Effects of Geometric Scaling on the Strain Rate Sensitivity of Composite Materials

The Sixth Triennial International Fire & Cabin Safety Research Conference, Atlantic City, NJ  Oct. 2010
Motivation & Key Issues

- Crashworthiness requirements
  - maintain survivable volume
  - dissipate kinetic energy → alleviate occupant loads

- Energy absorption
  - Composite structures / energy absorption (EA) devices
    - Controlled failure modes
    - Maximize damage volume
    - Provision for sustained stability
  - Influencing factors
    - EA device geometry
    - Material
    - Rate sensitivity (?)

FAA sponsored research..

- Material property characterization at different strain rates ($10^{-4}$ s$^{-1}$ to $10^{3}$ s$^{-1}$)
  - Phase-1: Tension, Compression & Shear
  - Phase-2: Open Hole Tension, Interlaminar Shear, Pin Bearing
  - Phase-3: Fracture Toughness (mode I & II)
  - Phase-4: Characterization of EA device, Scaling effect; Dynamic characterization of CMH-17 material (in progress)

**Material Systems**

- Newport NB321/3k70 Plain Weave Carbon Fabric (PWCF)
- Newport NB321/7781 Fiberglass
- Toray T700G-12K-50C/3900-2 Plain Weave Carbon Fabric (PWCF)
Some Observations..

- In-plane properties
- Delamination toughness
- Crushing behavior
Scaling Issues..

• Specimen size
  – Reduced specimen size to maximize strain rates
  – Reduced specimens size to minimize failure loads to within testing machine capability

ASTM standards

Specimen size used for high rate tests

Will the same strengths be observed irrespective of specimen size?
Geometric Scaling..

Sub-laminate scaling

Ply level scaling

Microstructure scaling (not practical)

References:
Geometric Scaling..

**Ply Level Scaling**

- Carillo & Cantwell (2007)
- Jackson et. al. (1992)

**Sub-Laminate Scaling**

- Jackson et. al. (1992)
- Kellas et. al. (1993)

References:
- Jackson, Kellas & Morton (1992), J. Comp. Mat. Vol.26
- Kellas, Morton & Jackson (1993), ASTM STP 1156
Weibull model

\[ \frac{\sigma}{\sigma_o} = \left( \frac{V}{V_o} \right)^{-\frac{1}{m}} \]

- \( \sigma_o \) ~ characteristic (reference) strength
- \( V_o \) ~ characteristic (reference) volume
- \( m \) ~ Weibull modulus

References:
- Weibull (1951), J. App. Mech., Vol.18
- Jackson, Kellas & Morton (1992), J. Comp. Mat. Vol.26
- Wisnom (1999), Comp. Sc. Tech., Vol.59
Objectives

• Investigate the geometric scaling effects on the tensile properties of composite materials at different strain rates
  – Are the scaling effects functions of strain rates?
  – Quantify effects in terms of Weibull modulus ‘m’
Scaling Experiments

- **Material Systems**
  - Newport NB321/7781 fiberglass
  - Toray T800/3900-2B Unitape

- **Scaling type**
  - Fabrics: 2D (planar) scaling
  - Unitape: 1D (length) scaling
  - Reduced loading capability

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>STACKING SEQUENCE</th>
<th>SCALE ( \lambda )</th>
<th>( L ) (mm)</th>
<th>( W ) (mm)</th>
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</thead>
<tbody>
<tr>
<td>NB321/7781 fiberglass, T700G-12K-50C/3900-2 PWCF</td>
<td>([0]_4 ) [+45/-45]_S</td>
<td>(1/4^*)</td>
<td>50.8</td>
<td>12.7</td>
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<td></td>
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<td>(1/2)</td>
<td>101.6</td>
<td>25.4</td>
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<tr>
<td></td>
<td></td>
<td>(1)</td>
<td>203.2</td>
<td>50.8</td>
</tr>
<tr>
<td>Toray T800S/3900-2B unitape</td>
<td>([0]_4)</td>
<td>(1/4^*)</td>
<td>50.8</td>
<td>12.7</td>
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</table>

*Specimen size used in phase-I
Tension Test Apparatus...
**Tension Test...Instrumentation**

- **Load Frames**
  - MTS electromechanical (slow rate)
  - MTS high rate (~ 0.5 in/s to 500in/s)

- **Load measurement**
  - Slow speed tests ~Strain gage based load cell (5 kip capacity)
  - Dynamic Tests ~Piezoelectric load cell
    - PCB Piezotronics model 206C
    - 10kip capacity
    - ~40kHz upper frequency limit

- **Strain measurement**
  - Strain gage CEA-06-250UW-120
  - Vishay 2210 signal conditioner
    - Excitation voltage : 1V
    - DC to 50kHz (-0.5dB max)
Test Results

- Sensitivity to strain rate observed at all volumes
- Scaling effects consistent with literature
  - Reduction in strength with increase in volume
  - No significant change in modulus
- Range of volumes investigated to date is limited. Larger volumes being investigated at present
## Failure modes..

<table>
<thead>
<tr>
<th>Strain Rate (1/s)</th>
<th>[0]₄ specimens</th>
<th>[+45/-45]ₚ Specimens</th>
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<tbody>
<tr>
<td>0.0002</td>
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Test Results.. Weibull Modulus

- Based on Weibull modulus, the scaling effects tend to diminish with increasing strain rates
  - Increase in ‘m’ dependent on material system and stacking sequence

Graph showing the relationship between average strain rate (1/s) and Weibull modulus (m) for different materials:

- [0]₄ [±45/-45]s Toray T800/3900-2B Unitape
- [0]₄ [45]₄ Newport NB321/7781
Strain Rate & Scaling effects..

Matrix (resin) behavior

Summary

- Rate sensitivity & geometric scaling (2D) effects on tensile properties of two material systems has been investigated experimentally
  - Rate sensitivity observed at all specimen volumes
    - Behavior attributed to rate sensitivity of matrix
  - Scaling effects tend to diminish with increasing strain rate
    - Limited volumes studied to date
    - Source of rate sensitivity on scaling should be investigated further

- Use of small coupons for dynamic testing may be acceptable (provided scaling is verified)
- Other loading modes (compression, shear) should be studied.