

COMPRESSION TESTING OF HIGH-STRENGTH COMPOSITE LAMINATES

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CHALLENGES

- ❑ Compression characterization of high strength composites is made difficult due to constraints related to stress decay and gage section buckling.
- ❑ Specimen geometries must have a length-to-thickness ratio (l/t) large enough to ensure uniform stress state yet have an (l/t) small enough to preclude buckling.
- ❑ High compression strengths and high material anisotropy make it difficult to select appropriate specimen geometries!

FOCUS/APPROACH

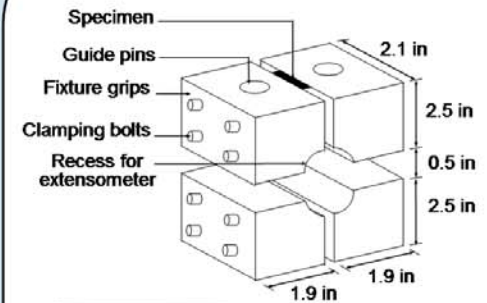
Focus of the present effort:

- ❑ Develop a methodology to design cross-ply composite laminate specimen geometries that ensure stress uniformity in the gage section and preclude buckling prior to material failure.

Approach:

- ❑ Employ finite element models to quantify stress decay in the gage section to define minimum (l/t) ratios for stress uniformity AND employ an analytical buckling equation to define maximum (l/t) ratios to preclude buckling.

CLC TEST FIXTURE (ASTM D 6641)



- ❑ Combined loading: shear loading + end loading.
- ❑ Avoids end crushing and brooming.

MATERIAL SYSTEM

HYBOR

- ❑ Boron-Graphite/Epoxy Hybrid
- ❑ Compression modulus: 41 Msi

- ❑ Nextel 610/AL-6061
- ❑ Compression strengths > 700 ksi

MMC



BIFURCATION ANALYSIS

- ❑ Buckling Strength

$$\sigma_b = \frac{E_x}{\frac{12(l)^2}{\pi^2} + 1.2 \left(\frac{E_x}{G_{xz}} \right)}$$
- ❑ Buckling Strain $\epsilon_b = \frac{\sigma_b}{E_x}$
- ❑ Geometry vs. Material

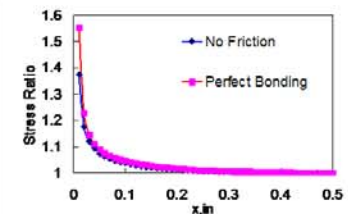
$$\frac{l}{t} = \left[\frac{\pi^2}{12} \left(\frac{1}{\epsilon_b} - 1.2 \frac{E_x}{G_{xy}} \right) \right]^{1/2}$$

FINITE ELEMENT MODEL

No Friction Perfect Bonding

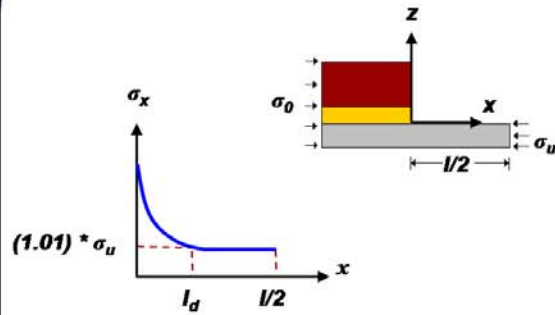
- MSC/PATRAN generate mesh
- ABAQUS performs analysis

EFFECT OF CLAMPING



- ❑ Friction effect on decay length is negligible.
- ❑ "No-friction" model is used in this study.

DECAY LENGTH

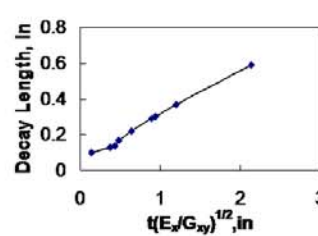


- FEA Decay length defined as distance where stress decays to within 1% of the applied uniform far field stress

DECAY LENGTH FOR HYBOR

St. Venant Stress Decay Length:

$$\lambda_{SV} \approx O \left[t \left(\frac{E_x}{G_{xz}} \right)^{1/2} \right]$$



$$(l_d)_{HYBOR} = \frac{t}{4} \left(\frac{E_x}{G_{xy}} \right)^{1/2}$$

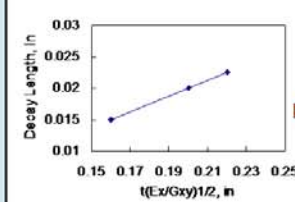
or

$$\left(\frac{l_d}{t} \right)_{HYBOR} = \frac{1}{4} \left(\frac{E_x}{G_{xy}} \right)^{1/2}$$

DECAY LENGTH FOR MMC

St. Venant Stress Decay Length:

$$\lambda_{SV} \approx O \left[t \left(\frac{E_x}{G_{xz}} \right)^{1/2} \right]$$

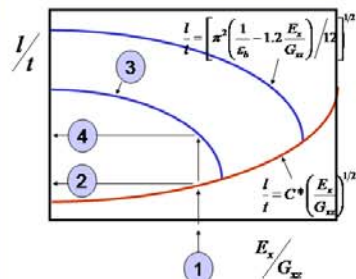


$$(l_d)_{MMC} = \frac{t}{8} \left(\frac{E_x}{G_{xy}} \right)^{1/2}$$

or

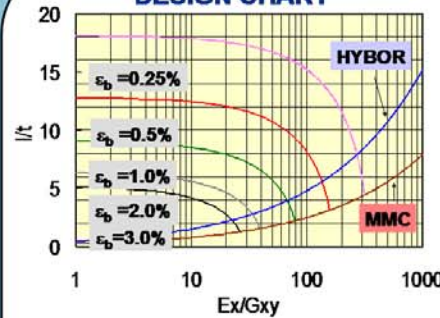
$$\left(\frac{l_d}{t} \right)_{MMC} = \frac{1}{8} \left(\frac{E_x}{G_{xy}} \right)^{1/2}$$

DESIGN PROCEDURE



- Estimate (E_x/G_{xy}) for laminate.
- Determine minimum (l/t) for stress uniformity.
- Estimate $(\epsilon_b = \sigma^u/E_x)$ for laminate.
- Determine maximum (l/t) to preclude buckling.

DESIGN CHART



For a given layup and buckling strain, an appropriate specimen geometry can be determined.

CONCLUSIONS

- A method has been developed to design cross-ply composite laminate specimen geometries that ensure stress uniformity in the gage section and preclude buckling prior to material failure.
- This method is currently being employed in a high-strength compression characterization program for cross-ply composite laminates of HYBOR and MMC materials.

PATH FORWARD

- Develop micromechanics model to account for "effects of defects."
- Validate nonlinear laminate stress and strain predictions with data.
- Design combined loading compression test fixture for MMC cylinders.
- Conduct compression testing of MMC cylinders.

ACKNOWLEDGEMENTS

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