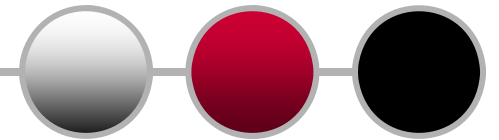


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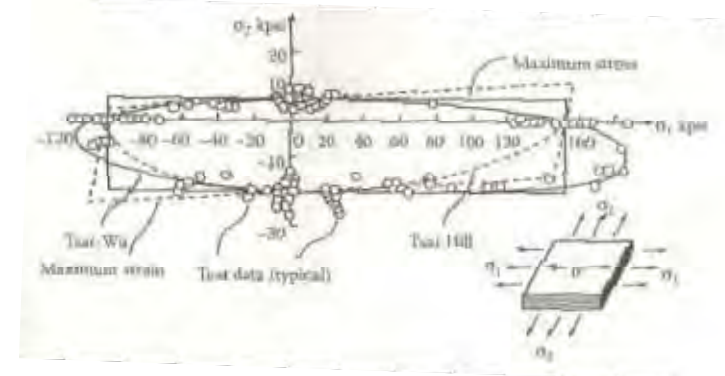


## **Maximum Strain as a General First Ply Failure Criterion in Laminated Composites**

**Lloyd Smith**  
**AMTAS 4-23-09**

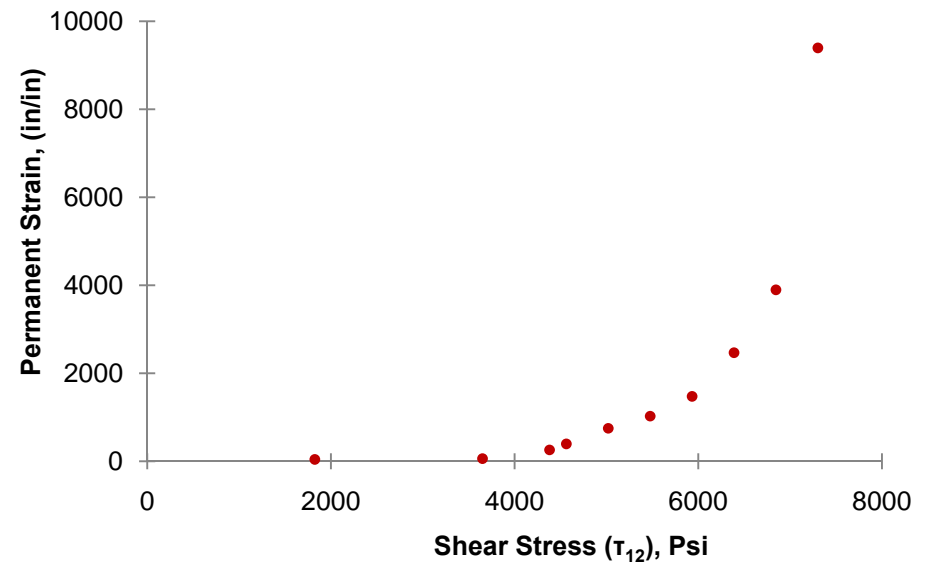
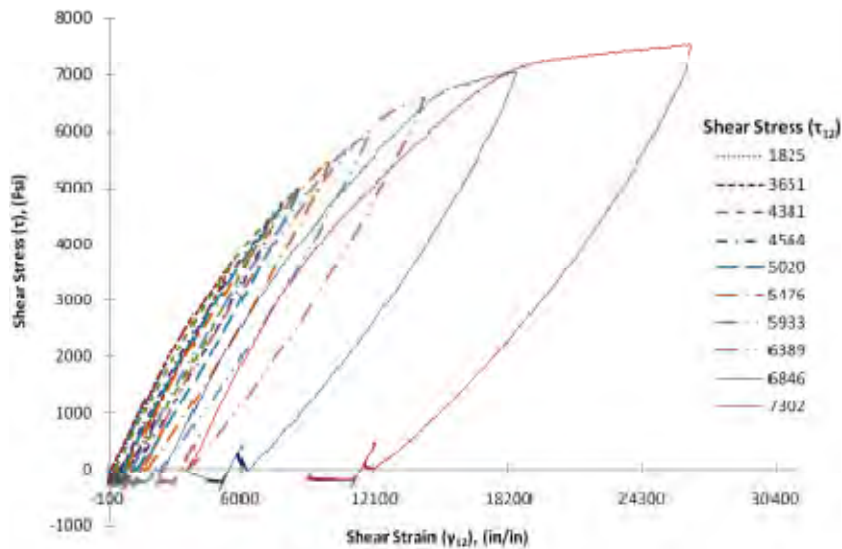
## Background

- **Composite failure criteria tend to be:**
  - too simple (often do not agree with experiment)
  - too complex (can be easier to build and test)
  - More multi-axial data is needed
- **Maximum Strain (stress) Failure Criterion**
  - Often used for fiber failure
  - Not applied to matrix failure
  - Sighted data is from lamina



# Strength Properties

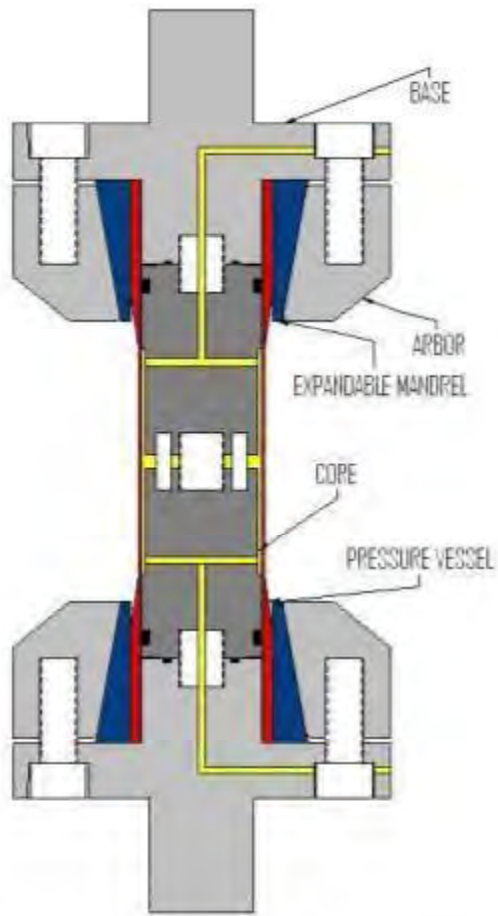
- Non-linear shear response decoupled from damage by loading-unloading of  $[(\pm 45)_3]_s$



## Two Examples

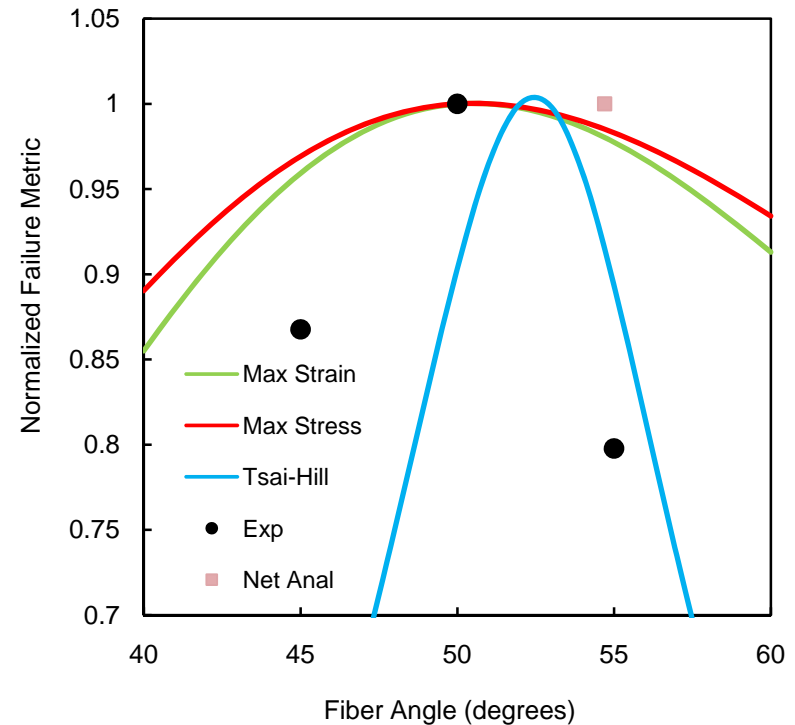
- **Some data suggest Maximum Strain may apply to matrix failure**
- **Examples**
  - **Pressure vessel with bias fiber orientation**
  - **Open hole tension test coupon**

# Pressure Vessel

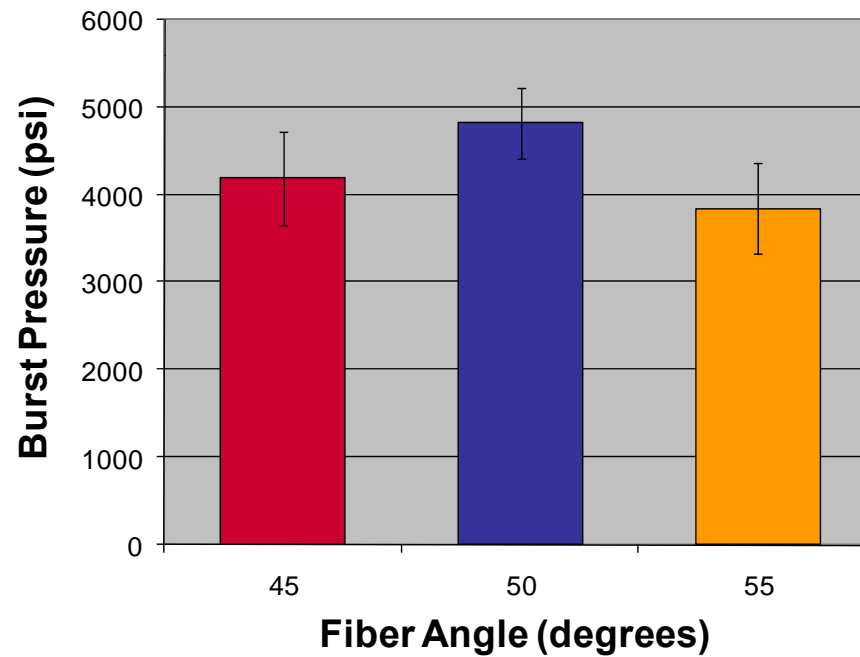


# Failure Criteria Results

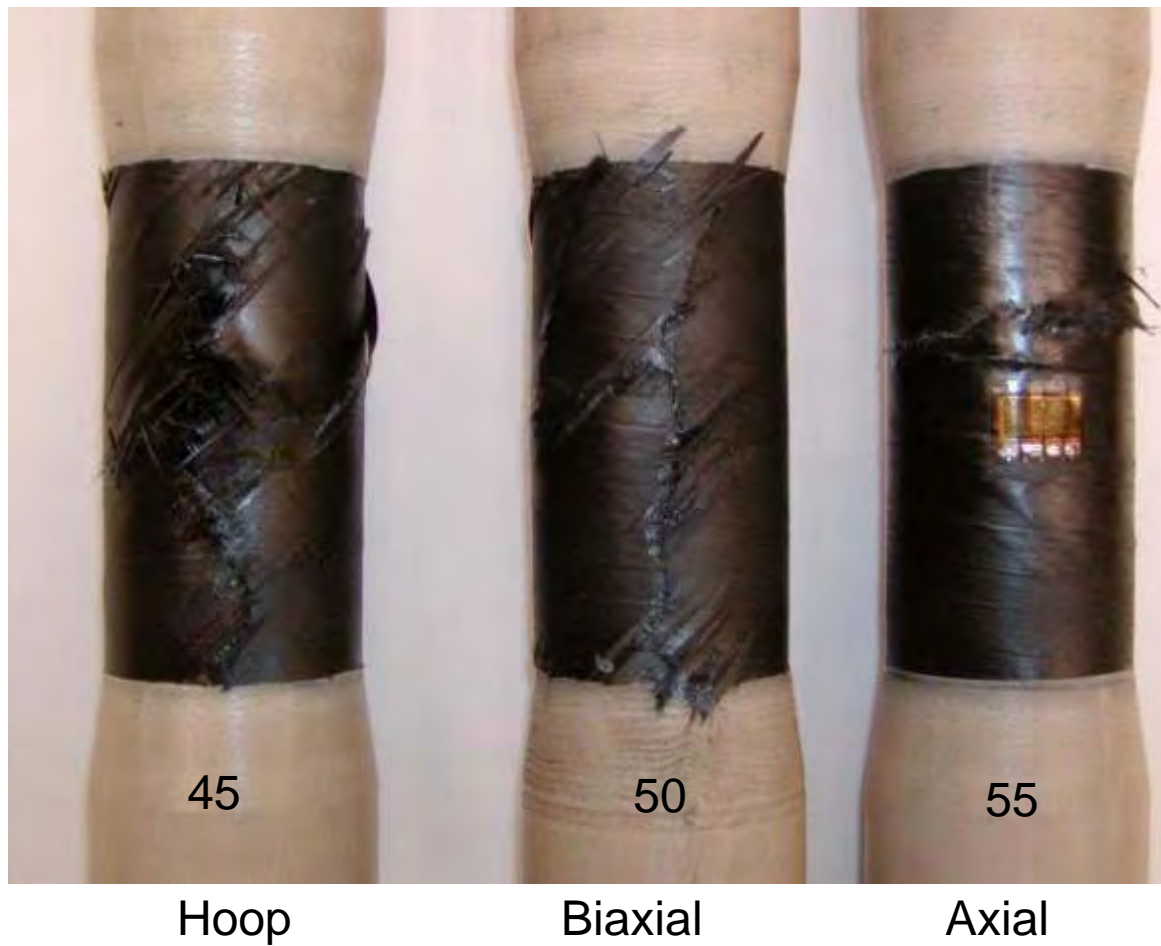
- **Maximum stress and strain**
  - **Optimum angle minimizes matrix strain**
- **Tsai-Hill**
  - **Does not identify failure mode**
  - **Optimum angle found by maximizing load factor**



# Results of Pressure Vessel Tests

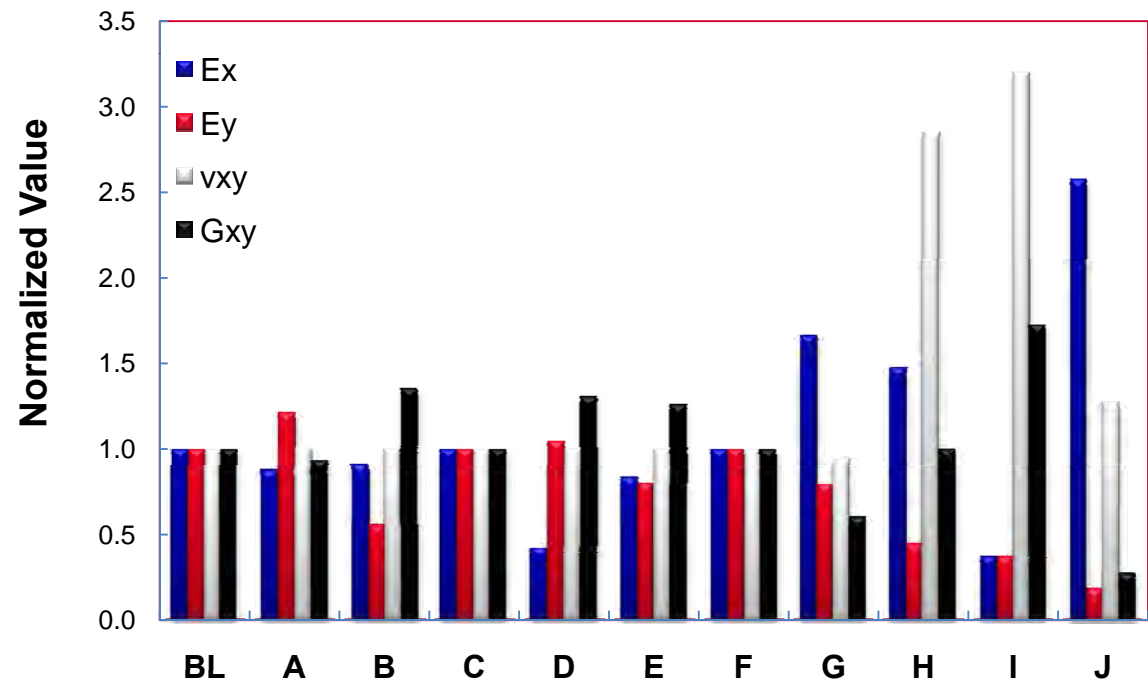


# Transverse Failure Mode

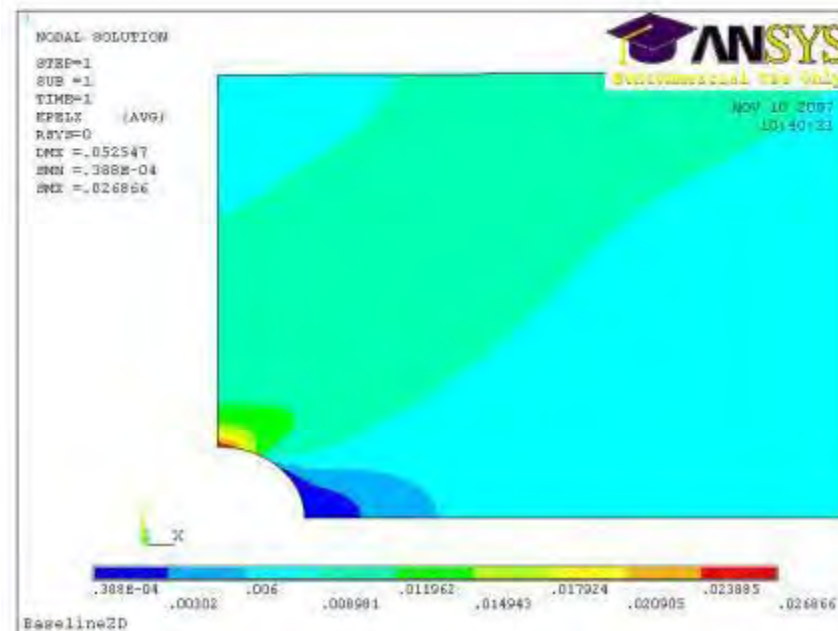


# Open Hole Tension

Laminate	Layup
BL	[(45/90/-45/0)2]s
A	[(54/90/-54/0)2]s
B	[(45/51/-45/0)2]s
C	[(45/0/-45/90)2]s
D	[(45/90/-45/57)2]s
E	[(54/54/-54/0)2]s
F	[(45/-45/90/0)2]s
G	[(21/90/-21/0)2]s
H	[(45/0/-45/0)2]s
I	[(±45)4]s
J	[0]16

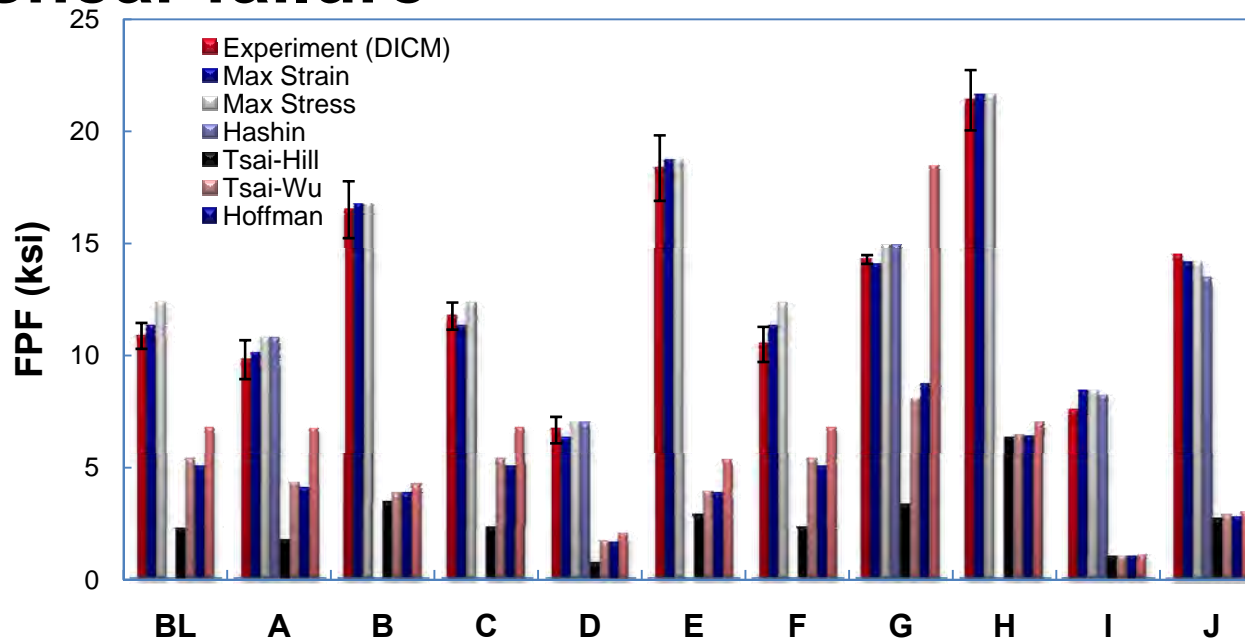


# Strain State From FEA



# Results

- Interactive criteria tend to be conservative
- Limit criteria correlate with failure for transverse and shear failure

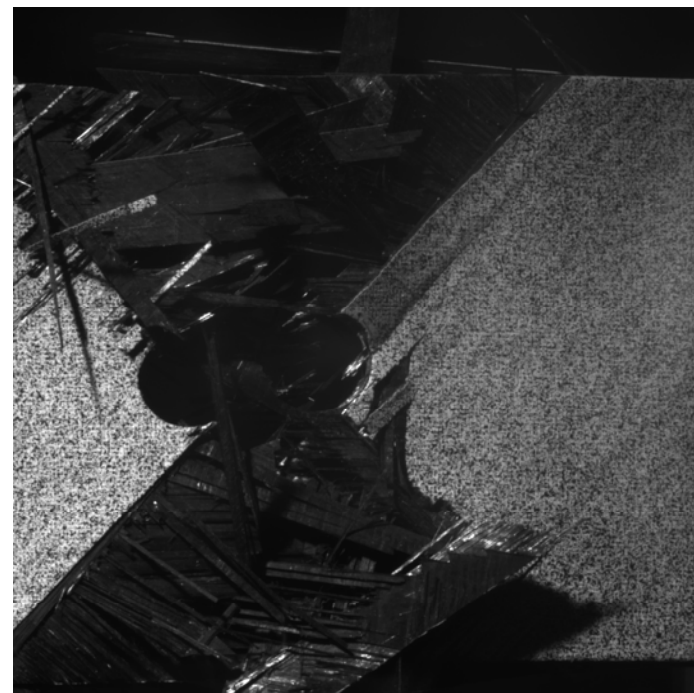


# Failure Modes

**Laminate A**  
**Transverse**



**Laminate B**  
**Shear**



## **Next Steps**

- **Biaxial results involved 2:1 stress ratio**
  - **Examine full failure envelope (normal and shear)**
  - **Consider notch under multi-axial stress**
- **Notched results involved tension and shear**
  - **Consider notched compression and flexure**
- **Evaluate brittle and toughened matrix systems**
- **Apply maximum strain to damage evolution and ultimate strength prediction**