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

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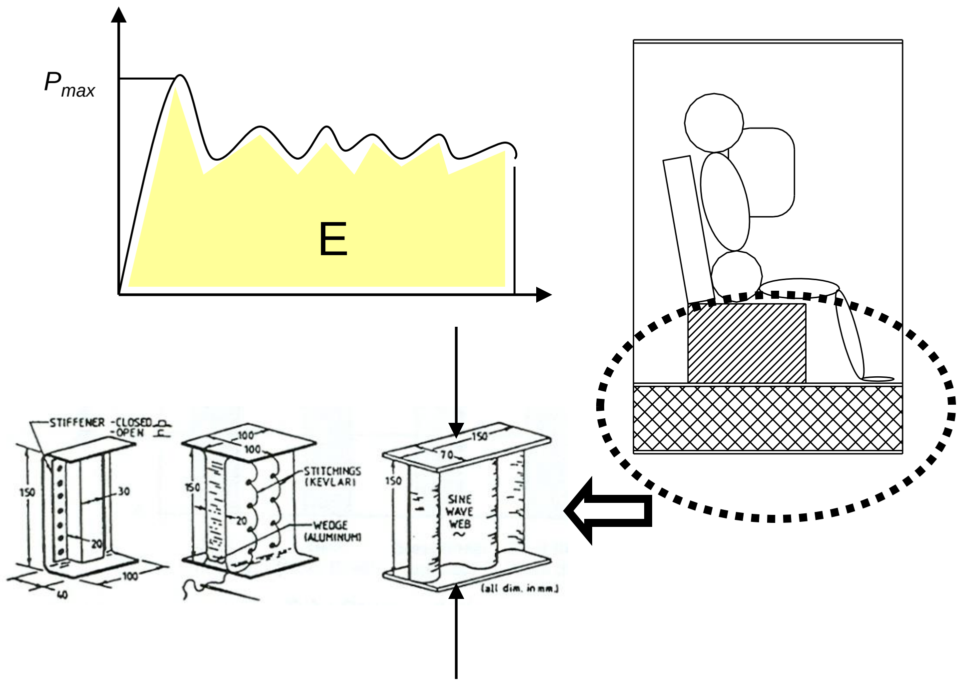
# Motivation & Key Issues

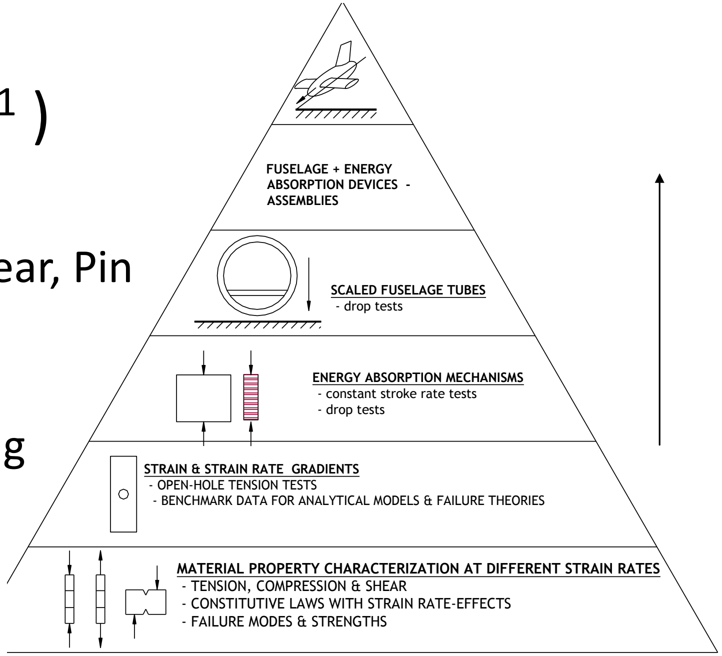



- Crashworthiness requirements
  - maintain survivable volume
  - dissipate kinetic energy → alleviate occupant loads
- Energy absorption
  - Composite structures /energy absorption (EA) devices
    - Controlled failure modes
    - Maximize damage volume
    - Provision for sustained stability
  - Influencing factors
    - EA device geometry
    - Material
    - Rate sensitivity (?)


Hull D (1991) Comp. Sci Tech, 40.
Bannerman & Kindervater (1984) in Structural Impact and Crashworthiness
Bolukbasi & Laananen (1995) Composites, 26.
Carruthers, Kettle & Robinson (1998) Appl Mech Rev, 51.

# FAA sponsored research..

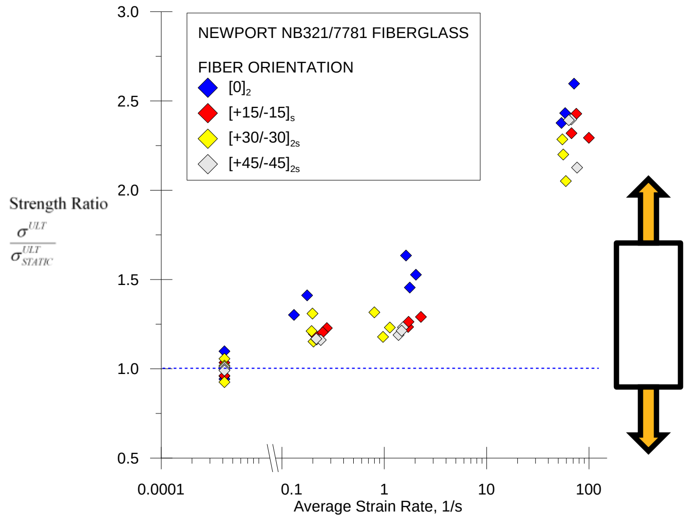
- Material property characterization at different strain rates ($10^{-4}\ s^{-1}$ to $10^{3}\ s^{-1}$ )
  - Phase-1 : Tension, Compression & Shear
  - Phase-2 : Open Hole Tension, Interlaminar Shear, Pin Bearing
  - Phase-3 : Fracture Toughness (mode I & II)
  - Phase-4 : Characterization of EA device,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

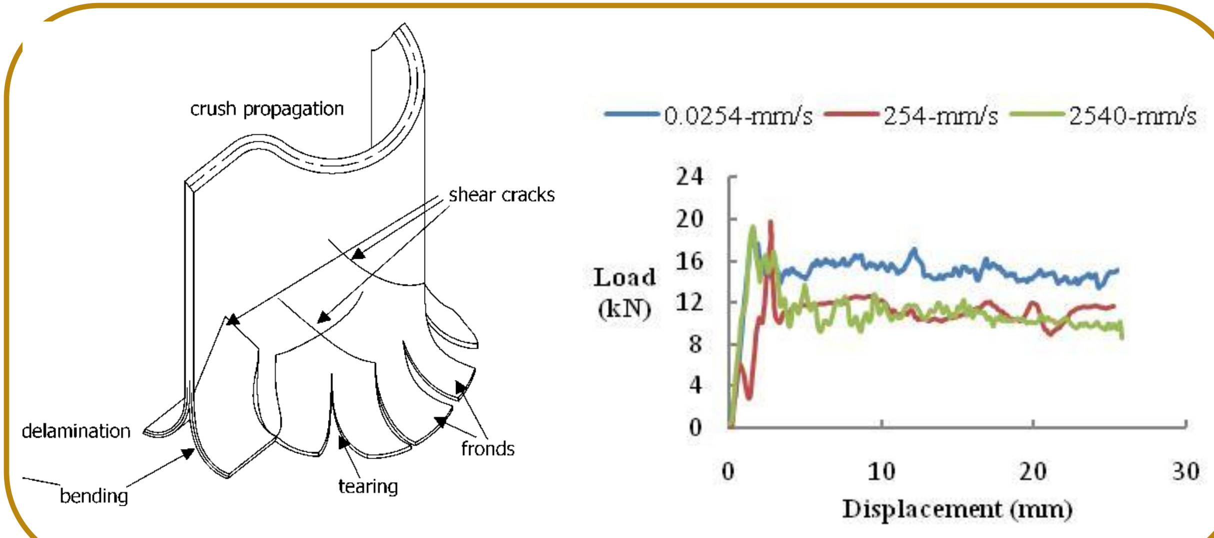


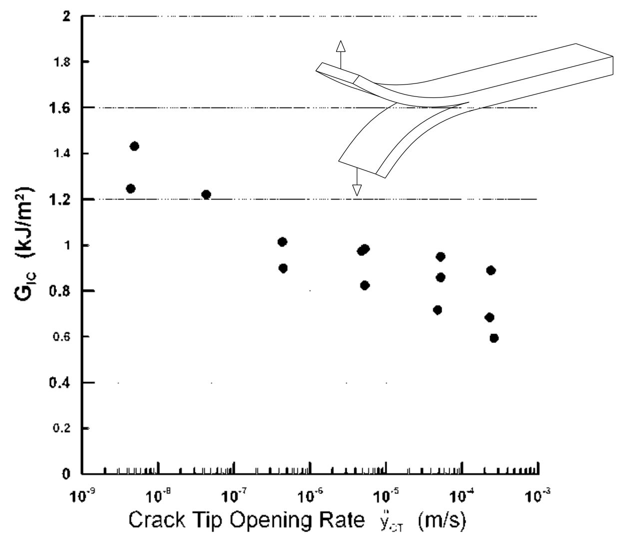

- Material Systems
  - Newport NB321/3k70 Plain Weave Carbon Fabric (PWCF)
  - Newport NB321/7781 Fiberglass
  - Toray T800S/3900-2B[P2352W-19] BMS8-276 Rev-H-Unitape
  - Toray T700G-12K-50C/3900-2 Plain Weave Carbon Fabric (PWCF)

# Some Observations..

- In-plane properties
- Delamination toughness
- Crushing behavior

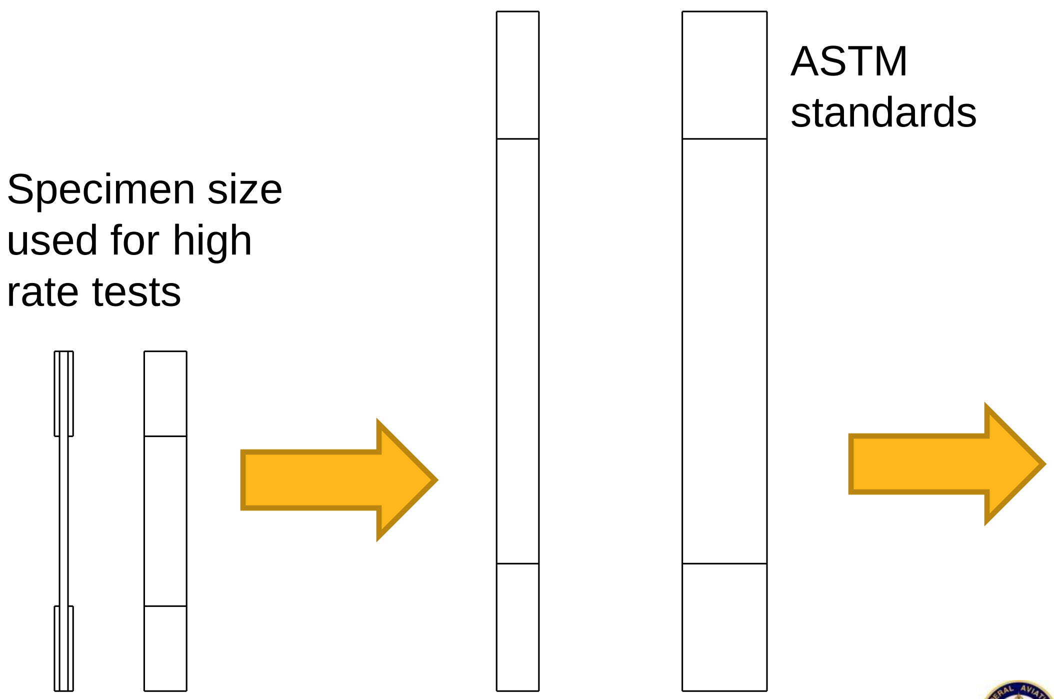


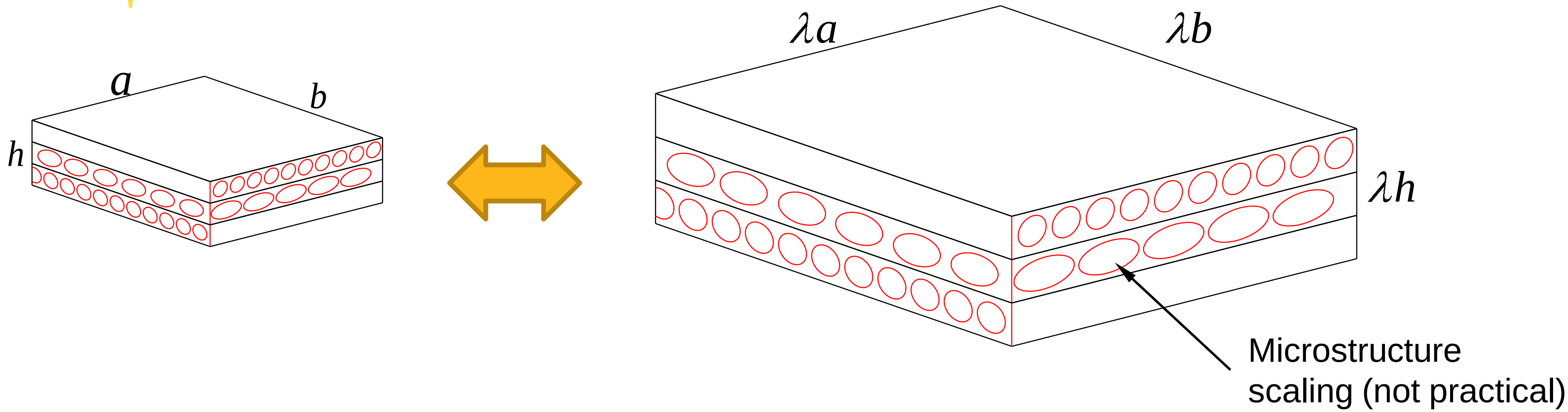
# Scaling Issues..

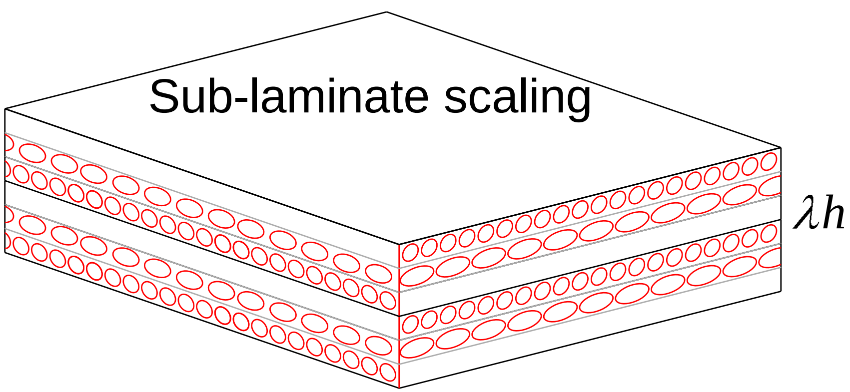
- Specimen size
  - Reduced specimen size to maximize strain rates
  - Reduced specimens size to minimize failure loads to within testing machine capability

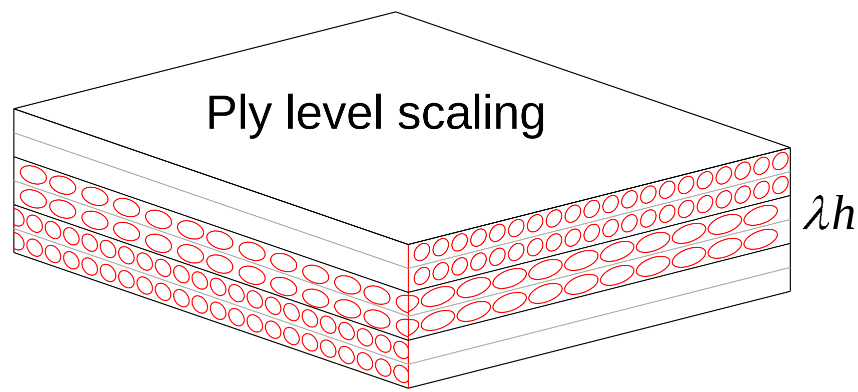



Will the same strengths be observed irrespective of specimen size ?

# Geometric Scaling..





References:
Morton, (1988) AIAA J. Vol. 26, No.8
Wisnom (1999), Comp. Sc. Tech. Vol.59

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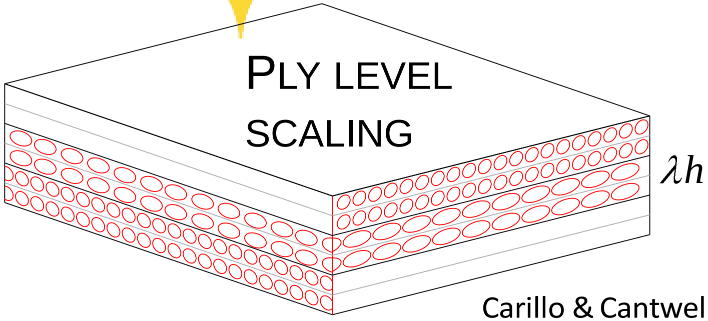
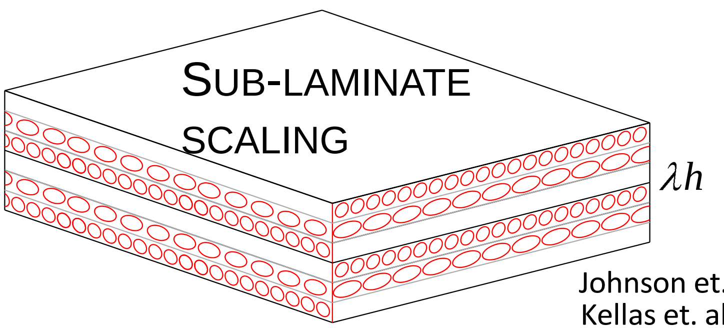
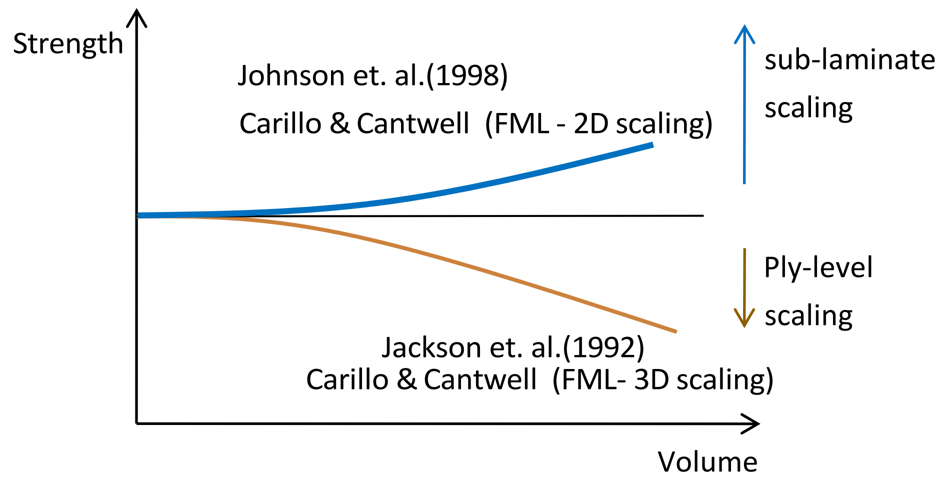
# Geometric Scaling..

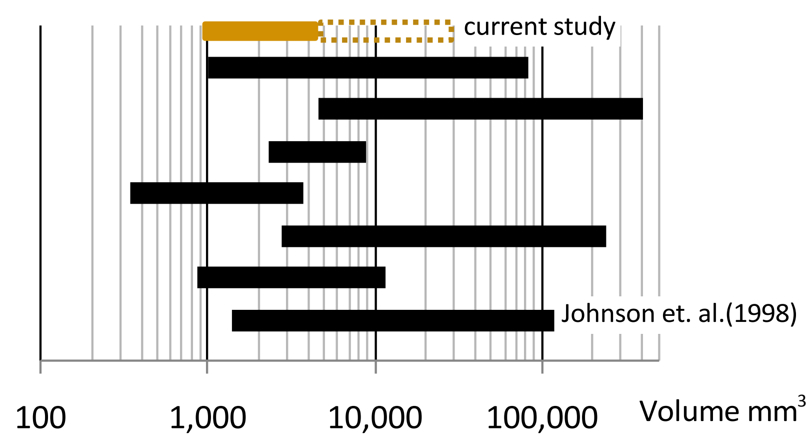



Carillo & Cantwell (2007)
Jackson et. al.(1992)
Kellas et. al.(1993)




Johnson et. al.(1998)
Kellas et. al.(1993)




References:
Wisnom (1999), Comp. Sc. Tech. Vol.59
Jackson,Kellas & Morton (1992), J. Comp. Mat. Vol.26
Kellas, Morton &Jackson (1993), ASTM STP 1156
Johnson, Morton , Kellas & Jackson (1998) AIAA J. Vol.36
Carillo & Cantwell (2007), Comp. Sc.Tech. Vol.67

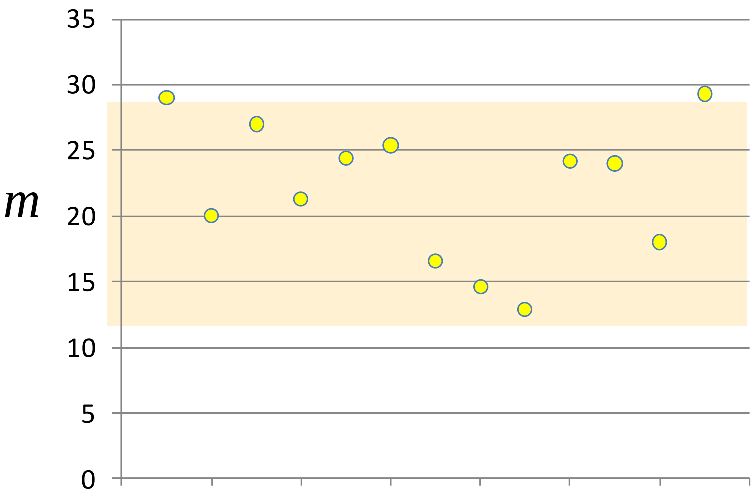
# Weibull model

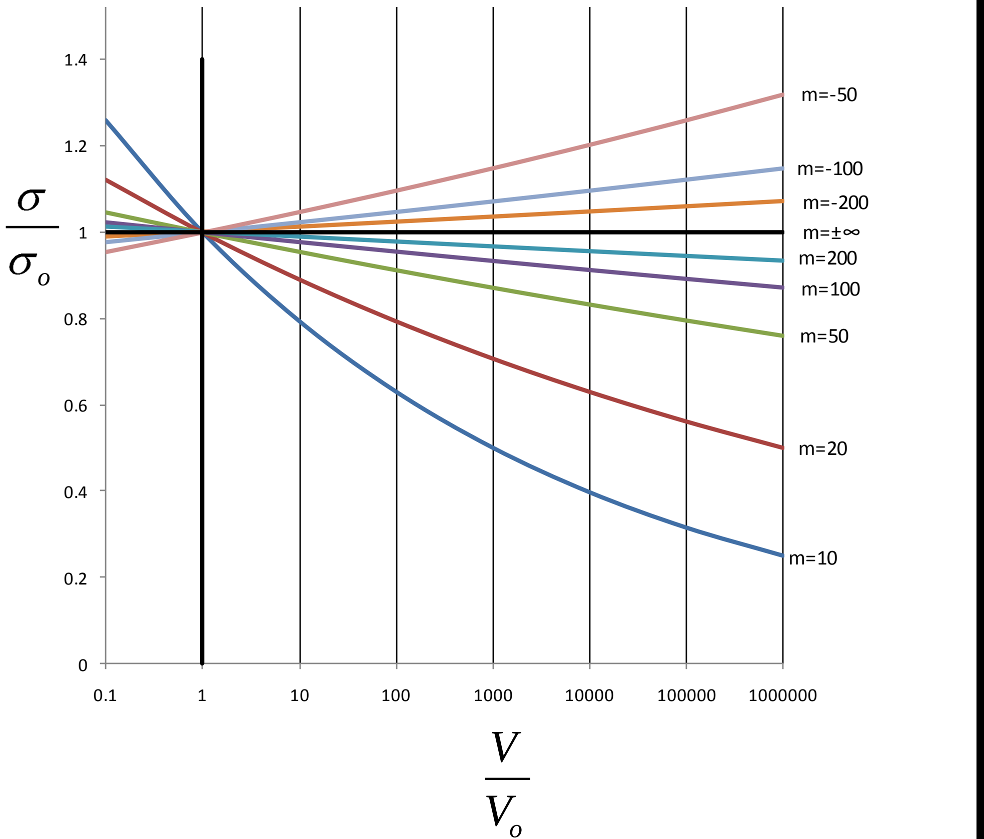
$$\frac{\sigma}{\sigma_o} = \left(\frac{V}{V_o}\right)^{-\frac{1}{m}}$$

$\sigma_o$ ~ characteristic(reference) strength

$V_o$ ~ characteristic(reference) Volume

$m$ ~ Weibull modulus





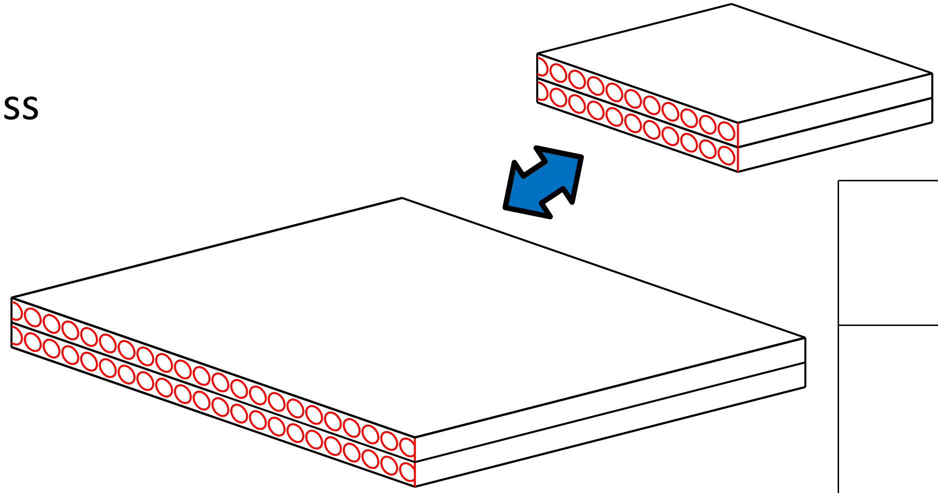
References:
Weibull (1951), J. App. Mech., Vol.18
Jackson,Kellas & Morton (1992), J. Comp. Mat. Vol.26
Wisnom (1999), Comp. Sc. Tech., Vol.59

# Objectives

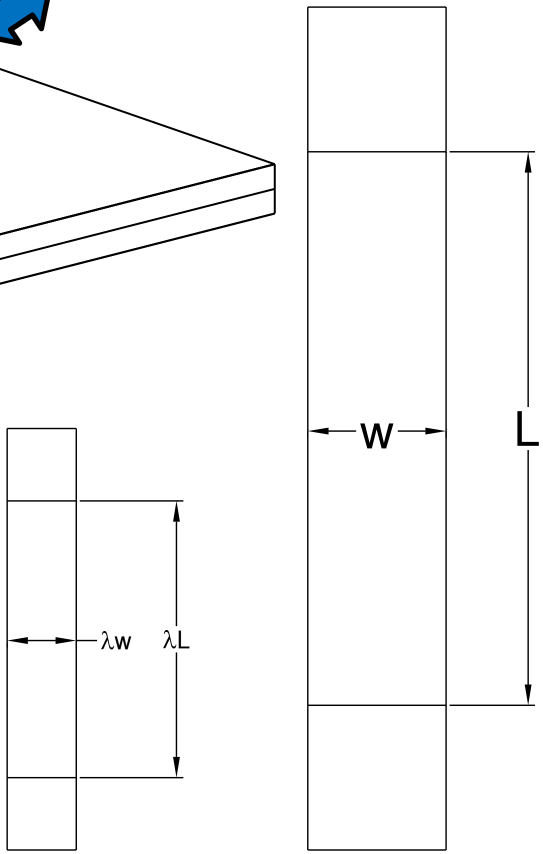
- **Investigate the geometric scaling effects on the tensile properties of composite materials at different strain rates**
  - **Are the scaling effects functions of strain rates?**
  - **Quantify effects in terms of Weibull modulus ‘m’**

# 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



| MATERIAL | STACKING SEQUENCE | SCALE λ | L (mm) | W (mm) |
|---|---|---|---|---|
| NB321/7781 fiberglass, T700G-12K-50C/3900-2 PWCF | $[0]_4$ $[+45/-45]_S$ | 1/4* | 50.8 | 12.7 |
| | | 1/2 | 101.6 | 25.4 |
| | | 1 | 203.2 | 50.8 |
| Toray T800S/3900-2B unitape | $[0]_4$ | 1/4* | 50.8 | 12.7 |
| | | 1/2 | 101.6 | 12.7 |
| | | 1 | 203.2 | 12.7 |
| | $[+45/-45]_S$ | 1/4* | 50.8 | 12.7 |
| | | 1/2 | 101.6 | 25.4 |
| | | 1 | 203.2 | 50.8 |






*Specimen size used in phase-I

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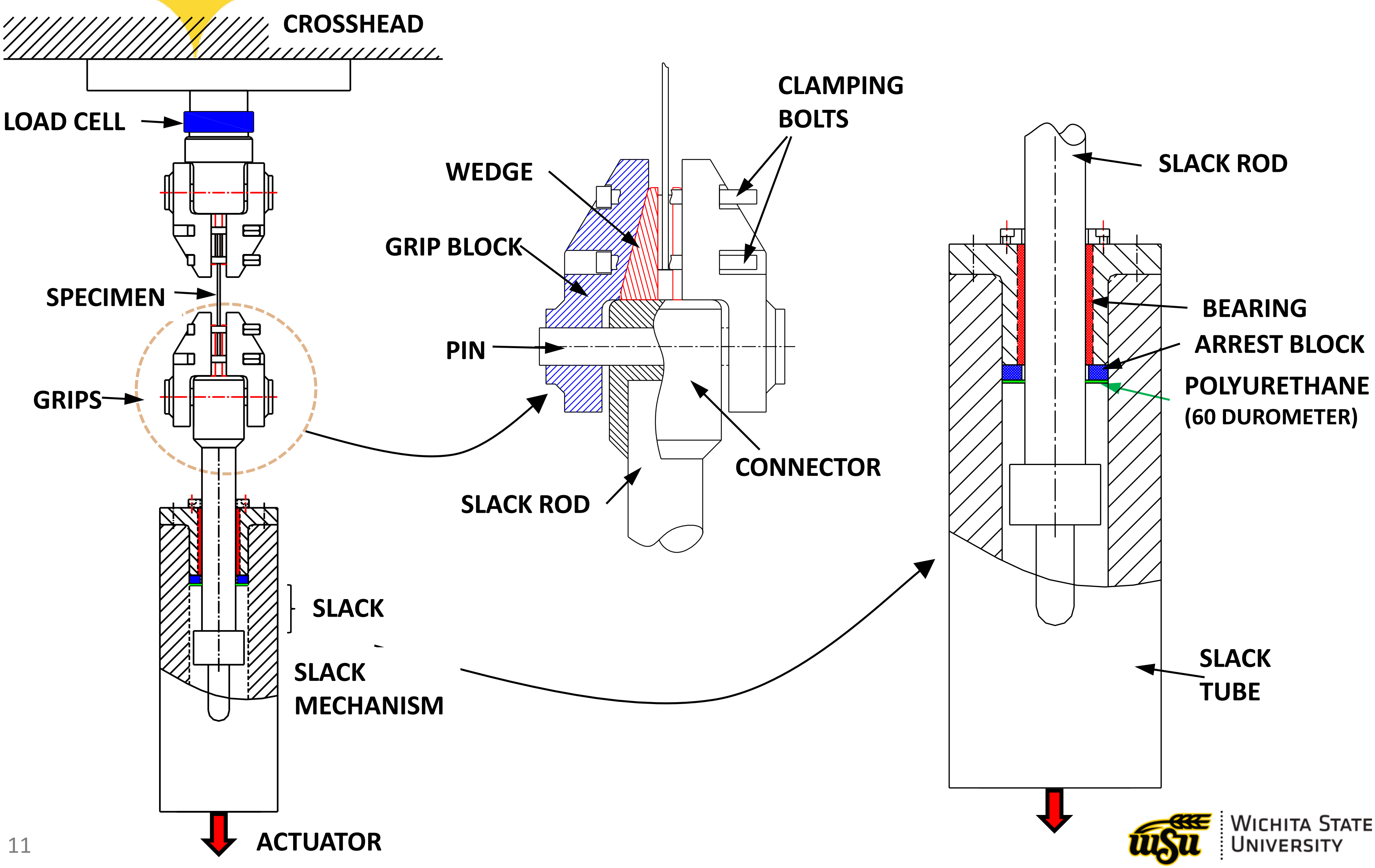
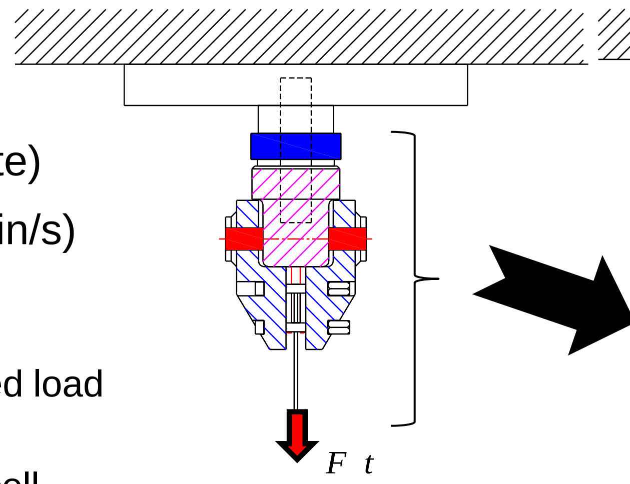
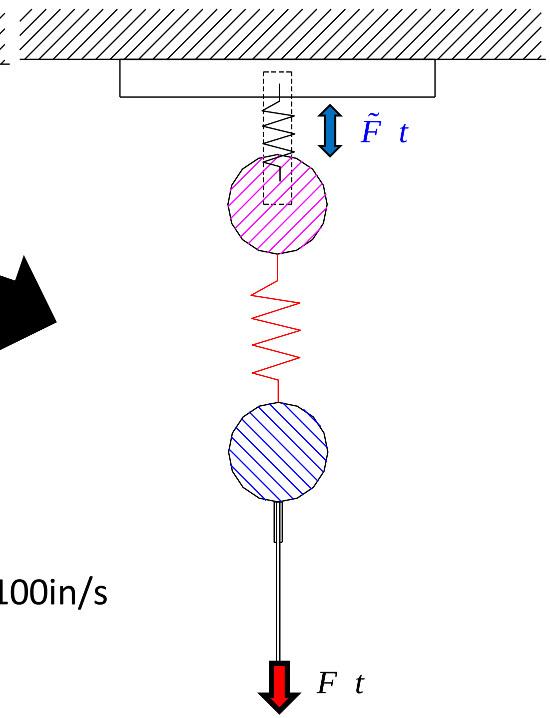
# Tension Test Apparatus…



# 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)



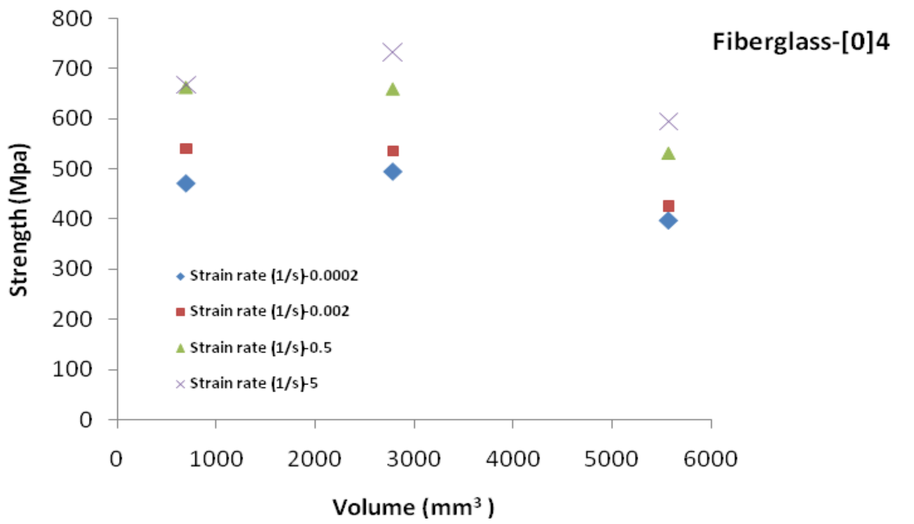



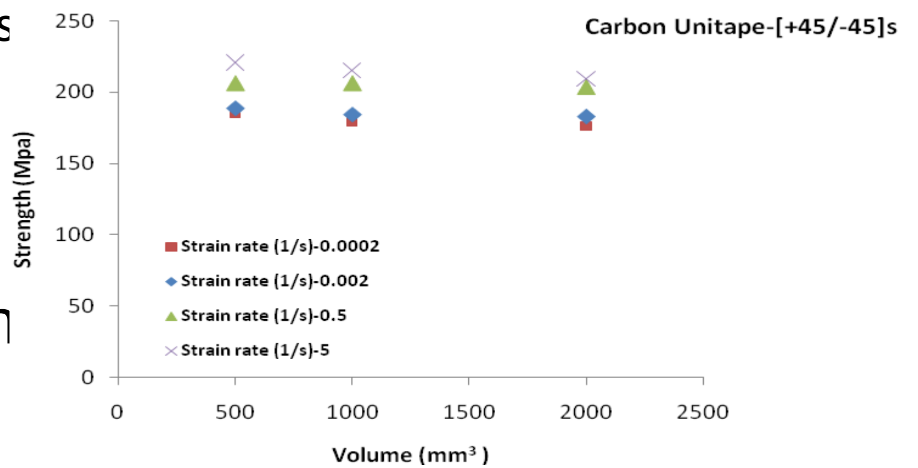

for stroke rates $\leq$100in/s

$\tilde{F}\ t \approx F\ t$

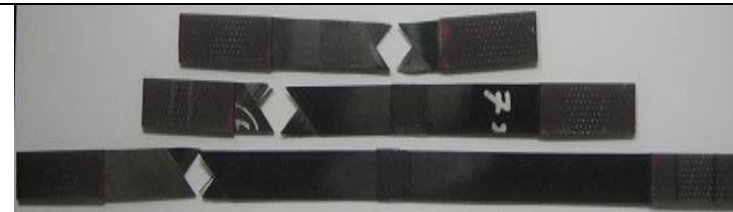
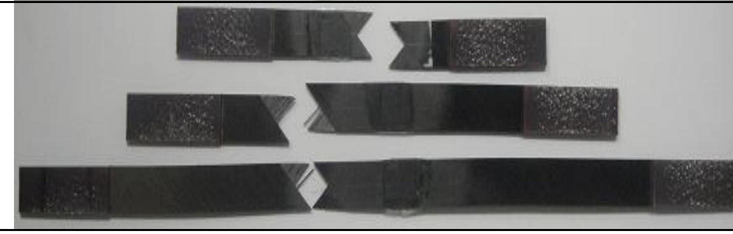
# Test Results

- 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 presen



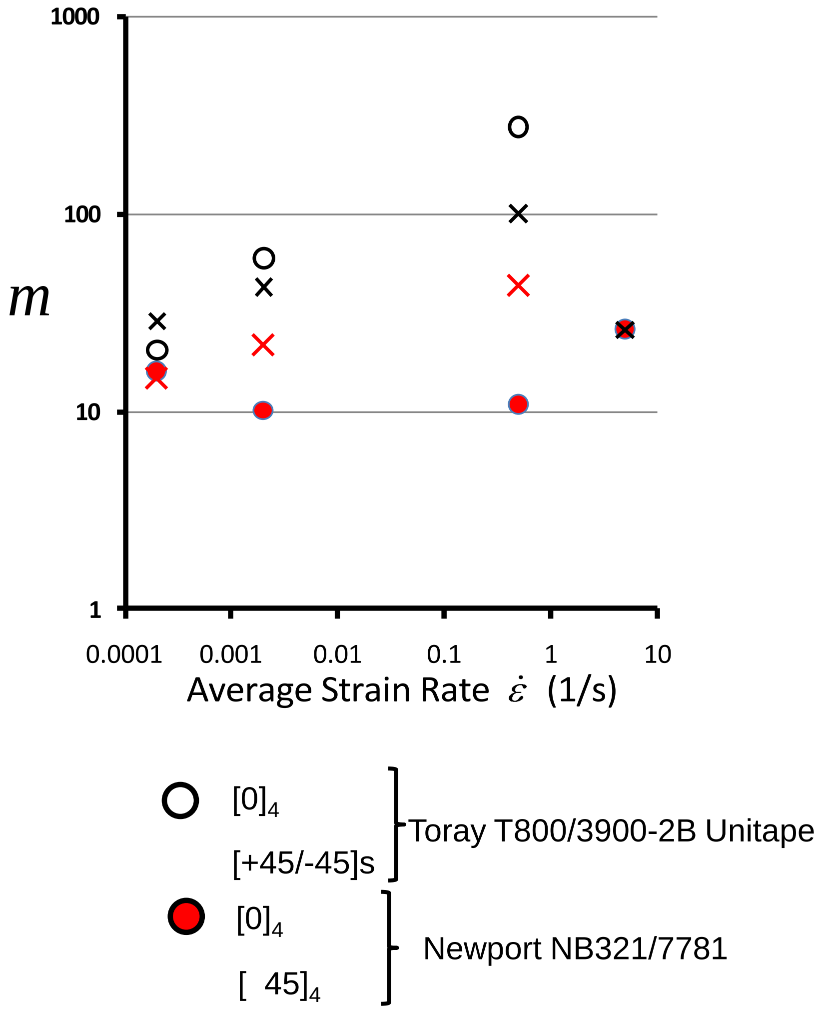



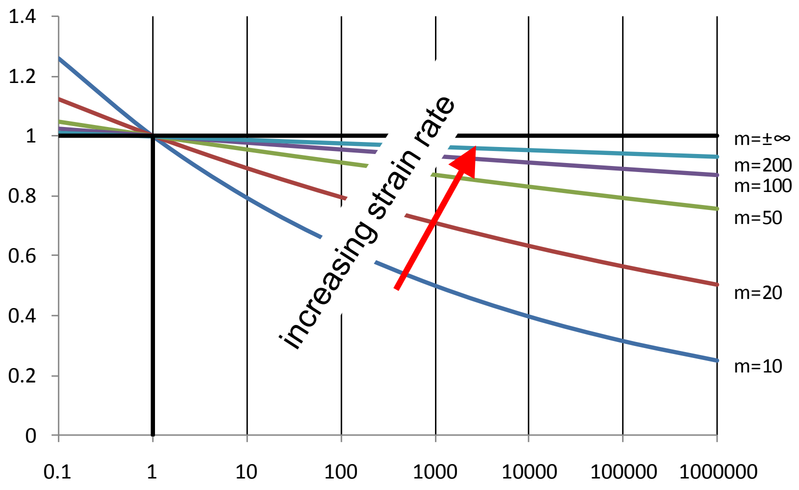
# Failure modes..

| Strain Rate (1/s) | $[0]_4$ specimens | $[+45/-45]_s$ Specimens |
|---|---|---|
| 0.0002 |  |  |
| 0.002 |  |  |
| 0.5 |  |  |

# Test Results..Weibull Modulus

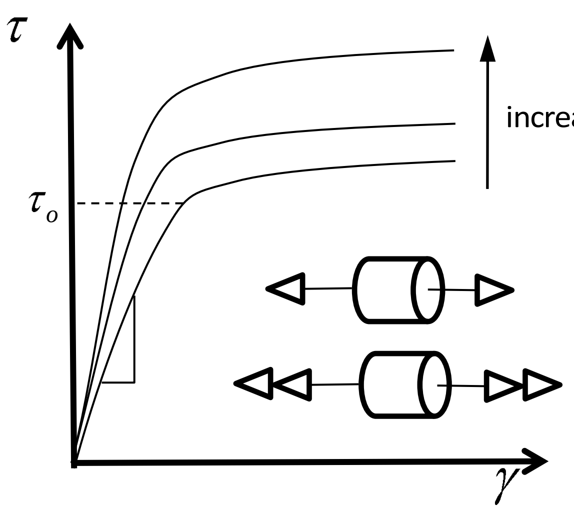
- Based on Weibull modulus, the scaling effects tend to diminish with increasing strain rates
  - Increase in 'm' dependent on material system and stacking sequence

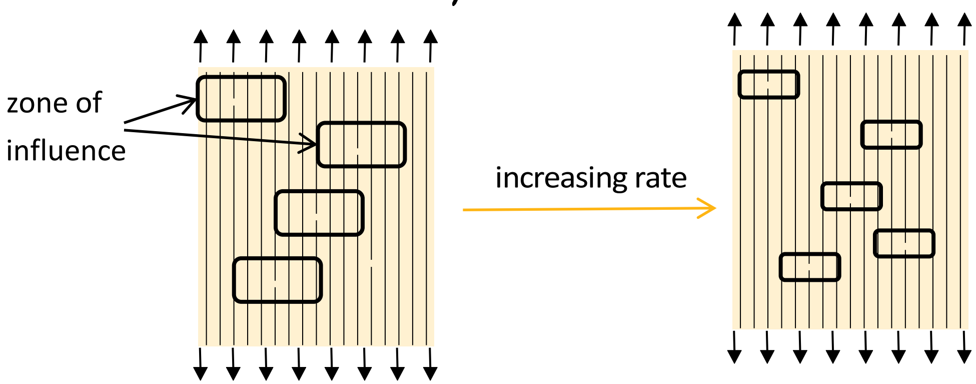


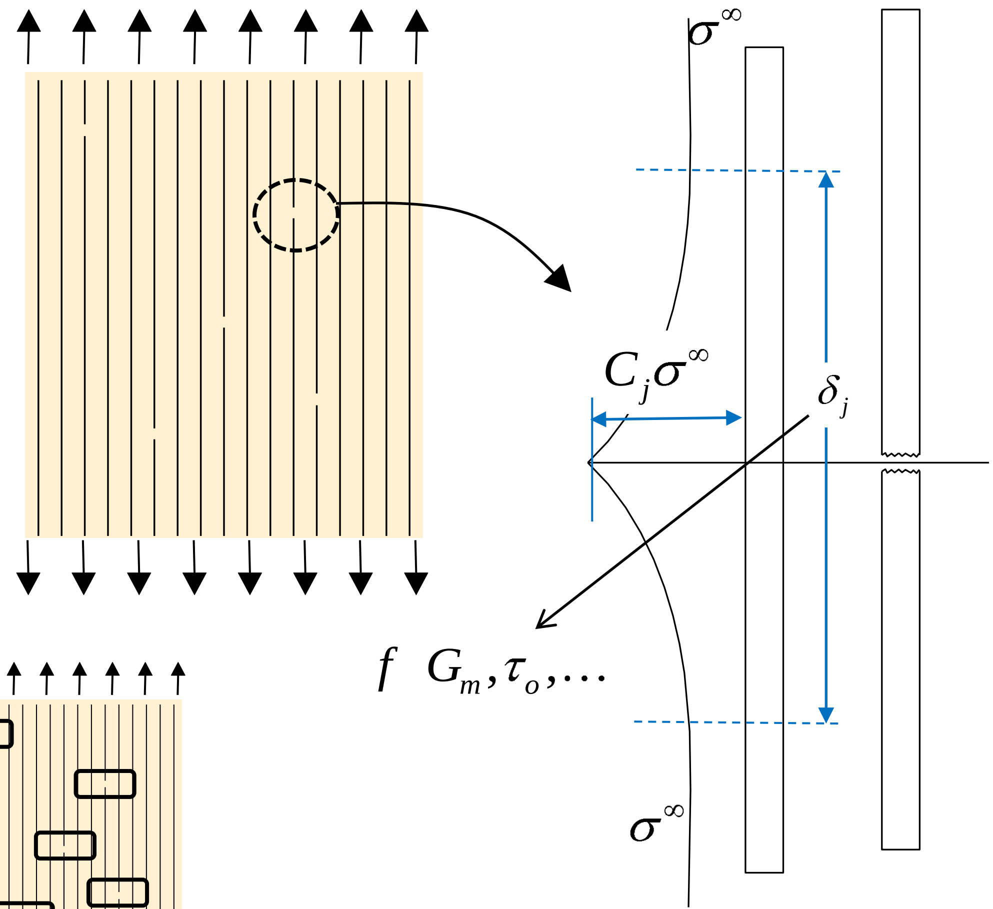



# Strain Rate & Scaling effects..

Matrix (resin) behavior




Batdorf, S.B., J. Reinf. Plastics & Composites, Vol.1, pp.153-164
Batdorf, S.B., J. Reinf. Plastics & Composites, Vol.1, pp.165-176

# 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.