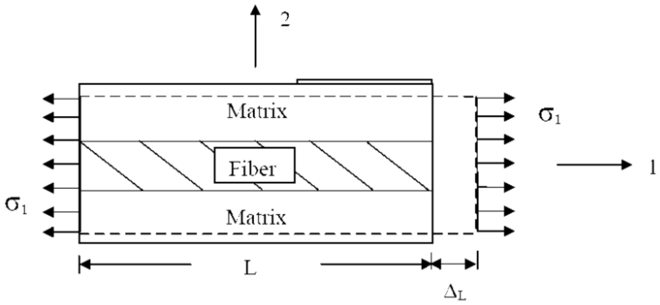
Composite Materials

Review Problems

A unidirectional pre-preg composite laminate for aerospace vehicles is designed from various matrices and fibers to support high stress due to environmental effects without crack formation. The stiffness of the material should be <u>at least</u> 100 GPa, the coefficient of thermal expansion should be <u>at most</u> $15*10^{-6}$/°C and the composite should withstand temperatures up to 300 C.

Matrix	**E (GPa)**	**G (GPa)**	**ν**	**α (10⁻⁶/°C)**	**Yield strength (MPa)**	**ϱ (g/cc)**	**maxT ©**
Mullite	150	60	0.25	5.3	100	2.8	1600
934 epoxy	4.35	1.59	0.37	43.92	83	1.34	136
PMR15 polyimide	3.45	1.31	0.35	36	70	1.3	300
2024 aluminum	73.11	27.58	0.33	23.22	270	2.78	410
Borosilicate glass	62.76	26.2	0.2	3.24	20	2.23	560
PEEK	4.22	3.4	0.4	50	98	1.35	250
			Fiber				
T300 Carbon	233	9	0.2	-0.54	2930	1.76	350
P100 Carbon	760	7	0.2	-1.4	2000	2.13	350
A-glass	69	29	0.18	9	2300	2.44	727
S-glass	87	35	0.23	1.6	2800	2.46	750
Kevlar 149	179	80	0.19	18	1800	1.47	160
Boron	400	5	0.15	8.3	3200	2.57	500



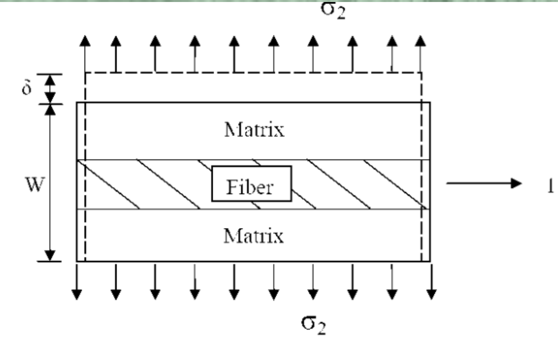
$E_{C1}\varepsilon_{C1} = E_{F1}\ \varepsilon_{F1}V_F + E_{M1}\ \varepsilon_{M1}V_M$

$$E_C = f_F * E_f + f_M * E_M$$

Linear rule of mixture for maximum properties

$\alpha_c < 15*10^{-6}/°C$

$$f_{F,crit} = \frac{\sigma_C - \sigma_{MY}}{\sigma_F - \sigma_{MY}}$$



$\frac{\sigma_{C2}}{E_{C2}} = \frac{\sigma_{F2}}{E_{F2}} V_F + \frac{\sigma_{M2}}{E_{M2}} V_M$

$$E_C = \frac{E_F * E_M}{f_F * E_M + f_M * E_F}$$

Inverse rule of mixture for minimum properties

$E_c > 100$ GPa

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$$l_{Cr} = \frac{\sigma_F * r_F}{\tau_{FM}}$$

$$\sigma_{Feff} = \eta * \sigma_F * \left(1 - \frac{l_{cr}}{2 * l_m}\right)$$

You are given the task to design a unidirectional laminate composite of borosilicate glass matrix with carbon fibers. The strength of the material should be at least 1000 MPa, the coefficient of thermal expansion should be at most $3.0*10^{-6}$/°C and the density should be around 2 g/cc. Determine the type and volume ratio of fiber to use as the reinforcement.

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Particle reinforcement

Mullite particles are added to aluminum matrix to improve the wear resistance and stiffness of the composite. Estimate the stiffness of the composite if the particle content is about 40%. Geometrical factor = 1

$E_C = E_M * (1 + 2 * f_P * S * q) / (1 - f_P * q)$ $q = (E_f / E_M - 1) / (E_f / E_M + 2S)$

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Porous composites

We want to produce open celled foams of aluminum for use as shock absorber components in vehicles

What would the cell thickness and foam edge length ratio be for an 80% porous aluminum foam?

How much porosity would be needed for the component to have a stiffness around 10 GPa?

$$\frac{\rho^*}{\rho_s} = C_o\left(\frac{t}{l}\right)^2$$

$$\frac{E^*}{E_s} = C\left(\frac{\rho^*}{\rho_s}\right)^n$$

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A porous mullite matrix is needed for a carbon fiber reinforced ceramic matrix composite. Efficient toughening mechanism will be provided if 30% macroporosity is incorporated to the matrix-fiber interface.
What is the stiffness of the composite made with 50% P100 carbon fiber?

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We want to produce spherical macroporosity in mullite matrix.
Calculate the stiffness and strength for 10%, 30%, 50% porous mullite

$$G = G_0 \exp(-b_G P)$$

For quantifyable porosity

$$E = E_0 \exp(-b_E P)$$

$$G = G_0(1 - b_G P)$$

For low porosity

$$E = E_0(1 - b_E P)$$

$$E = E_0\left[1 - \left(\frac{5a}{4c} + \frac{3}{4}\right) P\right]$$

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