EXPERIMENTAL MECHANICS OF COMPOSITE MATERIALS

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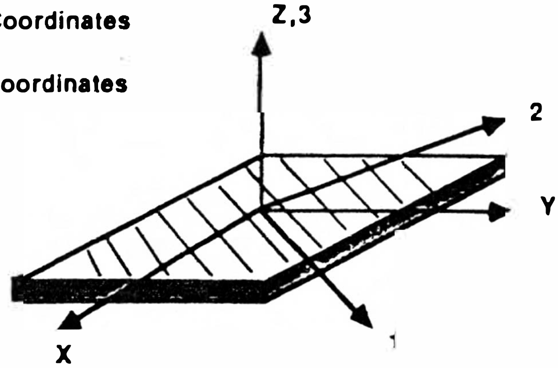
MECHANICS REVIEW

Coordinate Conventions

X,Y,Z Plate Coordinates

1,2,3 Fiber Coordinates



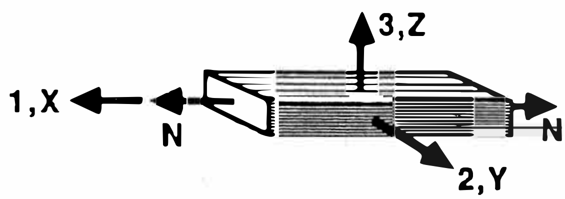
MECHANICS REVIEW

Lamina Response

Hookes Law (2-D)

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix}$$

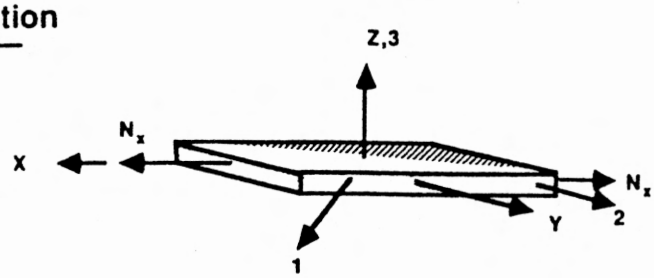
$$\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{Bmatrix} = \begin{bmatrix} S_{11} & S_{12} & 0 \\ S_{12} & S_{22} & 0 \\ 0 & 0 & S_{66} \end{bmatrix} \begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix}$$



MECHANICS REVIEW

Coordinate Transformation

$$\begin{Bmatrix} \sigma_1 \\ \sigma_2 \\ \tau_{12} \end{Bmatrix} = [T] \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix}$$



$$[T] = \begin{bmatrix} m^2 & n^2 & 2mn \\ n^2 & m^2 & -2mn \\ -mn & mn & m^2-n^2 \end{bmatrix}$$

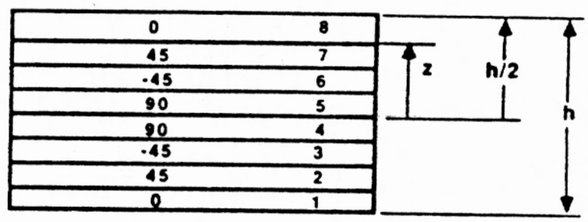
MECHANICS REVIEW

Laminate Notation

$[0/+45/-45/90]_s$

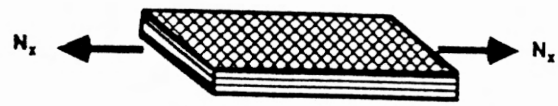
$[\,0_l\,/\,45_m\,/\,90_n\,]_{ps}$

Where l,m,n,p are integer constants



MECHANICS REVIEW

Laminate Response



$$\begin{bmatrix} N \\ \hline M \end{bmatrix} = \left[\begin{array}{c|c} A & B \\ \hline B & D \end{array}\right] \begin{bmatrix} \varepsilon^{\circ} \\ \hline \kappa \end{bmatrix}$$

$$N_x = \int_{-h/2}^{h/2} \sigma_x \, dz \qquad M_x = \int_{-h/2}^{h/2} \sigma_x \, z \, dz$$

$$A = \sum_{k=1}^{n} (Q_{ij})(z_k - z_{k-1})$$

$$B = \frac{1}{2} \sum_{k=1}^{n} (Q_{ij})(z_k^2 - z_{k-1}^2)$$

$$D = \frac{1}{3} \sum_{k=1}^{n} (Q_{ij})(z_k^3 - z_{k-1}^3)$$

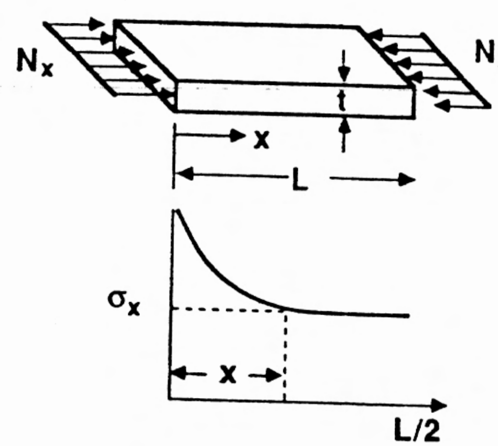
MECHANICS REVIEW

St. Venant's Principle:

$$\lambda \approx \frac{t}{2\pi} \left(\frac{E_x}{G_{xz}}\right)^{1/2}$$

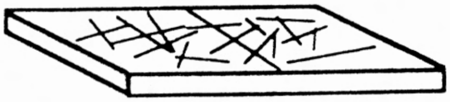
$$\lambda < \frac{t}{2\pi} \left(\frac{E_1}{G_{12}}\right)^{1/2}$$

$$\lambda \leq \frac{4.6t}{2\pi} \left(\frac{E_x}{G_{xz}}\right)^{1/2}$$



MECHANICS REVIEW

Discontinuous Fiber Composites

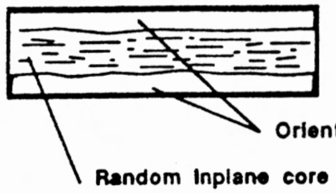


Orthotropic In-the-plane

↓

Homogeneous Orthotropic Sheet

$$\{ \sigma_i \} = [Q_{ij}] \{ \varepsilon_j \}$$



↓

Psuedolaminate

$$\left\{ \begin{matrix} N \\ \hline M \end{matrix} \right\} = \left[\begin{array}{c|c} A & B \\ \hline B & D \end{array} \right] \left\{ \begin{matrix} \varepsilon \\ \hline \kappa \end{matrix} \right\}$$

Basic Test Considerations

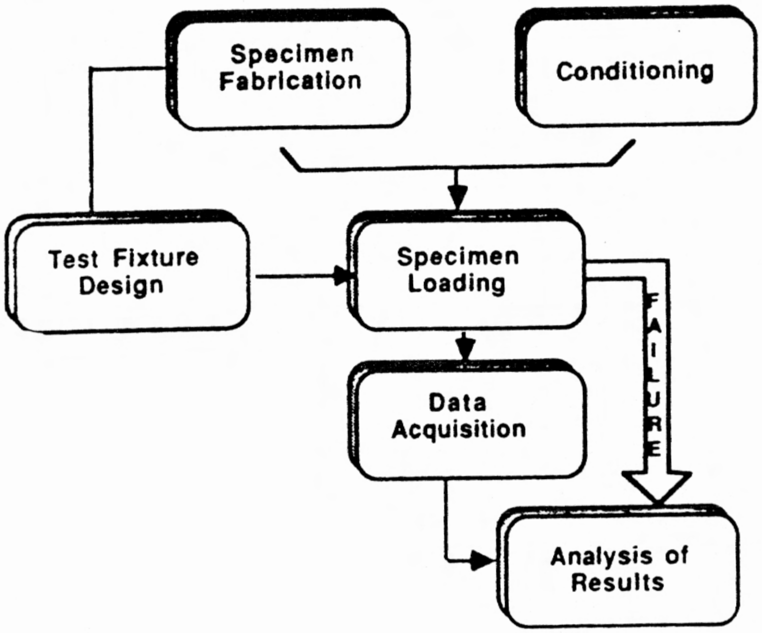
Types of Testing

Constituent Properties → Composite Properties → Structural Testing

- Constituent Properties ↓ Materials Design
- Composite Properties ↓ Structural Design
- Structural Testing ↓ Design Verification

TEST METHODOLOGY

Test Design



REPORTING DATA

- Material Type
- Processing Conditions
- Void Content
- Volume Fraction
- Observed Failure Mode
- Specimen Conditioning
- Test Conditions
- Fiber Orientation State

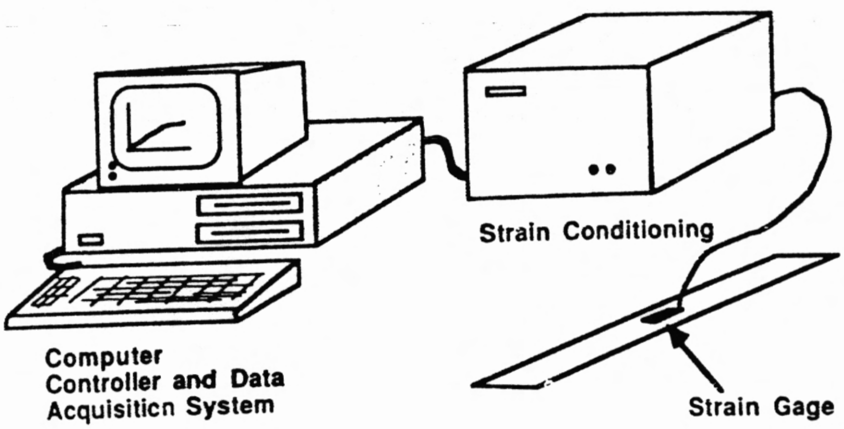
TEST INSTRUMENTATION

Loading Apparatus

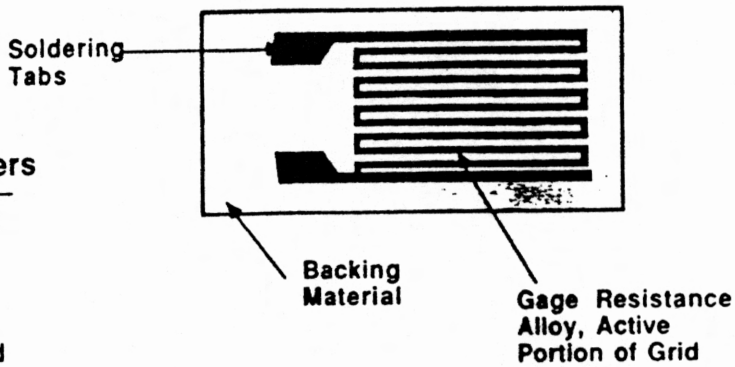
Screw Driven	Servo-Hydraulic	Electrodynamic
↓	↓	↓
Displacement Control	Load Control Displacement Control Strain Control	Load Control Displacement Control Strain Control
↓	↓	↓
Static Characterization	Static and Dynamic Characterization	Dynamic Characterization

TEST INSTRUMENTATION

Strain Measurement



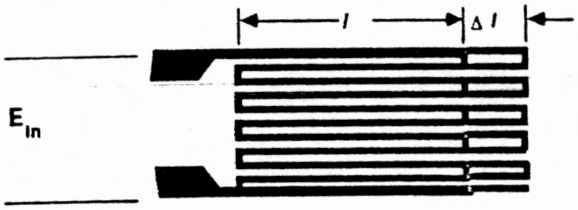
STRAIN GAGES



Important Parameters

- Resistance
- Gage Factor
- Grid Size
- Orientation of Grid
- Alloy of Gage
- Type of Backing

STRAIN GAGES



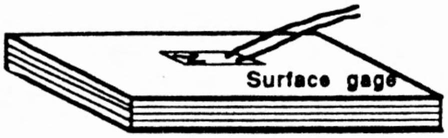
$$\varepsilon = \frac{1}{S_g}\left(\frac{\Delta R}{R}\right)$$

S_g = Gage Factor, contant relating Δl to ΔR allowing calibration to strain

ΔR = Change in resistance due to elongation of gage element

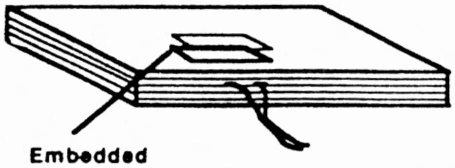
STRAIN GAGES

Surface Mounting



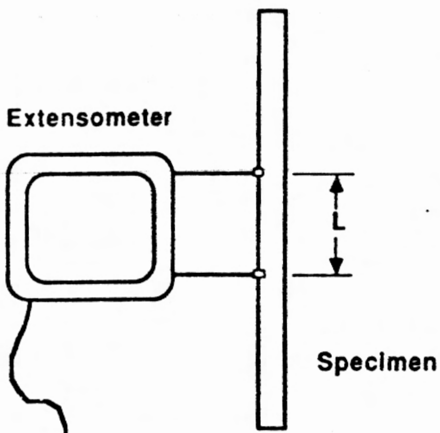
- Measured Surface Strain
- Averages Strain under gage grid

Embedded Mounting



- Measures strain within the embedded layer

E XTENSOMETER

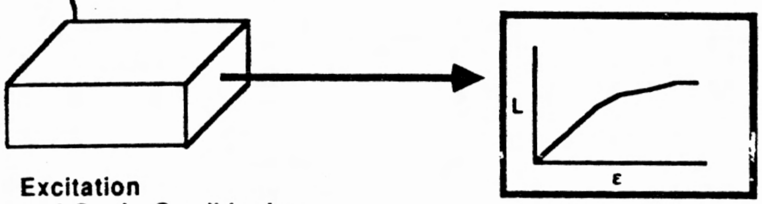


Advantages:

- low cost on per / test basis
- ease of installation

Disadvantages:

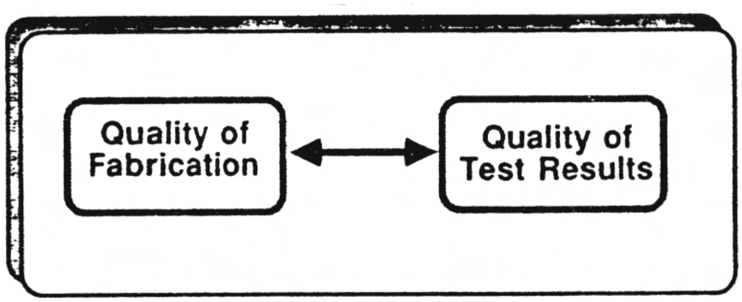
- poor repeatability
- nonlinear response



STRAIN GAGES

- Advantages
  - Excellent accuracy and reproducibility
  - Operator insensitive
- Disadvantages
  - Cost
  - Installation time requirements

SPECIMEN FABRICATION

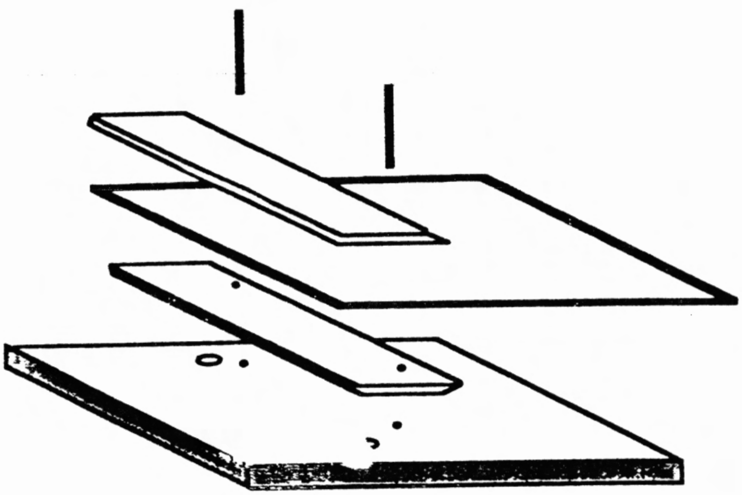


SPECIMEN FABRICATION

Issues

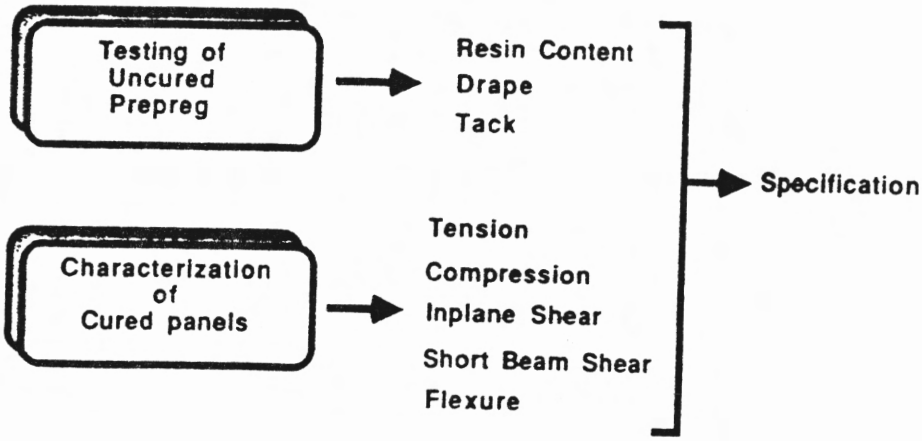
- Geometric Precision
- Machining Quality
- Alignment
- Material Equivalence
  (Test Specimen Matenal representative of Matenal in Part)
- Processing History
- Conditioning

SPECIMEN FABRICATION FIXTURING



QUALITY CONTROL TESTING

TESTING FOR MATERIAL SPECIFICATIONS



TENSILE TESTS

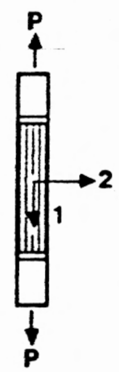
ASTM D3039*
D638

TYPES OF TENSILE TESTS

- Unidirectional lamina (continuous and discontinuous fiber) — *ply properties*
  - 0°
  - 90°
- Off-axis
- Laminate (continuous/discontinuous)
- Woven fabric
- Random orientation discontinuous fiber composites

PLY PROPERTIES

0° - Tension Test



E_1 - Young's modulus in fiber direction

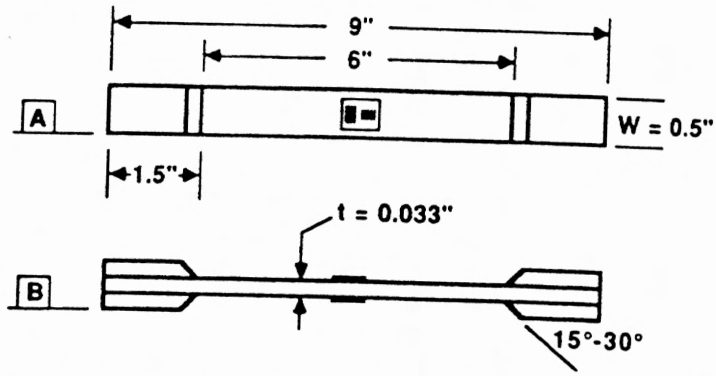
X_1^T - Ultimate tension strength in fiber direction

ν_{12} - Poisson's ratio

ε_1^T - Ultimate strain in fiber direction

COUPON GEOMETRY

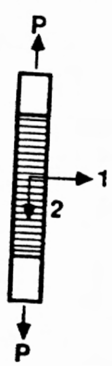
0° - Tension Test



Width ll to A within 0.005 in. Top ll to B withing 0.002 in.

PLY PROPERTIES

90° - Tension Test



E_2 - Young's modulus in transverse direction

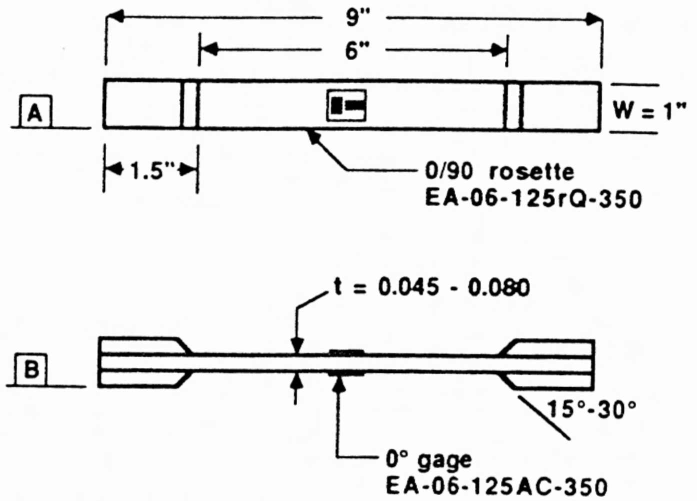
X_2^T - Ultimate tension strength in transverse direction

ν_{21} - Poisson's ratio (Minor)

ε_2^T - Ultimate strain in transverse direction

COUPON GEOMETRY

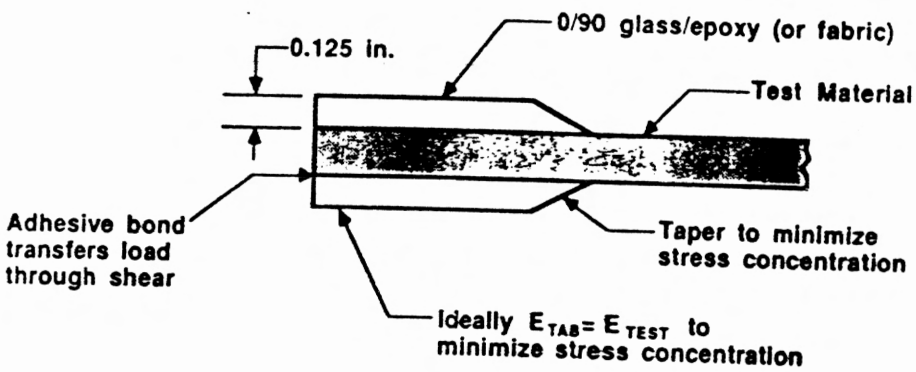
90° - Tension Test (8 ply)



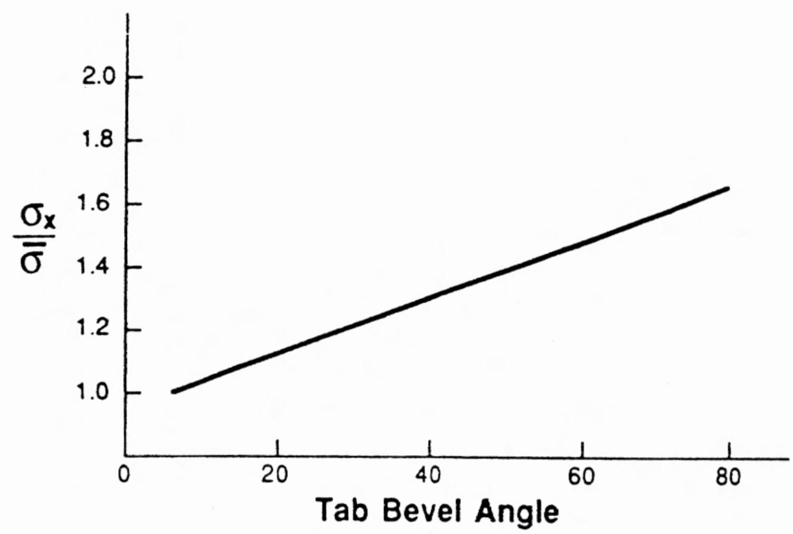
Width ∥ to A within 0.005 in.   Thickness ∥ to B within 0.002 in.

END TAB CONSIDERATIONS

Purpose: Prevent Crushing/Splitting of Test Material



PEAK STRESS AS FUNCTION OF TAB ANGLE



DATA REDUCTION

Tensile Modulus

$E_x = \sigma_x / \varepsilon_x$

Tensile Strength

$\sigma_x^{ULT} = P_x^{ULT} / A$

Poisson's Ratio

$\nu_{xy} = -\varepsilon_y / \varepsilon_x$

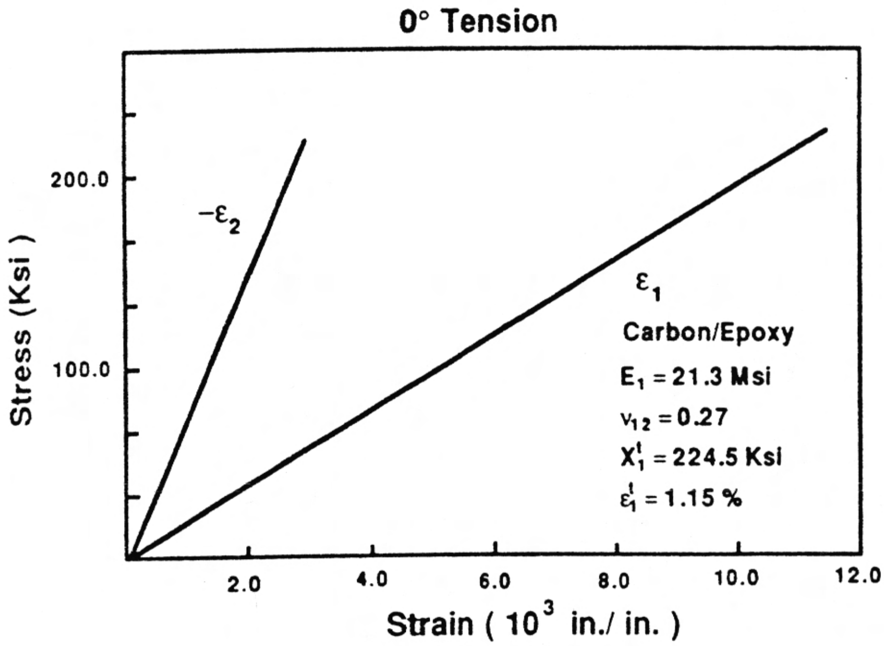
Where: $\sigma_x = P_x / A$

P = Load

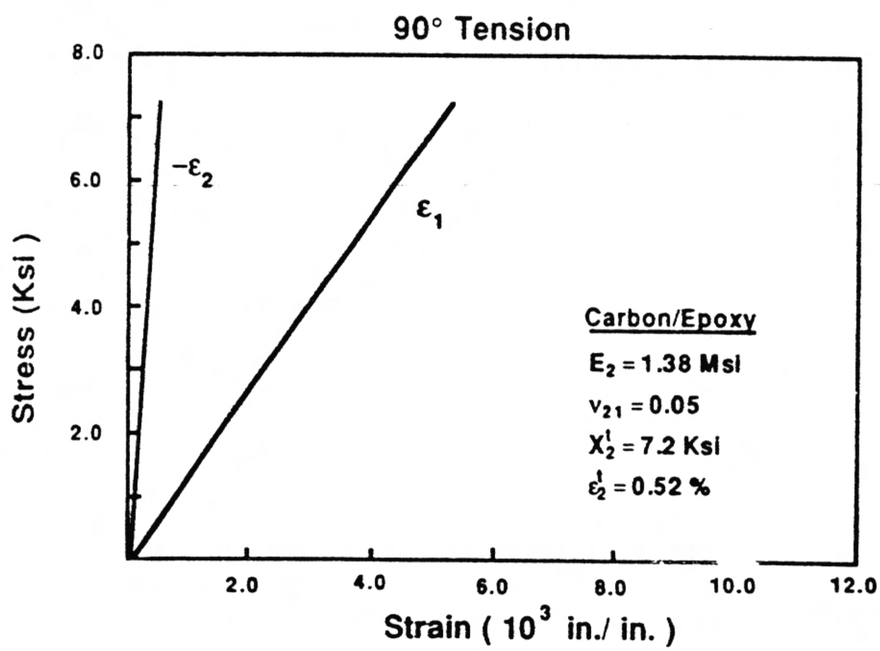
$A = w \times t$

ε_x, ε_y = Longitudinal, Transverse Strain

LAMINA TENSION RESPONSE



LAMINA TENSION RESPONSE



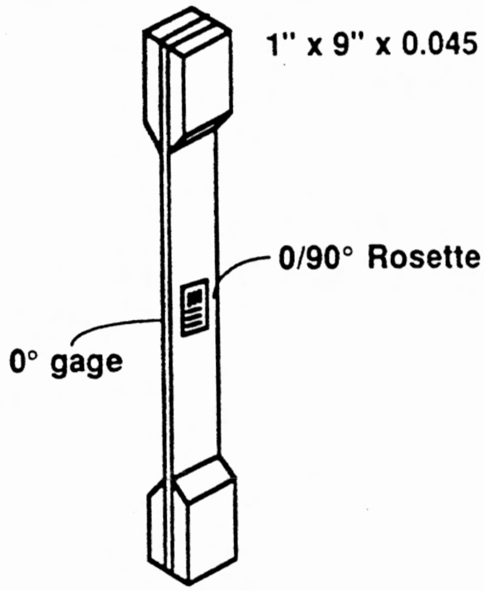
EFFECTIVE LAMINATE PROPERTIES

- Coupon geometry and test procedure same
- Potential problems

  Unsymmetric laminate
  → bending-extentional coupling

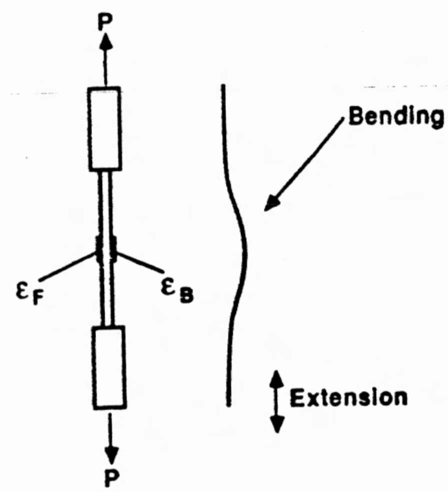
  Unbalanced laminate
  → shear coupling

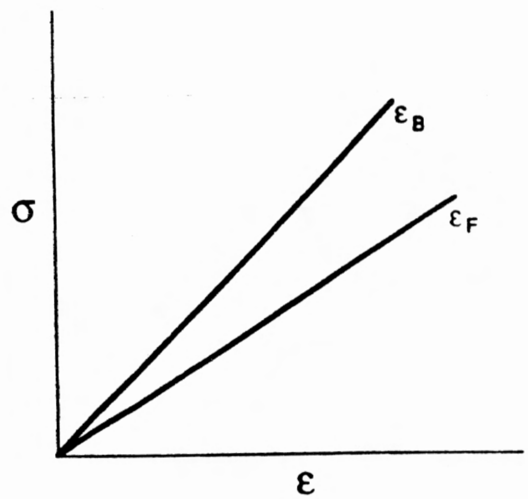
  Interlaminar edge effects



LAMINATES

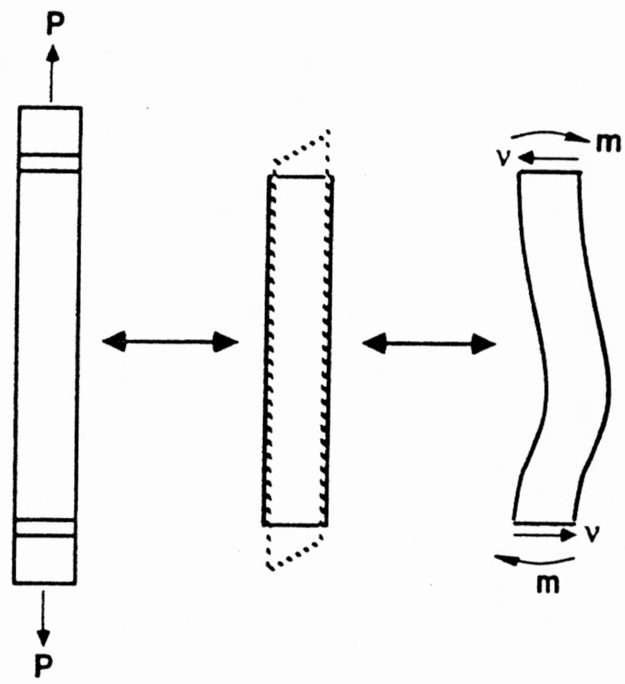
[0/90/0/90]





UNBALANCED LAMINATE

$[0/45/45]_s$



LAMINATE PROPERTIES

Measured Properties are Effective Properties

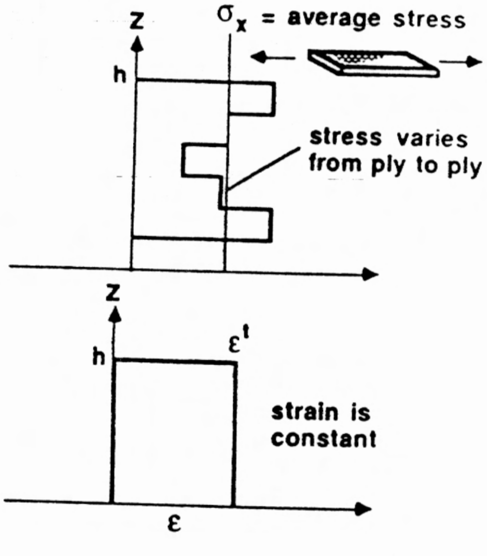
$E_x = (h\,H_{11})^{-1} = \sigma_x / \varepsilon_x$

$E_y = (h\,H_{22})^{-1}$

$\nu_{xy} = -H_{12} / H_{22}$

$G_{xy} = (h\,H_{33})^{-1}$

* Assume homogeneous through thickness



WOVEN FABRIC

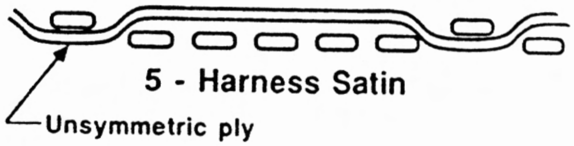
Tension Test

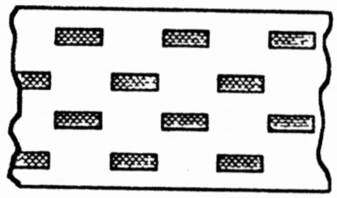
- $B_{ij} \neq 0$ for single ply
- Laminates can be made symmetric

  → Test procedures same as for laminate

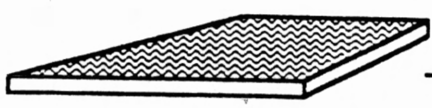
- Homogeneity

  → Strain measurements must reflect level of in homogeneity





DISCONTINUOUS FIBER COMPOSITES



Random, Planar

→ Treat like orthotropic sheet. Lamina methods.

0° tension
90° tension

Pseudo laminate of random planar orthotropic sheets

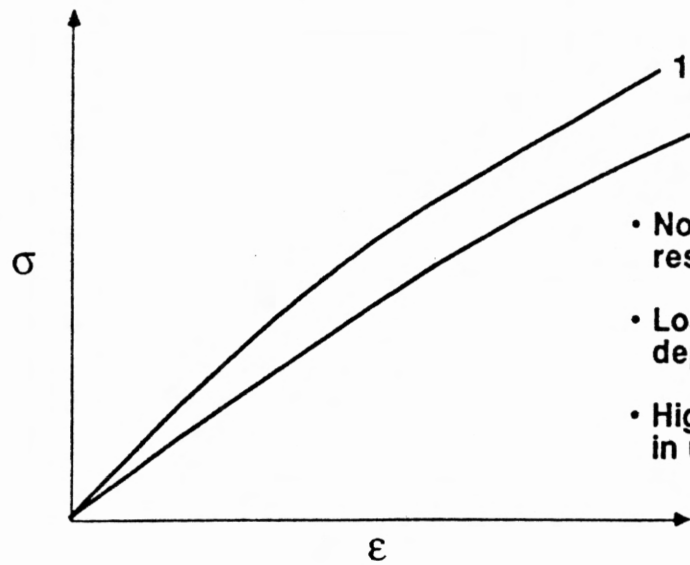
→ Treat like laminate.

x - direction tension
y - direction tension

Find "effective" properties

Balanced symmetric | Unbalanced unsymmetric

DISCONTINUOUS FIBER COMPOSITES



- Nonlinear σ-ε response
- Load history dependent
- High variability in ultimate strength

FLEXURE PROPERTIES

ASTM D790

- Flexural Strength
- Flexural Modulus

FLEXURAL TESTING

Objectives

- Materials Certification
  - comparative screening
- Structural Performance
  - bending properties

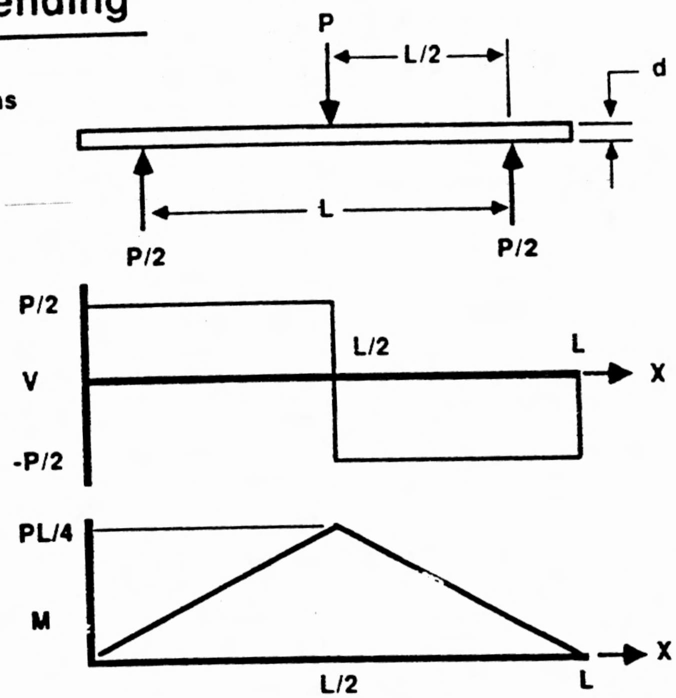
FLEXURE TESTING

Three-Point Bending

Nominal Dimensions

L = 4.0 in.

d = 0.1 in.



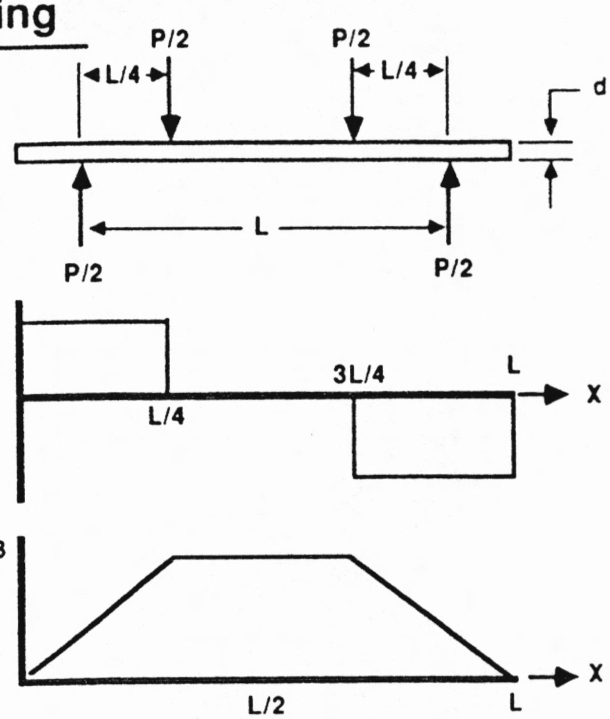
FLEXURE TESTING

Four-Point Bending

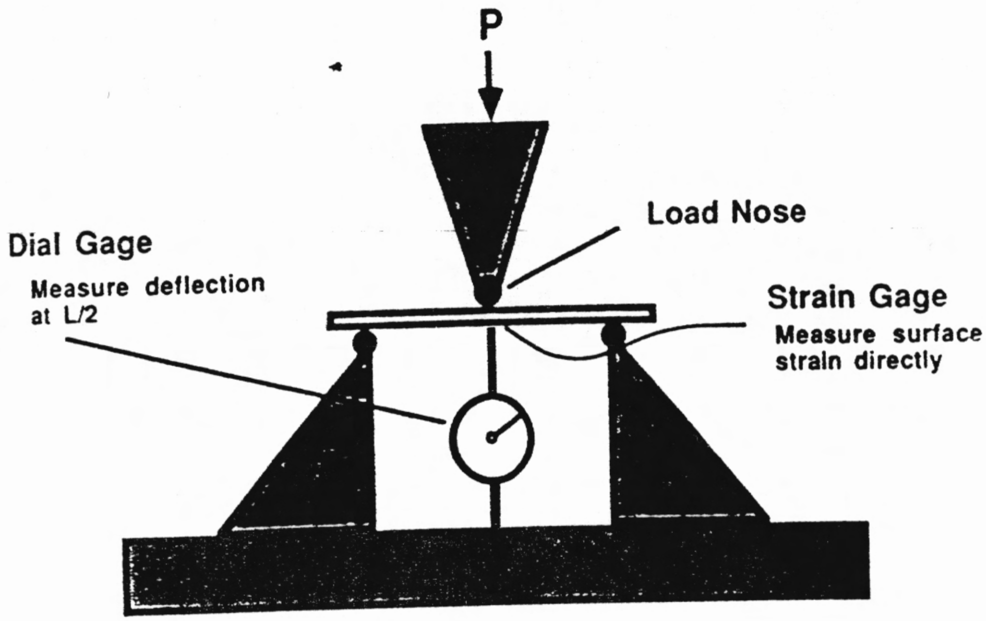
Nominal Dimensions

L = 4.0 in.

d = 0.1 in.



FLEXURE TESTING



FLEXURAL SPAN

Glass / Epoxy → L/h = 16

Graphite / Epoxy
Boron / Epoxy → L/h = 32 [0°]
L/h = 16 [90°]

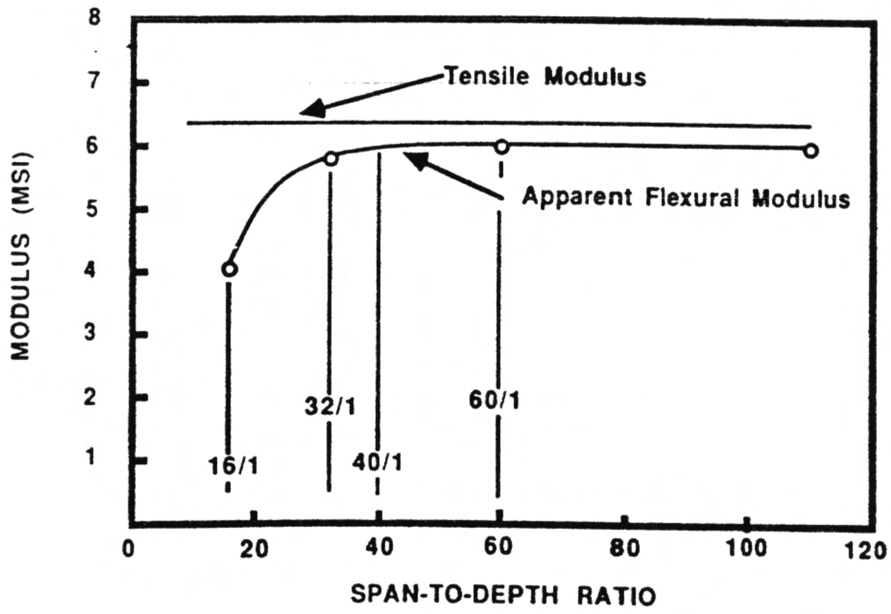
Kevlar / Epoxy → L/h > 32 (Modulus)
L/h < 32 (Strength)

$8 \geq R > 1 \longrightarrow L/h \leq 16$

$R > 8 \longrightarrow L/h > 16$

$$R = \frac{\sigma_x}{\tau_{xz}}$$

EFFECT OF SPAN ON MEASURED MODULUS



(ZWEBEN, ET AL, 78)

IMPORTANT TEST PARAMETERS

- Span-to-Depth Ratio, L/h

  function of ratio of tensile strength
  to interlaminar shear strength

- Beam Width, b

  (nominally 1/2 in. - 1.0 in.)

- Crosshead Rate, R

  $\dot{\varepsilon}$ = 0.01 in./in./ min.

ANALYSIS OF RESULTS

Three-Point Bending

Assumptions

- Homogeneous
- $E_c = E_t$
- Small deflection

Euler Beam Solution

$$\sigma = \frac{Mc}{I} \longrightarrow \sigma = \frac{3PL}{2bh^2}$$

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