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Measurement of Fracture Energy for Kink-Band Growth in Sandwich Specimens

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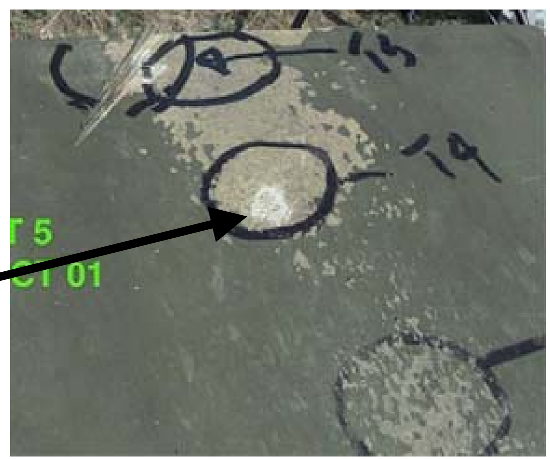
- Motivation
- Background
- Specimen and Test Method
- Parametric Studies
- Test Results
- Concluding Remarks

MOTIVATION

Extensive use of sandwich construction in military helicopters



Possible damage from out-of-plane loading

Method needed to predict compression after impact strength

BACKGROUND - CONTINUED

CAI Testing

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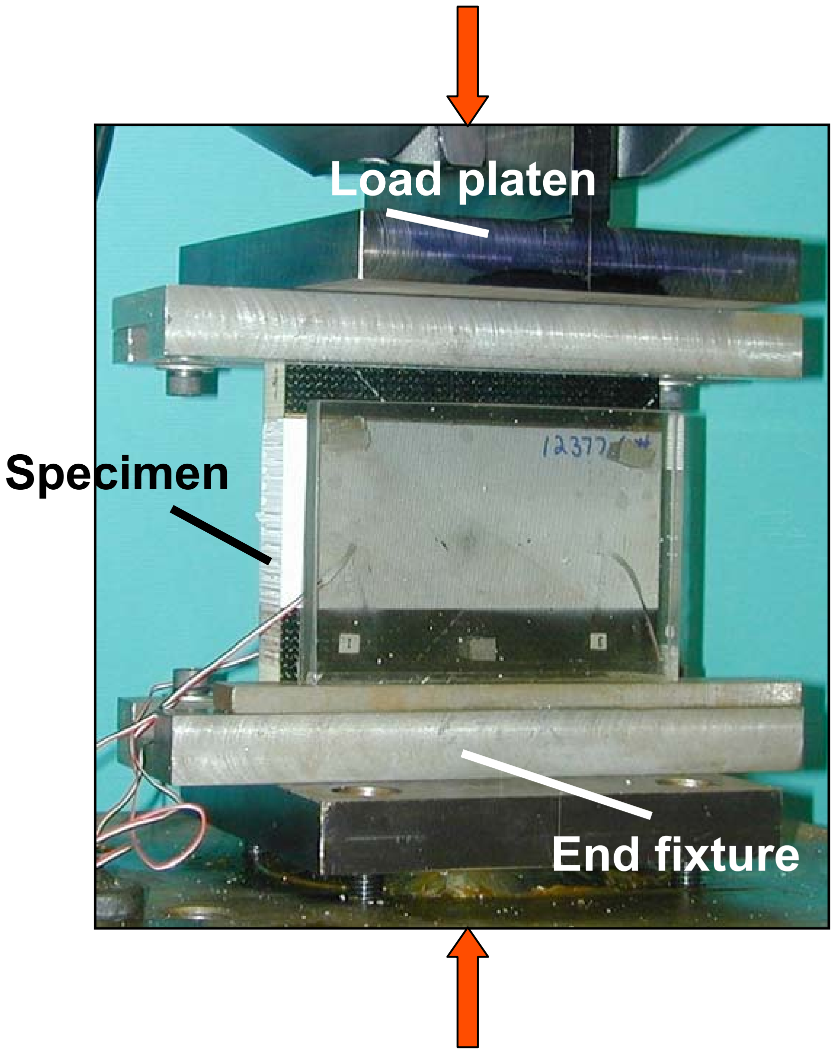
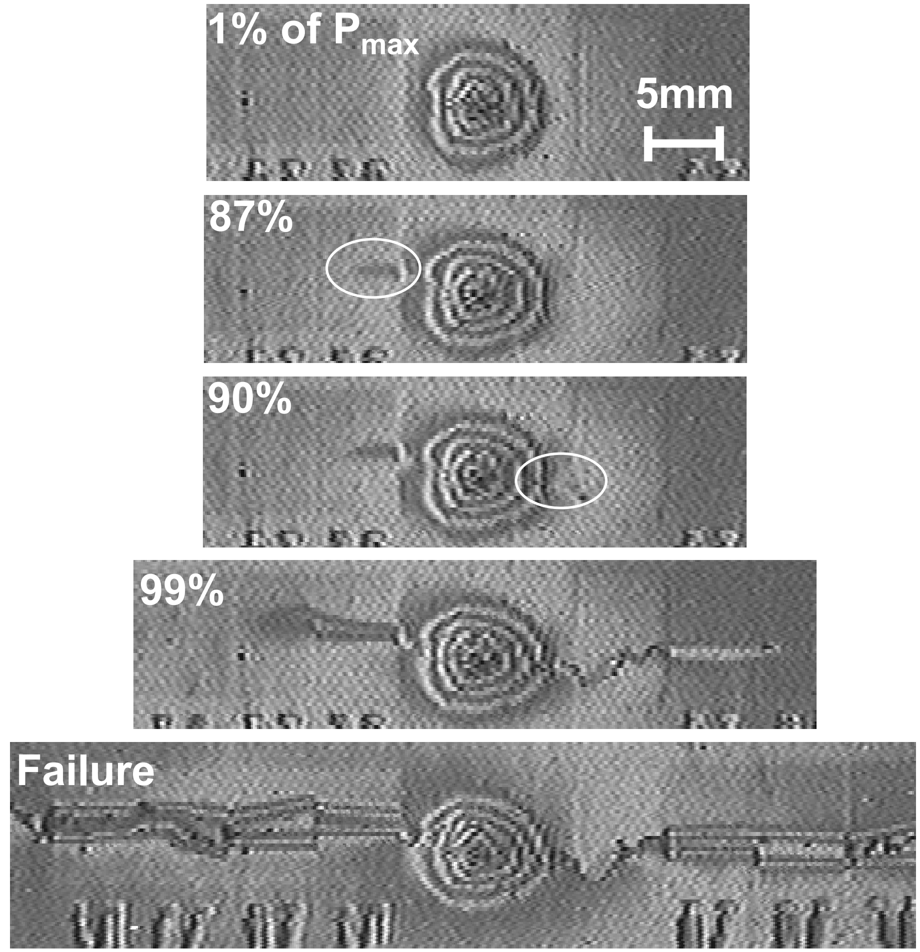
Specimen loaded under axial compression



Shadow Moiré Images



BACKGROUND - CONTINUED

CAI Strength Prediction

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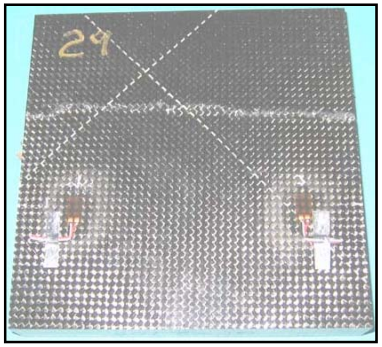
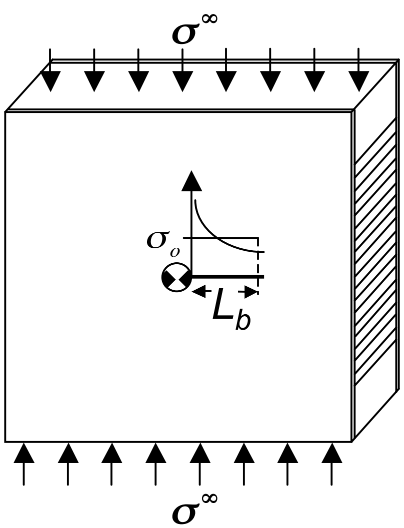
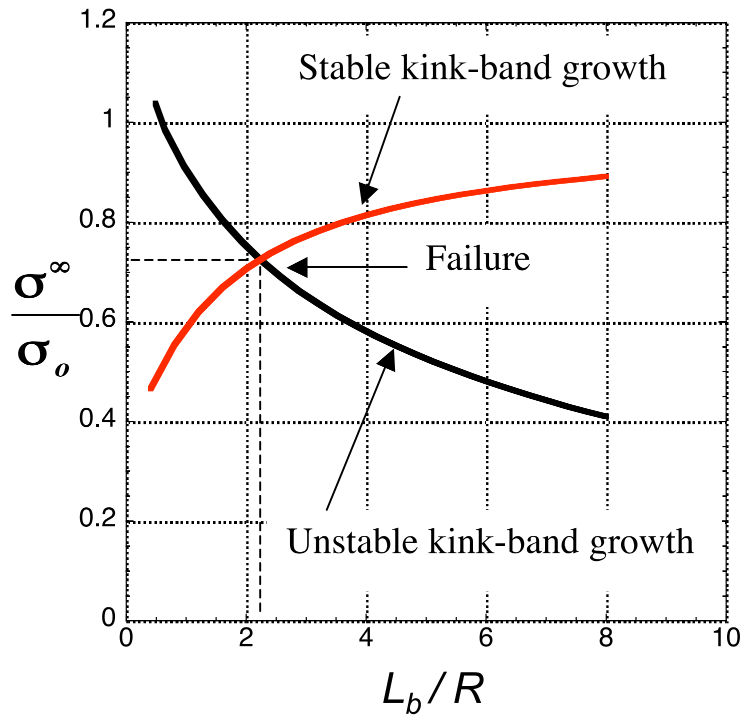
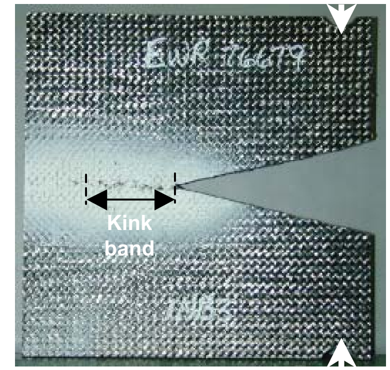


Unnotched strength, σ_o, compression test

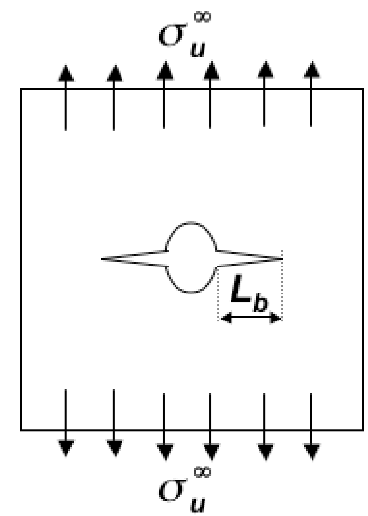


Average stress criterion used to calculate stable kink-band growth





K_{Ic} measured from new fracture test

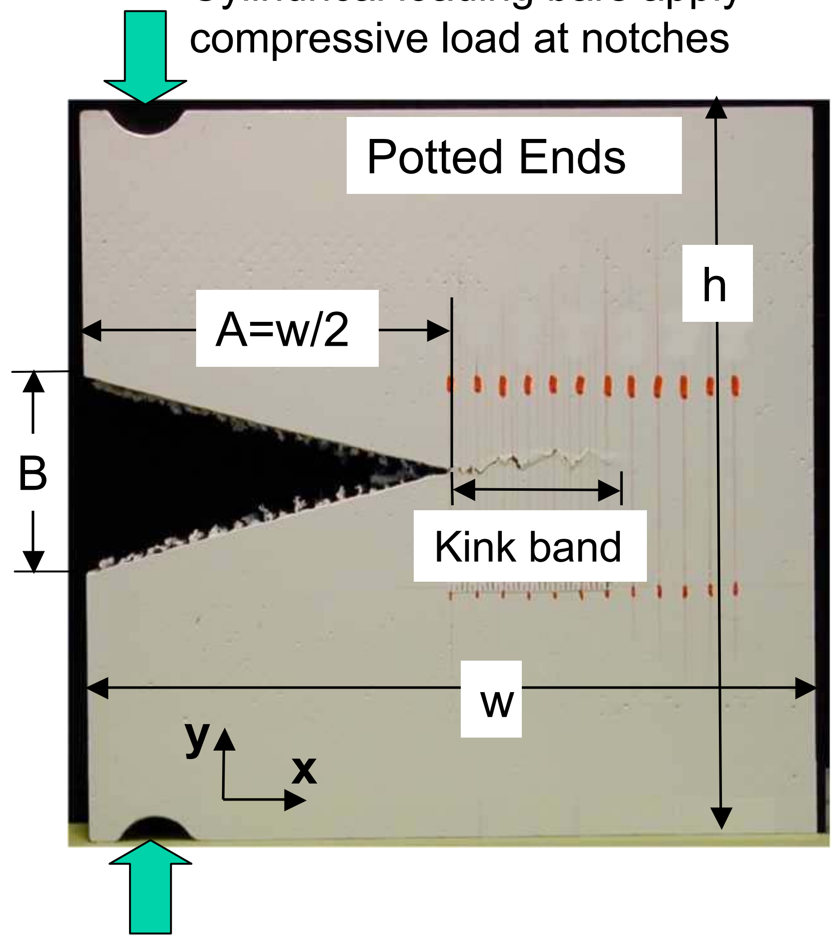


$$\sigma_u^\infty = \frac{K_{Ic}}{\sqrt{\pi L_b} f(L_b / R)}$$

"Compact Compression" Test

- **Test required to measure energy associated with kink-band growth (K_{Ic} calculated)**
- **Based on compact tension specimen used for metal fracture**
- **Displacement control (0.5 mm/min)**
- **Specimen loaded until kink band has extended 5-10mm then unloaded. Process repeated until kink band length is 50mm.**
- **Dissipated energy calculated for each load cycle**
- **Critical strain energy release rate, G_{Ic}, calculated for each growth increment**
- **K_{Ic} calculated from relationship with G_{ic} for an orthotropic plate**

Cylindrical loading bars apply compressive load at notches



Analysis of Specimen Geometry

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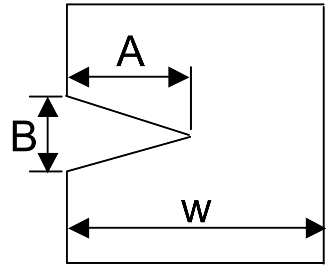
- Determine effects of geometry on strain energy release rate and stability.

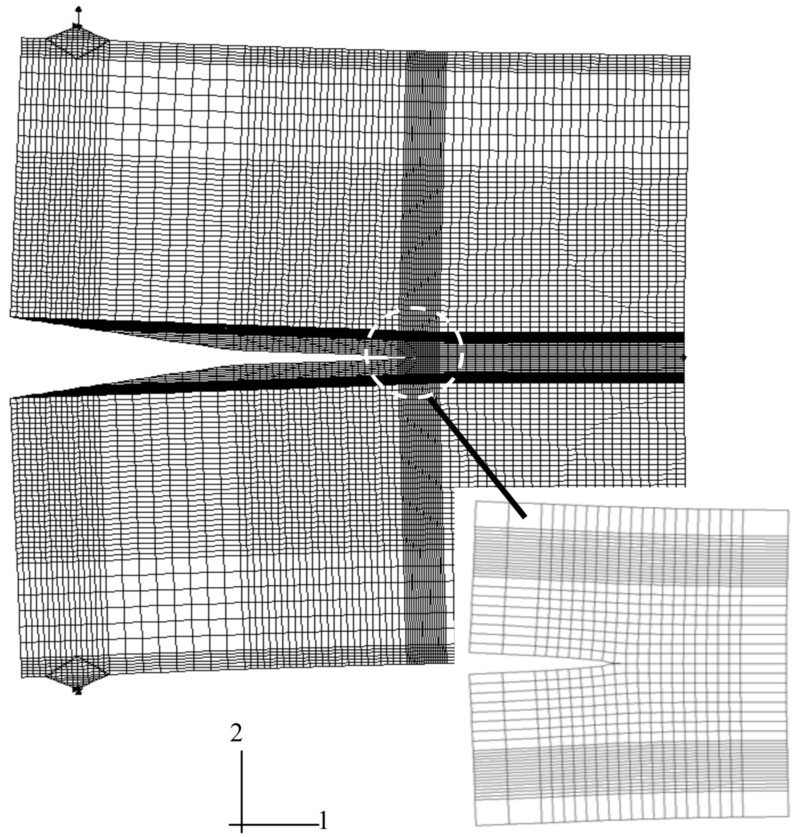
- Three specimen configurations modeled using finite elements:

  1. A=w/3, A/B=4
  2. A=w/3, A/B=0.8
  3. A=2w/3, A/B=8



- Finite element analysis used to calculate strain energy release rates. Analysis of each configuration repeated for a range of crack lengths.

- Relationship between strain energy release rate and crack length assumed the same in tension and compression.



Finite Element Results

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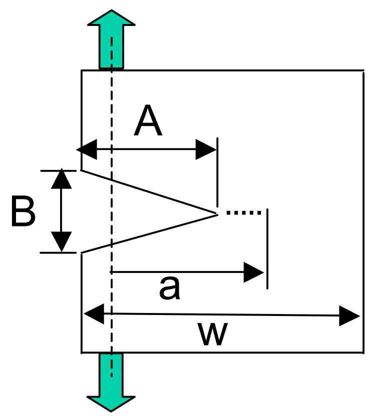
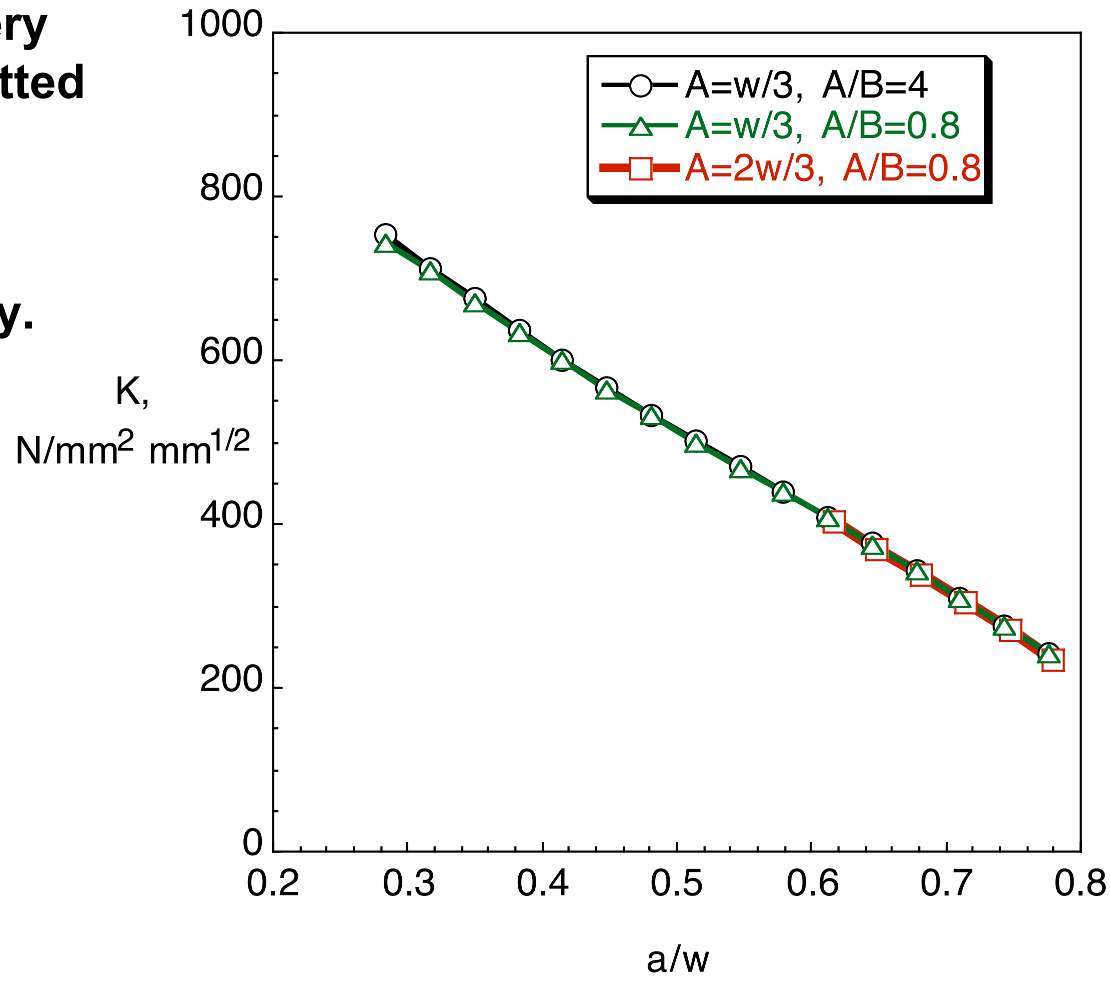
- **All configurations have very similar K curves when plotted as a function of "a."**
- **Notch geometry does not significantly affect stability.**
- **Geometry selected: A = w/2, A/B = 2**





Force-Displacement Behavior

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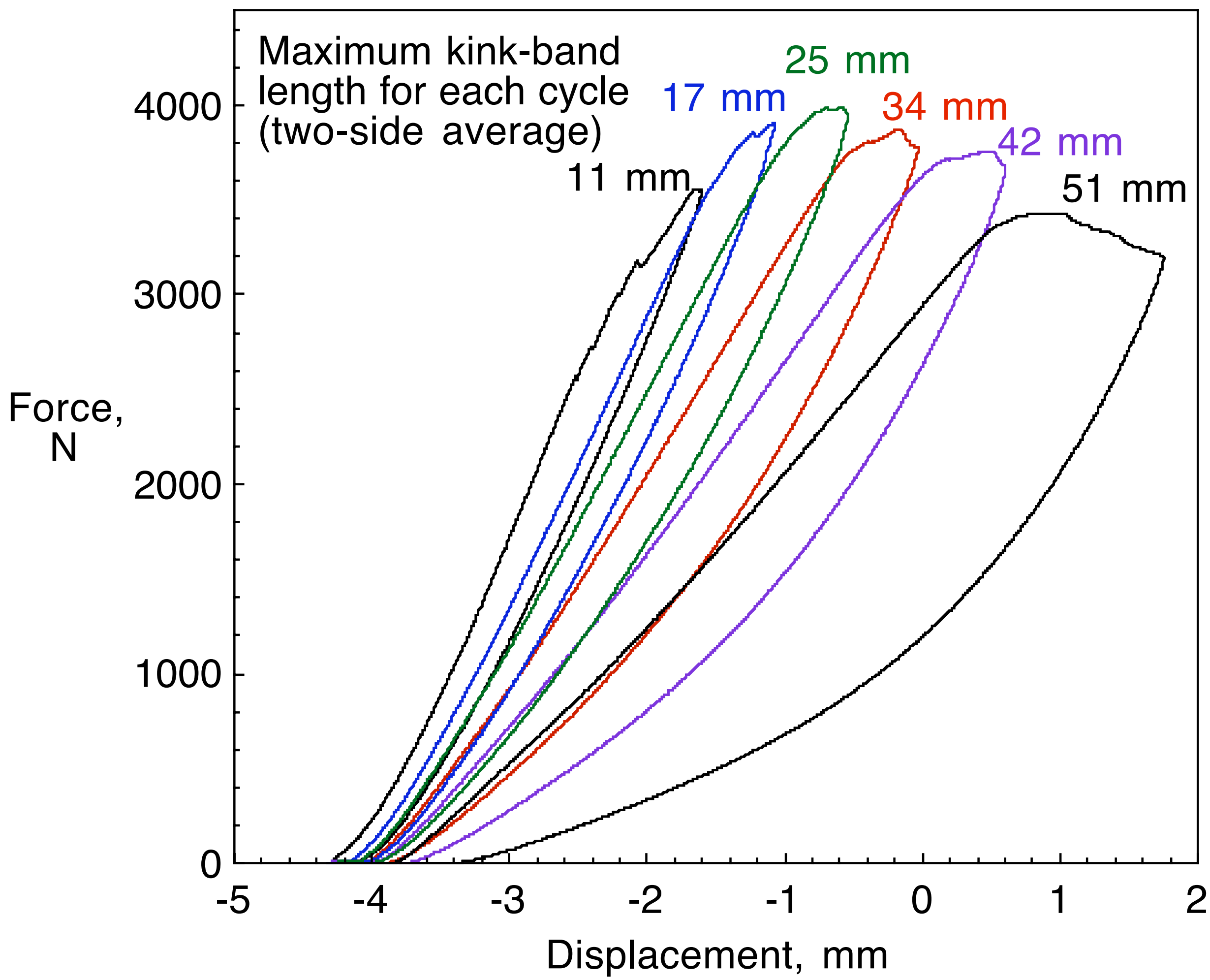
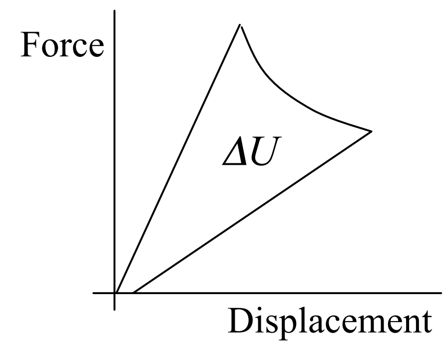


$$G = \frac{1}{2t_f}\frac{\Delta U}{\Delta L_b}$$



Monitoring Kink-Band Propagation

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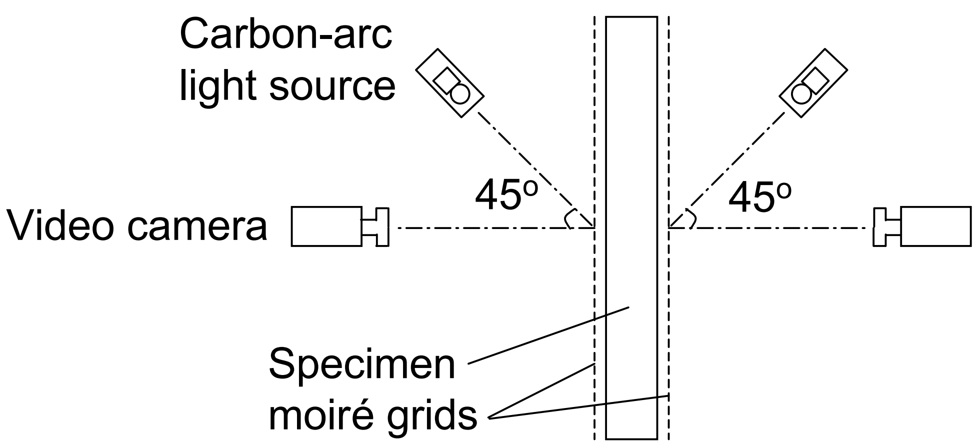
- **Shadow moiré used**
- **Moiré grid attached to both facesheets**
- **High-intensity, collimated light placed 45º to specimen**
- **Both sides of specimen monitored (recorded on video)**



Comparison of Techniques to Determine Kink-Band Lengths

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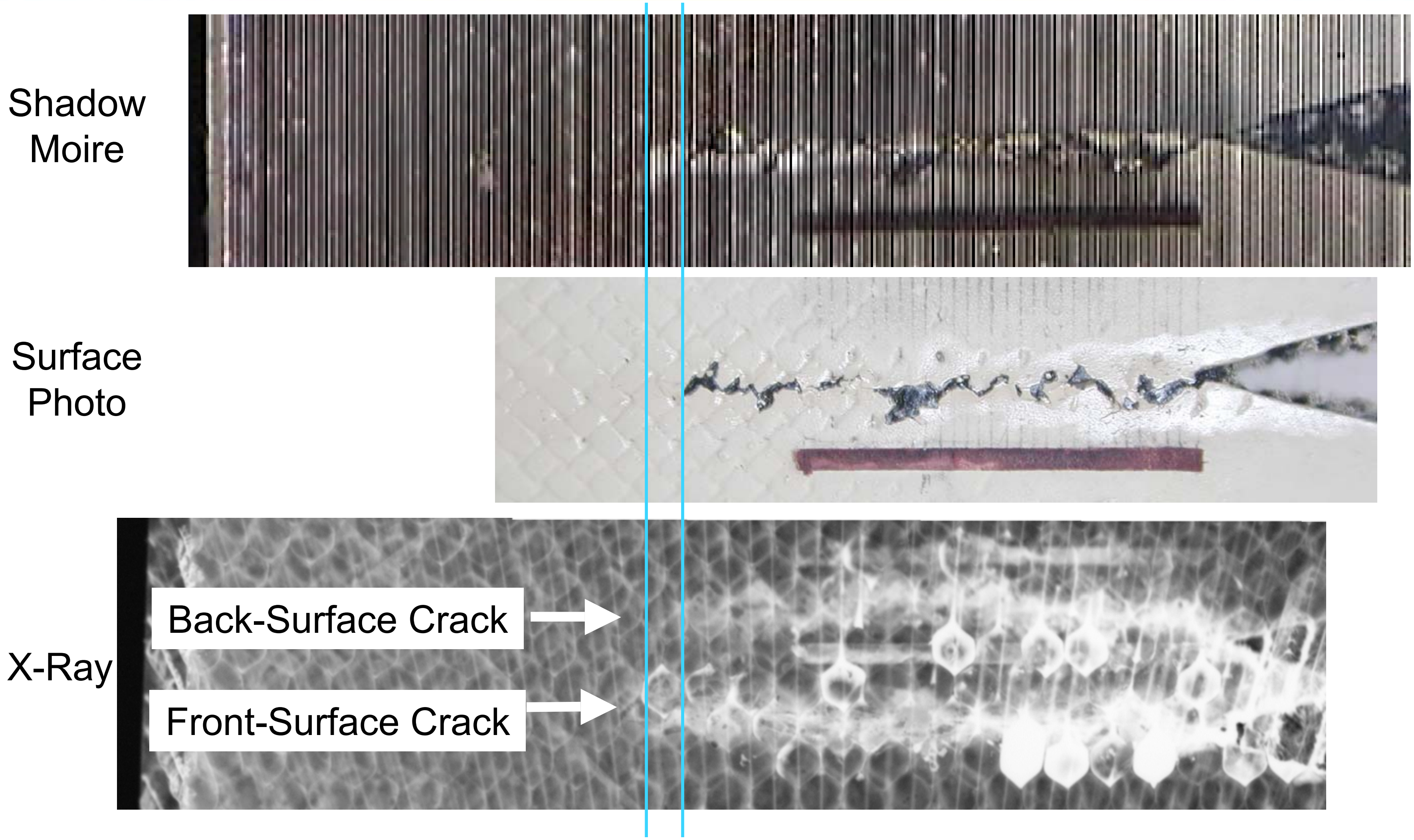
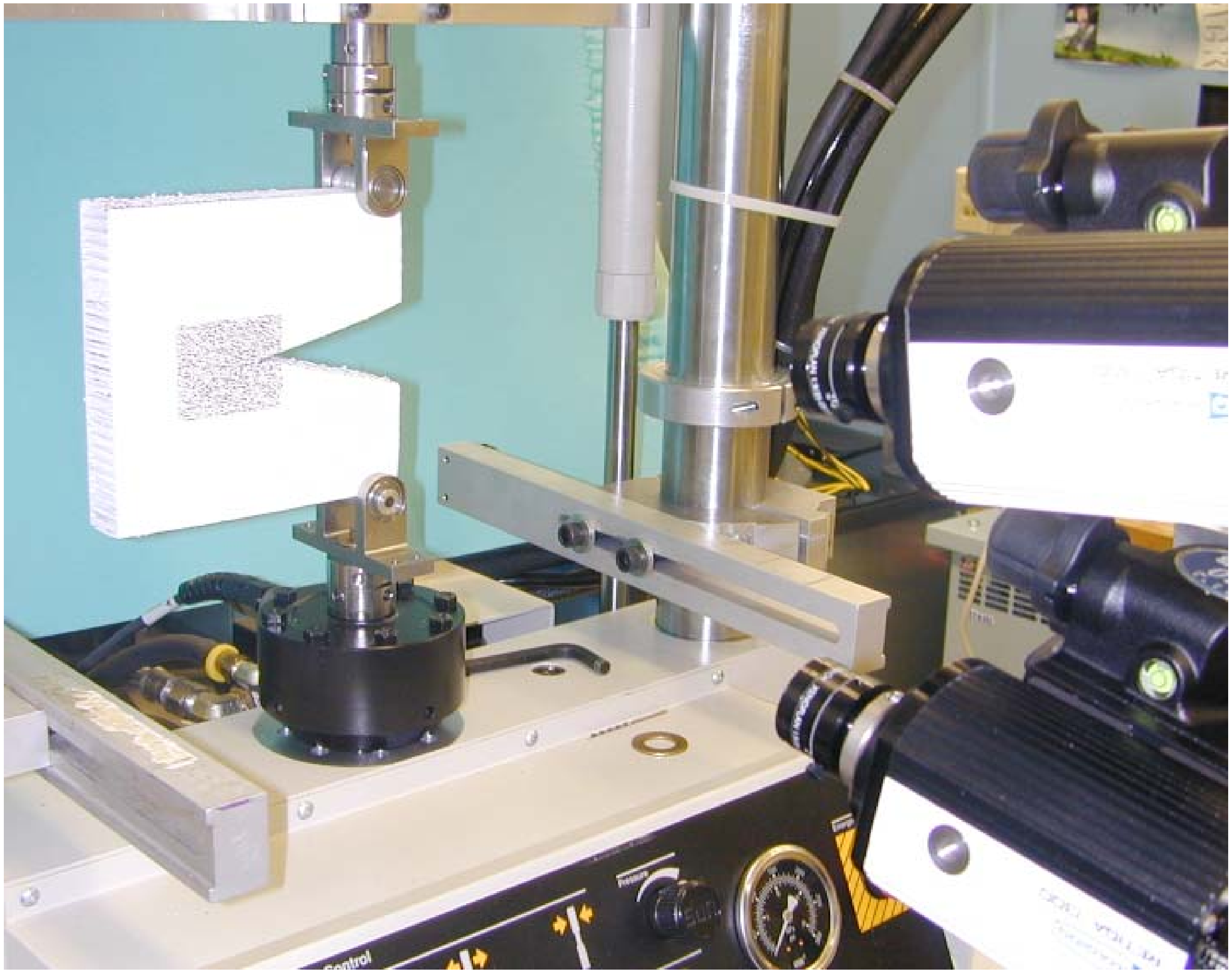


Optical Deformation Measurements

- **Measurements taken in speckled region**
- **One image recorded every 10 seconds**
- **All strains were calculated from an image of an unloaded specimen prior to the first load application**



Strain Field Animation

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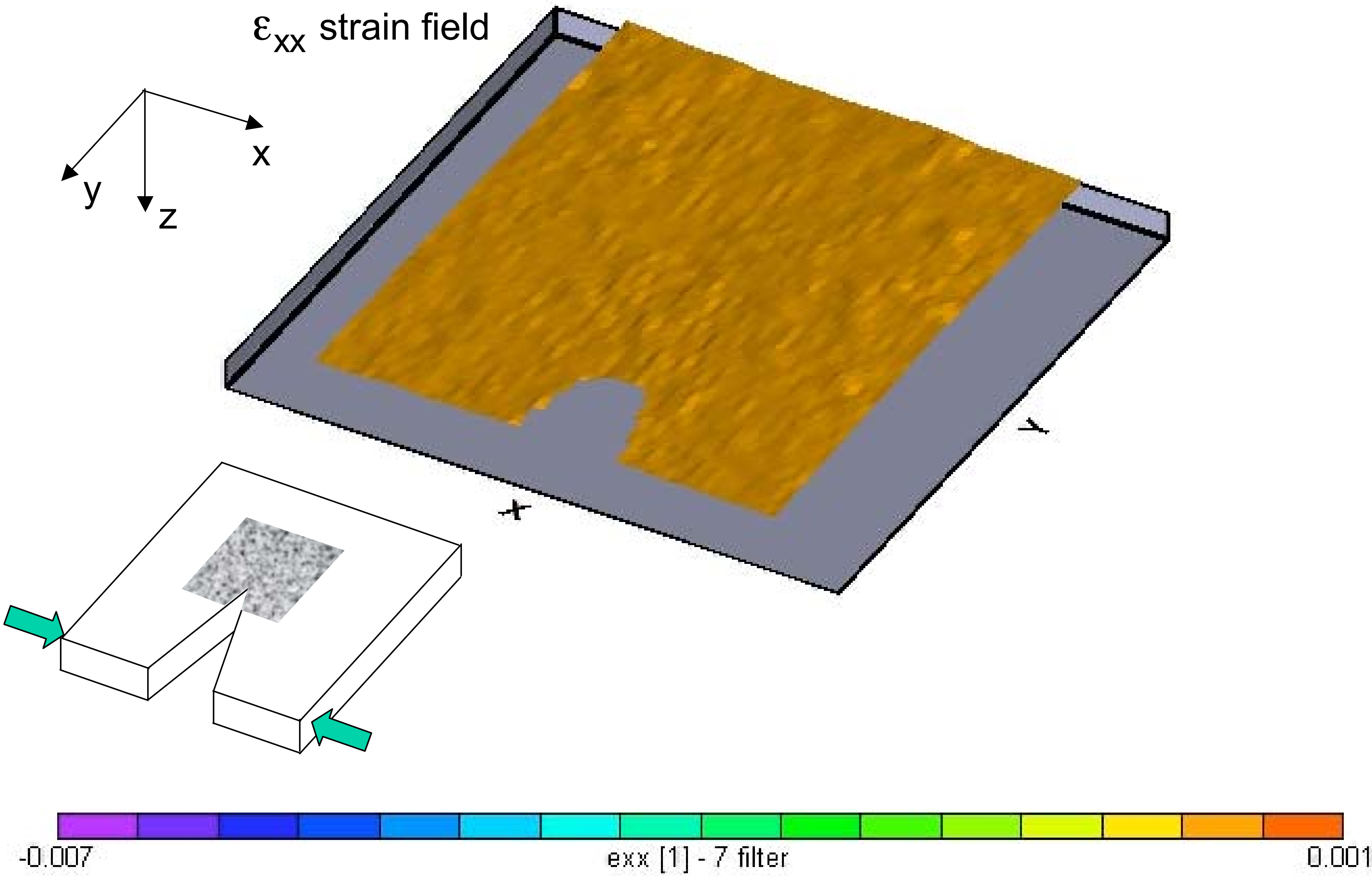

Compact Compression Test Matrix

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- **Objectives:**
  - **Evaluate specimen and test methodology**
  - **Generate data for CAI strength predictions**
  - **Investigate the effects of material and layup**
- **Plain-weave carbon fabric facesheets (3-6 plies)**
- **Nomex honeycomb**

Config	Material System	Facesheet Layup	Core Thickness
a	1 (toughened epoxy)	$[(\pm 45)/(0/90)]_S$	25 mm
b	1 (toughened epoxy)	[(±45)/(0/90)/(±45)]	25 mm
c	2 (epoxy)	$[(0\text{-}90)/(0\text{-}90)/(0\text{-}90)_{1/2}]$	25 mm
d	3 (epoxy)	$[(0\text{-}90)/(\pm 45)]_3$	29 mm
e	3 (epoxy)	$[(0\text{-}90)/(\pm 45)]_2$	19 mm

Specimen Geometry
Parametric Testing

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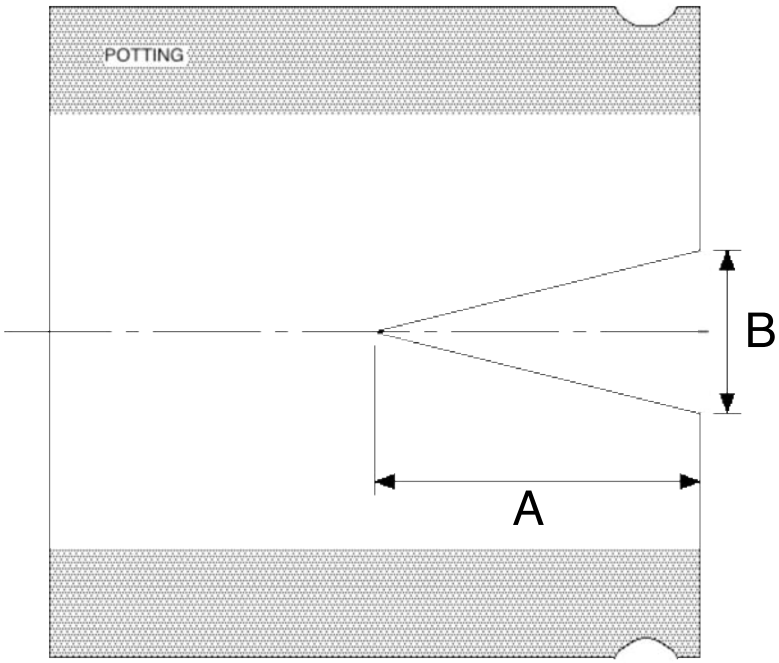
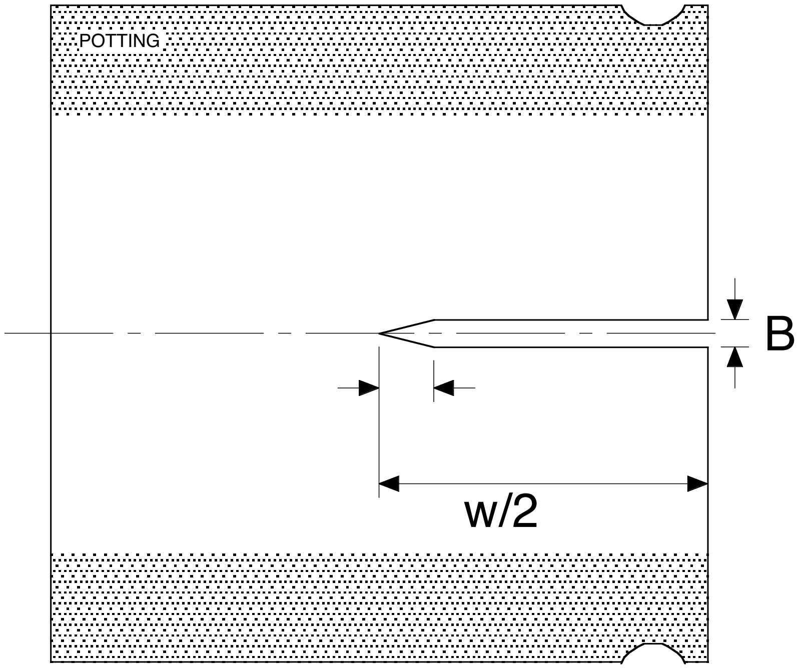
V Notch



Slot



1. A = w/2, A/B = 6
2. A = w/2, A/B = 2
3. A = w/2, A/B = 1.2
4. A = 2w/3, A/B = 4
5. A = 2w/3, A/B = 2

Configuration "a" used for testing

Fracture Toughness Measurements
Parametric Study

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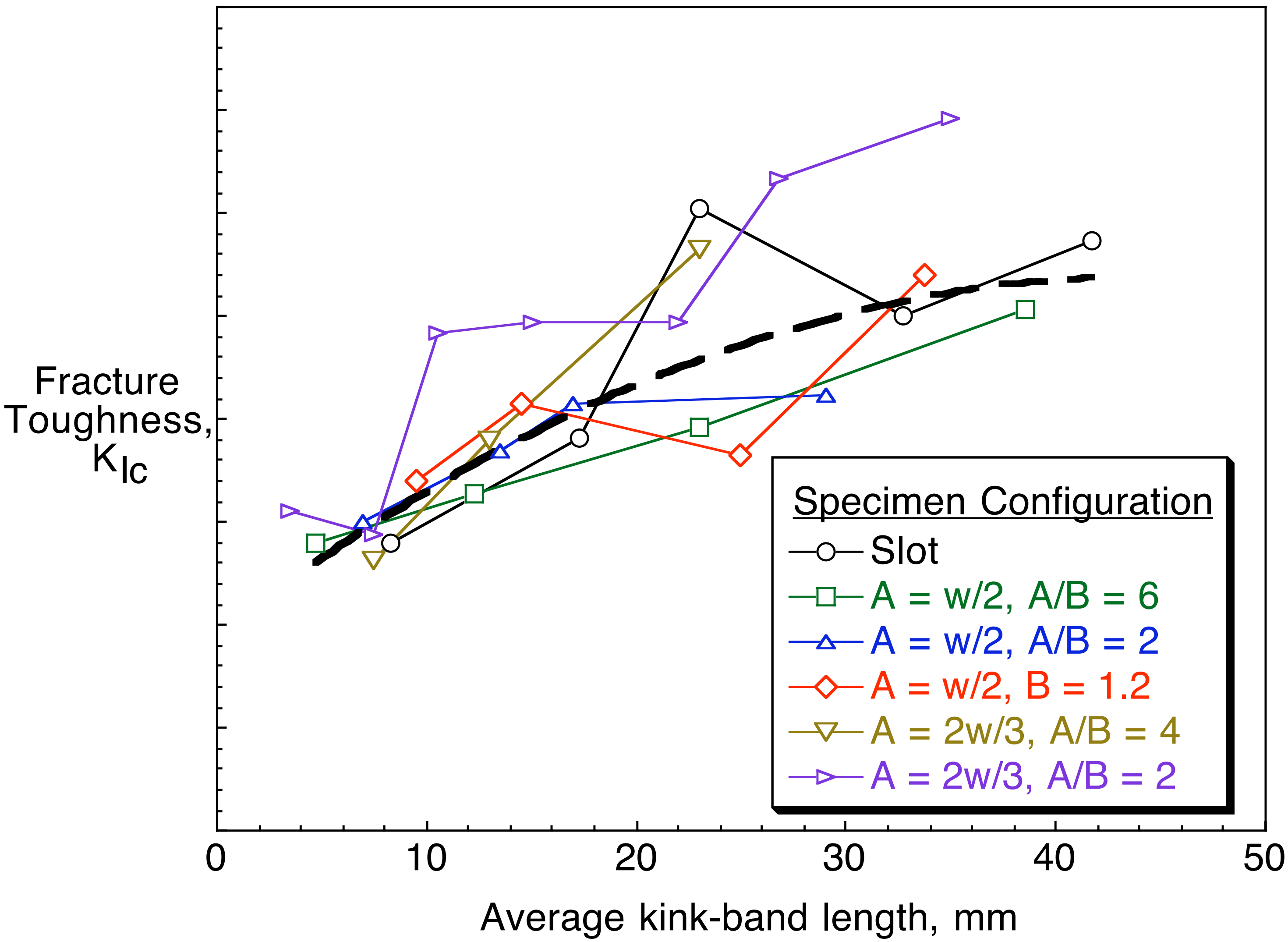
$[(\pm 45)/(0/90)]_S$ (Config "a")



Fracture Toughness Measurements

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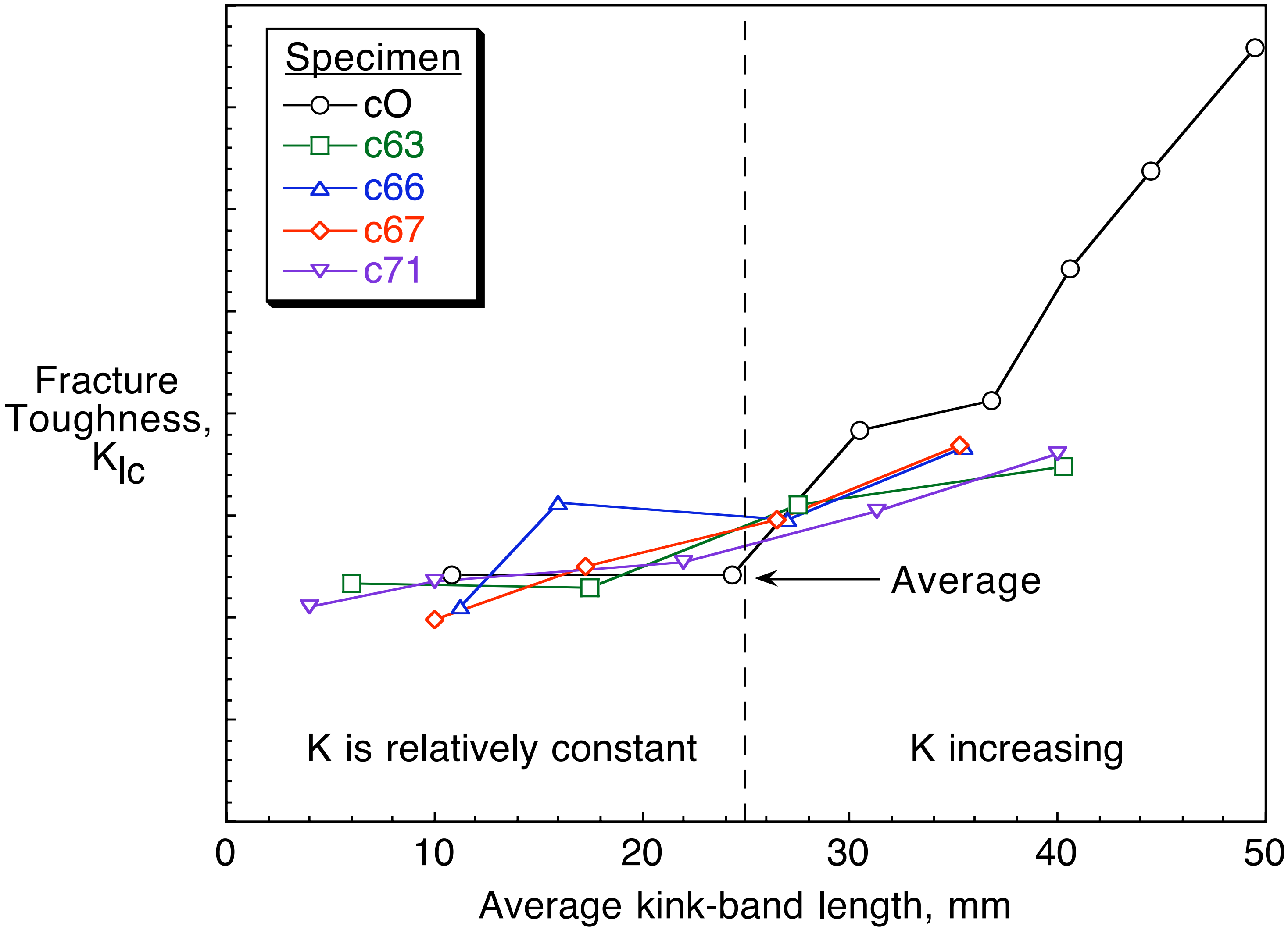
[(±45)/(0/90)/(±45)] (Config "b")



Fracture Toughness Measurements Comparison of Layups

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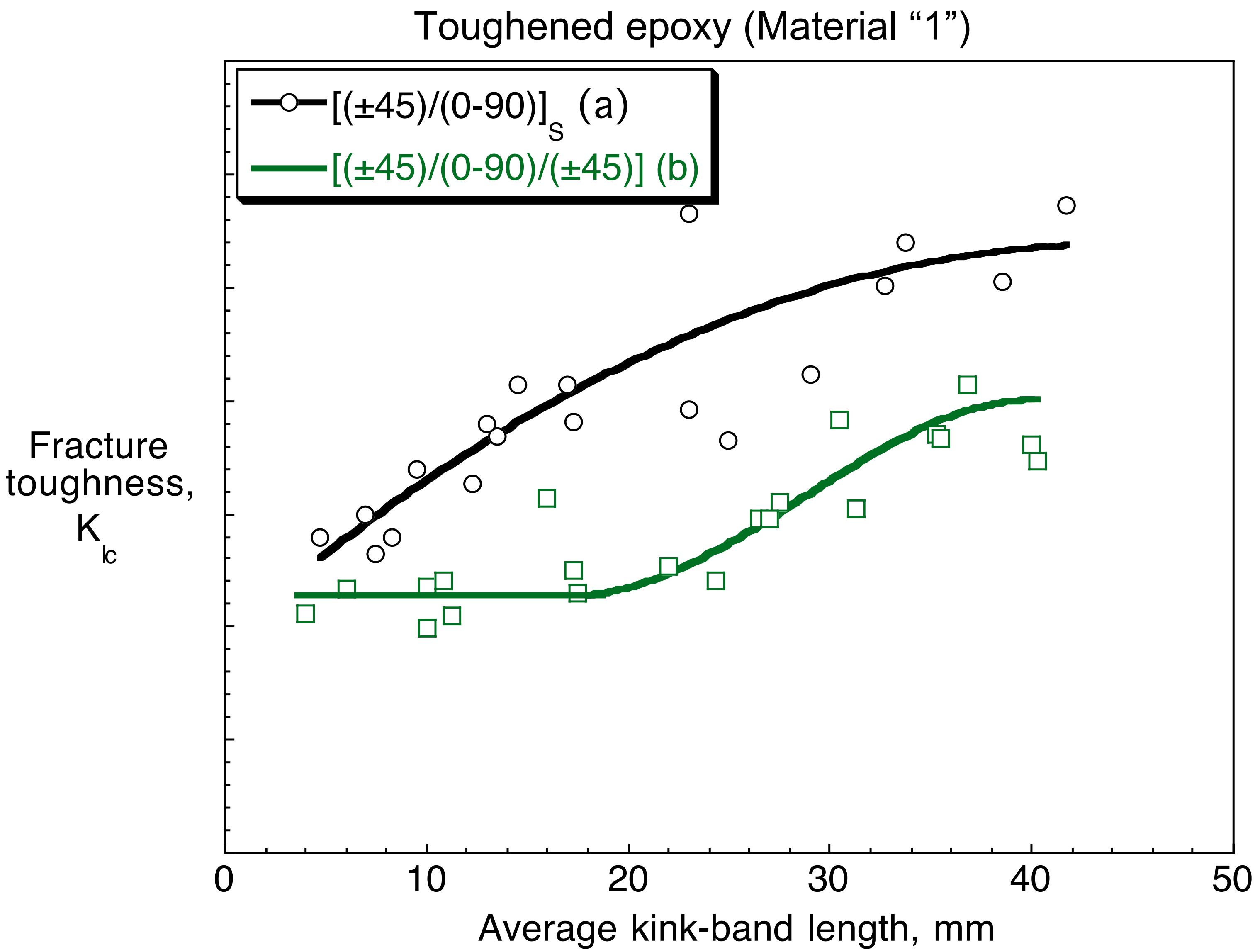
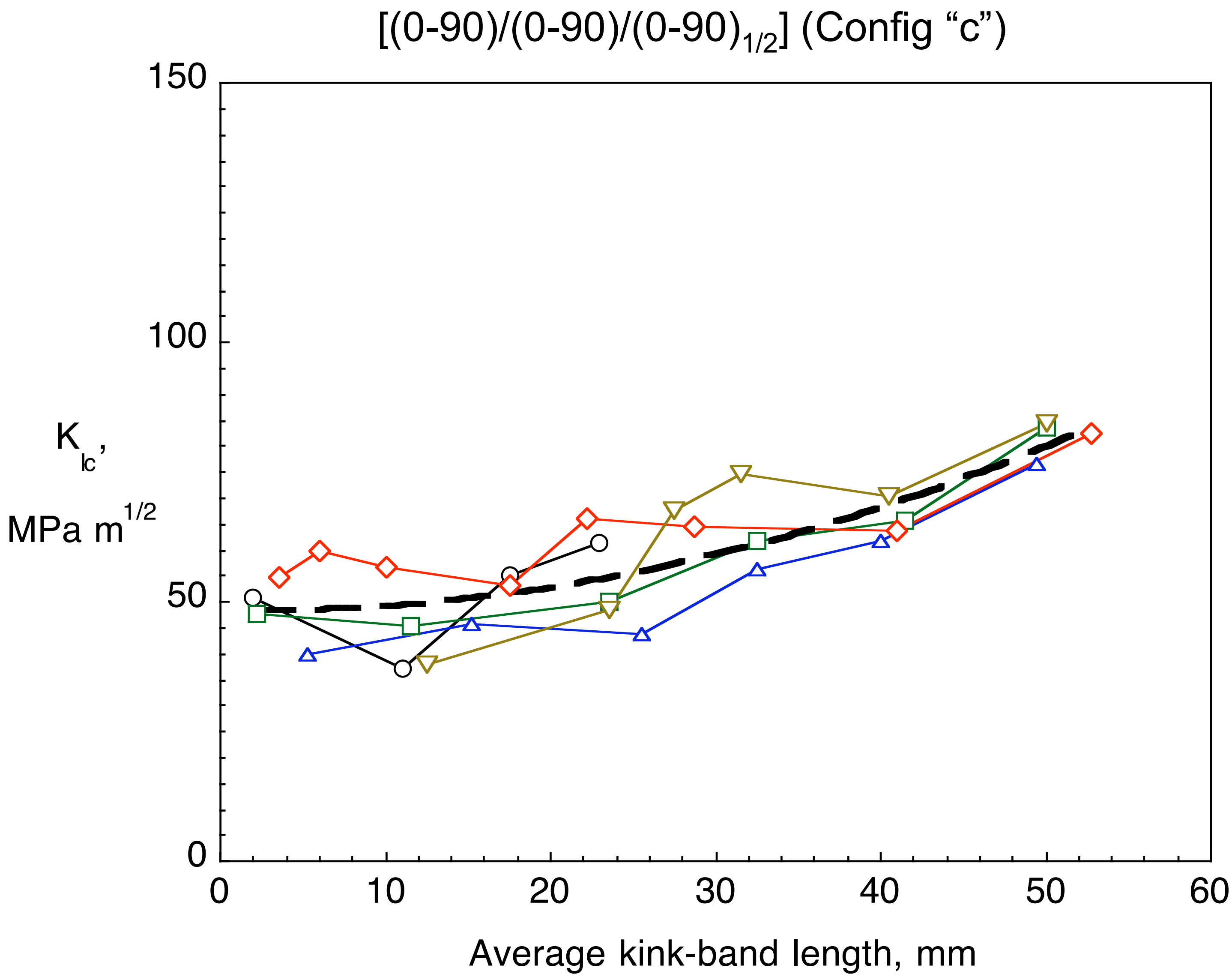
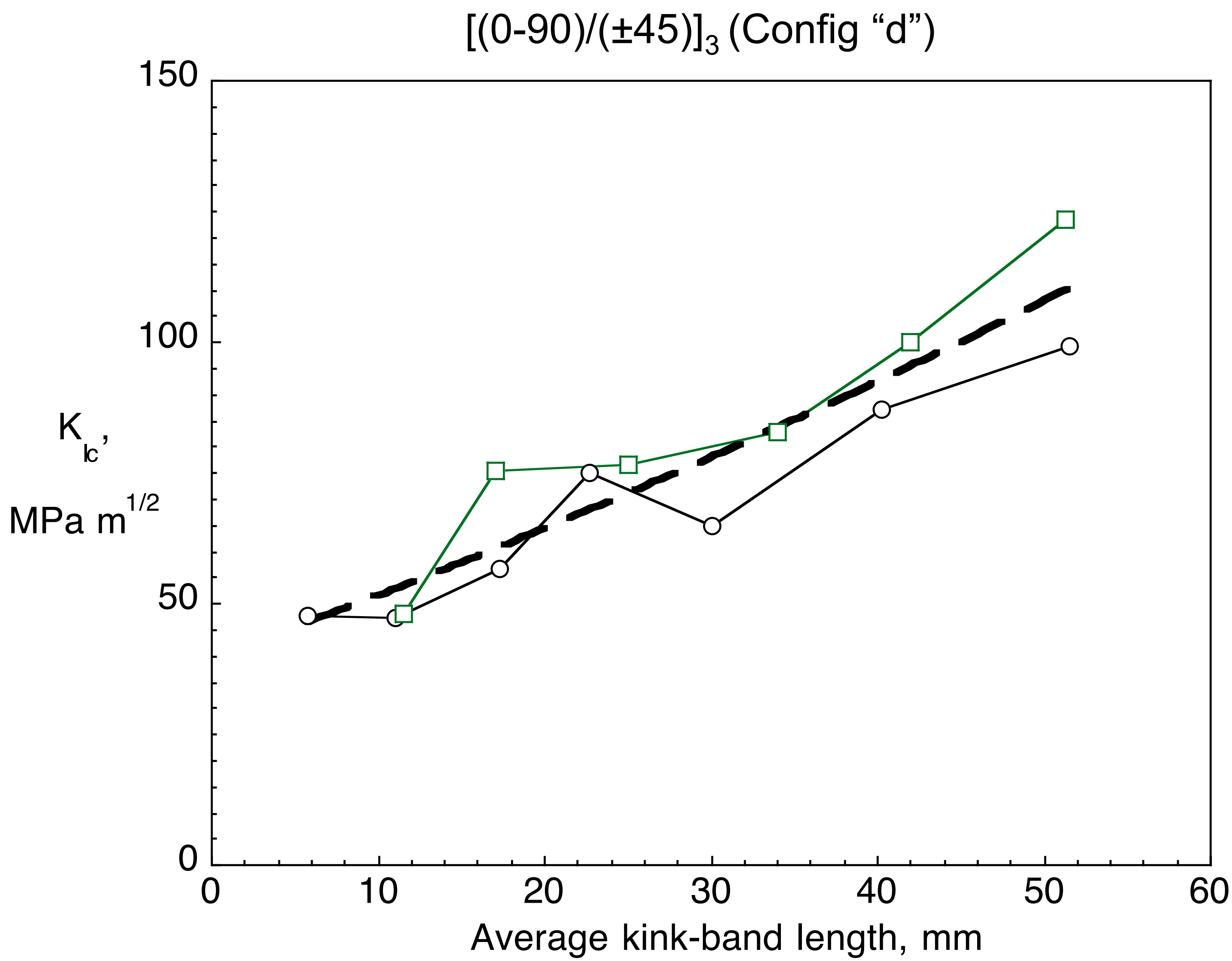


Fracture Toughness Measurements



Fracture Toughness Measurements



Fracture Toughness Measurements

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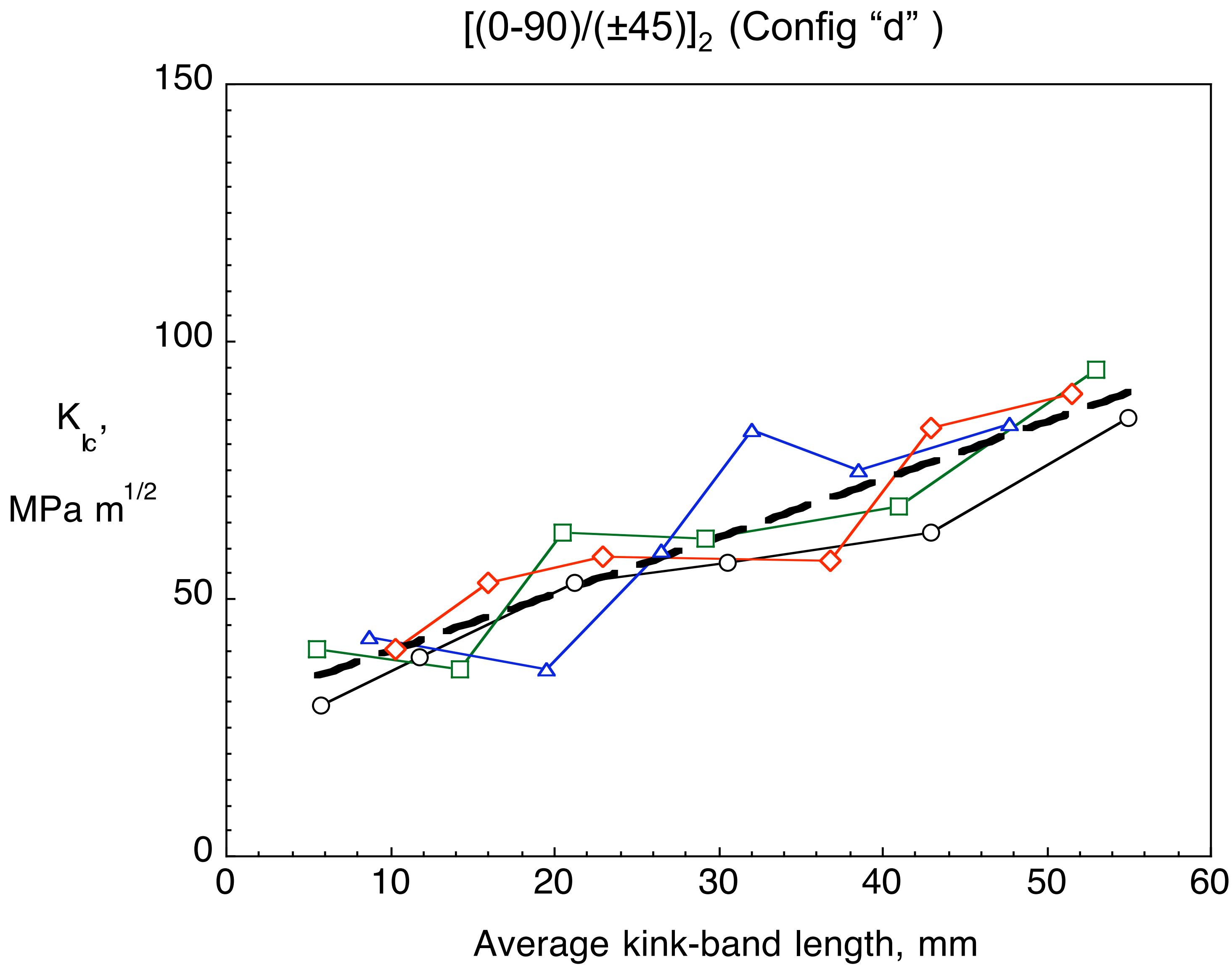

Fracture Toughness Comparison

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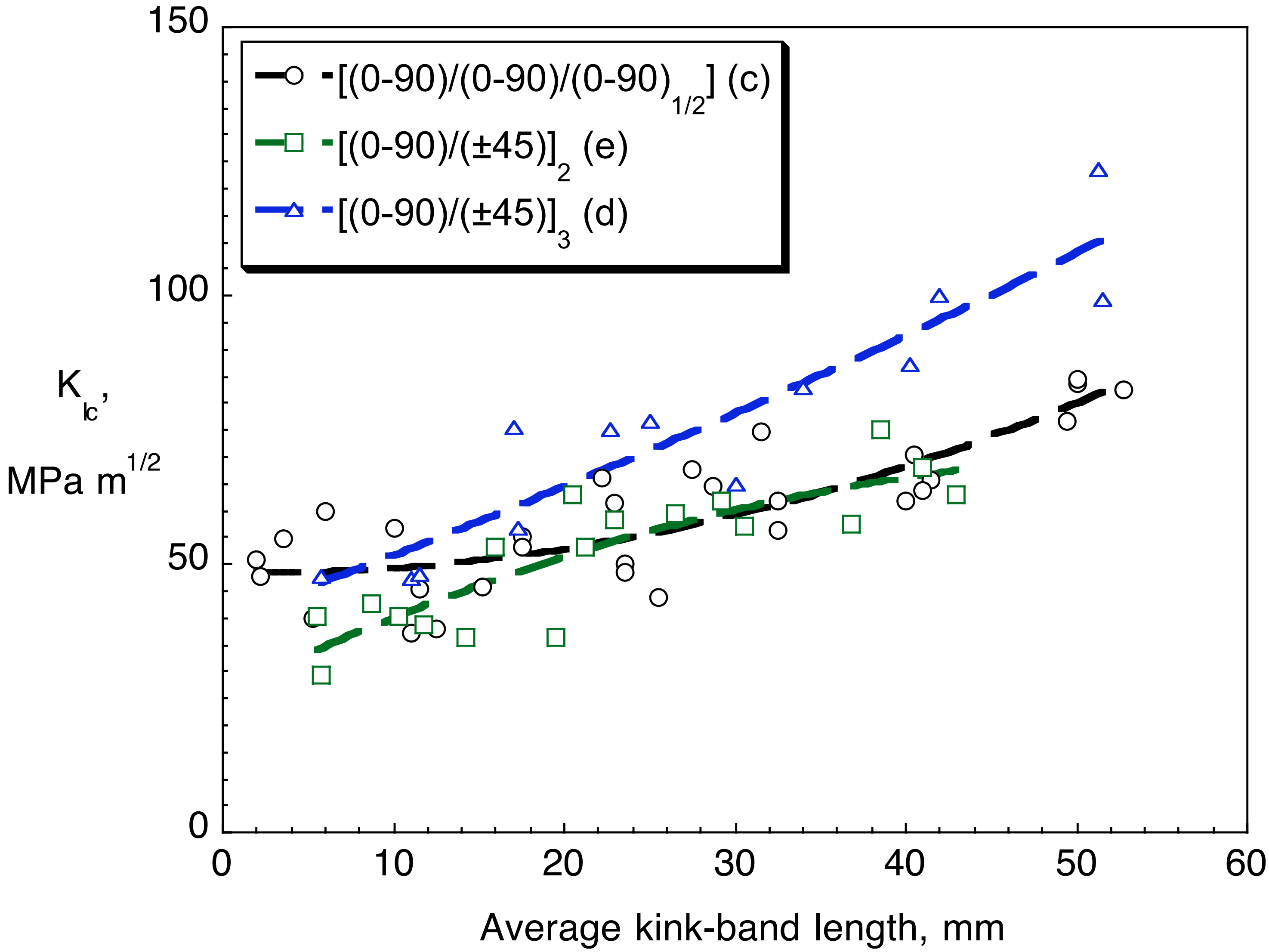

CONCLUDING REMARKS

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- Developed new test to obtain facesheet fracture toughness, K_{Ic}, needed for CAI strength predictions.
- Replicates kink-band growth observed during CAI testing.
- Captures energy dissipation associated with kink-band growth.
- Fracture energy measurements were not affected by specimen geometry.
- Fracture energy observed to increase with kink-band length.
- Lower bound values of K_{Ic} should be used to yield conservative CAI strength predictions.
- Scatter in fracture energy measurements does not significantly affect CAI strength predictions.
- Measured fracture energy was a function of facesheet thickness/layup (laminate property).

ACKNOWLEDGEMENTS

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