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How the fibre-dominated strength of a multidirectional laminate relates to the strength of a UD composite

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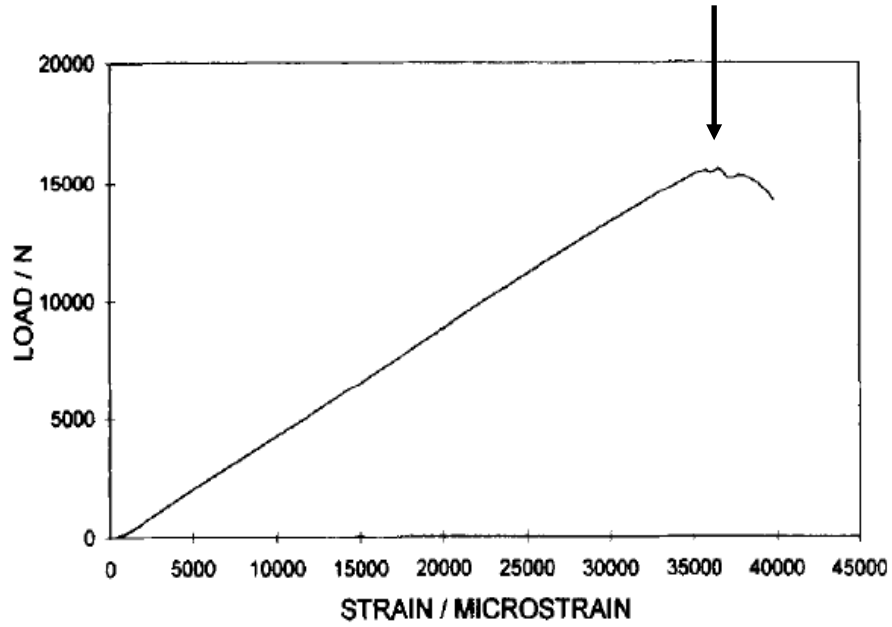
Definition of strength

At a previous workshop, the following definition was proposed:

The strength of a unidirectional composite is the maximum stress that the material can sustain under uniform uniaxial loading

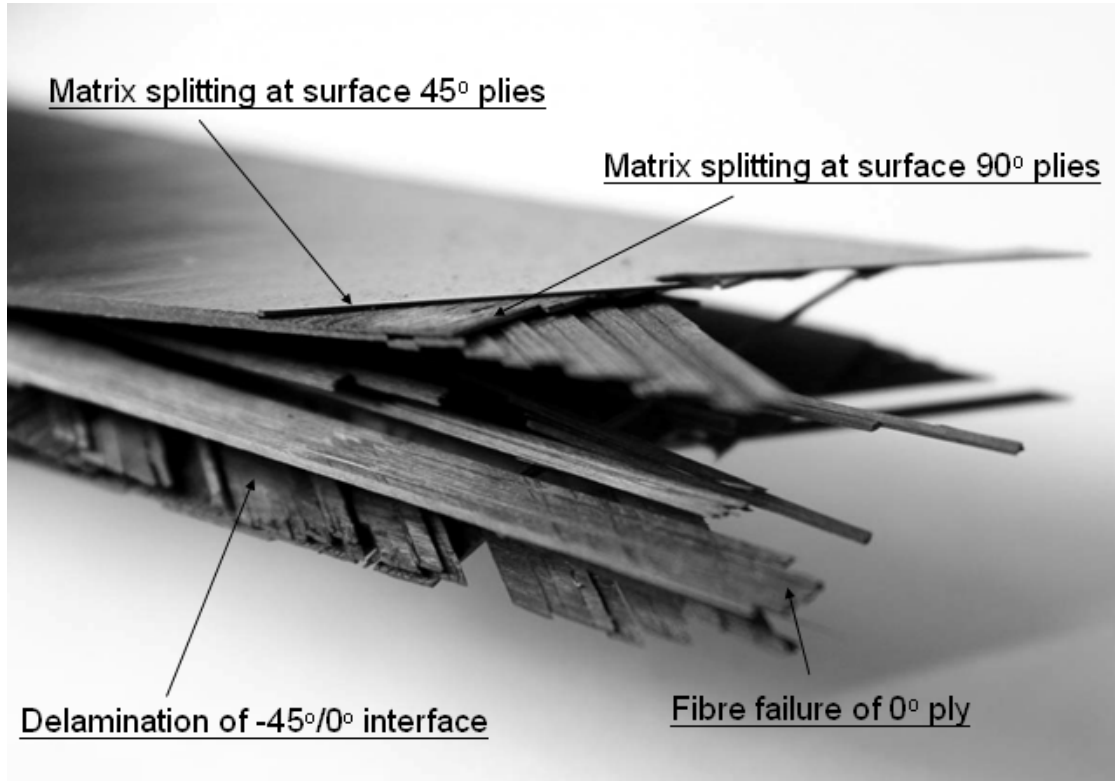
- Other definitions such as damage initiation stress are more subjective
- Can be applied to all the principal failure modes – tension, compression, shear, transverse
- How do these strengths relate to the fibre dominated strength of a laminate?



Wisnom and Paris, 2020

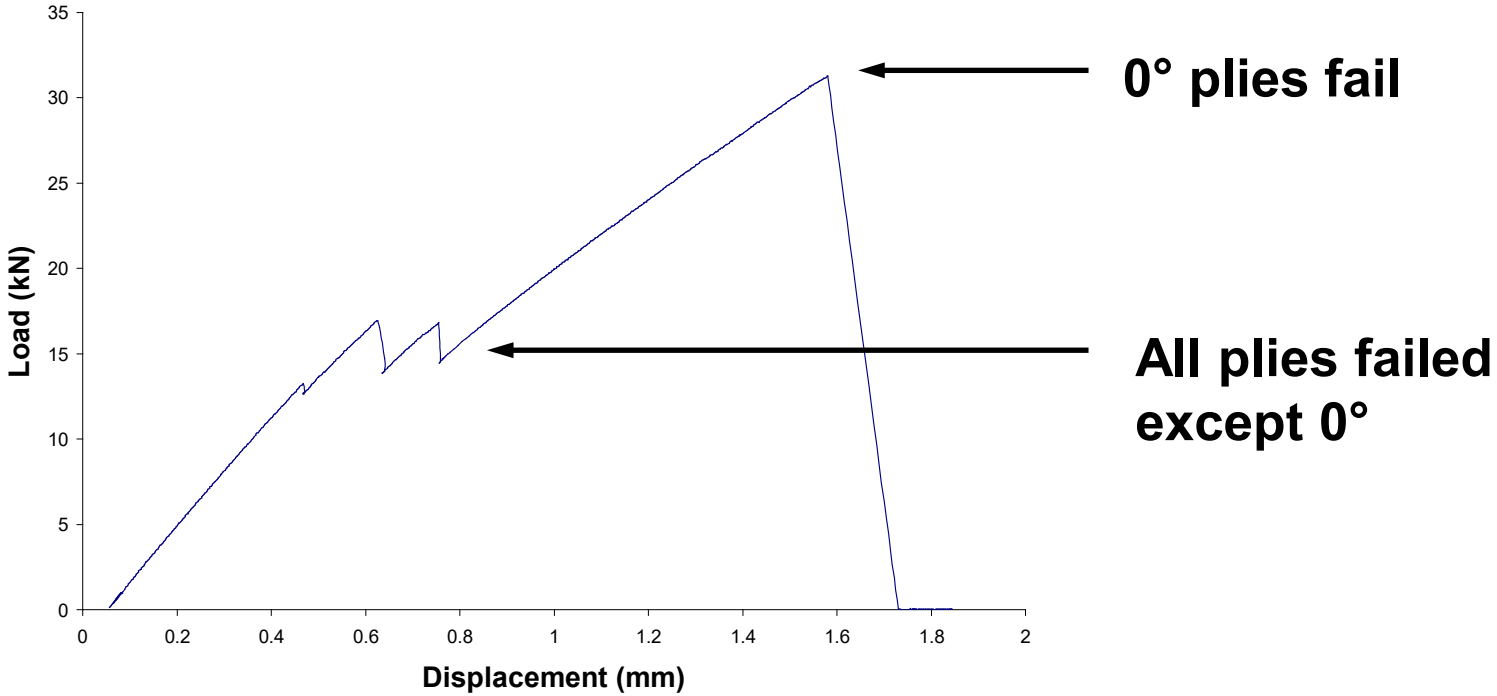
Relation between UD and laminate strength

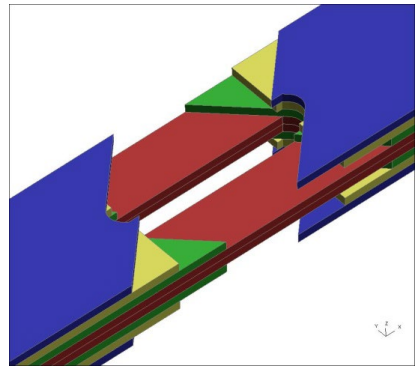
- Strength of laminates is determined by fibre failure
- In principle, might expect this to occur at the same strain as for UD
- Failure stress will obviously depend on the layup and laminate modulus
- BUT premature failure may occur due to different mechanisms
- Delamination particularly important



Laminate failure

- At what point has this QI laminate failed? $(45_8/90_8/-45_8/0_8)s$

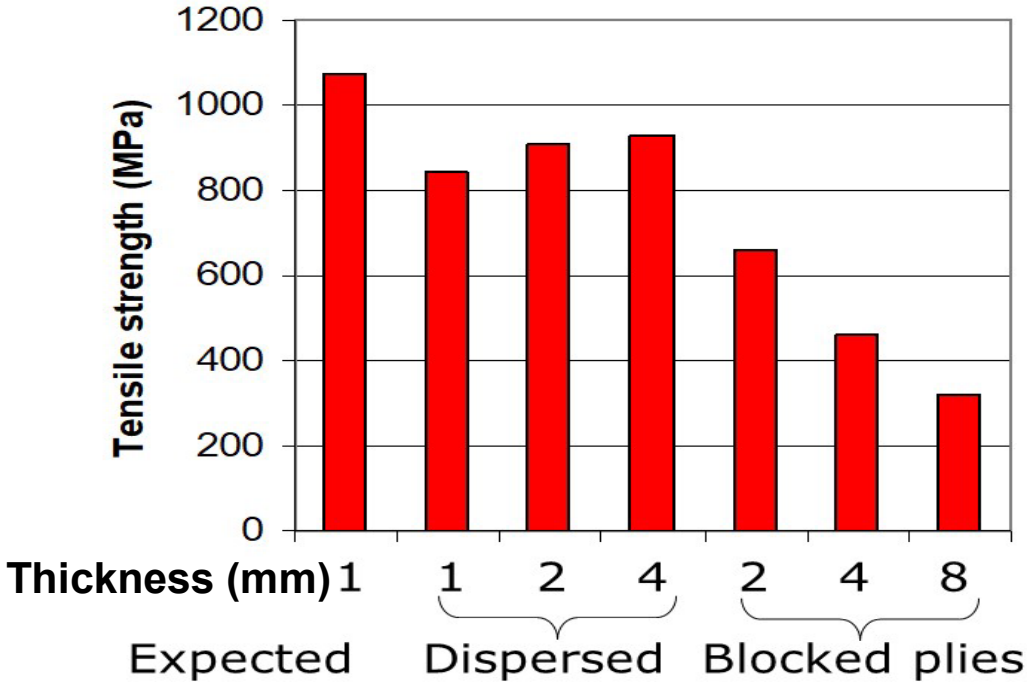


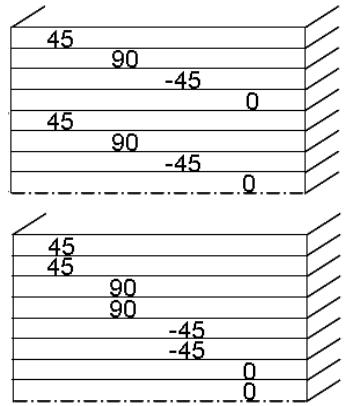


- Definition of strength of a laminate is less clear

Laminate strength - not a material property

- Strength of a QI laminate depends on stacking sequence
- Reason: premature failure due to delamination





Dispersed plies

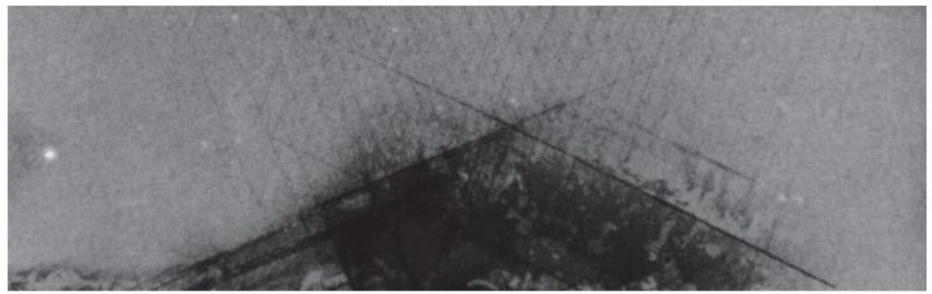
Blocked plies

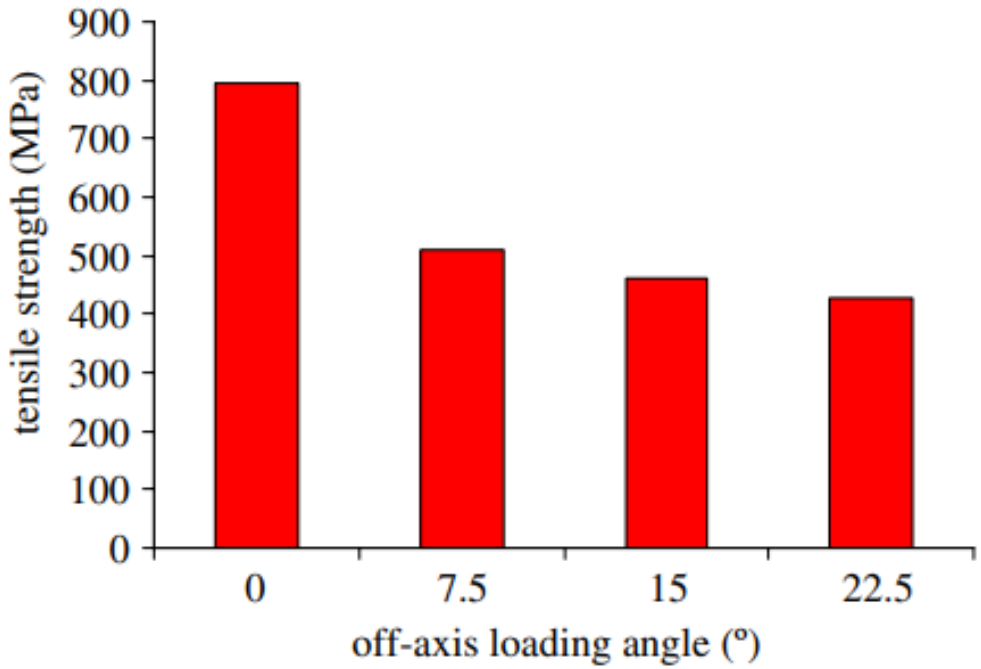
All QI IM7/8552 carbon/epoxy

Wisnom, Khan, Hallett, 2008

Strength depends on loading angle

- QI carbon/epoxy in tension
- Much stronger when loaded in a ply direction
- Off-axis loading causes premature edge delamination

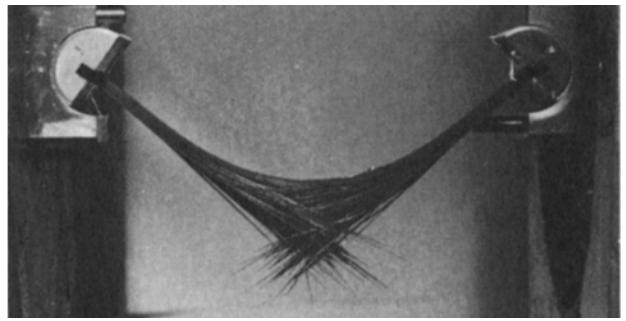


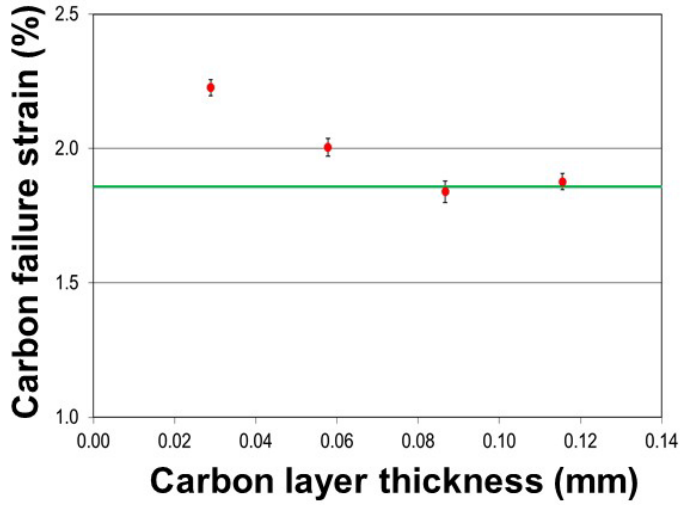


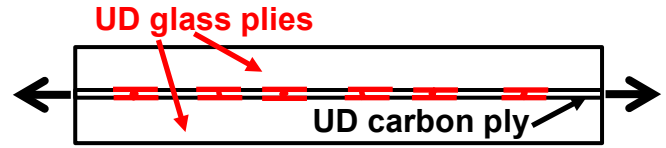
Sun & Zhou, 1988

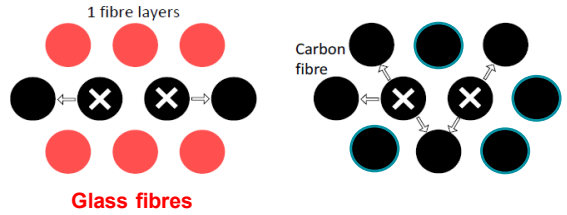
Constraint from adjacent plies

- Very thin carbon plies show higher tensile failure strain
- Constraint from adjacent plies delays formation of critical cluster of fibre breaks
- 20% higher failure strain for 0.03 mm ply
- In bending, surface plies may delay failure of the outermost 0° plies.





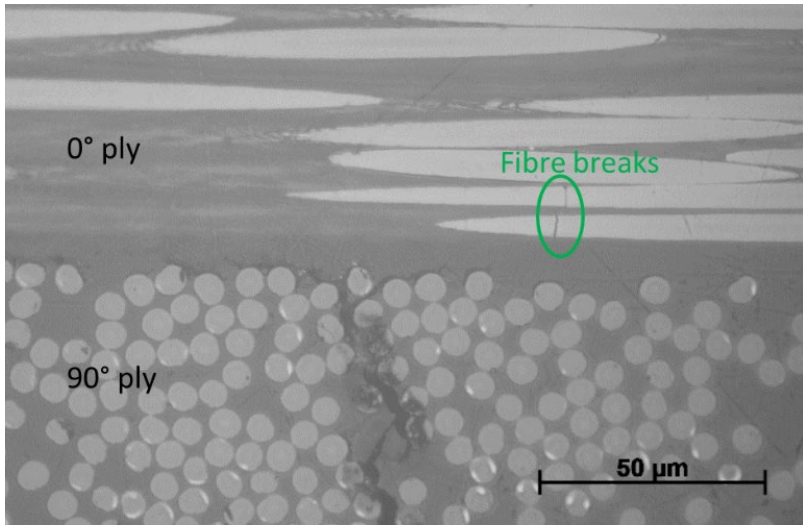




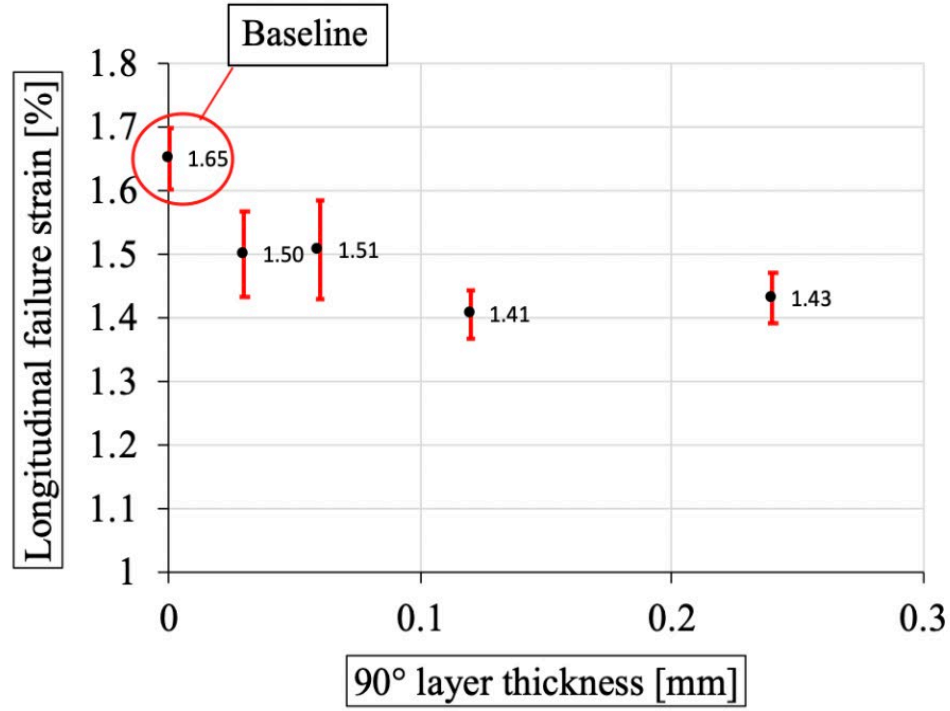
Wisnom, Czél, Swolfs, Jalalvand, Gorbatikh, Verpoest, 2016

Effect of transverse cracks - tension

- Cross-ply laminates show small reduction in fibre direction tensile failure strain
- Increased probability of fibre breaks near the tip of a transverse crack



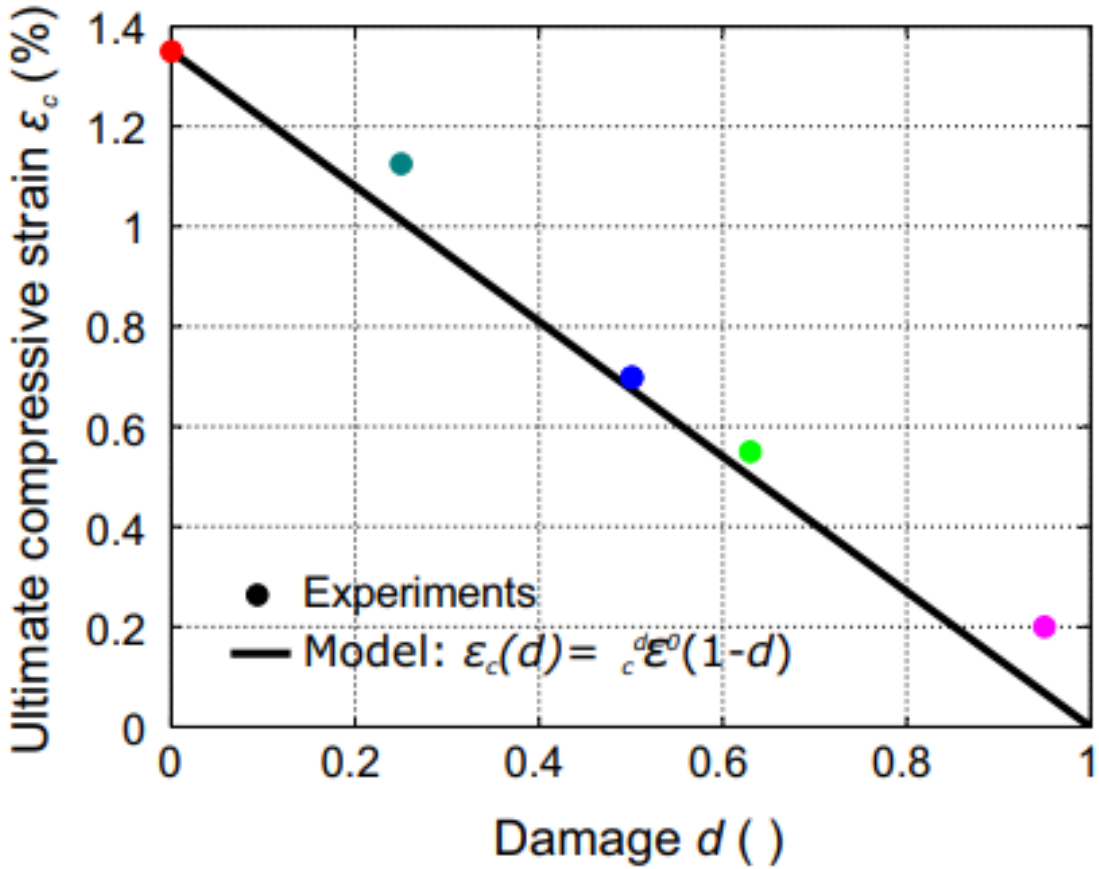
Debondt, 2017



Rev, Leone, Lovejoy, Wisnom, 2020

Effect of damage - compression

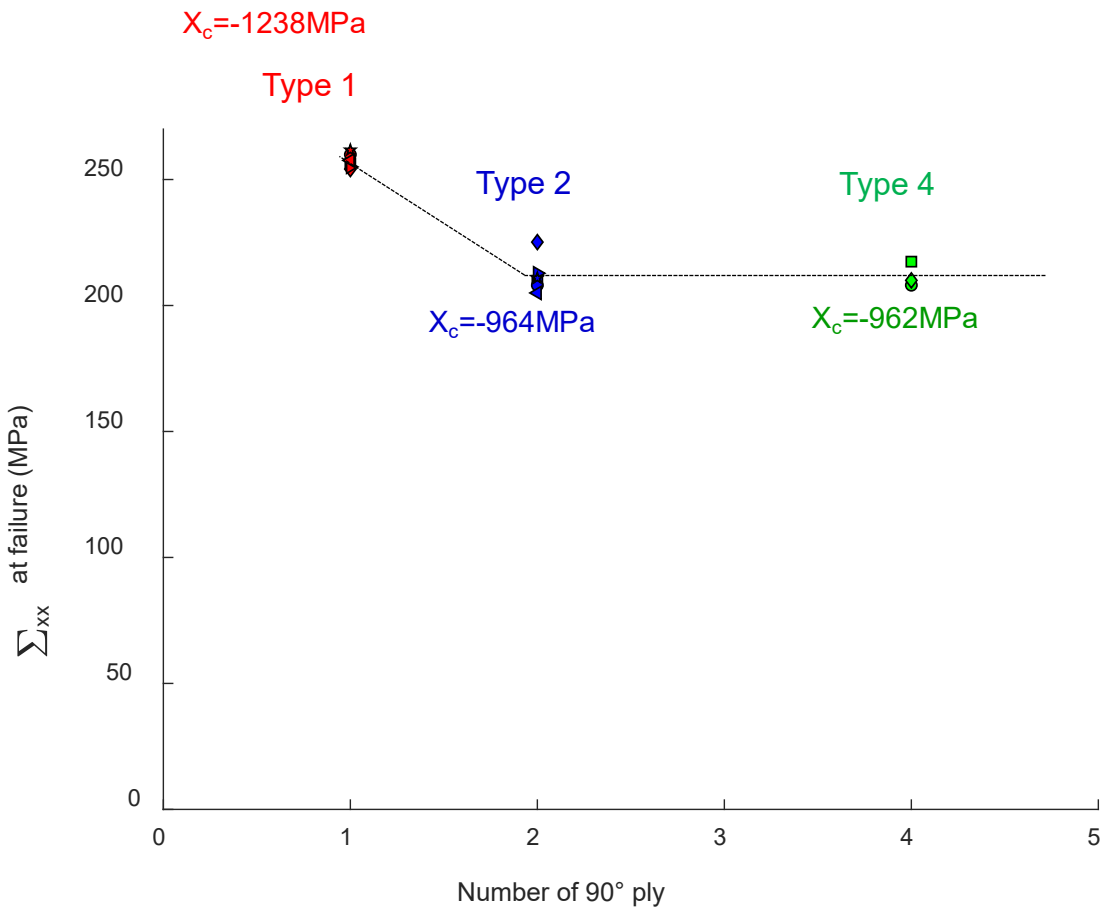
- Damage induced by fatigue in a tube in torsion
- Compressive strength then measured
- Substantial reduction!



Eyer, Montagnier, Hochard, Charles, 2017

Laminate compressive failure

- Adjacent plies can affect failure
- E.g. thin ply carbon/epoxy, t_{ply}=0.03mm
  1, 2 or 4 plies
  between ±45° plies
- Single ply substantially stronger
- Transverse cracks suppressed
- Failure constrained in thin ply



Rev, 2020

Other factors

- Residual thermal stresses present in laminates but not in UD, may have small effect
- Other stress components are present in laminates under uniaxial loading. Small effect in tension, but may affect compression
- Different volume of material – UD specimen of same dimensions has four times the volume as QI
- Tensile failure strain of QI and UD can be the same provided:
  - Premature failure is avoided
  - Stressed volume is taken into account - Xiaodong Xu presentation

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