Compression Testing of Advanced Composites and the Pursuit of the "Best Suited" Test Method

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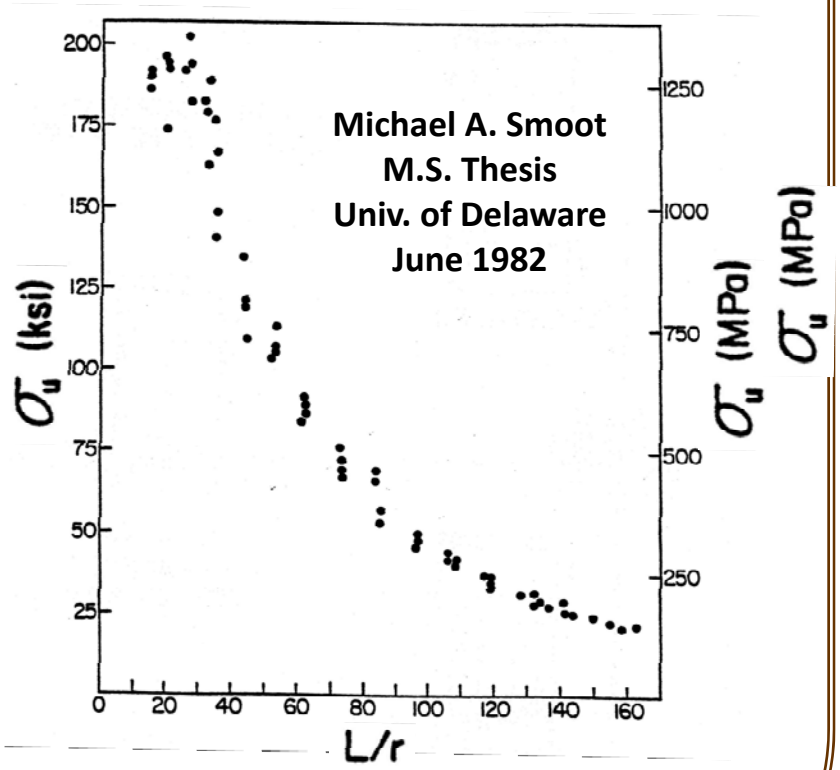
Introduction:

What is Meant By "*Best Suited*" Compression Test Method?

- **Traditionally, "*best suited*" has meant…**
  - **Highest measured 0° compression strength**
  - **Acceptable failure mode and failure location**
- **Where has this led us?**



AS1/3501-6 Carbon/Epoxy Unidirectional Composite

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Current Status:
Commonly Used Compression Test Methods

Shear loaded methods

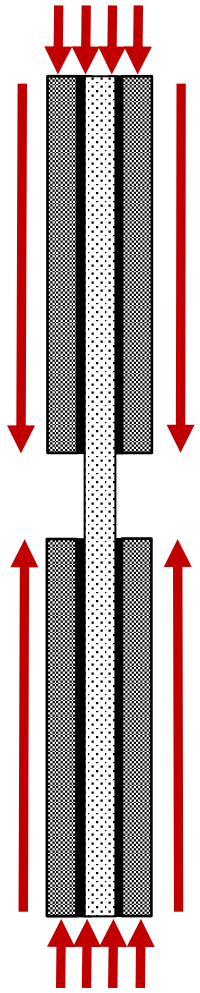
- IITRI compression test (ASTM D3410)

End loaded methods

- Boeing Modified ASTM D695

Combined loading methods

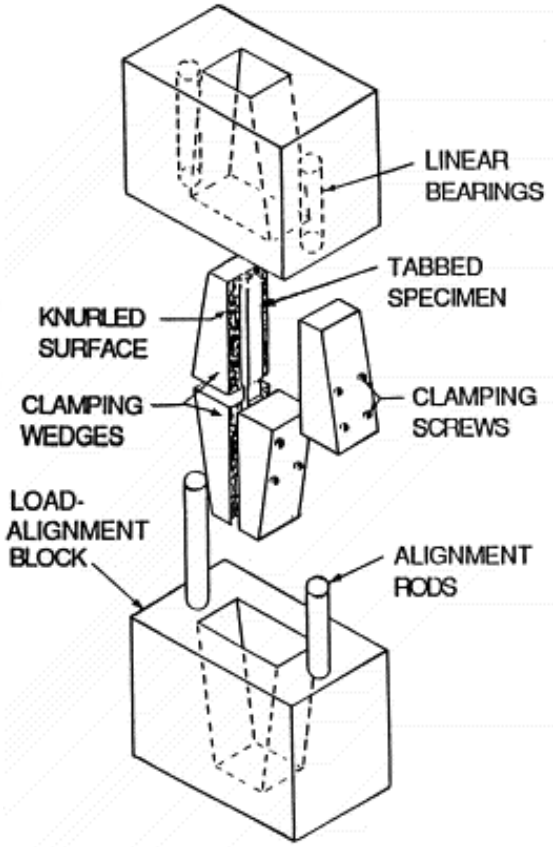
- Combined loading compression (CLC), ASTM D6641

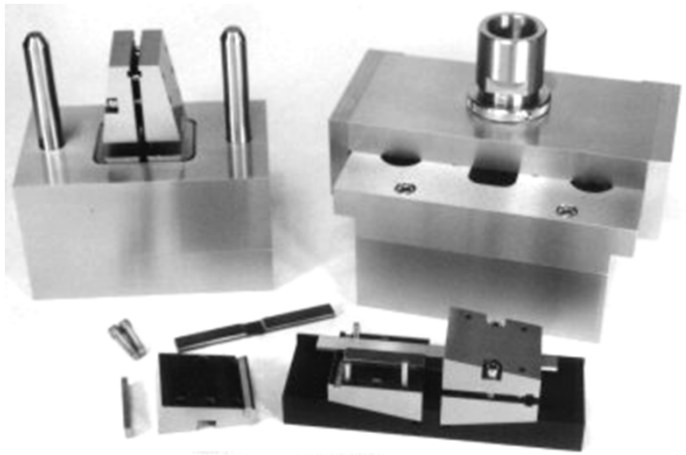


Note: ISO 14102 allows both shear loaded and end loaded methods

IITRI Compression Test: ASTM D 3410

- Side loaded tabbed specimens
- 140 mm long, 12.5 mm gage length
- 12.5 – 38 mm specimen width
- 4 – 15 mm tabbed thickness
- Heavy and expensive
- Versatile





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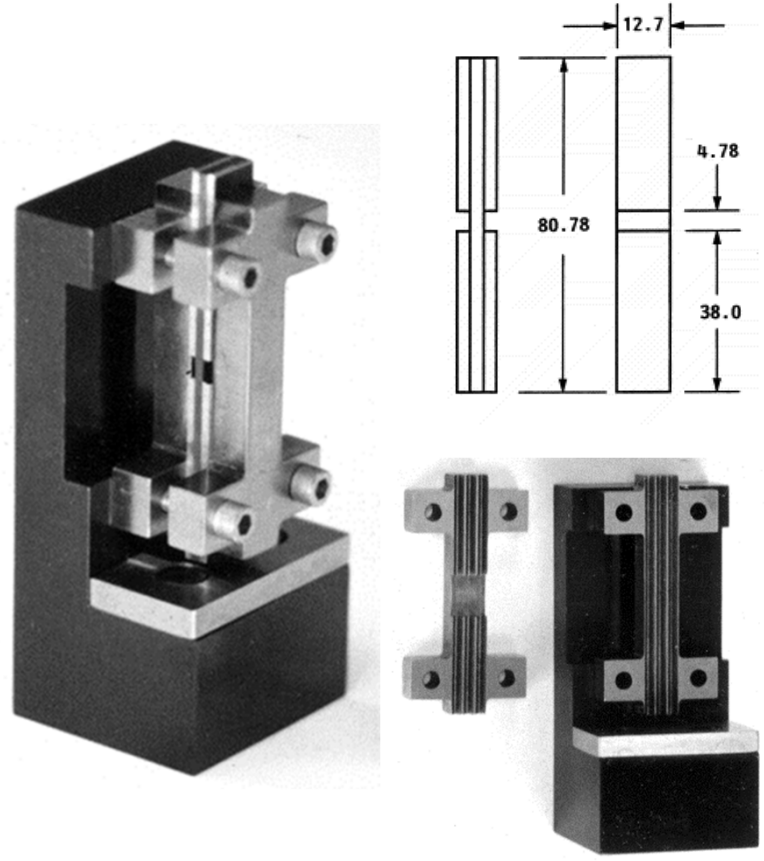
End-Loaded Compression Test Methods:
Boeing Modified ASTM D 695 (SACMA SRM 1R-94)

- Modified from ASTM D 695
  - Unreinforced plastics
  - Untabbed, dog-boned specimen
- 80.8 mm long, 12.7 mm wide specimen
- Separate specimens for modulus and strength measurement
  - Untabbed specimen for modulus
  - Tabbed specimen for strength (4.78 mm gage length)



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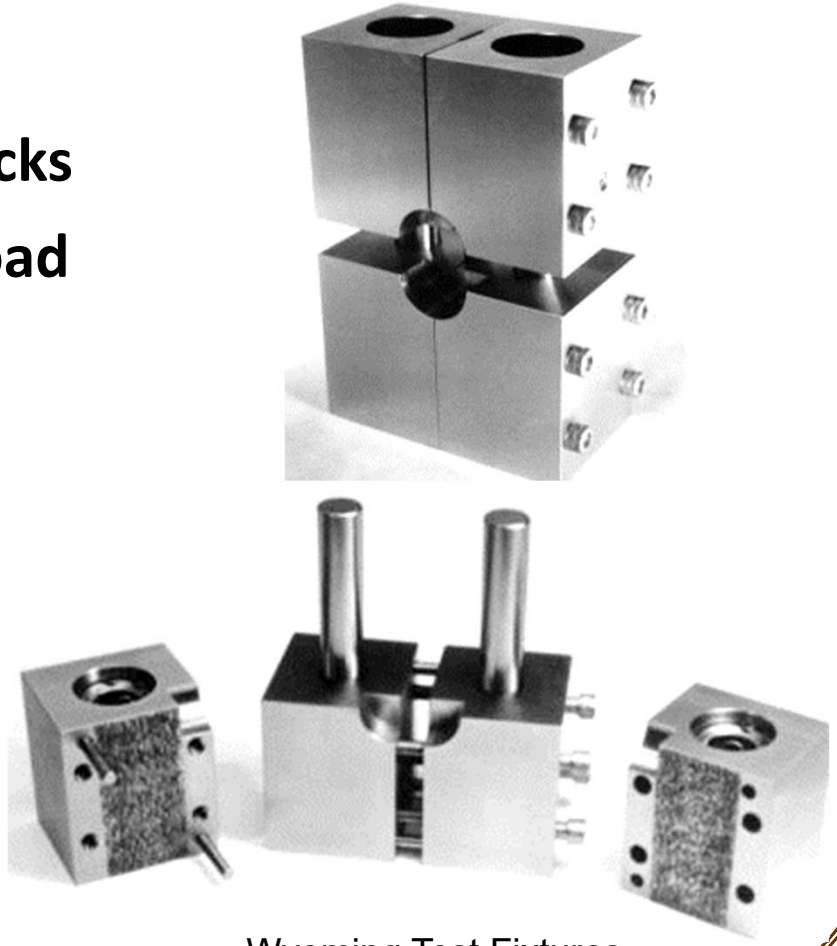
Combined Loading Compression (CLC) Test: ASTM D 6641

- Standardized by ASTM in 2001
- Two pairs of clamped steel blocks
- Combined end load and side load
- 140 mm long, 12.5 mm gage length (variable)
- Specimen widths to 30 mm
- Adjustable loading ratio via adjustable bolt torque



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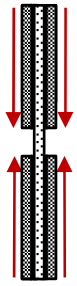
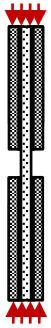
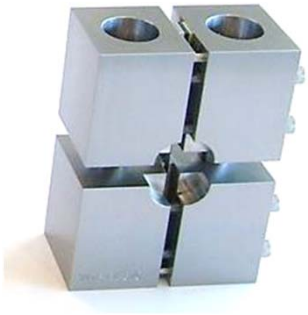
Fixture Comparison:
Common Compression Test Methods

IITRI
Shear loading

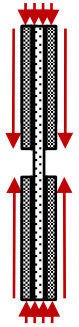


Modified D695
End loading





CLC
Combined
loading



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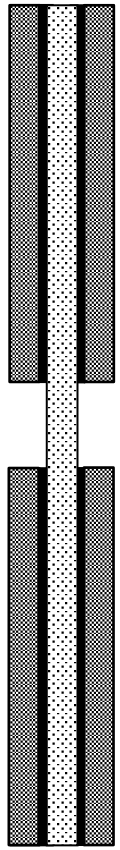
Challenges of Compression Testing

- Getting compression load into specimen
- Preventing adhesive bond failure
- Minimizing stress concentrations in tab termination region
- Eliminating buckling
- Minimizing bending
- Producing uniform, uniaxial compression stress state in gage section
- Producing gage-section failures



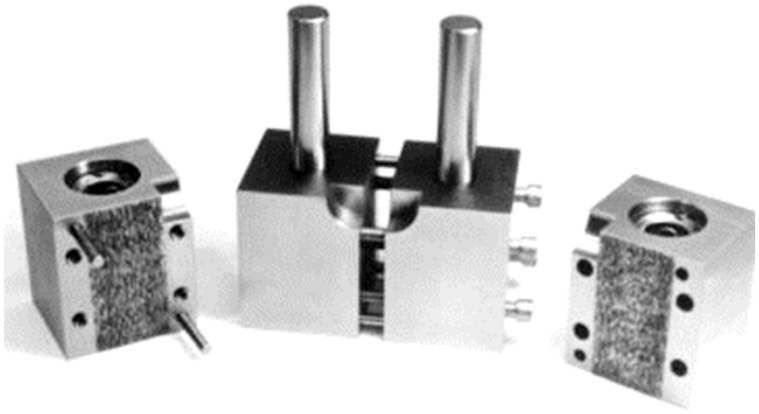
Pursuit of the "Best Suited" Test Method:

Compression Testing of Cross-Ply Laminates

Cross-ply: $[0/90]_{ns}$ & $[90/0]_{ns}$

Compression testing of cross-ply laminates…

- Reduces the applied stress (force) required to fail specimen
- Allows for the use of untabbed specimens
- Reduces stress concentrations associated with gripping
- Requires the use of a "back-out factor" to obtain the unidirectional strength



Combined loading compression test fixture
ASTM D6641
(Wyoming Test Fixtures)

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Back-Out Factors (BF):

Unidirectional Strength From Cross-Ply Laminates

- **Used for both stiffness and strength**
- **Based on Laminated Plate Theory (LPT)**
- **For symmetric, cross-ply laminates $[0/90]_{ns}$ & $[90/0]_{ns}$**

$$BF = \frac{\frac{1}{2} E_1(E_1 + E_2) - (\nu_{12} E_2)^2}{\frac{1}{4} (E_1 + E_2)^2 - (\nu_{12} E_2)^2}$$

where E_1, E_2, and ν_{12} are the axial modulus, transverse modulus, and Poisson's ratio of the unidirectional composite

- **Value of BF increases as axial modulus of laminate decreases**
  - **Unidirectional laminate, $[0]_n$** — **BF = 1.0**
  - **Cross-ply laminates, $[0/90]_{ns}$ & $[90/0]_{ns}$** — **BF ≈ 1.8**
  - **Quasi-isotropic laminates, $[0/\pm45/90]_{ns}$** — **BF ≈ 2.5**

$$BF = (Q^{\circ}_{11}A_{22} - Q^{\circ}_{12}A_{12})\, t/\, (A_{11}A_{22} - A_{12}^2)$$

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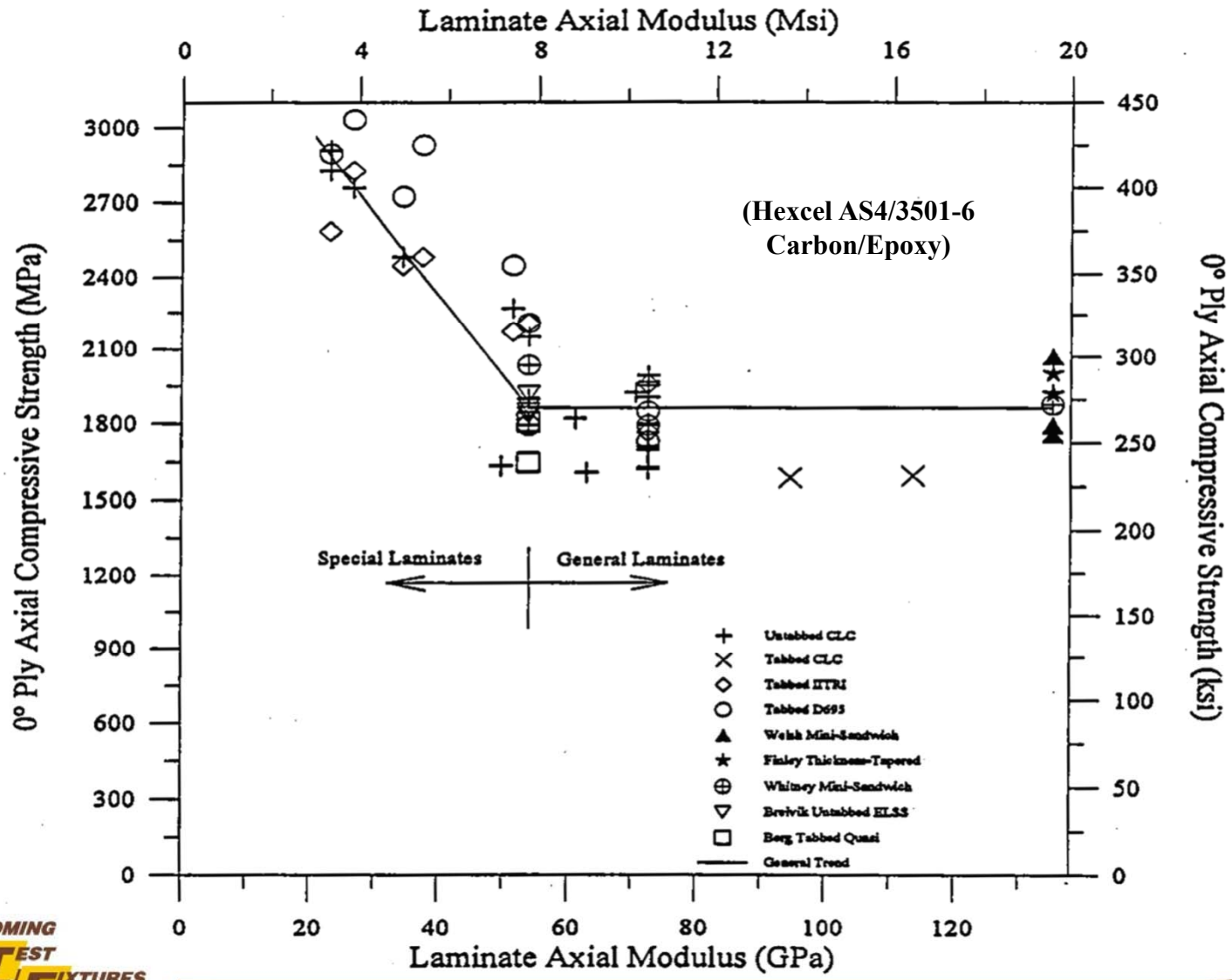
Back-Out Factors:
Effect of Tested Laminate on Unidirectional Strength



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In Summary…

Reasons for Compression Testing Using Cross-Ply Laminates

- Less data scatter using $[90/0]_{ns}$ laminates than $[0]_n$ laminates
- Bonded tabs are a major source of variation in measured strength – not needed with cross-ply laminates
- Classical lamination theory is well-accepted
- Increases in strength resulting from improved test methodology should be considered valid
- Cross-ply laminates are more representative of actual composite laminates used in structural applications