

## ANALYSIS, DESIGN, AND TESTING OF MMC CYLINDERS IN COMPRESSION

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### OBJECTIVE

- Develop metal matrix composites (MMCs) for high compression loading applications.
- Design a combined shear/end loading compression test fixture for MMC cylinders to prevent end crushing and brooming.
- Characterize the compressive stiffness and strength of MMC cylinders to realize the full potential of MMCs in structural applications.

### APPROACH

- Apply adhesive technology to realize the shear loading potential of fixture design.
- Use a shear lag model to balance shear and end loadings of fixture.
- Employ an elastic-plastic finite element method to refine the design of fixture.
- Conduct compression tests of MMC cylinders to verify the fixture design and measure the stiffness and strength of MMC cylinders.

### MATERIAL AND SPECIMEN

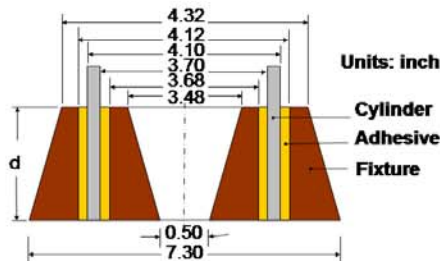


- Continuous Nextel 610 fiber
- AL 6061-T6 matrix
- 43% Fiber volume fraction

- $[0_2/90]_s$  layup
- Squeeze casting
- Length = 8 in
- Wall thickness = 0.2 in
- Outside diameter ~ 4 in

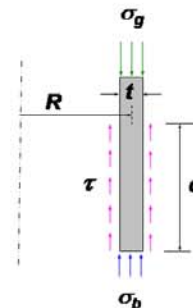


### CONCEPT DESIGN



- The fixture consists of inside and outside steel rings.
- Shear loading is introduced through adhesive bonding.
- Fixture height is selected to balance shear and bearing end loads.
- Tapered cross-sections are to reduce stress concentration.

### SHEAR LAG MODEL

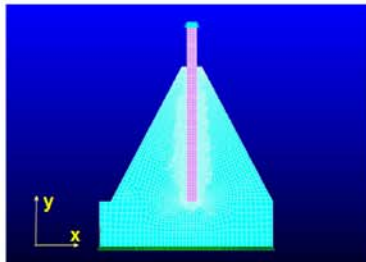


Shear lag model

$$\sigma_g A_w = \sigma_b A_w + \tau A_{sh}$$

- Failure bearing stress  $\sigma_b = 375$  ksi
- Adhesive shear strength  $\tau = 5$  ksi
- Fixture height  $d = 2.3$  in

### FINITE ELEMENT MODEL



- Elastic-plastic FEA to refine the design of fixture.
- Element type: PLANE 82 in ANSYS.
- A combined concentrated load/uniform axial displacement boundary constraint condition on the loading surface.

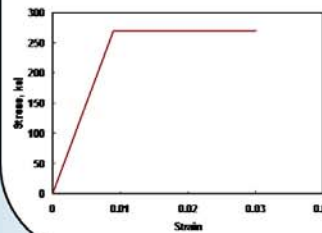
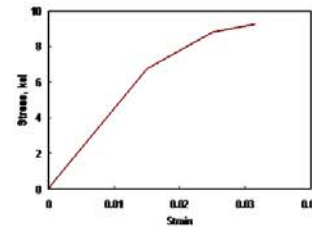
### MATERIAL NONLINEARITIES

**Hysol EA 9394**

$E_o = 0.6 \text{ Msi}$

$\nu = 0.37$

$\sigma_o = 9.25 \text{ ksi}$



**High-strength steel**

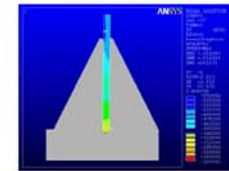
$E_o = 30 \text{ Msi}$

$\nu = 0.3$

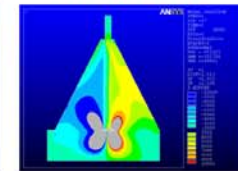
$\sigma_o = 270 \text{ ksi}$

### NUMERICAL RESULTS

**Axial stress**



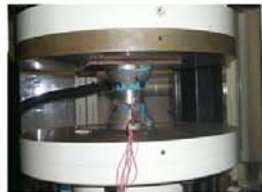
**Shear stress**



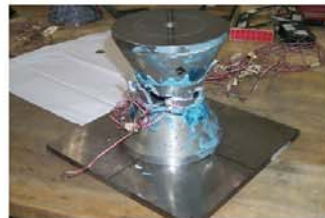
- Bearing stress was found to be nearly uniform at ~375 ksi.
- Shear stress in adhesive was found to be uniform at ~5 ksi.
- Local stress concentration mitigated to minimize potential for premature end failure.

### TEST PROCEDURE

- 1000-kip test machine
- 0.01 in/min constant crosshead displacement rate
- Ambient laboratory condition



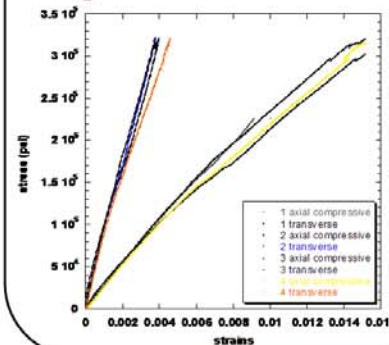
### FAILURE MODE



- Cylinders failed catastrophically in gage section.
- No evidence of premature end failure was observed.

### STRESS AND STRAIN DATA

**Strength = 356 ksi Modulus = 26.9 Msi**



### CONCLUSIONS

- A combined loading compression test fixture for MMC cylinders was developed.
- $[0_2/90]_s$  MMC cylinders were tested in compression.
- Measured failure stress and modulus were in good agreement with theoretical estimates.

### ACKNOWLEDGEMENTS

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