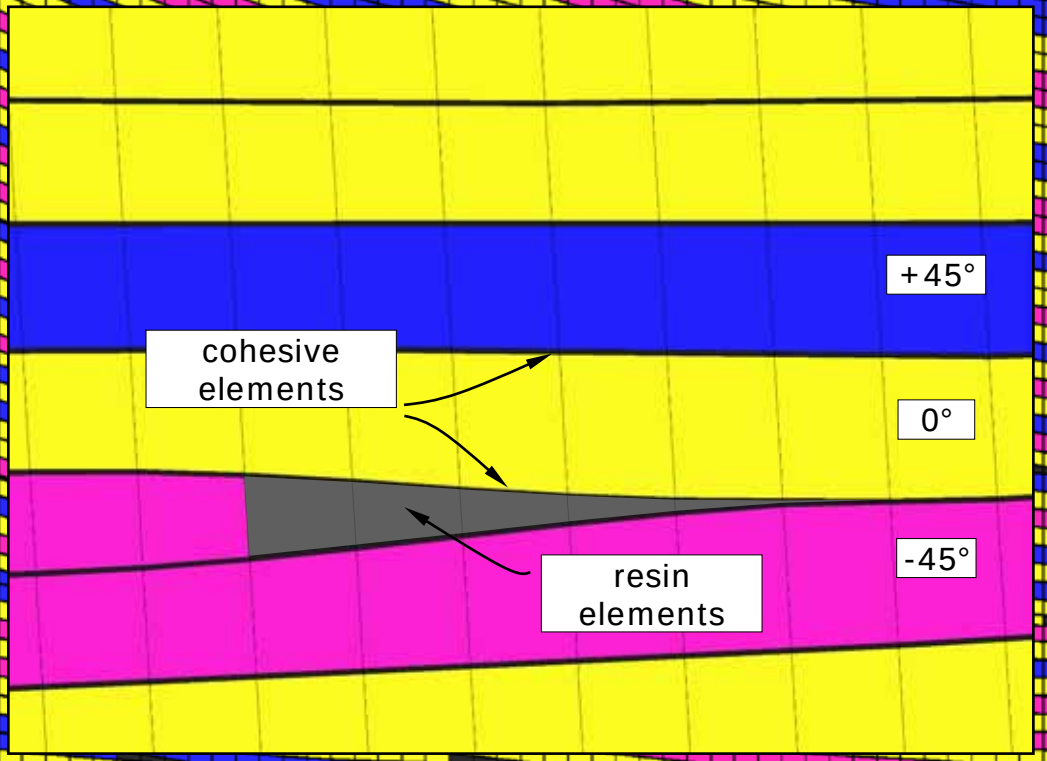


# High-Fidelity FE Modelling

- In house meshing tool builds a 3D model from a 2D drawing of specimen profile and layup

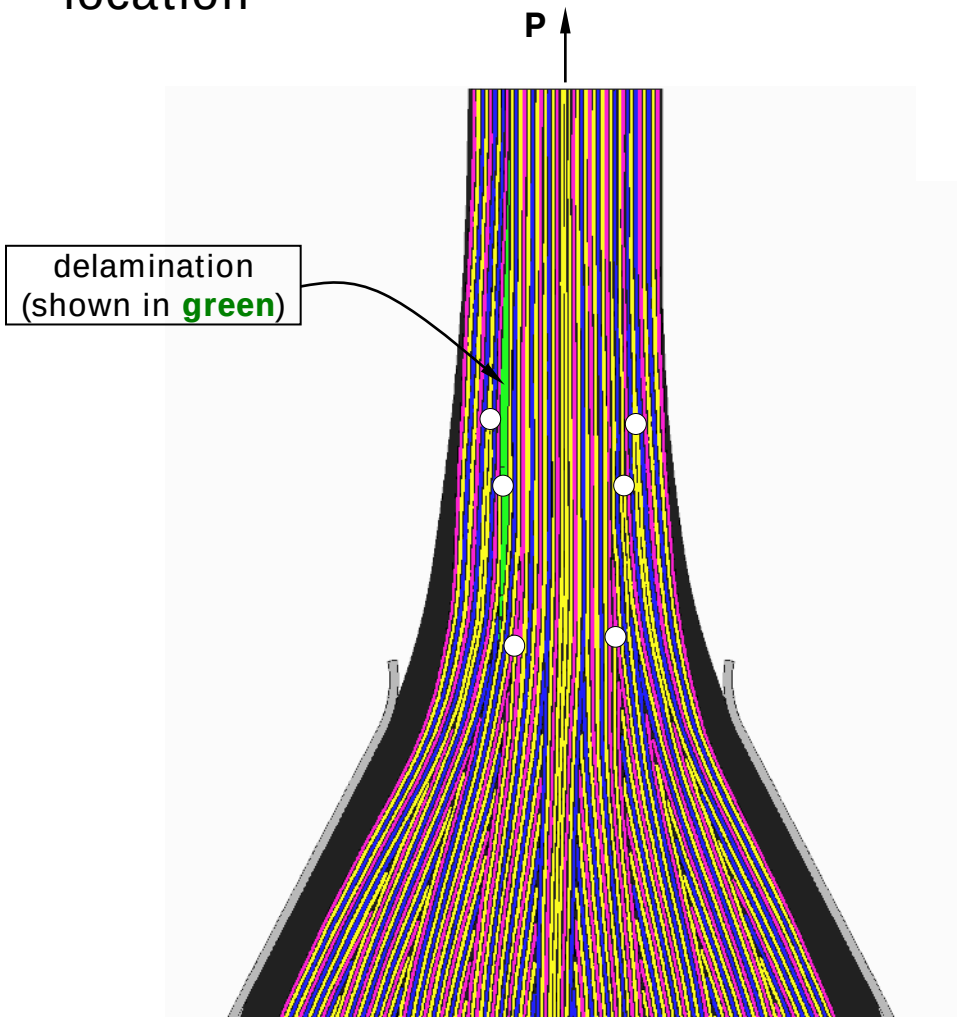
- Plies, resin pockets and cohesive elements are all generated automatically
- Creates realistic ply terminations (can be fine-tuned to match real laminate)

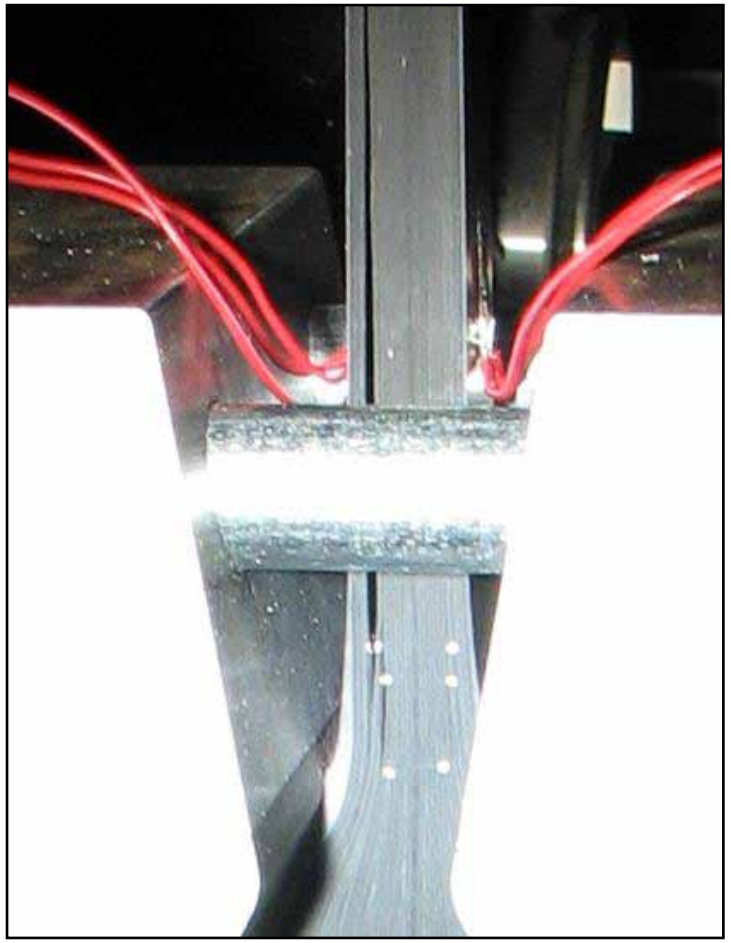




# Test/Model Correlation: Failure Location

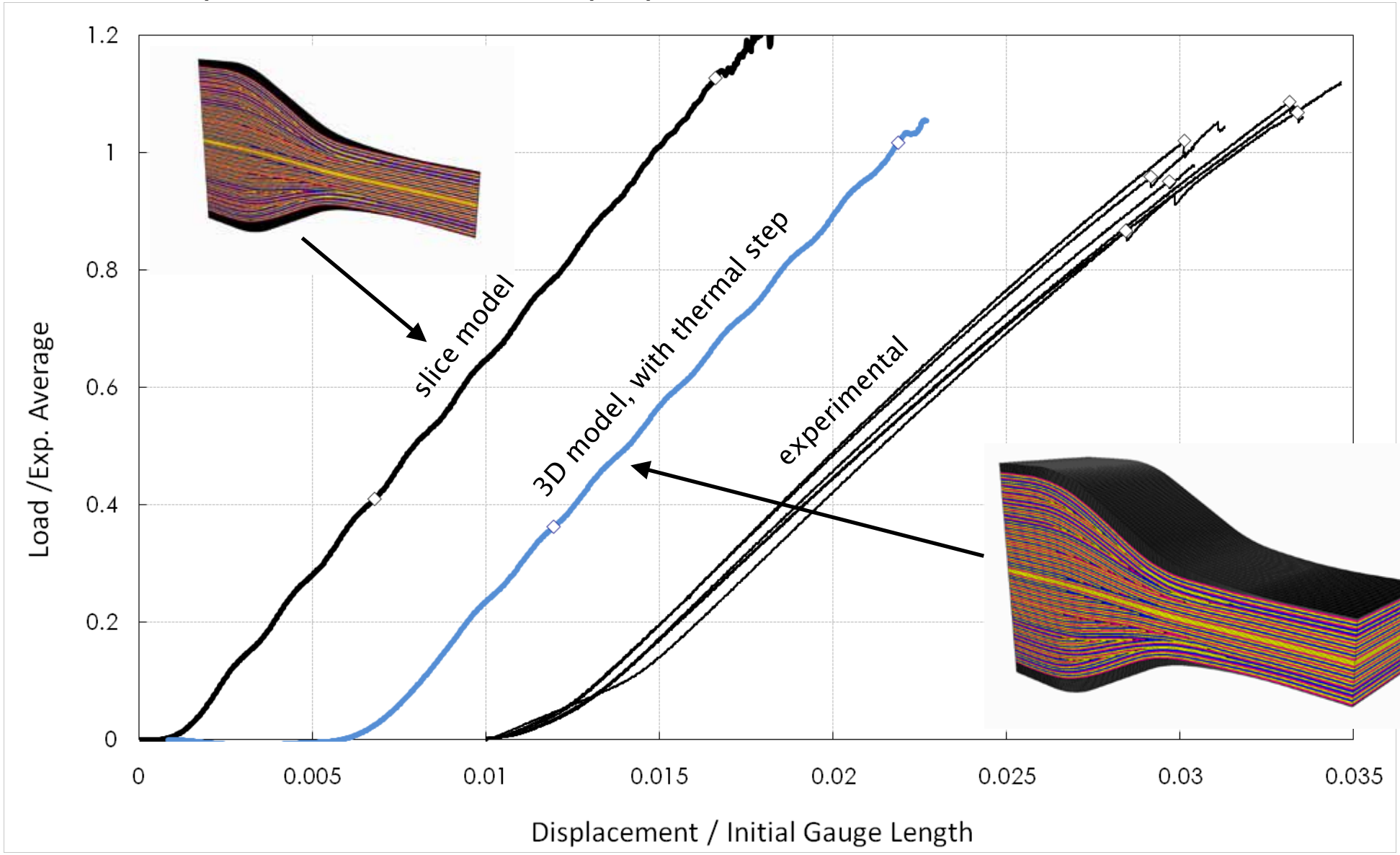
- FE results were used to **predict** the site of delamination initiation – useful for setting up the high-speed camera
- **5 out of 6 specimens** delaminated within 1-2 millimetres from predicted location



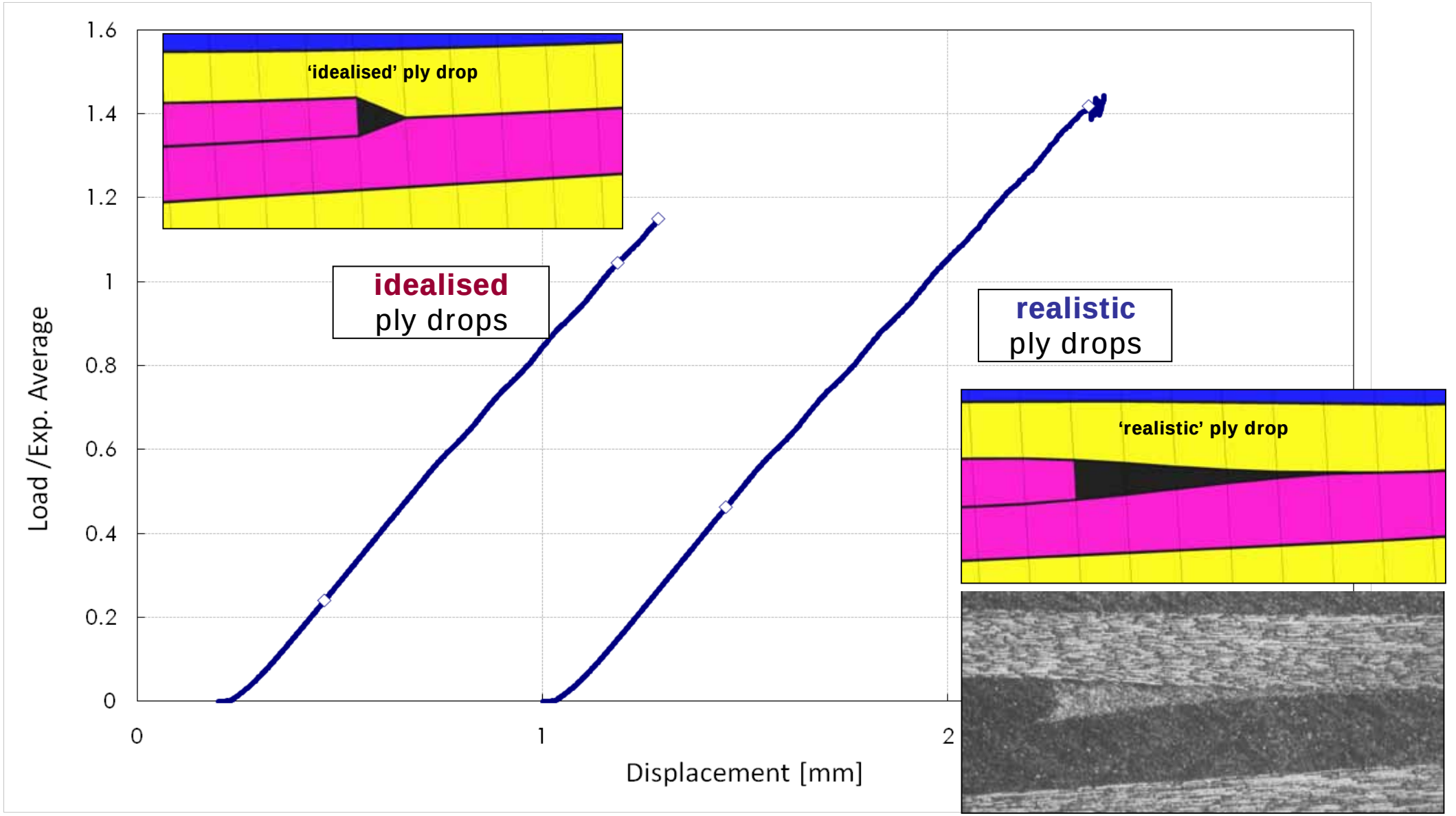



# Test/Model Correlation: Load-Displacement

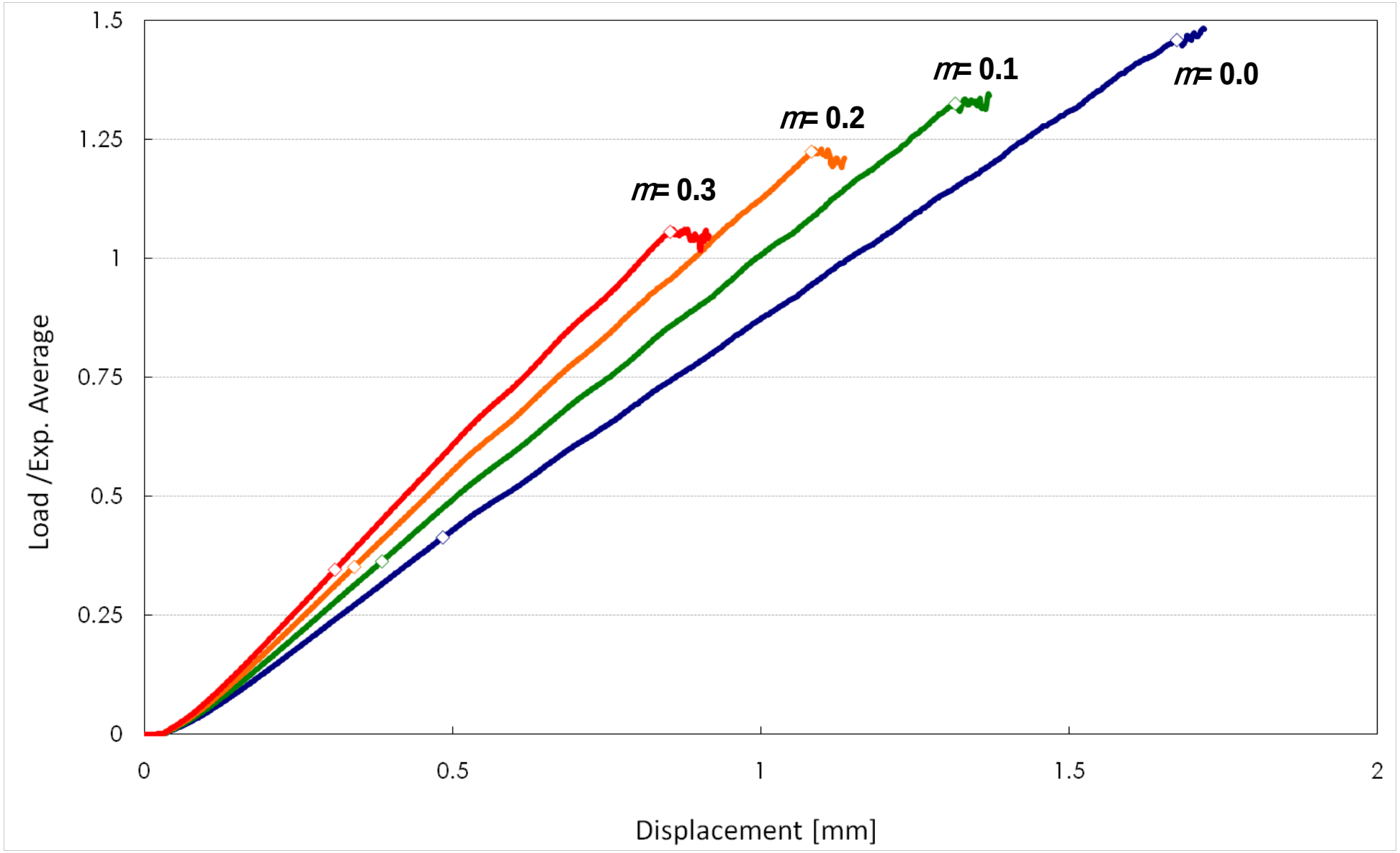
- Force-displacement curves for (2D) slice and 3D models



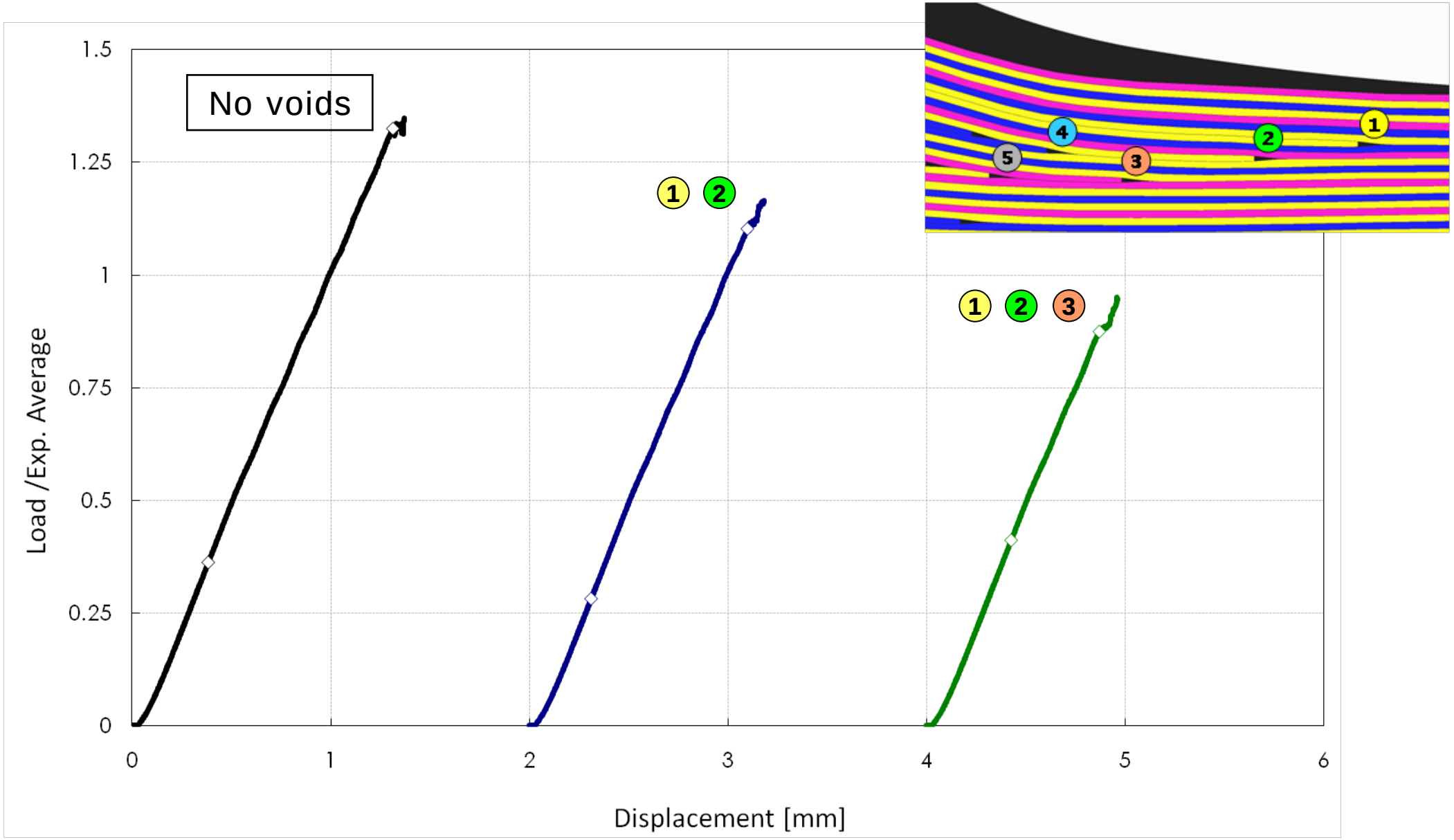
# Effect of Ply Drop Geometry



# Effect of Friction



# Effect of Voids



# Summary

- Testing has been undertaken on a severely tapered specimen with multiple ply drops
- Failure occurs in the region ahead of the contact area where delamination is not suppressed by compression
- Various experimental techniques have been used to identify failure initiation location
- Finite element analysis has been able to predict very similar behaviour
- Model results are very susceptible to small details; resin pocket geometry, friction, voids which need to be captured accurately from experimental work

# Acknowledgements

The authors would like to acknowledge Rolls-Royce plc for funding this work