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SOLUTIONS
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Material behaviour and design solutions

AQA AS 7407 and first-year A Level 7408 | OCR A AS H156 and A Level H556

Matching solutions and teaching prompts for the class review | 38 marks

Specification points covered

- AQA 7407 / 7408: 3.4.2.1 selected density, stress, strain, breaking stress, fracture and elastic/plastic behaviour; 3.4.2.2 selected Young modulus and graph analysis.
- OCR A H156 / H556: 3.2.4(a) density; 3.4.2(c), (d)(i), (e), (f) selected stress, strain, strength, modulus and material behaviour. The full experimental method is a separate worksheet.

The Aster warehouse robot sorts fragile parcels. Engineers must choose its inspection window, safety link and impact pad from measured material evidence. Graphs are schematic; crosses indicate fracture. Compare slopes only on the stated common scales.

1. Quantities used in a tensile test [3 marks]

The robot's safety link is tested in tension.

(a) Define tensile stress. [1 mark]

(b) Define tensile strain. [1 mark]

(c) State what is meant by breaking stress. [1 mark]

Answer / mark points: (a) Tensile force divided by cross-sectional area, $\sigma = F/A$. [1] (b) Extension divided by original length, $\varepsilon = \Delta L/L$; no unit. [1] (c) The tensile stress at which the specimen fractures. [1]

Teacher prompt / common error: A specimen deforms. Stress and strain are quantities; stress is not a force and strain is not an extension.

2. Testing the safety link [5 marks]

A round metal test wire has diameter 0.800 mm and original length 0.600 m. Under a tensile force of 150 N it extends by 0.900 mm, within its proportional region. Its measured breaking stress is 420 MPa.

(a) Calculate its cross-sectional area in m^2. [1 mark]

(b) Calculate its tensile stress. [1 mark]

(c) Calculate its tensile strain. [1 mark]

(d) Calculate the Young modulus of the metal. [1 mark]

(e) Decide whether the applied stress is below the measured breaking stress. [1 mark]

Answer / mark points: (a) $A = \pi(0.000800)^2/4 = 5.03 \times 10^{-7}\ m^2$. [1] (b) $\sigma = 150/A = 2.98 \times 10^8$ Pa = 298 MPa. [1] (c) $\varepsilon = 0.000900/0.600 = 0.00150$. [1] (d) $E = \sigma/\varepsilon = 1.99 \times 10^{11}$ Pa = 199 GPa. [1] (e) Yes: 298 MPa < 420 MPa. [1]

Teacher prompt / common error: Convert mm to m; use diameter in $\pi d^2/4$.

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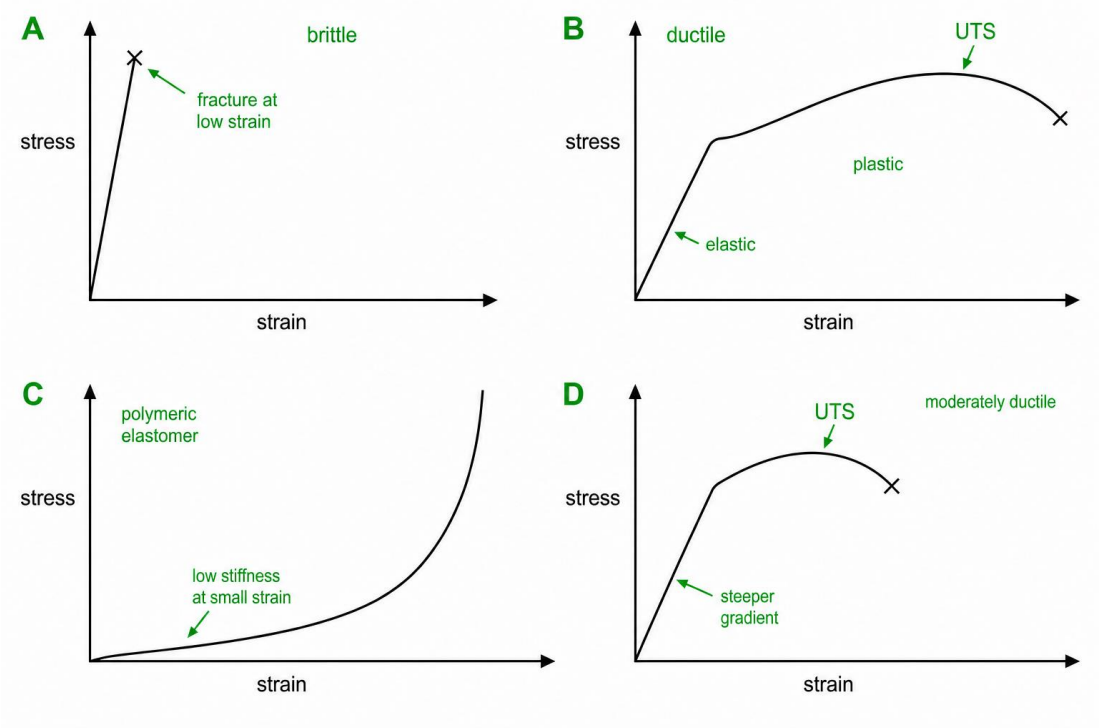
3. Reading the material curves [6 marks]

The four panels use common stress and strain scales. They are generic specimens, not numerical plots for the wire in Question 2. Curve C is a supplied model of a polymeric elastomer over its working range; it recovers its length when unloaded.



(a) Identify the brittle curve and support your choice with graph evidence. [2 marks]

(b) Which fractured specimen is most ductile? Support your choice. [2 marks]

(c) Which curve has the greatest initial gradient, and what property does that gradient represent? [1 mark]

(d) On curve B mark U at the maximum tensile stress and F at the fracture point. [1 mark]

Answer / mark points: (a) A [1]; it fractures at low strain with no appreciable plastic region. [1] (b) B [1]; it has the largest plastic deformation before the fracture cross. [1] (c) A; the initial stress–strain gradient gives Young modulus. Both required. [1] (d) U at the peak, F at the final cross. Both required. [1]

Teacher prompt / common error: The peak is ultimate tensile strength; breaking stress is the stress at the final fracture cross. On a necking curve these differ. The largest initial slope is not automatically the greatest strength.

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4. What happens after unloading [5 marks]

The steel catch link is loaded first within its elastic region and later beyond its elastic limit.

(a) Compare what remains after removing the load in these two cases. [2 marks]

(b) Explain where a plastic specimen's unloading line meets the strain axis and what that intercept means. [2 marks]

(c) Correct the sentence "The stress has plastically deformed." [1 mark]

Answer / mark points: (a) Elastic case: original dimensions recovered. [1] Plastic case: permanent change of length or shape remains. [1] (b) At non-zero strain when stress is zero. [1] The intercept is the remaining permanent strain. [1] (c) The link/material has undergone plastic deformation; a permanent strain remains after unloading. [1]

Teacher prompt / common error: Stress decreases to zero; the specimen deforms. A non-linear loading curve alone does not prove a permanent deformation: unloading evidence is needed.

5. Choosing the safety components [4 marks]

Use graph evidence and the supplied recovery/energy information.

(a) Recommend a curve for an impact-protected optical window that must show very small strain under normal stress. Justify your choice. [2 marks]

(b) Recommend a curve for a sacrificial catch link that must deform substantially before fracture. Justify your choice. [2 marks]

Answer / mark points: (a) A [1]; its steep initial gradient gives small strain for the applied stress. [1] Accept D if its stiffness is justified for the stated need. Impact protection is essential for brittle A. (b) B [1]; its large plastic strain before fracture allows substantial permanent deformation before failure. [1]

Teacher prompt / common error: Choose for the required property. Strong, stiff and ductile are not interchangeable. Do not infer the chemical identity of the specimens from qualitative graphs.

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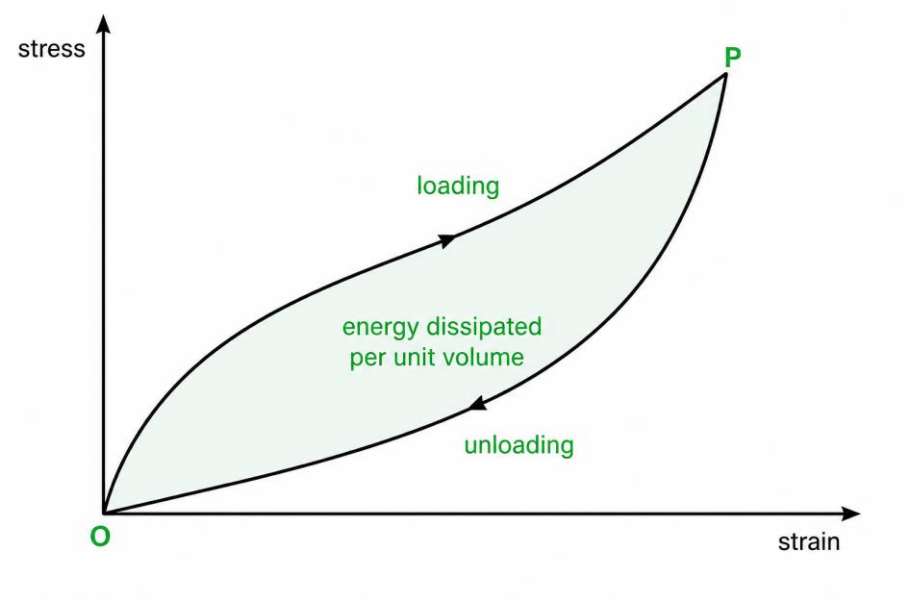
6. The impact pad loading cycle [5 marks]

The supplied elastomer loop returns to O after each cycle. For this test, enclosed stress–strain area equals energy dissipated per unit specimen volume. The measured loop area is 2.50 × 10^5 J m^{-3} and the pad volume is 36.0 cm^3.



(a) Identify the loading and unloading paths using the arrows. [1 mark]

(b) Use the supplied relationship to calculate the energy dissipated per cycle in joules. [2 marks]

(c) Explain why this behaviour reduces rebound. [2 marks]

Answer / mark points: (a) Upper O to P is loading; lower P to O is unloading. Both required. [1] (b) 36.0 cm^3 = 3.60 × 10^{-5} m^3. [1] E = 2.50 × 10^5 × 3.60 × 10^{-5} = 9.00 J. [1] (c) Less energy is returned mechanically during unloading. [1] Energy transferred to internal/thermal stores reduces the rebound kinetic energy and speed. [1]

Teacher prompt / common error: Stress–strain area is energy per unit volume, in J m^{-3} or Pa, not J. Multiply by volume for this pad. The supplied relationship, not specialist polymer recall, supports the application.

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7. Checking a material measurement [5 marks]

A technician proposes using one coarse calliper reading and one large load to determine the Young modulus of a thin metal wire.

(a) Improve the diameter measurements and explain how area is obtained. [2 marks]

(b) State a suitable force–extension graph and explain how its gradient gives E. [2 marks]

(c) Give one specific safety precaution for loading the wire. [1 mark]

Answer / mark points: (a) Use a micrometer with suitable resolution, checking/correcting zero error, at several positions and perpendicular orientations. [1] Use the mean diameter in $A = \pi d^2/4$. [1] (b) Plot force F vertically against extension ΔL horizontally using several loads in the proportional region. [1] $E = (L/A) \times$ gradient, where L is the original test length. [1] (c) For example, use a secured support and a catch tray for falling masses, or a suitable screen/eye protection against a snapping wire. [1]

Teacher prompt / common error: A graph of extension against force is valid if its reciprocal gradient is used: $E = L/(A \times \text{gradient})$. The dedicated Young modulus practical sheet develops plotting and uncertainty fully.

8. A lighter inspection window [5 marks]

A rectangular window is 0.200 m long, 0.100 m wide and 2.00 mm thick. Candidate glass has density 2500 kg m^{-3} and Young modulus 70 GPa; candidate aluminium has density 2700 kg m^{-3} and Young modulus 69 GPa. Only mass and modulus are considered in this screening test.

(a) Calculate the window volume in m^3. [1 mark]

(b) Calculate its mass if made from the glass. [1 mark]

(c) Calculate its mass if made from the aluminium. [1 mark]

(d) The mass limit is 0.105 kg and the minimum modulus is 60 GPa. Decide which material passes both numerical requirements. [2 marks]

Answer / mark points: (a) $V = 0.200 \times 0.100 \times 0.00200 = 4.00 \times 10^{-5}$ m^3. [1] (b) $m = 2500 \times 4.00 \times 10^{-5} = 0.100$ kg. [1] (c) $m = 2700 \times 4.00 \times 10^{-5} = 0.108$ kg. [1] (d) Both exceed 60 GPa. [1] Only glass also meets the mass limit: 0.100 < 0.105 kg, whereas aluminium is 0.108 kg. [1] This is not a complete window recommendation; optical and impact requirements remain.

Teacher prompt / common error: Use the stated screening criteria only: aluminium is not transparent. Density is a material property; mass also depends on volume. The design decision must satisfy both numerical constraints.

Review: support a material choice with a named graph feature or calculation. Keep Young modulus, breaking stress, maximum stress and permanent strain distinct.

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