Tensile Scaling Effects In Notched Composites

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CompTest 2004, Bristol, UK
21st - 23rd September

Introduction

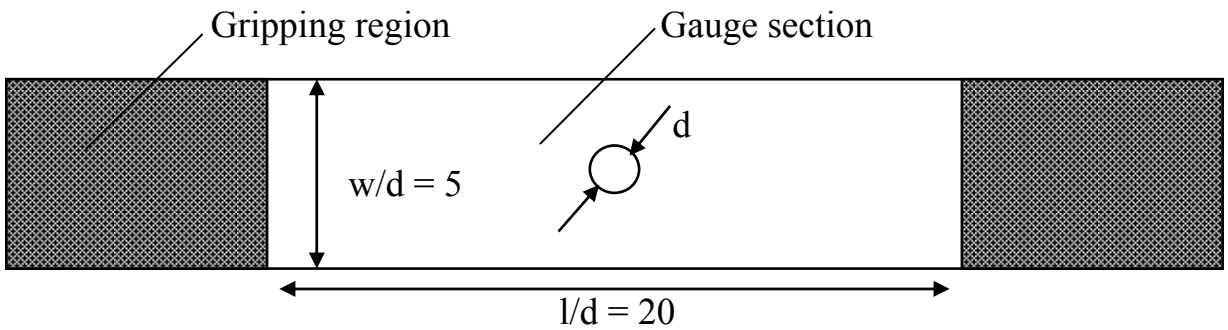
- Size effect: Strength of a material/ laminate *is* dependent upon size
  - Statistical/ deterministic
- For a notched specimen, notch size is also a factor
- Understanding this phenomenon will lead to more accurate strength predictions and hence more efficient component design

Summary

- Extensive experimental program undertaken with specimen size as the controlled variable
- Sub-critical damage growth and failure mechanism/ strength were investigated
- Results show a large variation in strength, and a change in failure mechanism, dependent upon specimen dimensions
- This is because of sub-critical damage growth

Specimen Design

- Quasi-isotropic specimens with a centrally-located circular hole tested in tension
- Carbon fibre/ epoxy IM7/8552 UD pre-preg
- Stacking sequence $(45/90/-45/0)_s$
- w/d=5 and l/d=20



Testing Matrix

t (mm)	Sublaminate-level Scaling Hole sizes (mm)				Ply-level Scaling Hole sizes (mm)			
	3.175	6.35	12.7	25.4	3.175	6.35	12.7	25.4
1	*				*			
2								
4								
8	*			*	*			*

- * = 6 specimens tested, otherwise 4 per condition
- 3 types of scaling investigated: 1-D, 2-D & 3-D

Thickness Scaling

t (mm)	Sublaminate-level Scaling Hole sizes (mm)				Ply-level Scaling Hole sizes (mm)			
	3.175	6.35	12.7	25.4	3.175	6.35	12.7	25.4
1								
2								
4								
8								

1-D

1-D

- All in-plane dimensions kept constant

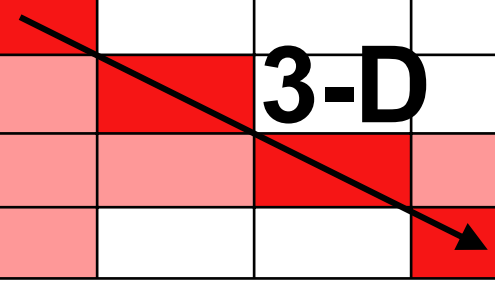
In-Plane Scaling

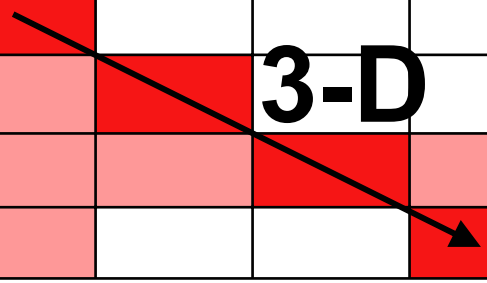
t (mm)	Sublaminate-level Scaling Hole sizes (mm)				Ply-level Scaling Hole sizes (mm)			
	3.175	6.35	12.7	25.4	3.175	6.35	12.7	25.4
1								
2		2-D				2-D		
4	→				→			
8								

- Laminate thickness is constant

3-Dimensional Scaling

t (mm)	Sublaminate-level Scaling Hole sizes (mm)				Ply-level Scaling Hole sizes (mm)			
	3.175	6.35	12.7	25.4	3.175	6.35	12.7	25.4
1								
2								
4								
8								



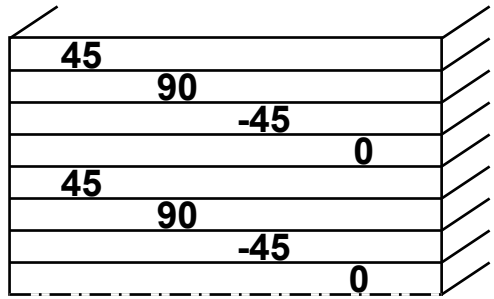


- Both thickness and in-plane dimensions are scaled simultaneously

Increasing Laminate Thickness

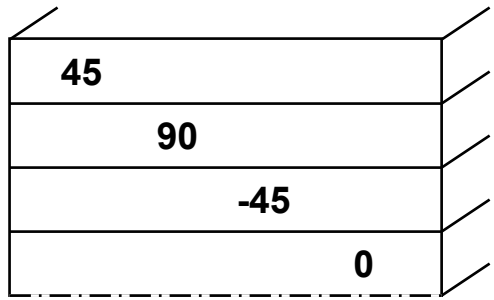
- 2 methodologies are used to increase laminate thickness:
  - Sublaminate-level scaling

    Ply thickness remains constant, sequence is repeated as required.



  - Ply-level scaling

    Plies are blocked together to increase effective ply thickness.



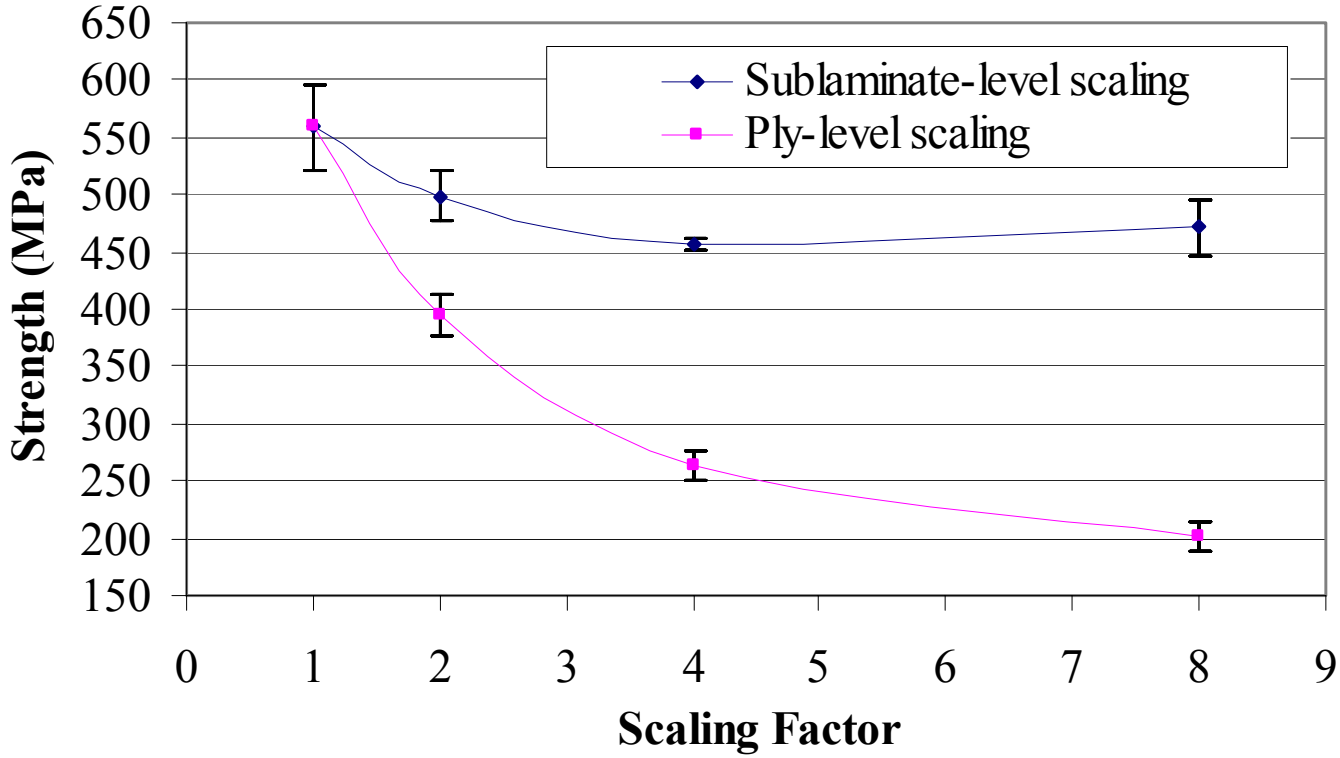
Results: Strength

t (mm)	Sublaminate-level Scaling Hole sizes (mm)				Ply-level Scaling Hole sizes (mm)			
	3.175	6.35	12.7	25.4	3.175	6.35	12.7	25.4
1	560				560			
2	499	417			394	475		
4	457	416	359	313	263	279	342	391
8	471			323	202			225

- Failure stress (MPa)

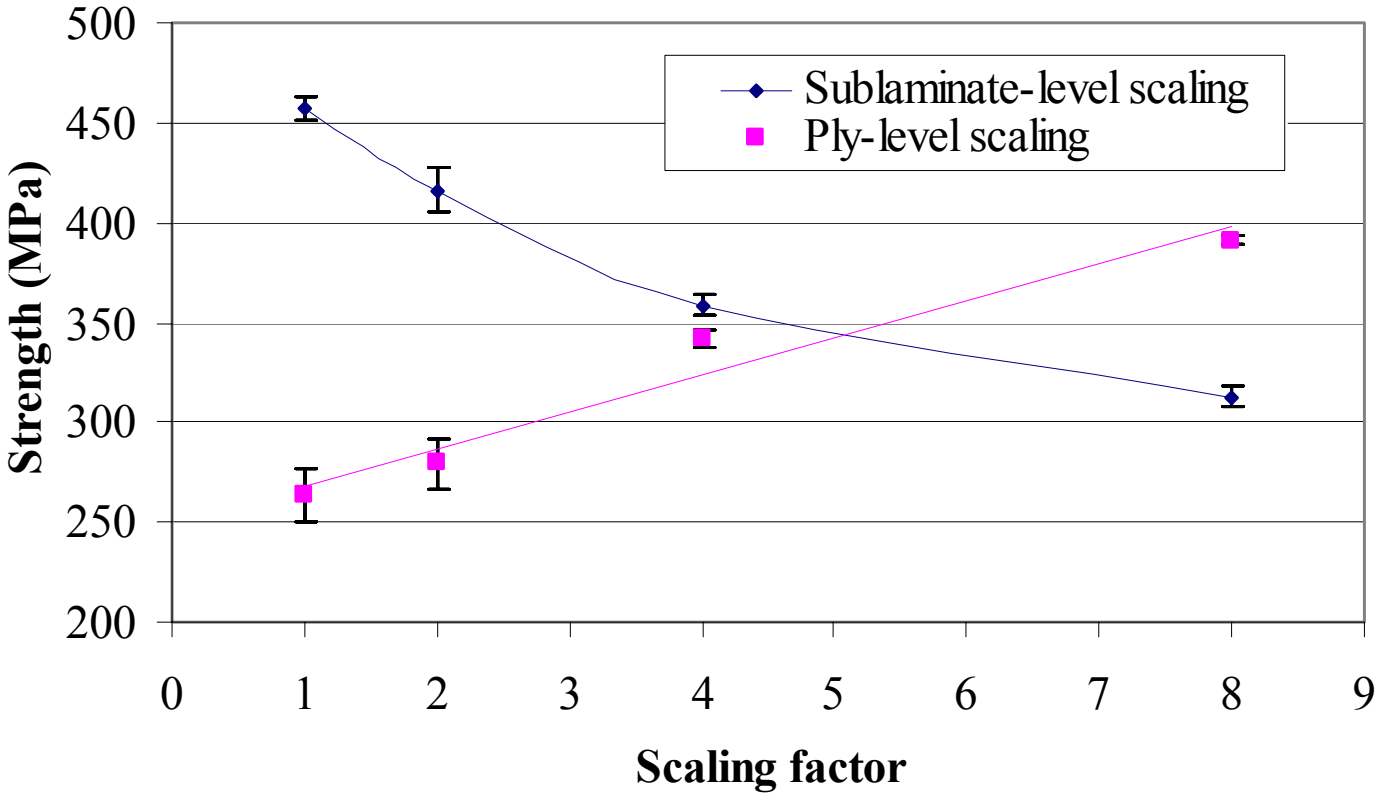
  (Stress at first major load drop)

Thickness Scaling



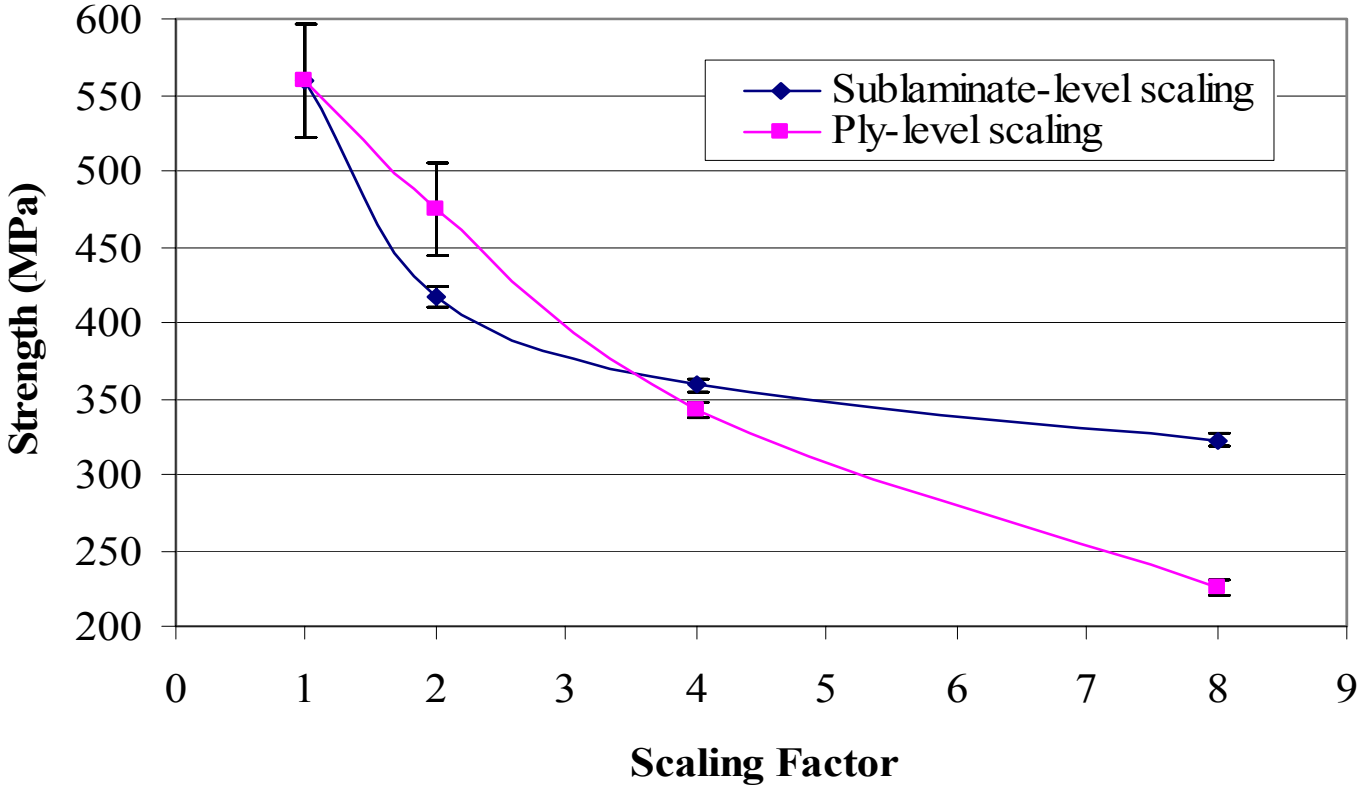
- Sublaminate-level scaling: 18% decrease
- Ply-level scaling: 64% decrease

In-Plane Scaling



- Sublaminate-level scaling: 32% decrease
- Ply-level scaling: 49% increase

3-Dimensional Scaling



- Sublaminate-level scaling: 42% decrease
- Ply-level scaling: 60% decrease

Results: Failure Mechanisms

t (mm)	Sublaminate-level Scaling Hole sizes (mm)				Ply-level Scaling Hole sizes (mm)			
	3.175	6.35	12.7	25.4	3.175	6.35	12.7	25.4
1	560				560			
2	499	417			394	475		
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Failure stress (MPa)

“Pull-out” failure

“Delamination” failure

“Brittle” failure

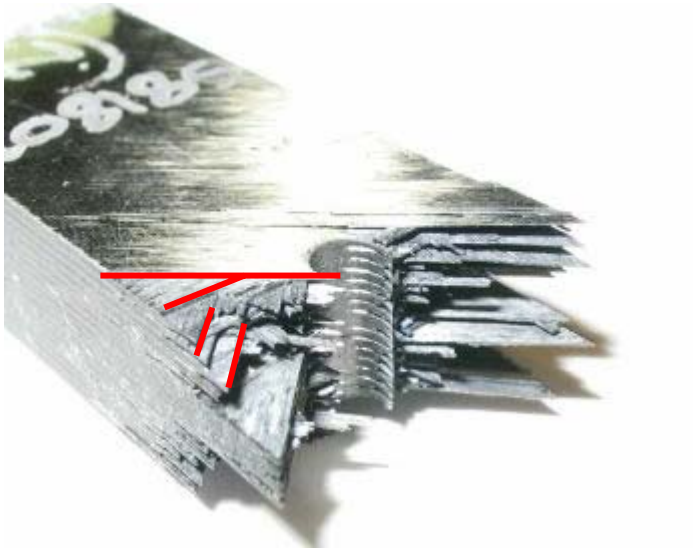
Failure Mechanism A: Pull-out

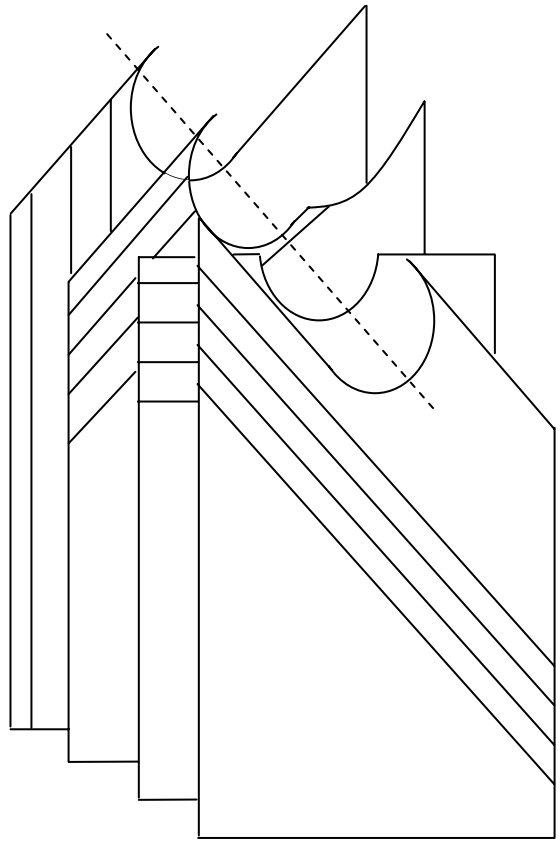
- Sublaminate-level scaled specimens with d = 3.175mm
- Ply-level scaled specimens with t = 2mm and d = 6.35mm

t (mm)	Sublaminate-level Scaling Hole sizes (mm)				Ply-level Scaling Hole sizes (mm)			
	3.175	6.35	12.7	25.4	3.175	6.35	12.7	25.4
1	**560**				**560**			
2	**499**	417			394	**475**		
4	**457**	416	359	313	263	279	342	391
8	**471**			323	202			225

Failure Mechanism A: Pull-out

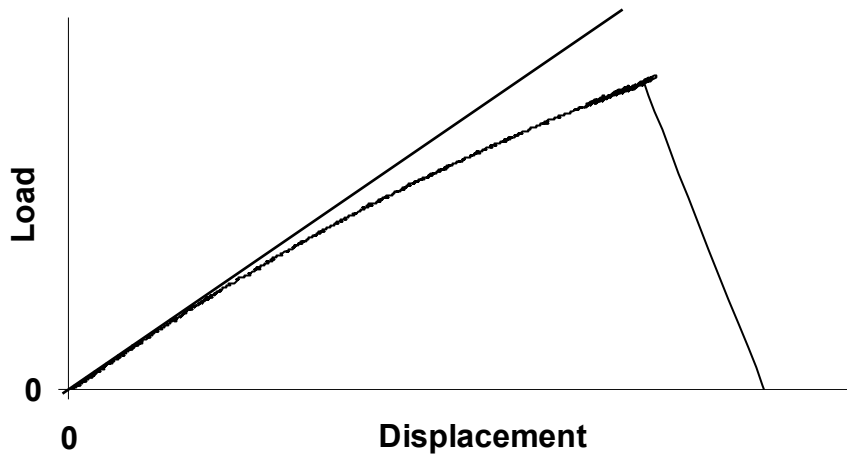
- Failure is fibre-dominated
- Off-axis plies fail via splitting adjacent to hole





Failure Mechanism A: Pull-out

- Sub-critical damage is present during loading, throughout the thickness of the laminate
- Splitting initiates at the hole in off-axis plies
- This leads to delamination at the 45/90 and 90/-45 interfaces
- These propagate steadily across the width
- Damage corresponds to non-linearity of L-D curve



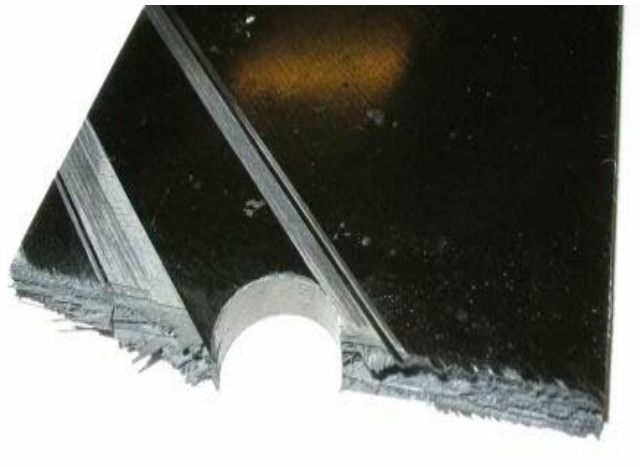
Failure Mechanism B: Brittle

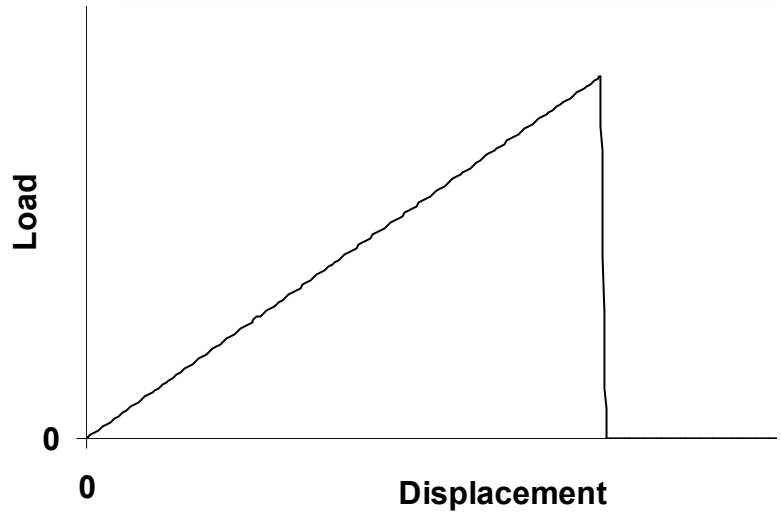
- Sublaminate-level scaling with $d \geq 6.35mm$
- Strength is independent of thickness

t (mm)	Sublaminate-level Scaling Hole sizes (mm)				Ply-level Scaling Hole sizes (mm)			
	3.175	6.35	12.7	25.4	3.175	6.35	12.7	25.4
1	560				560			
2	499	**417**			394	475		
4	457	**416**	**359**	**313**	263	279	342	391
8	471			**323**	202			225

Failure Mechanism B: Brittle

- Fibre failure throughout thickness of laminate
- Little or no sub-critical damage apparent during/ after loading
- L-D curve is linear to failure





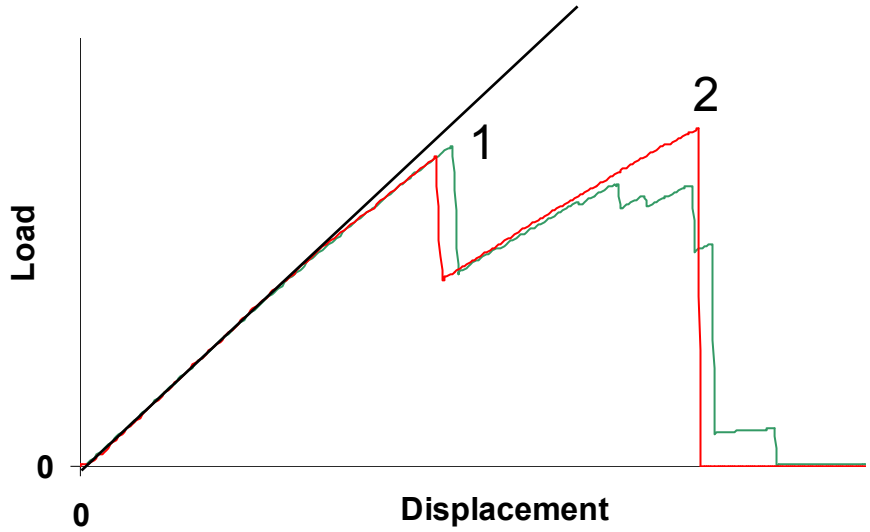
Failure Mechanism C: Delamination

- Occurs for ply-level scaled specimens where ply t ≥ 4mm, plus those where ply t = 2mm and d = 3.175mm
- Failure stresses are –45/0 delamination stresses

t (mm)	Sublaminate-level Scaling Hole sizes (mm)				Ply-level Scaling Hole sizes (mm)			
	3.175	6.35	12.7	25.4	3.175	6.35	12.7	25.4
1	560				560			
2	499	417			**394**	475		
4	457	416	359	313	**263**	**279**	**342**	**391**
8	471			323	**202**			**225**

Failure Mechanism C: Delamination

- -45/ 0 delamination stress is first load drop (1)
- Occurs over whole specimen
- 0^o ply continues to be loaded
- Grip failure then ensues (2)



Failure Mechanism C: Delamination

- Sub-critical damage occurs as for pull-out failure mode, ie. splitting, and 45/90 & 90/-45 delamination initiating at hole
- Non-linearity on L-D curve seen to correspond to 45/90 delamination:

t (mm)	Ply-level Scaling Hole sizes (mm)			
	3.175	6.35	12.7	25.4
1	n/a			
2	189	266		
4	132	131	164	173
8	99			63

45/90 Delamination stress (MPa)

Analysis: Sub-Critical Damage

- Splitting, and 45/90 & 90/-45 delaminations initiating at the hole boundary
- Thicker ply blocks more susceptible to delamination as more energy is available
  - 1-D ply-level scaled series
- As hole size increases, delamination stress increases
  - 2-D ply-level scaled series

Analysis: Failure Stress

- Failure at point of first gross damage:
  - Fibre failure in 0^o plies, or
  - -45/0 delamination
- Fibre failure stress decreases with increasing hole size
- Delamination stress increases with increasing hole size
- Delamination also dependent on ply thickness

Conclusions

- A scaling effect has been observed in notched composites
- This will affect the failure stress and possibly the failure mechanism
- This is dependent upon the level of sub-critical damage present
- The notch size and ply/ laminate thickness determine the extent of this growth

Acknowledgements

The authors would like to acknowledge the support of Airbus UK, the Engineering and Physical Sciences Research Council and the Ministry of Defence for this research.