A new test specimen to extract the traction-separation response for Mode I delamination

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Content: [1] Hartlen D, Montesano M, Cronin D. A composite rigid double cantilever beam specimen for assessing the traction-separation response of Mode I delamination in composite laminates. Experimental Mechanics 2023;63:1273-1283.

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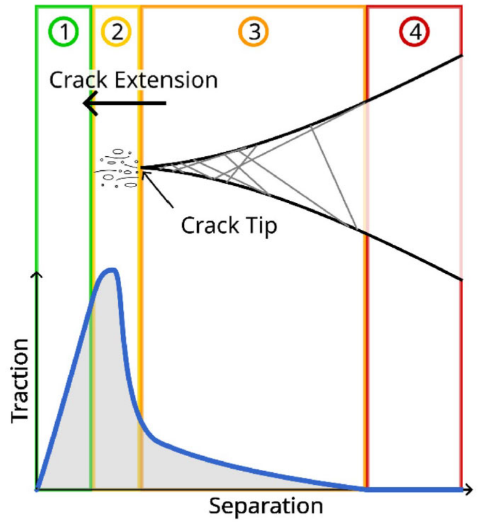
Motivation: Cohesive Zone Models (CZMs)

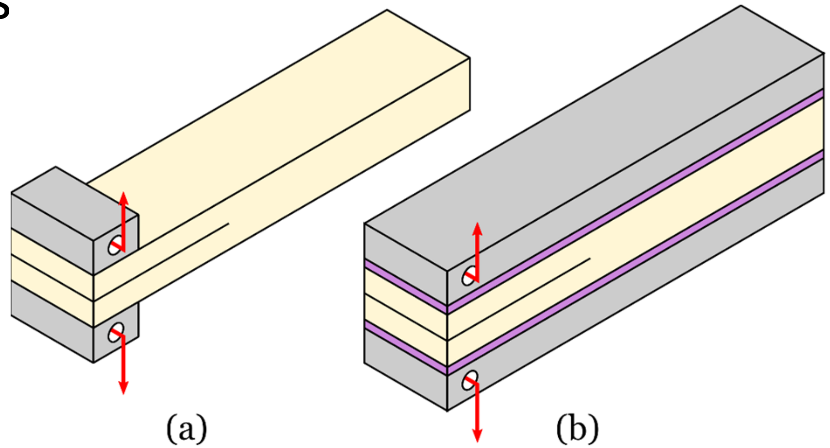
- Widely used CZMs require that the delamination response is represented via a traction-separation law (TSL)
  - Describes damage onset and growth within the FPZ preceding crack propagation
  - Common forms include bilinear, trapezoidal, trilinear



Schematic of damage evolution for Mode I delamination and representative TSL [1].

Challenge: Existing Test Protocols for Mode I Delamination

- Developed to capture fracture toughness, R-curve
- Not well suited to directly measure TSL parameters
  - Data processing schemes cannot capture the early portion of TSL, i.e., damage onset and early accumulation [2]
  - Require laminate stiffness a priori or specimen loaded under a pure bending moment [3]
  - Difficult to accurately track the crack tip
- Require supplemental analysis techniques, such as inverse modelling
  - Calibration of TSL parameters difficult for DCB specimens

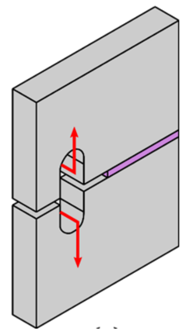


Schematic of (a) standard DCB specimen (ASTM D5528), and (b) reinforced DCB specimen [1].

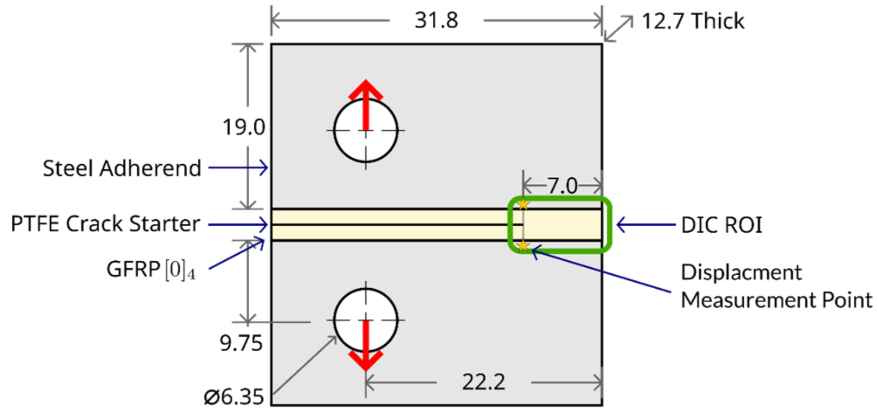
[2] Svensson D, Alfredsson KS, Biel A, Stigh U. Measurement of cohesive laws for interlaminar failure of CFRP. Compos Sci Technol 2014;100:53–62.
[3] Sørensen BF, Jacobsen TK. Determination of cohesive laws by the J integral approach. Eng Fract Mech 2003;70:1841–1858.

Proposed Solution: Rigid DCB Specimen

- In recent work [4], a rigid DCB specimen was developed to characterize Mode I fracture of a toughened adhesive enabling capture of the TSL
  - Smaller specimen size/mass conducive to high-deformation-rate testing
- Technique adapted for assessing Mode I delamination in laminates [1]
  - UD glass/epoxy prepreg layers co-cured to steel adherends via compression molding
  - Several iterations undertaken to ensure stable delamination crack propagation and repeatability
  - Separation tracked optically via displacement measurement points



Schematic of rigid DCB specimen for adhesives [4].



Schematic of rigid DCB specimen for laminates [1].

[4] Watson B, Liao C-H, Worswick MJ, Cronin DS (2018) Mode I traction-separation measured using rigid double cantilever beam applied to structural adhesive. J Adhes 1–21.

Rigid DCB: Analysis Procedure to extract TSL

- Assumptions
  - Stresses (tractions) are uniform across the specimen width
  - Linear elastic compressive response at the interface
  - Steel adherends are rigid (δ ~ Δ)
  - Perfect bonding
- Force and moment balance leads to expressions for traction (σ)
  - Pivot point location (μ) must also be determined

$$\sigma(\delta) = \frac{d\Delta}{d\delta_o}\frac{d}{d\Delta}\left(\frac{P\Delta}{B(l-\mu)} + \frac{\mu^2 k_m \Delta^2}{2(l-\mu)^2}\right)$$

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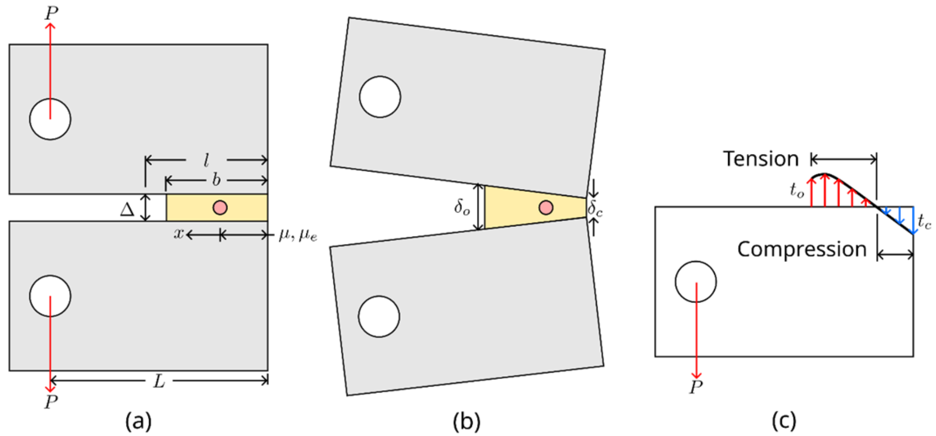
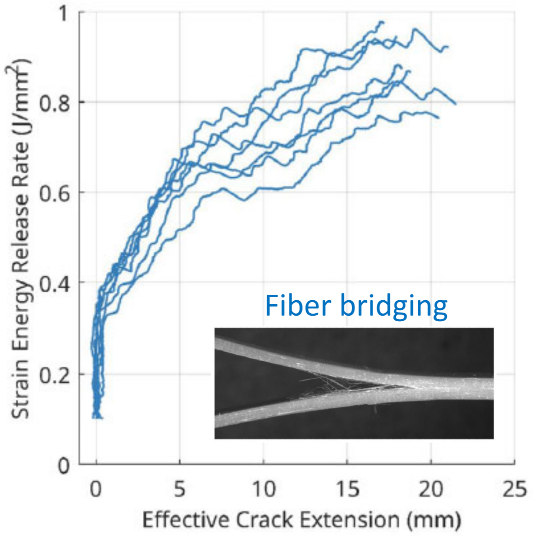


(a) Critical dimensions used to extract TSL, (b) deformed specimen, (c) FBD showing distribution of tensile and compressive stresses [1].

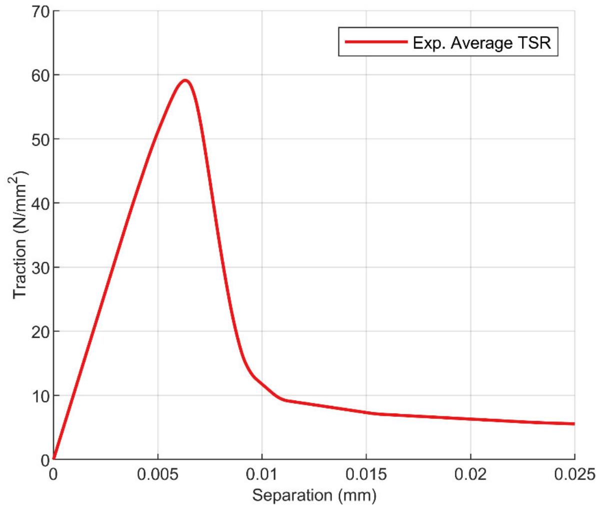
Rigid DCB vs. Standard DCB



R-curve captured using DCB specimen [1].

$G_{Ic,\ onset}$ = 0.35 J/mm²

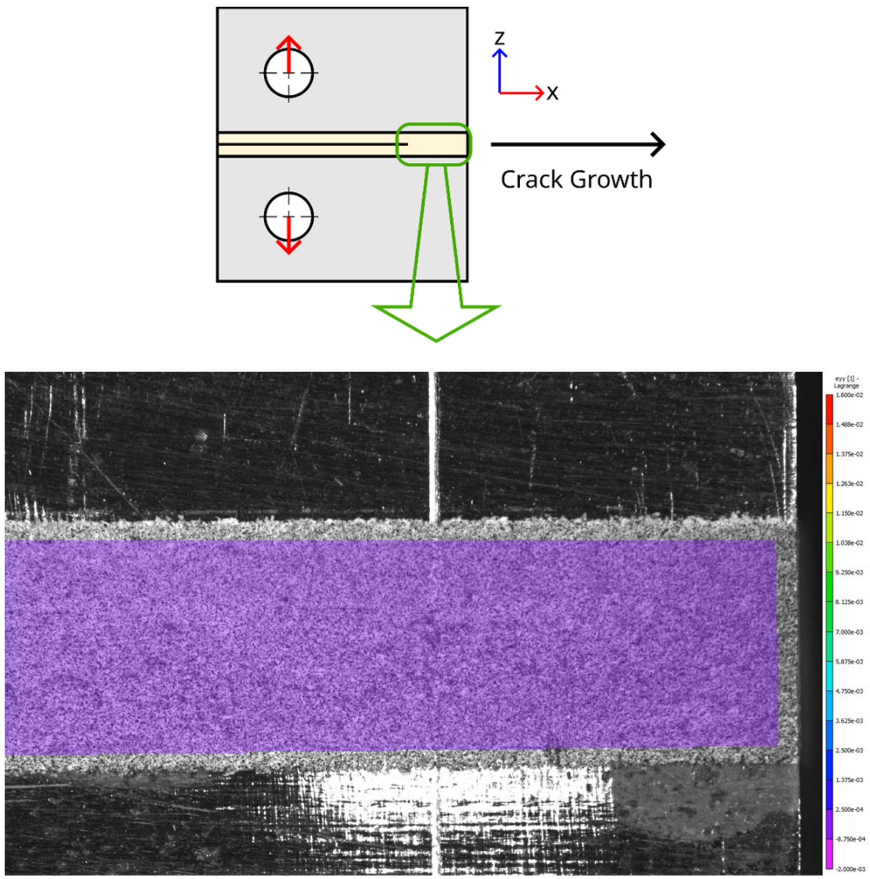
$G_{Ic,\ steady}$ = 0.8 – 1.1 J/mm²



TSL extracted experimentally using rigid DCB specimen.

$G_{Ic,\ onset}$ = 0.32 J/mm²

$G_{Ic,\ steady}$ = ?



Strain contour captured via DIC in ROI (~3 min elapsed time).