

**Recitation #3**  
**Tuesday, September 23, 2003**

COMPOSITE MATERIALS: generally a combination of a “reinforcing component” and a “matrix”  
i.e. fiber reinforced, woven, short fiber chopped, particulate.

Composites are related using the ELASTIC MODULUS: Young’s Modulus  
Why?

*As temperature increases, the elastic modulus,  $E$ , changes for crystalline materials and rubbers. Here we relate each type of behavior to fundamental properties of each class of material.*

Crystalline Materials: experience a decrease in elastic modulus as the temperature is increased. Increasing the temperature causes the atoms to move further apart, due to thermal expansion. As atomic distances increase, the modulus decreases.

Rubber Materials: experience an increase in elastic modulus as the temperature is increased. Pulling a rubber in tension causes the chains to align, lowering the order (entropy) in the system. For rubbers, the entropy governs elastic response. As temperature is increased, entropy increases. The increase in entropy will therefore increase the resistance of the material to deformation, increasing the elastic modulus.

For Fun and Enlightenment:

*Aluminum 7075 T6 is an aluminum alloy with 1.6% copper, 2.5% magnesium, 5.6% Zinc, 0.23% chromium by weight. Explain why the modulus of this alloy ( $E = 70.7 \text{ GPa}$ ) and pure aluminum ( $E = 70 \text{ GPa}$ ) are nearly the same. Why is the modulus of the alloy slightly higher than the pure material?*

The elastic modulus derives from atomic bonding strength and atomic separation distances. The alloy composition after adding about 10% of other atoms still consists of mainly aluminum. If alloying elements do not change the bonding type or atomic spacing appreciably, the modulus will not change dramatically, as is the case.

The slight increase in modulus is due to the higher average modulus of the alloying elements. Alloying with lower modulus elements will have the opposite effect.

### Example Problem:

The stiffness of Nylon 66 plus 25 volume fraction carbon fibers is 14GPa, whereas the stiffness of an epoxy resin plus 60 volume fraction carbon fibers is 220GPa. If the elastic modulus of carbon fibers is 390GPa, speculate on the nature of the two composites in question in terms of fiber length and fiber orientation. Also calculate the lower bound modulus for the Nylon66 + 25vol. frac. Carbon fiber composite.

(NOTE: I have not made m, f, or // subscripts)

Ignore stiffness contribution of nylon and epoxy in the two composites. (I am ignoring the  $v_mE_m$  (volume fraction of matrix \* modulus matrix) For the case of the ideal epoxy resin-carbon fiber composite modulus,

$E_{//} = v_f E_f = 0.6(390\text{GPa}) = 234\text{GPa}$ . (Compares well w/ the cited 220GPa, so it appears fibers are oriented long, well bonded to matrix, oriented parallel to the loading axis)

$E_{//} = v_f E_f = 0.25(390\text{GPa}) = 97.5\text{GPa}$ . (considerably larger than reported value. Therefore, one must conclude that either the fibers are not oriented parallel to loading axis or are very short.

Calculate it for the perpendicular E.

$E_{\text{perpendicular}} = (E_f E_m) / (v_f E_m + (1 - v_f) E_f) = (2.9\text{GPa})(390\text{GPa}) / (.25(2.9\text{GPa}) + (1 - .25)(390\text{GPa})) = 3.857\text{GPa}$ .

Gives composite modulus in direction normal to the reinforcing phase. Gives more accurate answer than 97GPa.

TRUSSES:

See PowerPoint File.