inkPhysics

ANSWER BOOK

Stress, strain and the Young modulus

Materials · Year 12

AQA 3.4.2.2 · CIE 6.1.5, 6.1.6 · OCR A 3.4.2(c), 3.4.2(d)(i), 3.4.2(d)(ii), 3.4.2(e)

18 questions · 54 marks

NAVY EDITION

SECTION A · Warm-up

A1 Tensile stress = force / cross-sectional area ($\sigma = F/A$), unit pascal (Pa) (1). Tensile strain = extension / original length ($\varepsilon = \Delta L/L$), which has no unit (1). [2]

A2 $\sigma = F/A = 40/(2.0 \times 10^{-6})$ (1)
$\sigma = 2.0 \times 10^{7}$ Pa (1) [2]

A3 $\varepsilon = \Delta L/L = 1.0 \times 10^{-3}/2.5$ (1)
$\varepsilon = 4.0 \times 10^{-4}$ (1) [2]

A4 A brittle material fractures with little or no plastic deformation (1). Its stress–strain graph is a straight line that ends suddenly at the fracture point, with no extended plastic region (1). [2]

A5 E is the gradient of the straight region $= \sigma/\varepsilon = 8.0 \times 10^{7}/(4.0 \times 10^{-4})$ (1) $= 2.0 \times 10^{11}$ Pa (1). [2]

SECTION B · Standard

B1 (a) $\sigma = 60/(1.5 \times 10^{-6}) = 4.0 \times 10^{7}$ Pa (1) [4]
(b) $\varepsilon = 0.80 \times 10^{-3}/2.0 = 4.0 \times 10^{-4}$ (1)
(c) $E = \sigma/\varepsilon$ (1)
$E = 1.0 \times 10^{11}$ Pa (1)

B2 $\Delta L = FL/(AE)$ (1) [3]
$= (50 \times 3.0)/(1.0 \times 10^{-6} \times 2.0 \times 10^{11})$ (1)
$\Delta L = 7.50 \times 10^{-4}$ m (0.75 mm) (1)

B3 The graph is a straight line from the origin up to the limit of proportionality (1), then curves; the elastic limit lies just beyond it (1). The Young modulus is the gradient of the straight, initial part (stress ÷ strain) (1). [3]

B4 (a) $E = \tfrac{1}{2}F\Delta L = \tfrac{1}{2} \times 60 \times 0.80 \times 10^{-3}$ (1) [3]
$E = 0.024$ J (1)
(b) energy density $= \tfrac{1}{2}\sigma\varepsilon = \tfrac{1}{2} \times 4.0 \times 10^{7} \times 4.0 \times 10^{-4} = 8000$ J m^{-3} (1)

B5 $\Delta L = FL/(AE)$, and $A \propto d^2$, so doubling the diameter makes $A_P = 4A_Q$ (1). $\Delta L_P/\Delta L_Q = (L_P/A_P)/(L_Q/A_Q) = 2/4$ (1) $= 0.5$: P extends half as much as Q (1). [3]

B6 A long wire, and the larger stress a small cross-section gives, both make the extension larger for a given load (1). A larger extension carries a smaller percentage uncertainty, so the value of E is more precise (1). [2]

B7 Weight of wire = mass × g = ρALg, and the top of the wire supports all of it (1). Stress = weight/A = $\rho ALg/A = \rho gL$, independent of the area (1). $\sigma = 7800 \times 9.81 \times 120 = 9.2 \times 10^6$ Pa (1). [3]

SECTION C · Stretch

C1 $A = \pi(d/2)^2 = \pi \times (0.25 \times 10^{-3})^2 = 1.96 \times 10^{-7}\ m^2$ (1) [3]
Maximum force = $\sigma_{break}A = 4.0 \times 10^8 \times 1.96 \times 10^{-7}$ (1)
F = 79 N, to the two significant figures the stress and the diameter carry (1)

C2 $A = FL/(E\Delta L)$ (1) [4]
$= (100 \times 1.5)/(2.0 \times 10^{11} \times 0.50 \times 10^{-3})$ (1)
$A = 1.50 \times 10^{-6}\ m^2$ (1)
$d = \sqrt{(4A/\pi)} = 1.38$ mm (1)

C3 Clamp a long thin wire, hang increasing known loads and measure the extension with a marker and ruler (or vernier) (1), plus the original length with a rule and the diameter with a micrometer (to get area) (1). Plot stress against strain; the gradient of the straight region gives E (1). [3]

C4 $A = \pi(d/2)^2 = \pi \times (3.0 \times 10^{-3})^2 = 2.83 \times 10^{-5}\ m^2$ (1). Working stress = F/A = $8000/(2.83 \times 10^{-5}) = 2.8 \times 10^8$ Pa (1). Maximum permitted stress = ½ × $5.0 \times 10^8 = 2.5 \times 10^8$ Pa (1). The working stress exceeds this, so the cable may not be used; a larger diameter is needed (1). [4]

C5 The same tension of 40 N acts throughout both sections (1). $\Delta L_{steel} = FL/(AE) = (40 \times 1.0)/(2.0 \times 10^{-7} \times 2.0 \times 10^{11}) = 1.0$ mm (1). $\Delta L_{brass} = (40 \times 1.0)/(2.0 \times 10^{-7} \times 1.0 \times 10^{11}) = 2.0$ mm (1). Total extension = 3.0 mm (1). [4]

C6 Both graphs begin with a straight region through the origin whose gradient is the Young modulus (1). The ductile metal passes a yield point, beyond which it undergoes a large plastic strain at little extra stress (1); the maximum stress it withstands is its breaking stress, and fracture occurs at large strain (1). The brittle material's graph stays straight until it fractures, with little or no plastic region (1). The area under the brittle graph is far smaller, so the brittle material absorbs little energy and fails suddenly, without warning (1). [5]