# FIBER REINFORCEMENTS

Features Sought

High Strength

High Modulus

Low Density

Uniform

Wide Service Temperature

Compatibility

Low Cost

Easy Processing

Continuous

# FIBER REINFORCEMENTS

Questions/Issues

Why Fibers?

Why Small diameters?

Why Anisotropic?

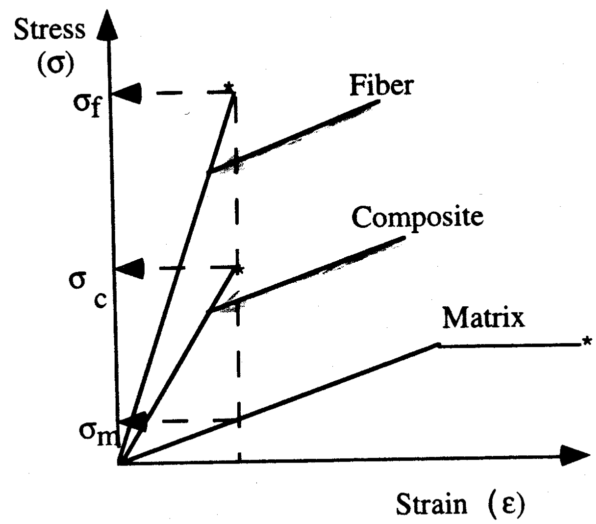
Why low compression strength?

Why low thermal expansion?

Why expensive?

Why not high strength <u>and</u> high modulus?

**Tensile properties of Fiber Reinforced Polymers (Plastics)**




Rule of Mixtures

$$\sigma_c = \sigma_f v_f + \sigma_m v_m$$

$$E_c = E_f v_f + E_m v_m$$

- Polymer Matrix
  - > Transfers loads
  - > Protects Fibers

## Sample Calculation

- Carbon Fiber ( Hercules AS 4 )

  $E_f = 32$ msi ( $32 \times 10^6$ psi ) (220 GPa )

  $\sigma_{fu} = 450$ ksi ( 450,000 psi ) ( 3.1 GPa )

  $\varepsilon_{fu} = 0.012$

- Epoxy Matrix

  $E_m = 350$ ksi

  $\sigma_{mu} = 12$ ksi

  $\varepsilon_{mu} = 0.034$

- Composite ( $v_f = 0.60$, unidirectional )

  $E_c = 32\ (0.6) + 0.35\ (0.4) = 19.3$ msi

  ( 99 % fiber)

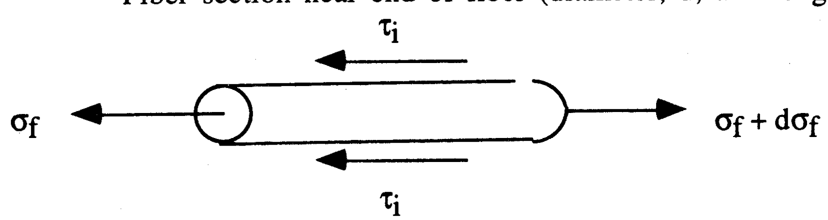
  @ $\varepsilon_{fu} = 0.012$, $\sigma_m = 350\ (0.012) = 4.2$ ksi

  $\sigma_c = 450\ (0.6) + 4.2\ (0.4) = 272$ ksi

  ( 99 % fiber)

**Need High Aspect Ratio to reach Ultimate Strength of Fibers**

- Assume stress transfer by shear
- Assume constant interfacial shear stress
- Fiber section near end of fiber (diameter, d, and length, dx )




(interfacial shear stress)

- Force balance:

$$(\sigma_f + d\sigma_f)(\pi d^2/4) - \sigma_f(\pi d^2/4) - \tau_i(\pi d)\,dx = 0$$

$$\frac{d\sigma_f}{dx} = \frac{4\tau_i}{d} \quad \text{or} \quad \sigma_f = \frac{4\tau_i x}{d}$$

- Critical length, $l_c = 2x_c$, when $\sigma_f = \sigma_{fu}$

$l_c/d = s_c$ = critical aspect ratio or $s_c = \dfrac{\sigma_{fu}}{2\tau_i}$

- Sample calculation

Carbon fiber ( AS 4 ): $\sigma_{fu}$ = 450 ksi, d = 8 μm

Epoxy matrix: assume $\tau_i = \dfrac{\sigma_{mu}}{2}$ = 6 ksi

$$s_c = \frac{450}{2(6)} = 37.5$$

$l_c$ = 37.5 ( 8 μm ) = 300 μm = 0.3 mm = 11.8 mils

- Goals

$s \geq 50\, s_c$

$\tau_i = \dfrac{\sigma_{my}}{2}$ where $\sigma_{my}$ is the marix yield strength

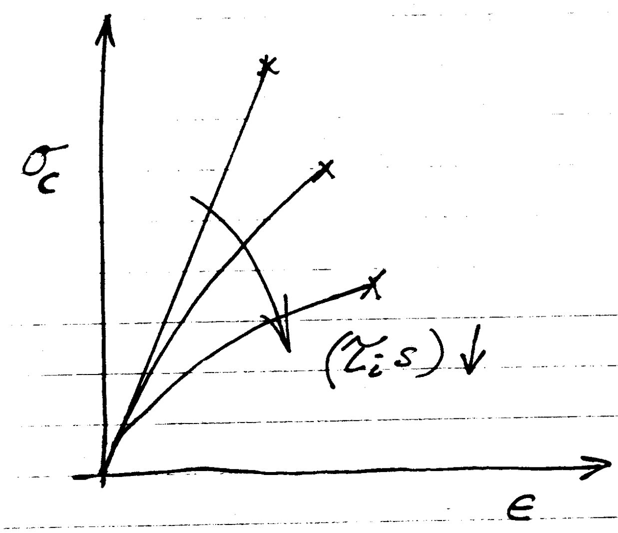
Stress-strain relationship including aspect ratio and interfacial shear stress

$$\frac{\sigma_c}{\epsilon} = (E_f v_f + E_m v_m) - \frac{v_f E_f^2 \epsilon}{4 \tau_i s}$$

where

$$s = \frac{l}{d} > s_c$$

$$\tau_i \leq \frac{\sigma_{my}}{2} \quad \text{(typically)}$$




Goals

$$s \geq 50\, s_c$$

$$\tau_i = \sigma_{my}/2$$

# SMALL DIAMETER FIBERS HAVE SMALLER STRESS CONCENTRATIONS

Thus:
- Tensile strength increases
- Modulus not altered

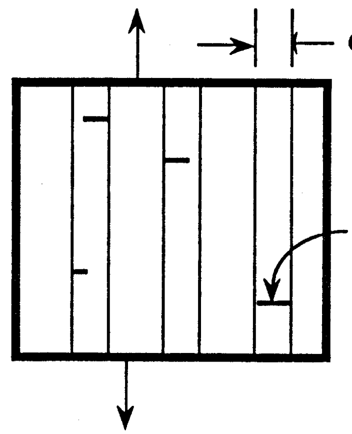
Griffith/Erwin Crack Growth Model

$$\sigma^2 = \frac{EG}{Y(1-\upsilon^2)a_c}$$

$\sigma$ = Failure Stress
E = Modulus
G = Work of Fracture (Strain Energy Release Rate)
Y = Geometric Factor
$\nu$ = Poisson's Ratio
$a_c$ = Critical Crack Length at Failure

# Sample Calculation

Assume $a_c \leq d_f$ (fiber diameter)




Al 6061 - T6 Alloy

$E$ = 69 GPa (10 msi)

$G$ = 10 kJ/m$^2$ = 10 kPa•m

$Y$ = $\pi$ (thin flat plate, width $>> a_c$)

$\nu$ = 0.3

$$a_c = 10 \mu m \quad \Downarrow \quad \sigma = 4.9 \text{ GPa}$$

$$a_c = 10{,}000 \mu m \ (1 cm) \quad \Downarrow \quad \sigma = 0.16\ GPa$$

($\sigma$ of alloy = 0.28 GPa)