University of BRISTOL

Experimental study of damage propagation in overheight compact tension tests

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ADVANCED COMPOSITES CENTRE FOR INNOVATION & SCIENCE

Overview

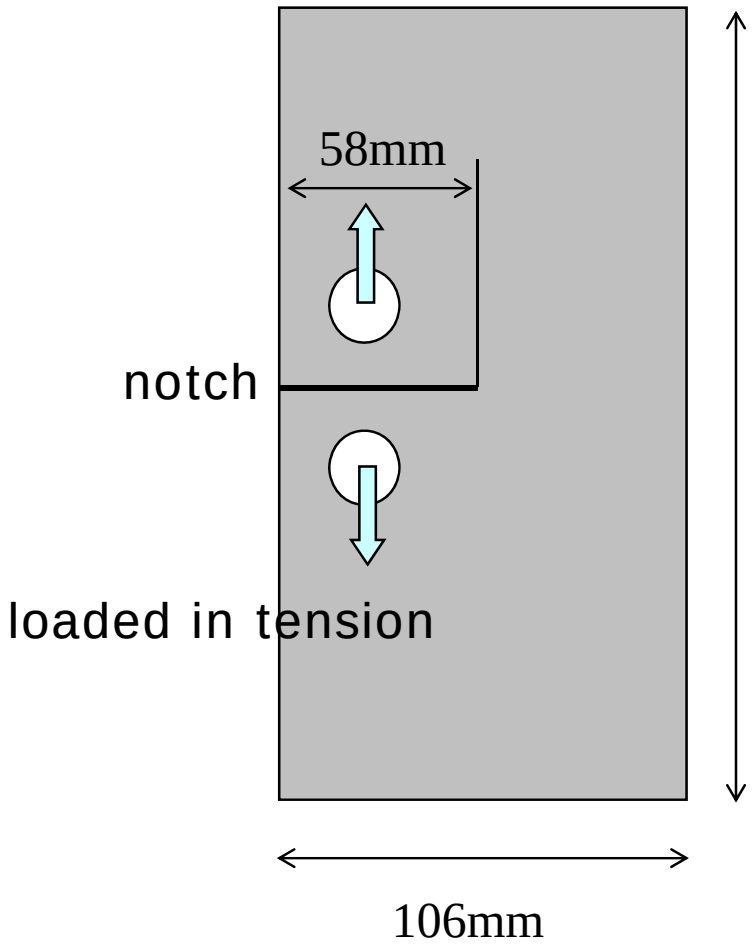
- Introduction
- Over-Height Compact Tension (OCT) testing
- Material and lay-ups
- Testing results and analysis
- C-scan results of tested specimens
- Discussion and conclusion

Introduction

- Composites failure is dominated by local effects
- Sub-critical damage occurs at load levels well below ultimate failure
- Matrix cracks and delaminations interact with fibre stress to determine ultimate failure mode and strength
- A set of tests using the Overheight Compact Tension (OCT) specimen have been conducted to investigate the the influence of sub-critical damage on fibre failure
- The OCT test is advantageous as it allows for stable crack growth, typical of large composite structures

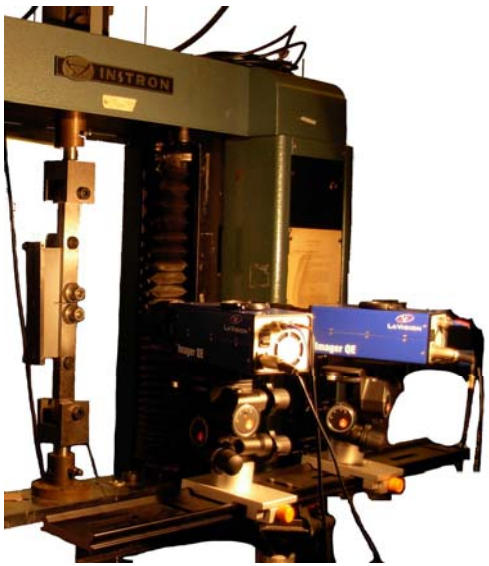
OCT Testing (1)

- OCT testing set-up



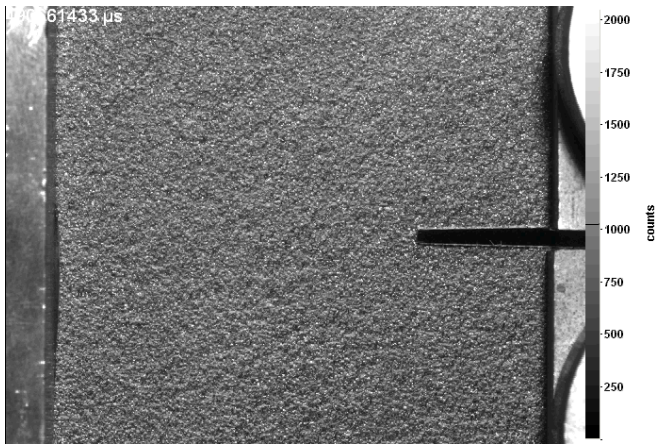
Extensometer to measure pin opening displacement (POD)

Anti-buckling support

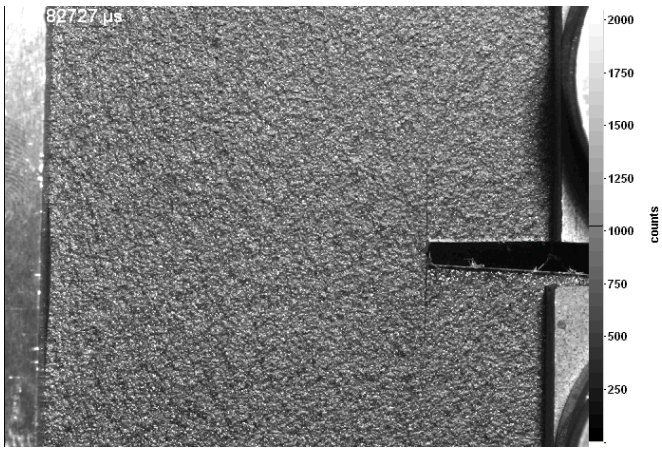


Testing (2)

- Advantages of OCT testing
  - Forming stable damage zone ahead of the crack tip



$[0/90]_{8s}$



$[0_4/90_4]_{2s}$

  - Providing good opportunity to study the influence of the sub-critical damage on the progression of composites failure.

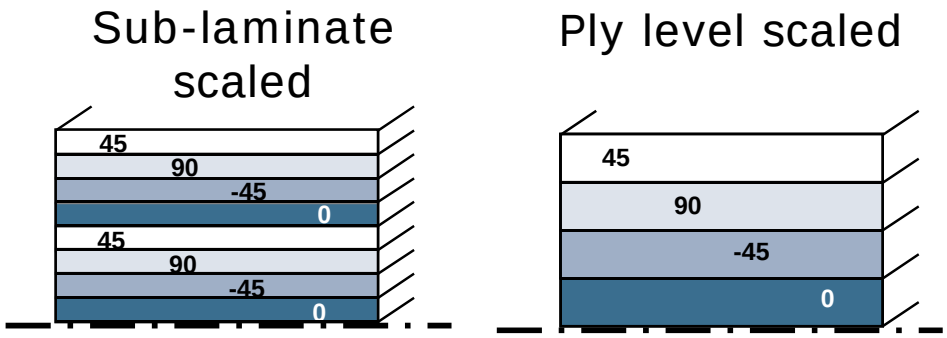
Testing Material and Lay-ups

- Material

  IM7/8552 carbon-epoxy

- Lay-ups

  - Single ply thickness: 0.125mm
  - Tested lay-ups:



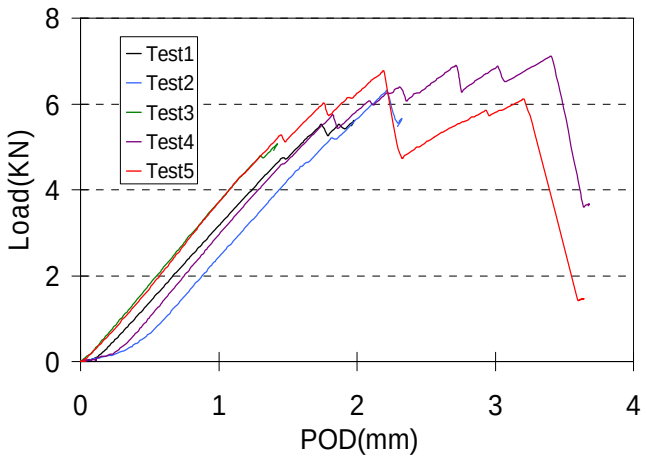
Sub-laminate level scaled		Ply level scaled	
Layup	**Thickness**	**Layup**	**Thickness**
$[0/90]_{4s}$	(2mm)	$[0_2/90_2]_{2s}$	(2mm)
$[0/90]_{8s}$	(4mm)	$[0_4/90_4]_{2s}$	(4mm)
$[45/90/-45/0]_{2s}$	(2mm)	$[45_2/90_2/-45_2/0_2]_s$	(2mm)
$[45/90/-45/0]_{4s}$	(4mm)	$[45_4/90_4/-45_4/0_4]_s$	(4mm)

- 6 samples were tested for each lay-up.
  3 complete failure tests
  3 interrupted tests at different loading levels.

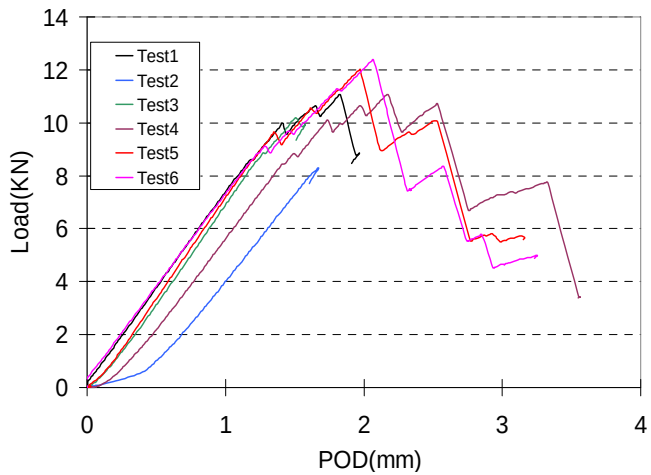
Testing Results(1) - Cross-ply layups

Sub-laminate level scaled

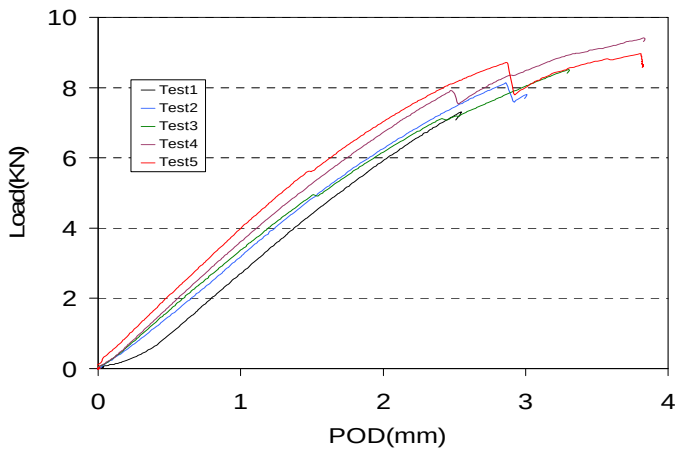
$[0/90]_{4s}$ (2mm)



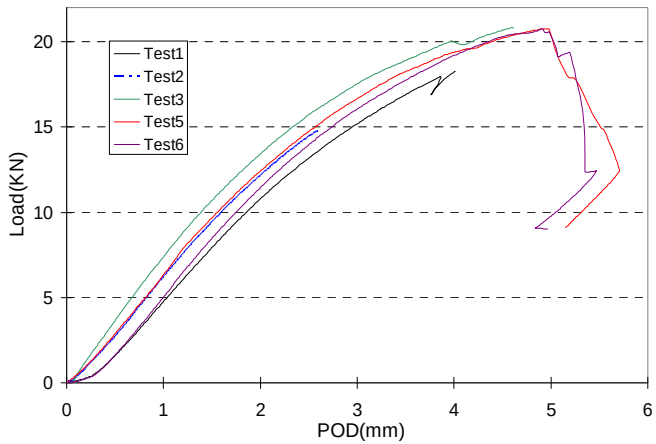
$[0/90]_{8s}$ (4mm)



Ply level scaled



$[0_2/90_2]_{2s}$ (2mm)

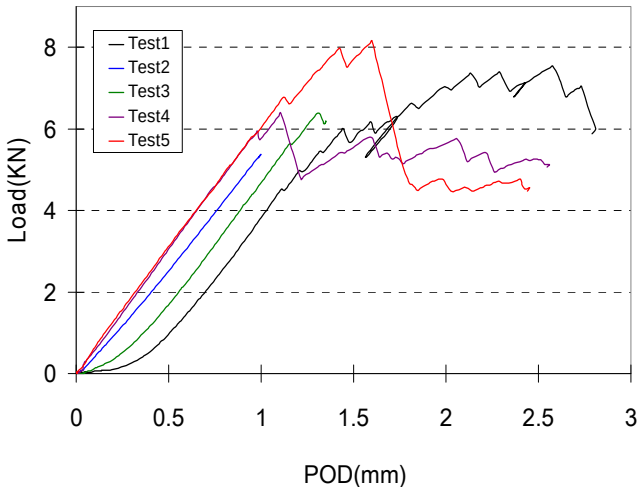


$[0_4/90_4]_{2s}$ (4mm)

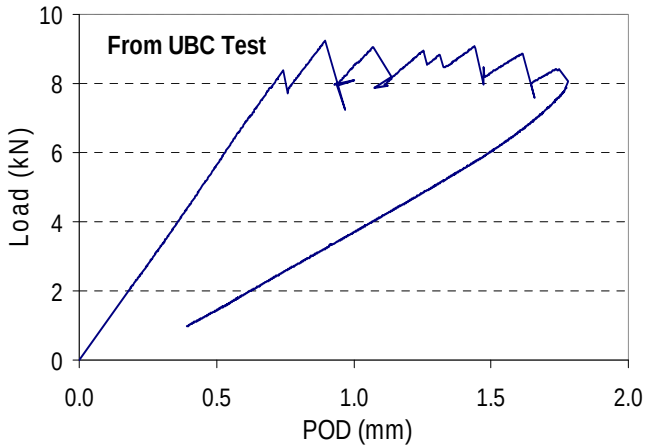
Testing Results(2) - Quasi-isotropic lay-ups

Sub-laminate level scaled

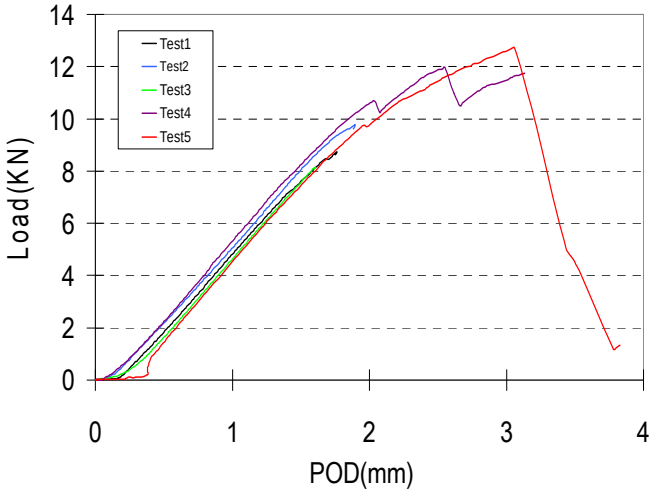
$[45/90/-45/0]_{2s}$ (2mm)



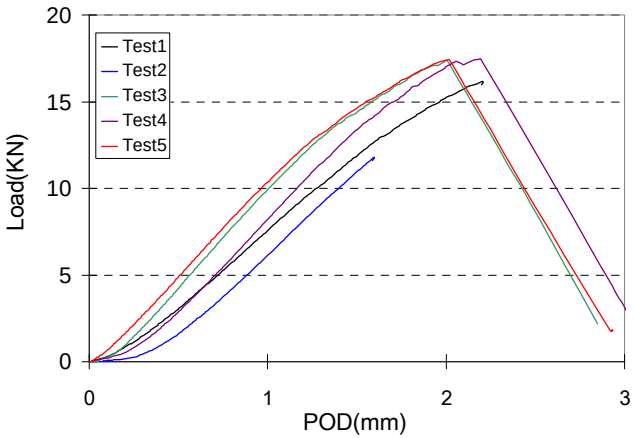
$[45/90/-45/0]_{4s}$ (4mm)



Ply level scaled



$[45_2/90_2/-45_2/0_2]_s$ (2mm)

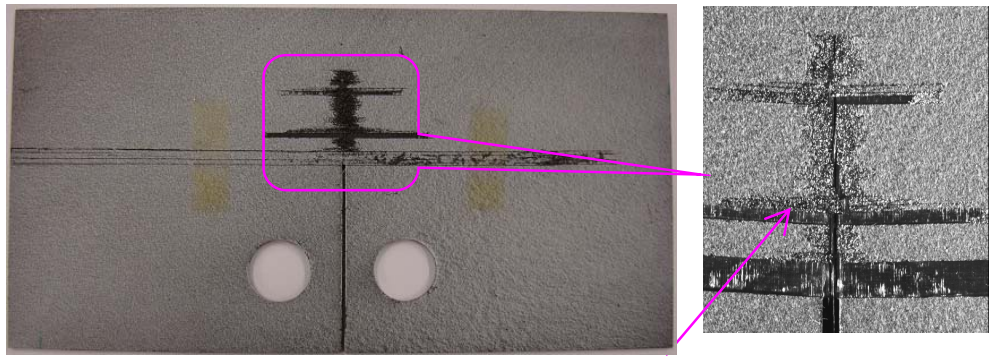


$[45_4/90_4/-45_4/0_4]_s$ (4mm)

Testing Results(3)-Typical Surface Failure

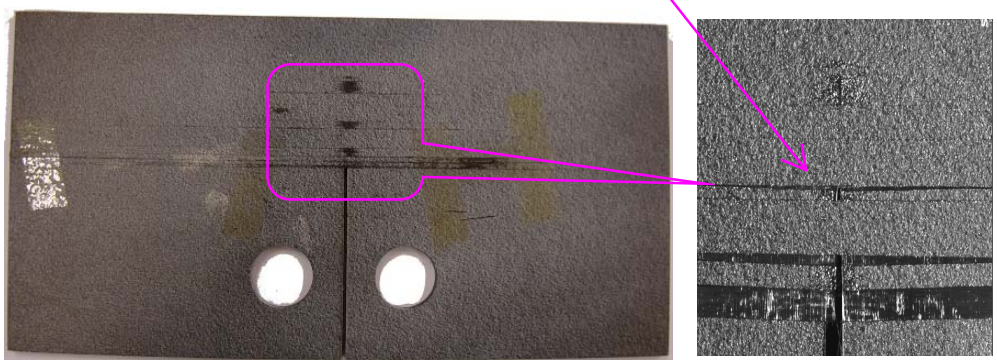
- Cross-ply Lay-ups

Sub-laminate level scaled



$[0/90]_{4s}$ (2mm)

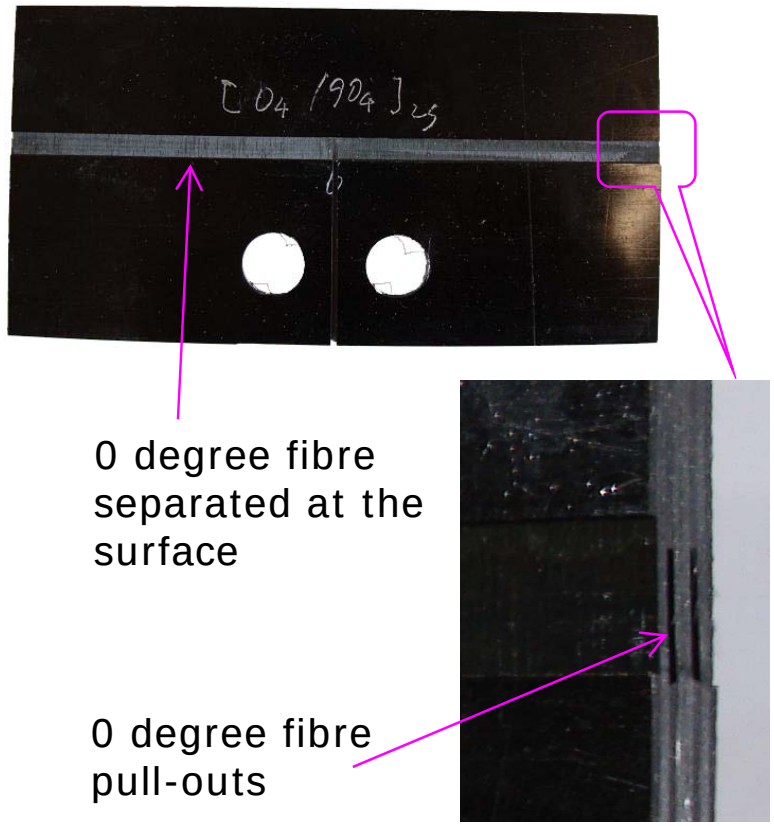
Fibre breakage developed along the central line of the notch



$[0/90]_{8s}$(4mm)

Ply level scaled

($[0_4/90_4]_{2s}$ - 4mm)



0 degree fibre separated at the surface

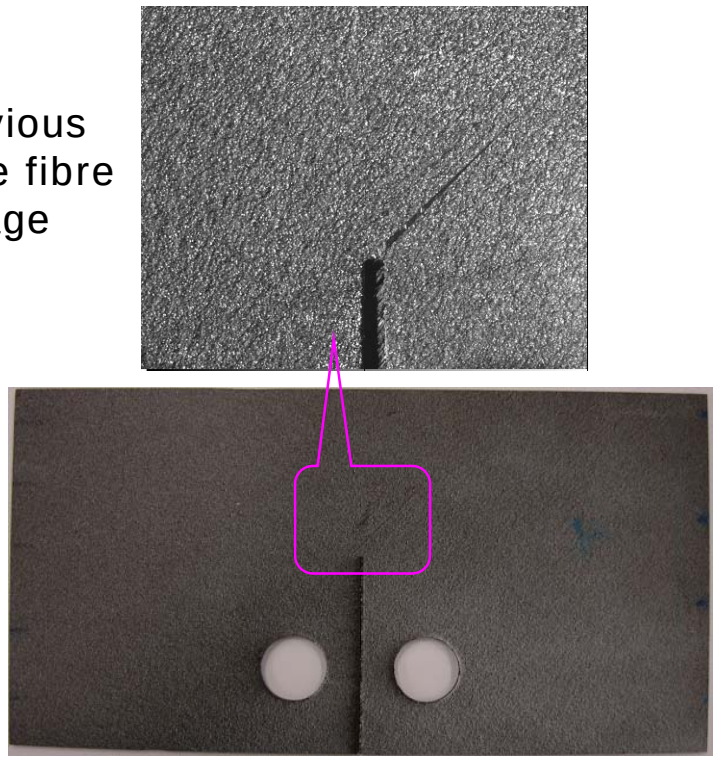
0 degree fibre pull-outs

Testing Results(3)-Typical Surface Failure

- Quasi-isotropic Lay-ups

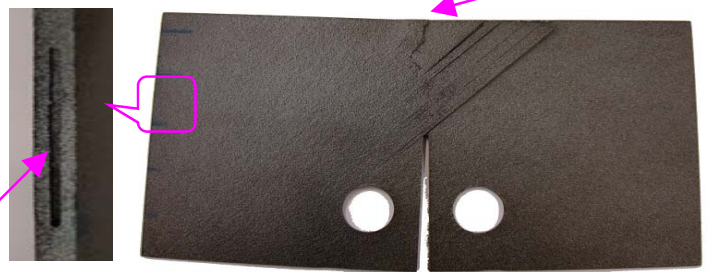
Sub-laminate level scaled

No obvious surface fibre breakage



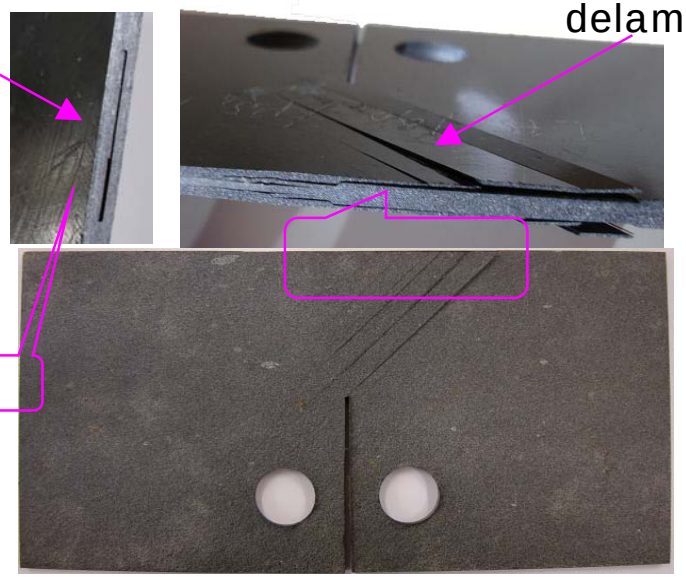
$[45/90/-45/0]_{2s}(2mm)$

Ply level scaled



0 degree ply pull-out

$[45_2/90_2/-45_2/0_2]_s(2mm)$



$[45_4/90_4/-45_4/0_4]_s(4mm)$

Testing Results(4)

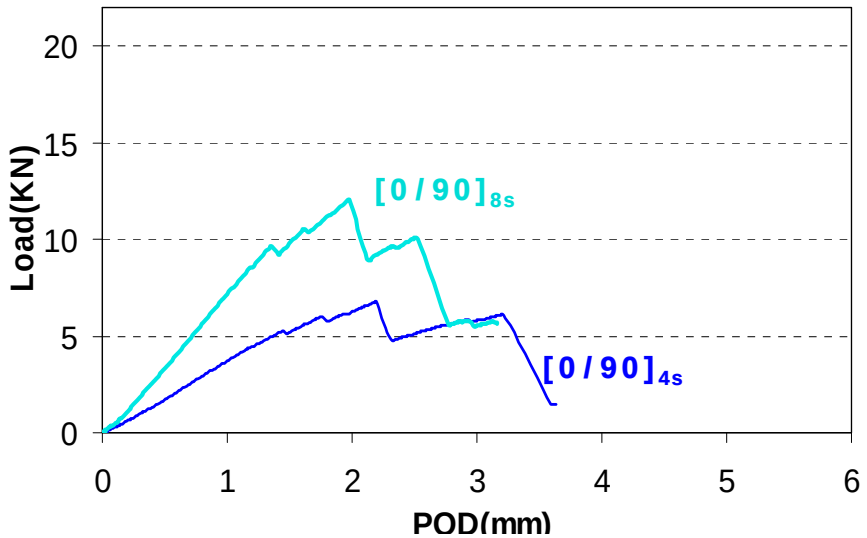
- Typical Load-POD curves of various lay-ups

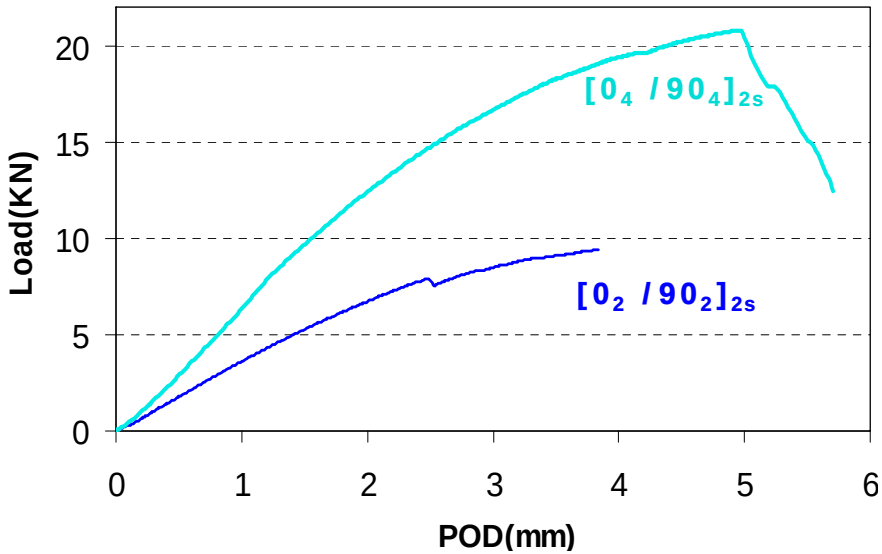
Sub-laminate level scaled

- Well scaled Failure strength
- Elastic behaviour before first failure
- Constant crack growth

Ply level scaled

- Nonlinear behavior before first failure
- Sharp final failure
- Size effect of failure strength
- Higher strength than sub-laminate scaled lay-ups





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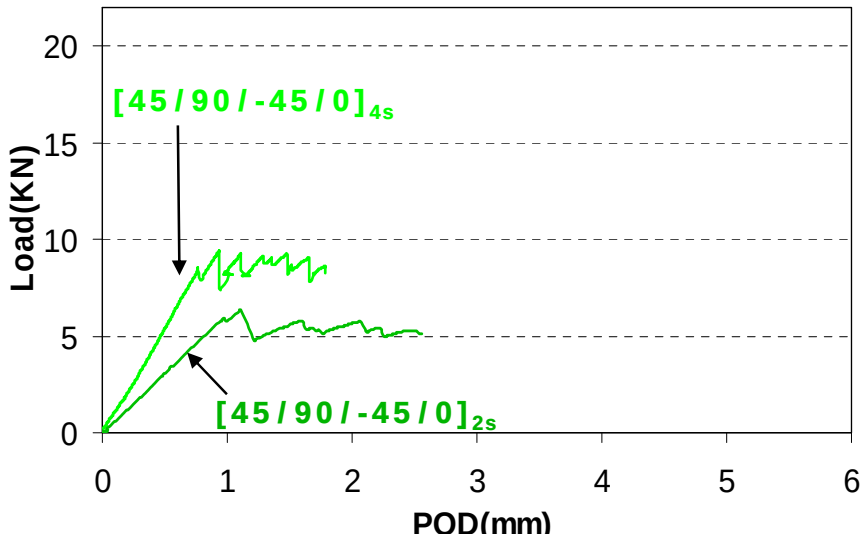

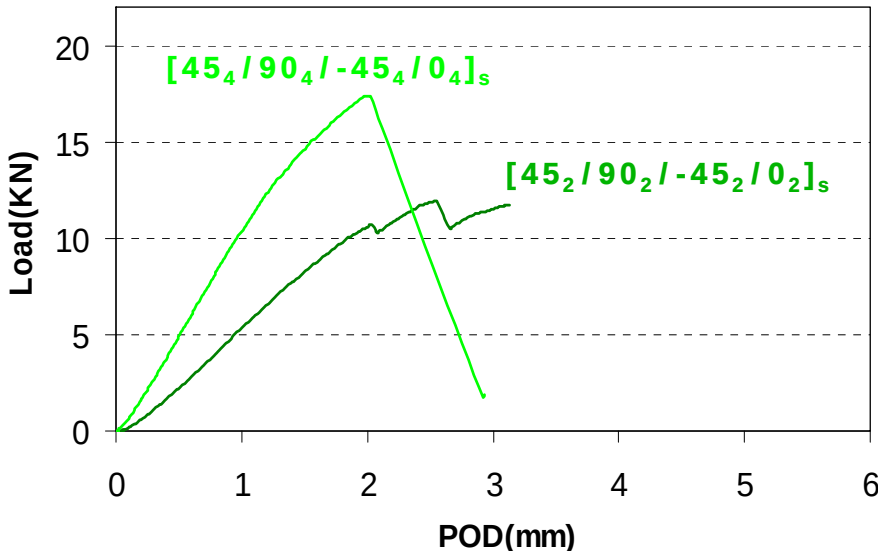

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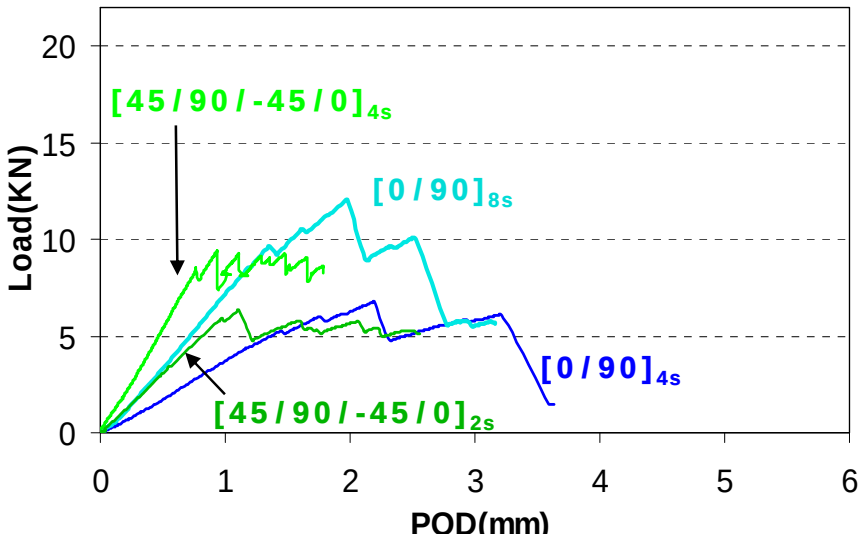
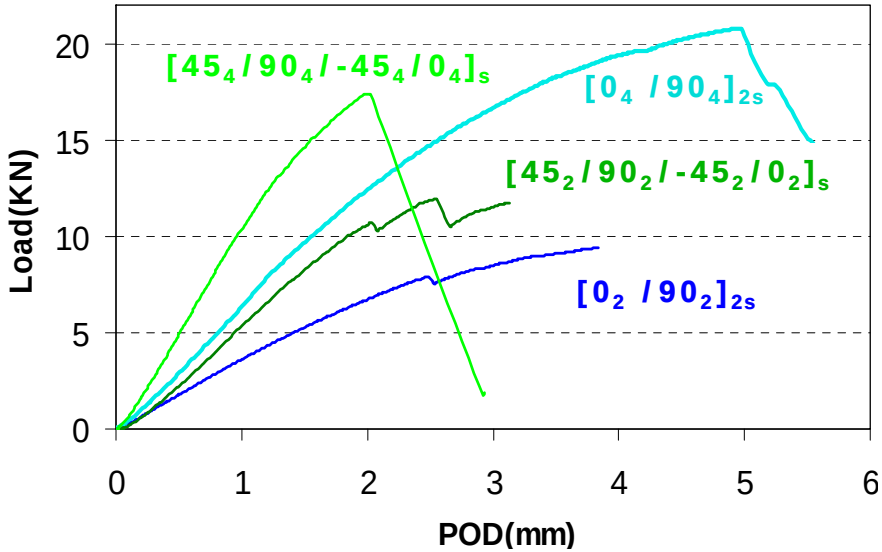
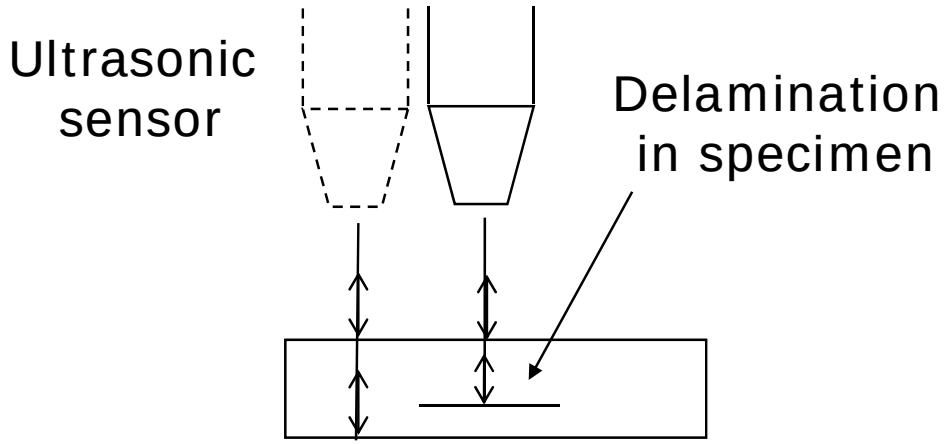




C-scan of Tested Specimens(1)

- Schematic C-scan



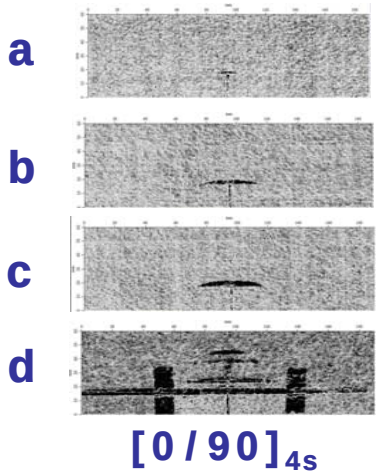
- Capability of C-scan
  - Detect the in-plane size of the delamination by reflected signal
  - Determine the through-thickness position of the delamination by elapse time of the reflected signal

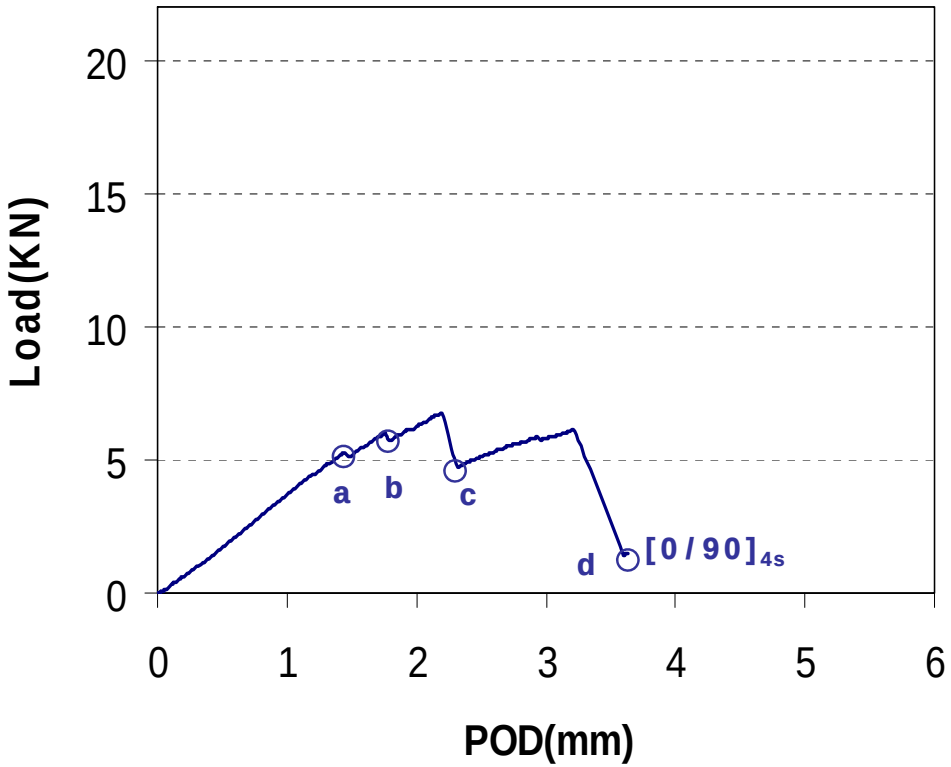
C-scan of Tested Specimens(2)

- Cross-ply lay-ups (load levels of interrupted tests are marked with a,b,c,d on typical Load-POD curves)

Sub-laminate level scaled

Ply level scaled





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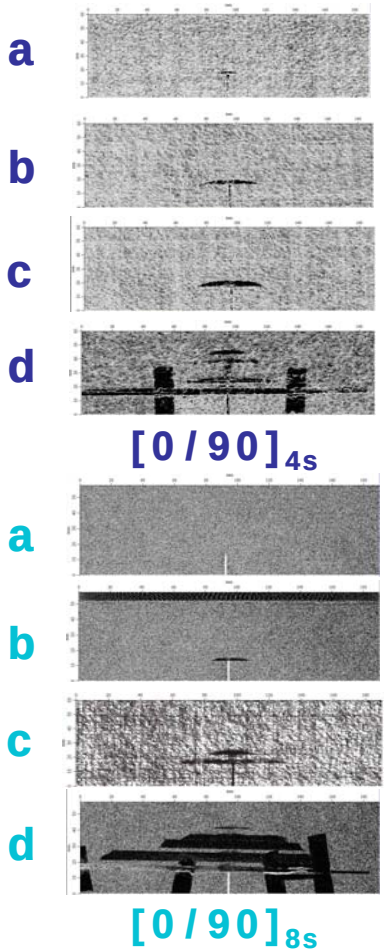
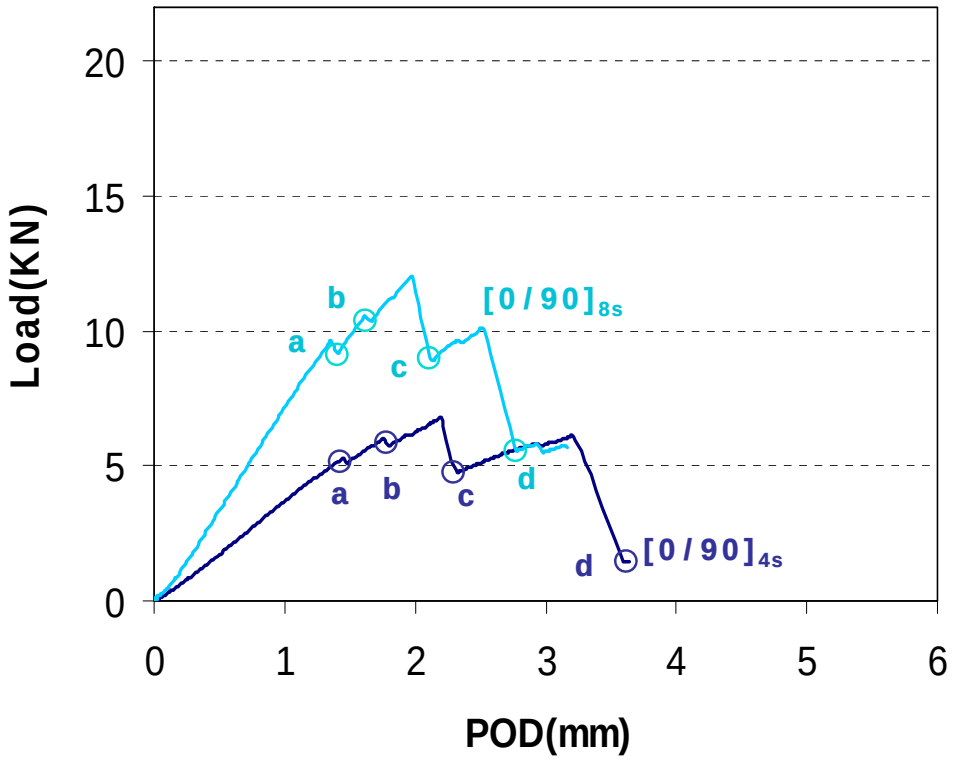


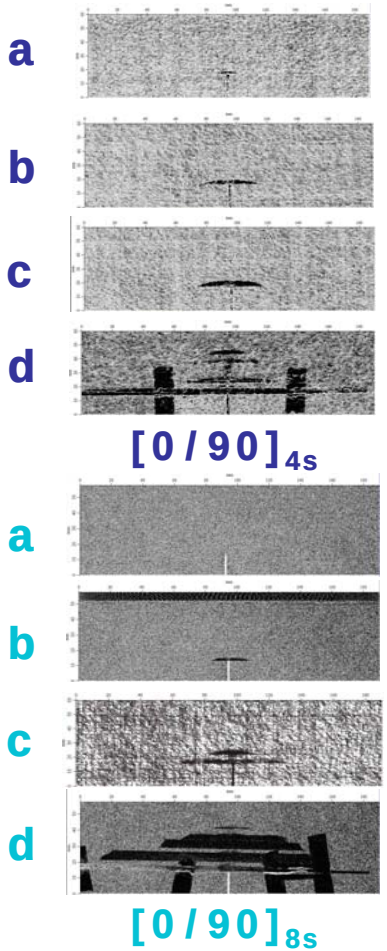
Ply level scaled

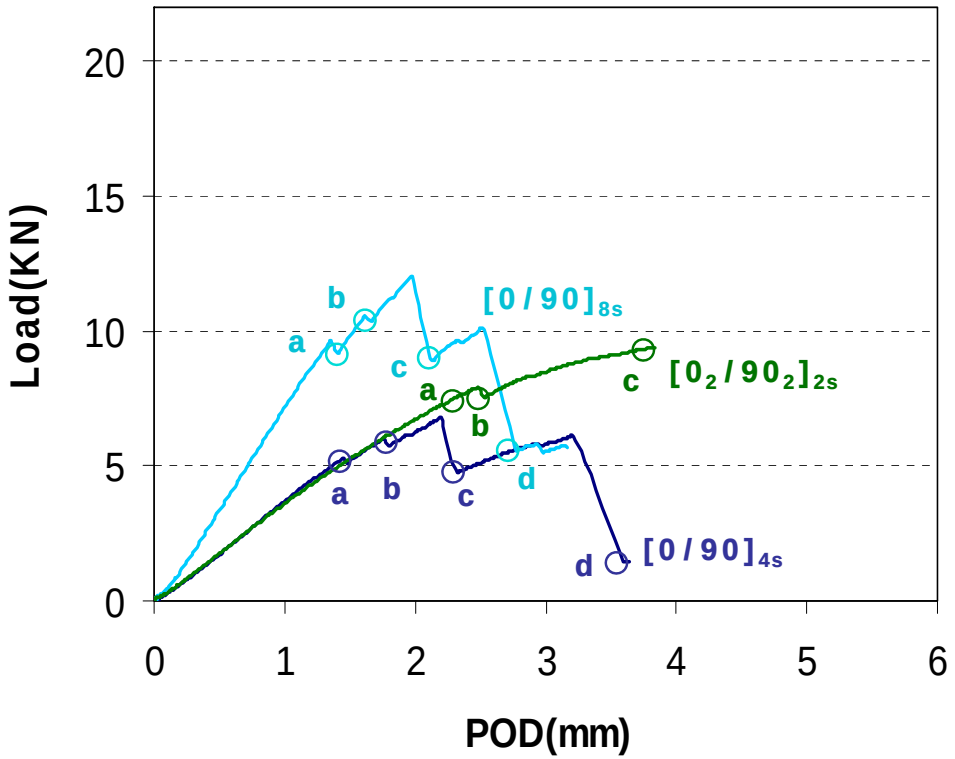


C-scan of Tested Specimens(2)

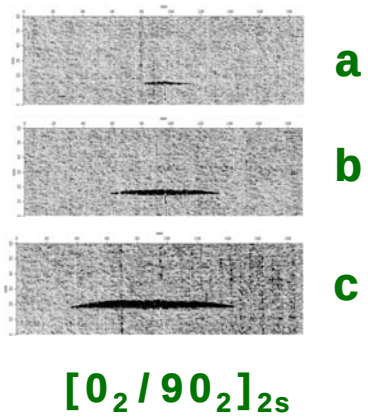
- Cross-ply lay-ups (load levels of interrupted tests are marked with a,b,c,d on typical Load-POD curves)

Sub-laminate level scaled





Ply level scaled



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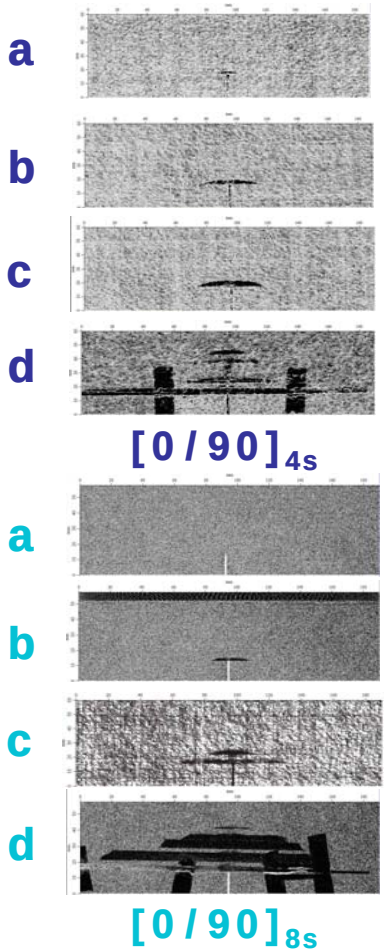
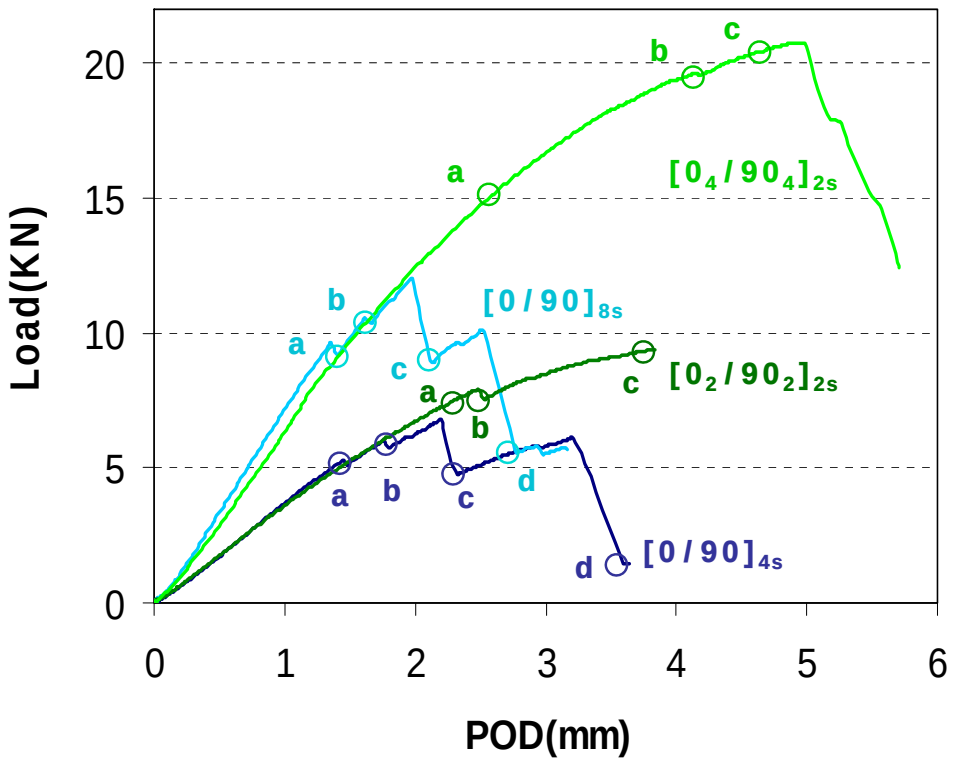
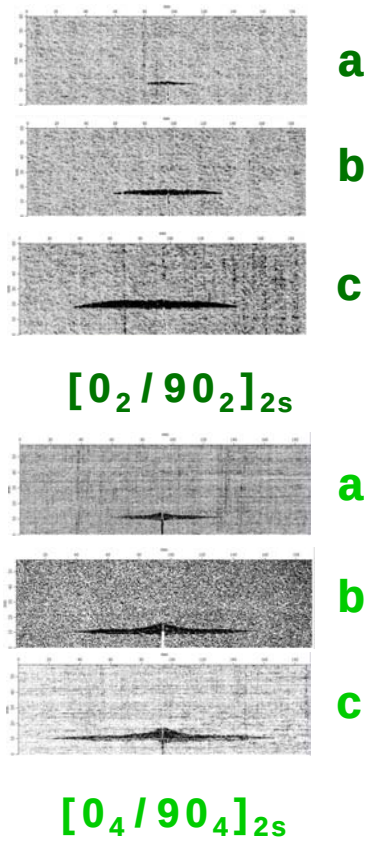




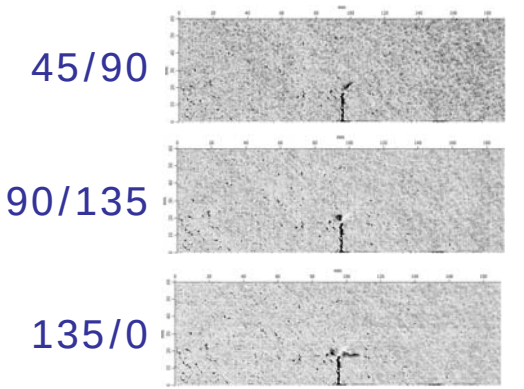
Ply level scaled



C-scan of Tested Specimens(3)

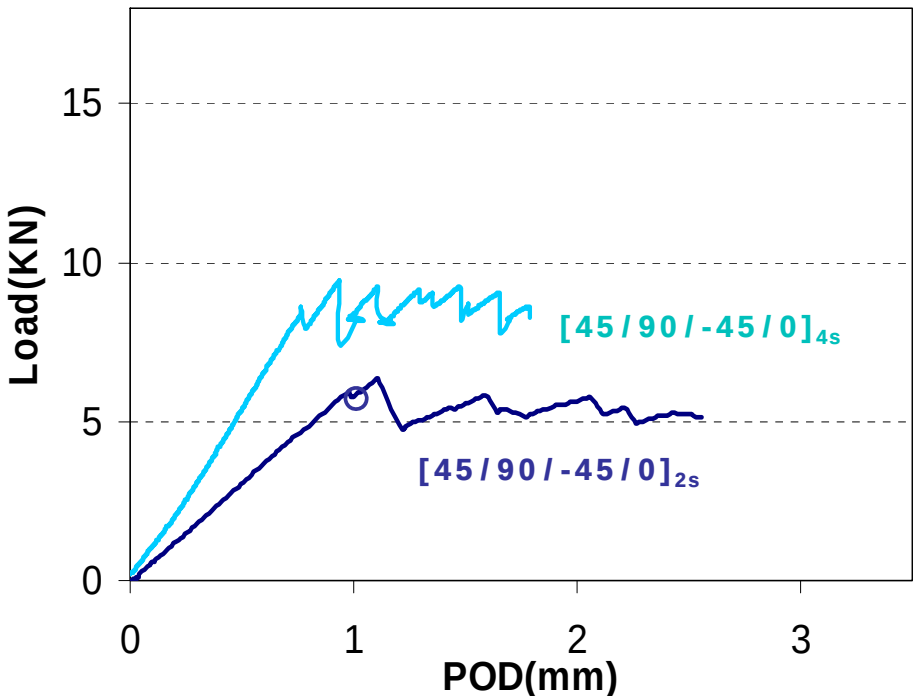
- Quasi-isotropic lay-ups (load levels of interrupted tests are marked with 'o' on typical Load-POD curves)

Sub-laminate level scaled



$[45/90/-45/0]_{2s}$

Ply level scaled



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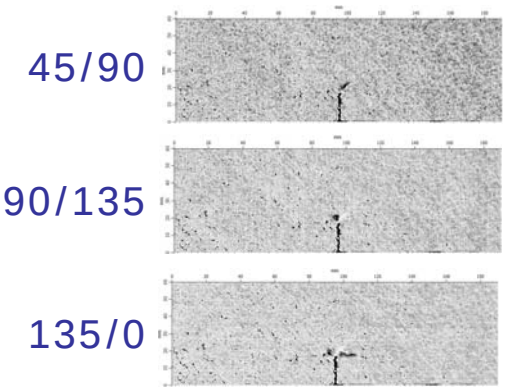
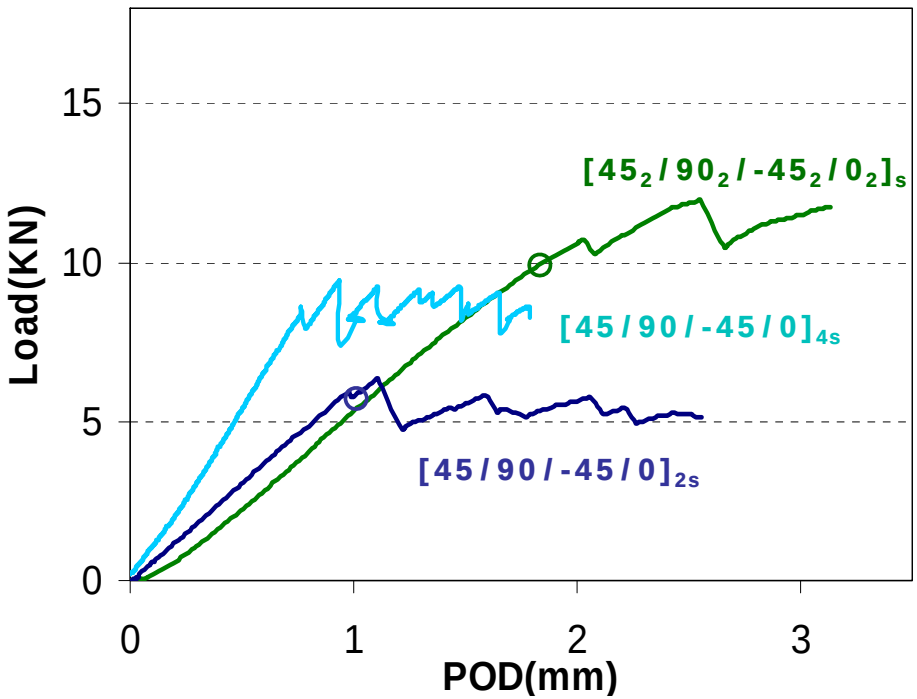
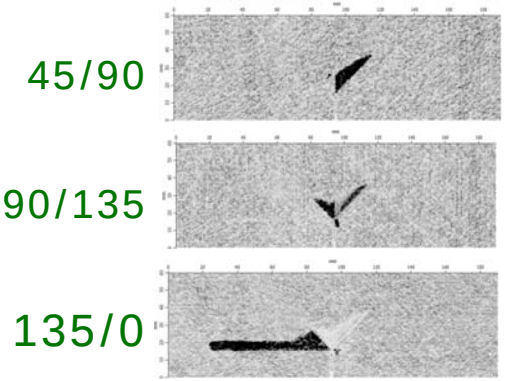


$[45/90/-45/0]_{2s}$



Ply level scaled



$[45_2/90_2/-45_2/0_2]_s$

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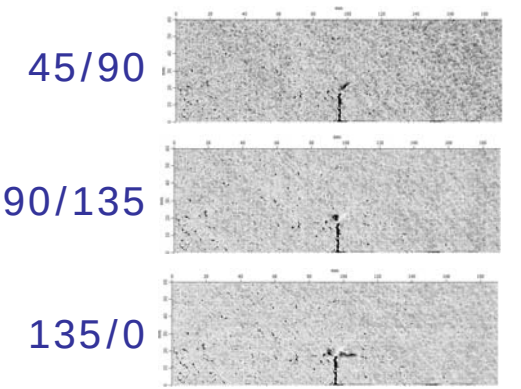
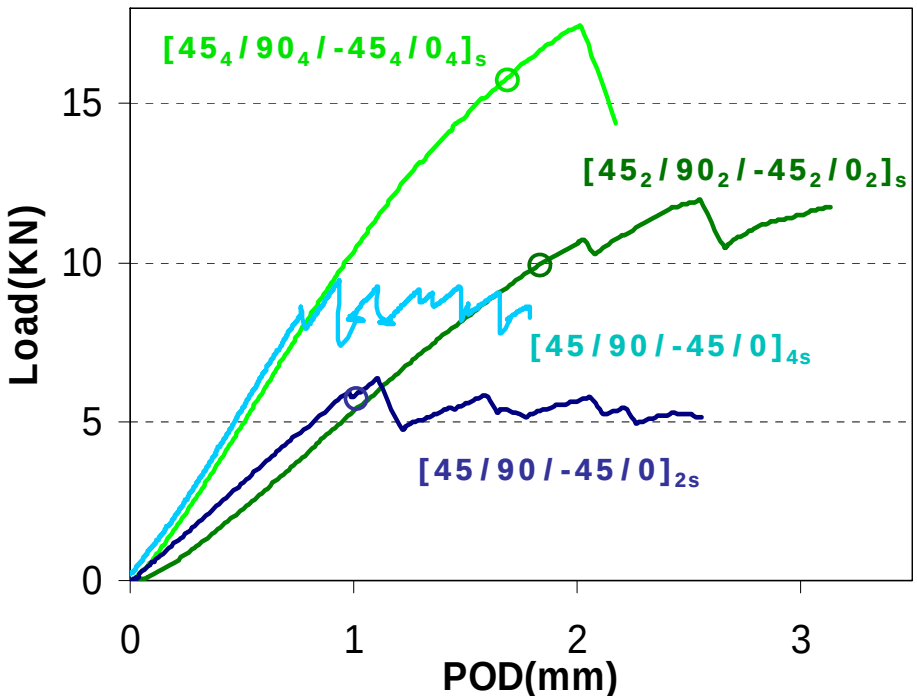
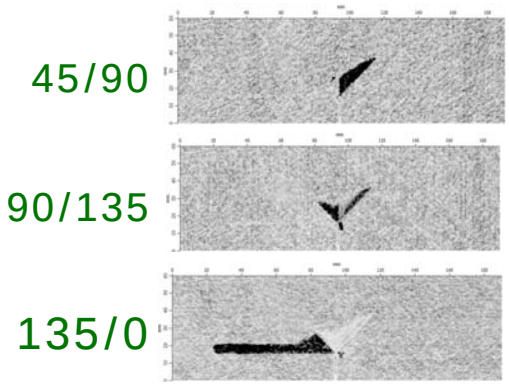


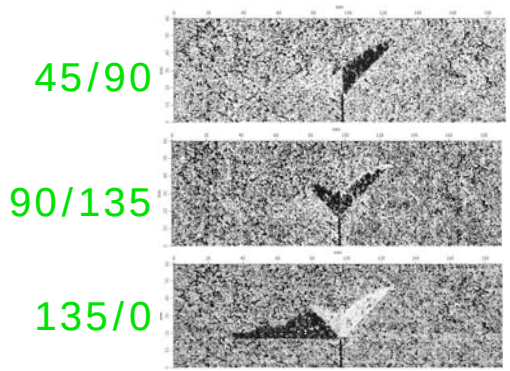
$[45/90/-45/0]_{2s}$



Ply level scaled



$[45_2/90_2/-45_2/0_2]_s$



$[45_4/90_4/-45_4/0_4]_s$

Summary and Conclusion (1)

- Sub-laminate scaled load curves are approximately linear before the first load drop
- The crack of sub-laminate scaled specimens progresses across the width of the specimen in a series of small “jumps” which result in further load drops.
- The overall trend is for the crack growth to progress at approximately constant load.
- The sub-laminate scaling in the thickness direction promotes fibre failure and through-the-thickness crack growth

Summary and Conclusion (2)

- Ply block scaled specimen load curves show large degree of nonlinearity.
- The ply block scaled specimens generally failed sharply due to fibres pulling out.
- Ply block scaling in the thickness direction promotes large amount of splitting and delamination and causes larger process zone
- The ply block scaled laminates show higher strength than the sub-laminate scaled specimens.
- Damage initiation or “first ply failure” is lower but this in turn results in an ultimately tougher laminate