Exercise walk-through

4.4 Polymers, ceramics and composites

University Mechanical Engineering

Bonding sets the property family

metallic
steel, aluminium
ductile, tough, conducts heat and charge

covalent / ionic
alumina, silicon carbide
stiff, hard, brittle, insulating, heat-resistant

polymer chains
nylon, epoxy
light, compliant, viscoelastic, creeps

> Polymer chains give light, viscoelastic solids

Selection in action: one method, two answers

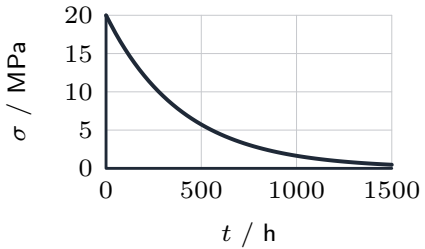
1. **Rank** $\sqrt{E}/\rho$: CFRP 7.37 wins stiffness-per-mass at 2.4× aluminium.
2. **Eliminate** Plain nylon fails the T_g constraint; ceramics fail the survival probability at these loads.
3. **Split** The mount ships quenched-and-tempered steel (620 MPa, 16%); the carry-handle ships CFRP.

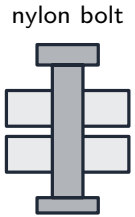
The project sheet, reproducible

1. **Structure** BCC 0.6802, FCC 0.7405; Hall-Petch 183.6 $\rightarrow$ 262.3 MPa for 50 $\rightarrow$ 10 µm.
2. **Certificate** Rod 191.0 MPa: 0.477 vs 1.364 mm; true ln 1.2 $=$ 0.1823; **toughness** 92.8 MJ/m^3.
3. **Choice** Routes 280/24, 260/26, 620/16, 950/8; Chvorinov 22.2 vs 50.0 s; Basquin 303.1 at 10^5, 250 at 10^6; Goodman 175.0; index 7.37 / 3.10 / 1.80 / 1.23 - steel mount, CFRP handle.

Exercise 2.1

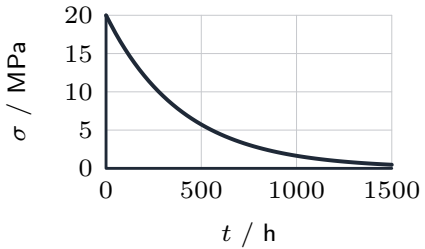
2.1 A nylon bolt clamps two plates with an initial stress of 20 MPa. The clamp is held at constant strain, and the nylon relaxes with $\tau = 400$ h. Find the stress after 1000 h, and the time for the stress to halve. [3]

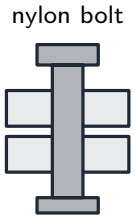




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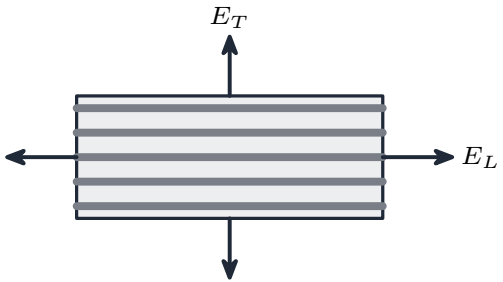


2.1

$\sigma = 20e^{-1000/400} = \mathbf{1.6\ MPa}$; $t_{1/2} = \tau \ln 2 = \mathbf{277\ h}$: nylon bolts must be re-tightened or replaced

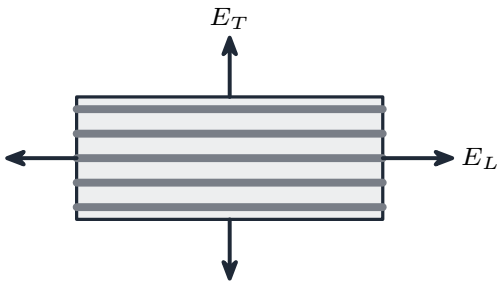
Exercise 2.2

2.2 A glass fibre composite has $V_f = 0.50$, $E_f = 72$ GPa and $E_m = 3.0$ GPa. Find E_L and E_T. [3]



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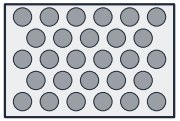


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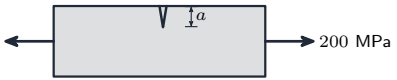
$E_L = 0.50 \times 72 + 0.50 \times 3.0 = \mathbf{37.5\ GPa}$; $E_T = \left(\dfrac{0.50}{72} + \dfrac{0.50}{3.0}\right)^{-1} = \mathbf{5.8\ GPa}$

Exercises 2.3·2.4

2.3 Glass fibre has $\rho = 2.55$ Mg/m^3 and the matrix 1.20 Mg/m^3. Find the density of the composite in 2.2 and its specific stiffness E_L/ρ. Compare with steel (200 GPa, 7.85 Mg/m^3). [2]

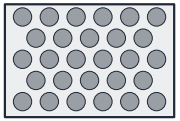


2.4 A silicon carbide plate ($K_{IC} = 3.5$ MPa m$^{1/2}$) carries 200 MPa. Find the largest surface crack it can survive ($Y = 1.12$). [3]



Exercises 2.3·2.4

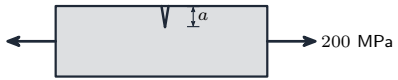
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2.3

$\rho = 0.50 \times 2.55 + 0.50 \times 1.20 = 1.88$ Mg/m^3, $E/\rho =$ **20**; steel gives 25.5: this composite is **not** stiffer per kilogram than steel; its gains are strength per kg and corrosion resistance

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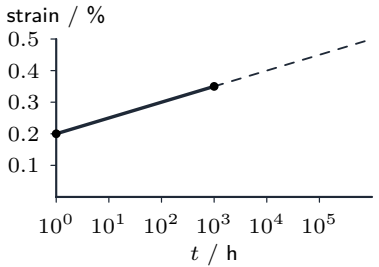
$$a = \frac{1}{\pi}\left(\frac{K_{IC}}{Y\sigma}\right)^2 = \frac{1}{\pi}\left(\frac{3.5}{224}\right)^2 = \mathbf{78}\ \boldsymbol{\mu}\mathbf{m}$$

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Exercise 3.1

3.1 A PVC pipe is tested at a constant stress of 5.0 MPa. Its creep strain is 0.20% after 1 h and 0.35% after 1000 h, and it rises by the same amount in each tenfold step of time.

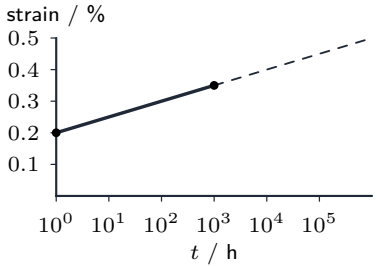
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3.1

$$E_c = \frac{5.0}{0.0020} = \mathbf{2.5\ GPa} \text{ and } \frac{5.0}{0.0035} = \mathbf{1.4\ GPa}$$

strain rises 0.05% per decade; 50 years $= 4.4 \times 10^5$ h $= 5.64$ decades: $\varepsilon = 0.48\%$; $E_c = \mathbf{1.0\ GPa}$, less than half the short-time value

Exercise 3.2

3.2 A bar of the carbon fibre composite in worked example 1 carries 500 MPa along the fibres.

Find the strain, the stress in the fibres and in the matrix, and the share of the load carried by the fibres. Explain why the matrix is still needed. [4]



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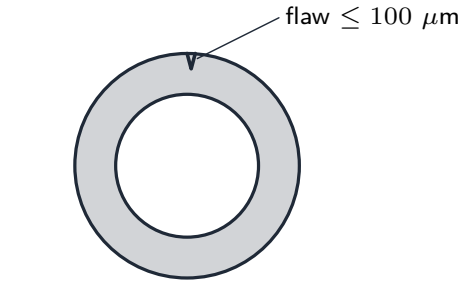
$\varepsilon = \dfrac{500}{139\,400} = 3.59 \times 10^{-3}$; $\sigma_f = 230\,000\varepsilon = \mathbf{825\ MPa}$, $\sigma_m = \mathbf{12.6\ MPa}$

share $= \dfrac{0.60 \times 825}{500} = \mathbf{99}\%$; the matrix holds the fibres in line, passes load between them and protects them

Exercise 3.3 (a)

3.3 A pump seal ring has a peak local stress of 300 MPa. The inspection can find flaws only down to 100 μm, so flaws up to 100 μm may be present ($Y = 1.12$). Two ceramics are possible: alumina ($K_{IC} = 4.0$ MPa m$^{1/2}$) and transformation-toughened zirconia ($K_{IC} = 10$ MPa m$^{1/2}$).

(a) Find the fracture stress of alumina with a 100 μm flaw. [3]

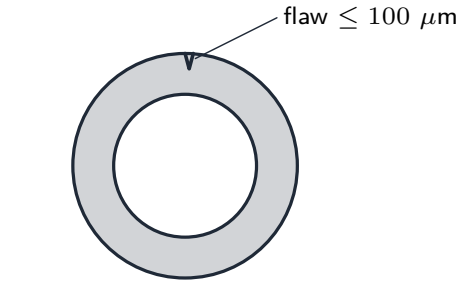


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(a) Find the fracture stress of alumina with a 100 μm flaw. [3]



(a) $\sigma_f = \dfrac{4.0}{1.12\sqrt{\pi \times 10^{-4}}} = \mathbf{201\ MPa}$; $201 < 300$: alumina **fails**

Exercise 3.3 (b)

3.3 A pump seal ring has a peak local stress of 300 MPa. The inspection can find flaws only down to 100 μm, so flaws up to 100 μm may be present ($Y = 1.12$). Two ceramics are possible: alumina ($K_{IC} = 4.0$ MPa m$^{1/2}$) and transformation-toughened zirconia ($K_{IC} = 10$ MPa m$^{1/2}$).

(b) Find the fracture stress and factor of safety of zirconia. [2]

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(b) Find the fracture stress and factor of safety of zirconia. [2]

(b) $\sigma_f = \mathbf{504\ MPa}$; factor of safety $\dfrac{504}{300} = \mathbf{1.7}$

Exercise 3.3 (c)

3.3 A pump seal ring has a peak local stress of 300 MPa. The inspection can find flaws only down to 100 μm, so flaws up to 100 μm may be present ($Y = 1.12$). Two ceramics are possible: alumina ($K_{IC} = 4.0$ MPa $\text{m}^{1/2}$) and transformation-toughened zirconia ($K_{IC} = 10$ MPa $\text{m}^{1/2}$).

(c) Find the flaw size the inspection would have to find for alumina to have a factor of safety of 1.5. Choose a material. [3]

Exercise 3.3 (c)

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(c) Find the flaw size the inspection would have to find for alumina to have a factor of safety of 1.5. Choose a material. [3]

(c) need $\sigma_f = 450$ MPa: $a = \frac{1}{\pi}\left(\frac{4.0}{1.12 \times 450}\right)^2 =$ **20 μm**; far finer than the inspection can see, so choose **zirconia**