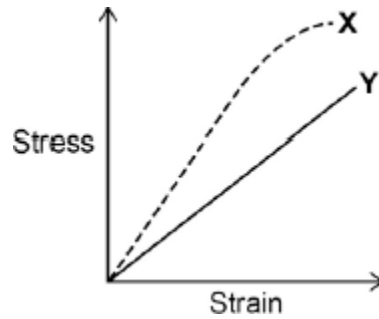


1

The diagram shows how the stress varies with strain for metal specimens X and Y which are different. Both specimens were stretched until they broke.



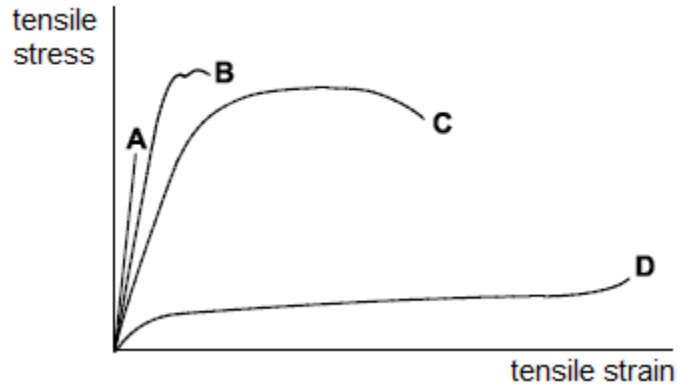
Which of the following is incorrect?

- A X is stiffer than Y ☐
- B X has a higher value of the Young modulus ☐
- C X is more brittle than Y ☐
- D Y has a lower maximum tensile stress than X ☐

(Total 1 mark)

2

The diagram below shows the tensile stress–tensile strain graphs for four materials, **A**, **B**, **C** and **D**, up to their breaking stress.



- (a) State what is meant by tensile stress and tensile strain.

tensile stress _____

tensile strain _____

(2)

- (b) Identify a property of material **A** using evidence from the graph to support your choice.

property _____

evidence _____

(2)

- (c) A cylindrical specimen of material **A** under test has a diameter of 1.5×10^{-4} m and a breaking stress of 1.3 GPa.

Calculate the tensile force acting on the specimen at its breaking point.

tensile force = _____ N

(3)

- (d) Discuss which of the four materials shown on the graph is most suitable for each of the following applications:

- the cable supporting a lift in a tall building
- a rope or cable attached to a person doing a bungee jump.

For each application, you should discuss the reason for your choice and why you rejected the other materials.

(6)

(Total 13 marks)

3

An aerospace engineer has built two differently designed wings. One wing is made from an aluminium alloy and the other is made from a carbon fibre composite.

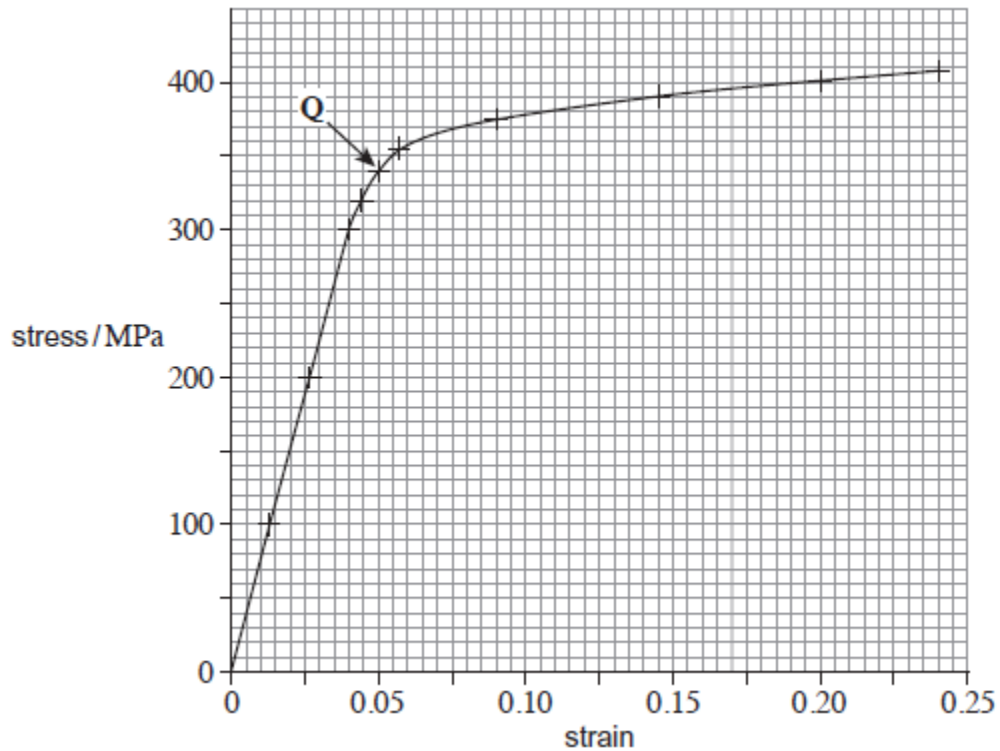
The engineer tests a sample of each material by applying a varying stress.

- (a) Tick (✓) **two** of the boxes in the table below to indicate which are properties of the material from which the wing is made.

breaking stress	
stiffness constant, k	
tensile strain	
tensile stress	
Young modulus	

(1)

- (b) Below is the stress–strain graph that the engineer obtains for the aluminium alloy.



- (i) The engineer has labelled a point **Q** on the graph. This is a point beyond which the behaviour of the material changes irreversibly. State the name for this point.

(1)

- (ii) Use the graph to determine the Young modulus of the aluminium alloy.
Show your working.

Young modulus = _____ Pa

(2)

- (c) The engineer who carried out the experiment to obtain the stress–strain graph decided to stretch another sample to a strain of 0.10. She then gradually reduced the stress to zero.

Show by drawing on the graph how you would expect the stress to vary with strain as the stress is reduced.

(2)

- (d) Calculate the volume of 25.0 kg of the aluminium alloy.

density of aluminium alloy = $2.78 \times 10^3 \text{ kg m}^{-3}$.

volume = _____ m^3

(1)

- (e) 1.28% of the aluminium alloy's volume is copper.
Calculate the mass of pure aluminium needed to make 25.0 kg of the aluminium alloy.

density of pure aluminium = $2.70 \times 10^3 \text{ kg m}^{-3}$.

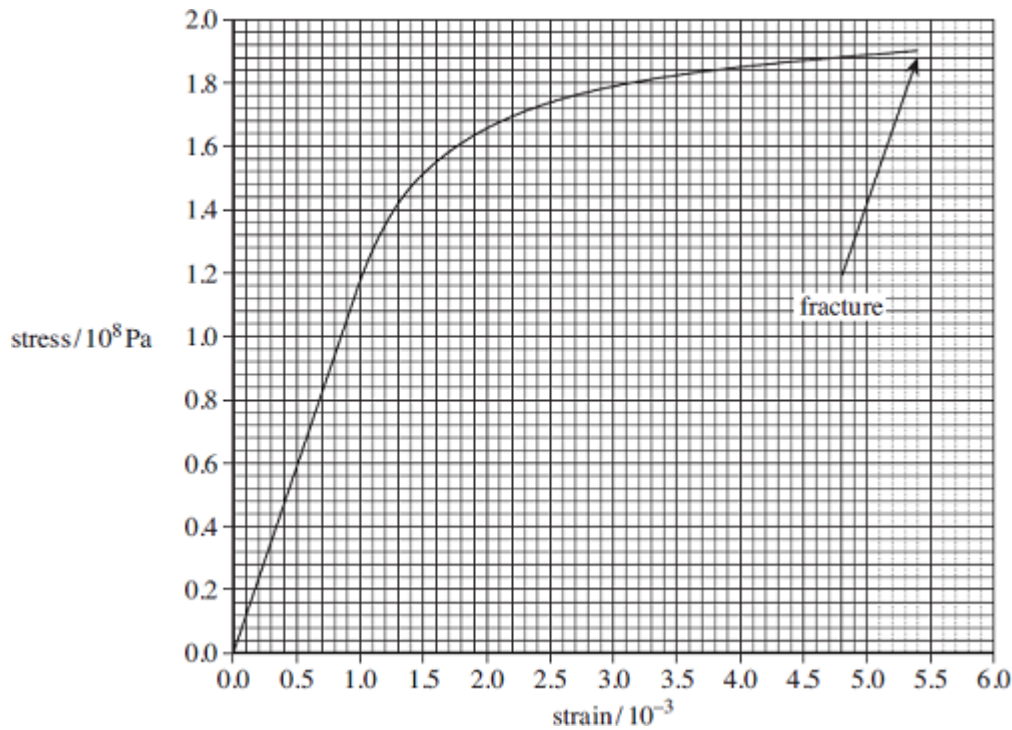
mass of pure aluminium = _____ kg

(2)

(Total 9 marks)

4

The figure below shows a stress-strain graph for a copper wire.



- (a) Define tensile strain.

(1)

- (b) State the breaking stress of this copper wire.

answer = _____ Pa

(1)

- (c) Mark on the figure above a point on the line where you consider plastic deformation may start.

Label this point **A**.

(1)

- (d) Use the graph to calculate the Young modulus of copper. State an appropriate unit for your answer.

answer = _____

(3)

- (e) The area under the line in a stress-strain graph represents the work done per unit volume to stretch the wire.
- (i) Use the graph to find the work done per unit volume in stretching the wire to a strain of 3.0×10^{-3} .

answer = _____ J m⁻³

(2)

- (ii) Calculate the work done to stretch a 0.015 kg sample of this wire to a strain of 3.0×10^{-3} .

The density of copper = 8960 kg m⁻³.

answer = _____ J

(2)

- (f) A certain material has a Young modulus greater than copper and undergoes brittle fracture at a stress of 176 MPa.

On the figure above draw a line showing the possible variation of stress with strain for this material.

(2)

(Total 12 marks)

5

- (a) When determining the Young modulus for the material of a wire, a *tensile stress* is applied to the wire and the *tensile strain* is measured.

- (i) State the meaning of

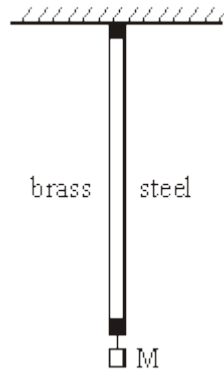
tensile stress _____

tensile strain _____

- (ii) Define the Young modulus _____

(3)

- (b) The diagram below shows two wires, one made of steel and the other of brass, firmly clamped together at their ends. The wires have the same unstretched length and the same cross-sectional area. One of the clamped ends is fixed to a horizontal support and a mass M is suspended from the other end, so that the wires hang vertically.



- (i) Since the wires are clamped together the extension of each wire will be the same. If E_S is the Young modulus for steel and E_B the Young modulus for brass, show that

$$\frac{E_S}{E_B} = \frac{F_S}{F_B},$$

where F_S and F_B are the respective forces in the steel and brass wire.

- (ii) The mass M produces a total force of 15 N. Show that the magnitude of the force $F_S = 10$ N.

the Young modulus for steel = 2.0×10^{11} Pa

the Young modulus for brass = 1.0×10^{11} Pa

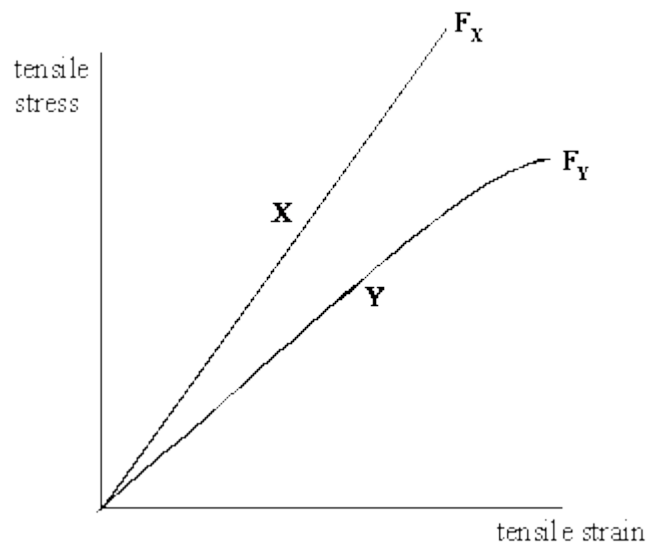
- (iii) The cross-sectional area of each wire is $1.4 \times 10^{-6} \text{ m}^2$ and the unstretched length is 1.5 m. Determine the extension produced in either wire.

(6)

(Total 9 marks)

6

- (a) The graph shows the variation of *tensile stress* with *tensile strain* for two wires **X** and **Y**, having the same dimensions, but made of different materials. The materials fracture at the points F_X and F_Y respectively.



You may be awarded marks for the quality of written communication provided in your answer to the following questions.

State, with a reason for each, which material, **X** or **Y**,

- (i) obeys Hooke's law up to the point of fracture,

- (ii) is the weaker material,

(iii) is ductile,

(iv) has the greater elastic strain energy for a given tensile stress.

(8)

- (b) An elastic cord of unstretched length 160 mm has a cross-sectional area of 0.64 mm^2 . The cord is stretched to a length of 190 mm. Assume that Hooke's law is obeyed for this range and that the cross-sectional area remains constant.

the Young modulus for the material of the cord = $2.0 \times 10^7 \text{ Pa}$

(i) Calculate the tension in the cord at this extension.

(ii) Calculate the energy stored in the cord at this extension.

(5)

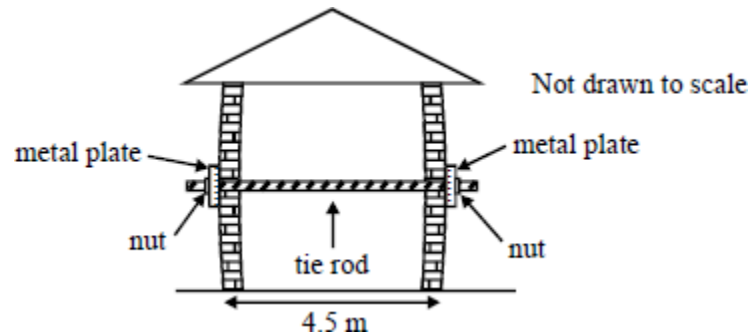
(Total 13 marks)

7

- (a) Explain why an engineer needs to consider *the yield stress* of a metal such as steel when deciding on its suitability for use in the construction of a building or a bridge.

(2)

- (b) In order to prevent the collapse of walls of old buildings a metal rod is often used to tie opposite walls together, as shown below.



In one case a steel tie rod of diameter 19 mm is used as shown above. When the nuts are tightened, the rod extends by 1.5 mm. The Young modulus of steel is 2.1×10^{11} Pa.

Calculate:

- the force exerted on the walls by the rod;
- the elastic strain energy in the rod when it is extended by 1.5 mm.

(3)

(2)

(Total 7 marks)

8

- (a) State what is meant by the *yield stress* of a material.

(3)

- (b) A steel piano wire has a diameter of 1.8×10^{-3} m and a length of 1.55 m. When tightened to emit a note of the required frequency it extends by 1.3×10^{-3} m. The Young modulus of the steel is 2.1×10^{11} Pa.

- Calculate the force exerted on the frame of the piano by this wire.
- Calculate the strain energy stored in this stretched wire.

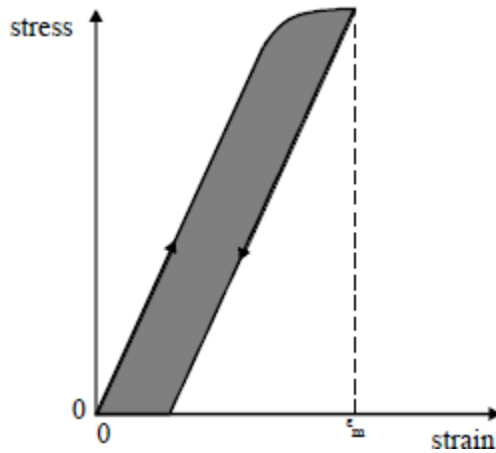
(3)

(2)

(Total 8 marks)

9

The graph shows the variation of stress with strain for a ductile alloy when a specimen is slowly stretched to a maximum strain of ϵ_m and the stress is then slowly reduced to zero.



The shaded area

- A represents the work done per unit volume when stretching the specimen
- B represents the energy per unit volume recovered when the stress is removed
- C represents the energy per unit volume which cannot be recovered
- D has units of J m^{-1}

(Total 1 mark)

10

Figure 1 and **Figure 2** both show the side view of a steel bolt.

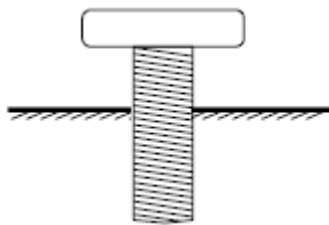


Figure 1

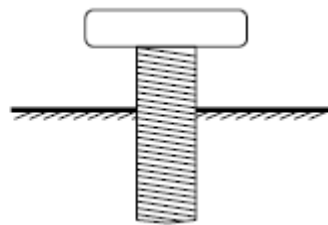


Figure 2

- (a) Show on **Figure 1** forces acting on the bolt which would produce a tensile strain.

(1)

- (b) The ultimate tensile stress of steel is 5.0×10^8 Pa, the elastic limit is 2.5×10^8 Pa and the Young modulus of steel is 2.0×10^{11} Pa.

Defining any terms used, state what is meant by:

- (i) *tensile stress*;

(1)

- (ii) *tensile strain*;

(1)

- (iii) *the elastic limit*.

(1)

- (c) When the main engines of a space shuttle are fired, they develop a total thrust of 4.5×10^6 N. In a test firing the shuttle is held to the launch pad by 8 steel bolts each of diameter 9.0×10^{-2} m. Using data given in (b):

- (i) calculate the strain for each bolt during the test;

(4)

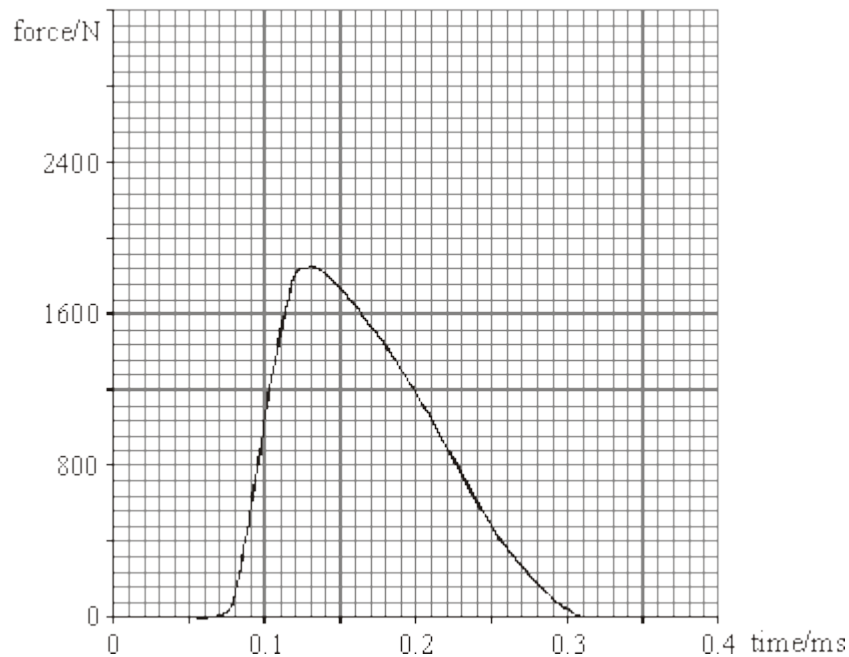
- (ii) determine the minimum number of bolts that could have been used when carrying out the test.

(3)

(Total 11 marks)

11

The diagram below shows how the impact force on the heel of a runner's foot varies with time during an impact when the runner is wearing cushioned sports shoes.



- (a) Estimate the maximum stress on the cartilage pad in the knee joint as a result of this force acting on the cartilage pad over a contact area of 550 mm^2 .

(4)

- (b) On the diagram above, sketch the graph of force against time you would expect to see if a sports shoe with less cushioning had been used.

(3)

(Total 7 marks)

Mark schemes

1

C

[1]

2

- (a) tensile stress is the force exerted per/over cross sectional area ✓
can use equation but must define terms

1

tensile strain is the extension per/over original length ✓
NOT compared to

1

- (b) material is brittle ✓

2nd mark dependent on first

1

shown on graph by little or no of plastic behaviour OR by linear
behaviour/straight line to breaking stress ✓

OR

material has high Young modulus OR material is stiff ✓

shown on graph by large gradient/steep line (compared to other materials) ✓

1

- (c) $\text{area} = \pi \times (1.5 \times 10^{-4})^2 / 4 = 1.77 \times 10^{-8}$ ✓

1

tensile force = 1.77×10^{-8} ✓

1

= 23 (N) ✓

1

if use diameter as radius -1

if use incorrect formula ($d^2 2\pi r$ etc. -2)

range 22.5 – 24

power of ten error -1

if calculated area incorrectly get following answers

diameter as radius = 92 (2 marks)

$d^2 = 7.3$ (1 mark)

$2\pi r = 610\,000$ (1 mark)

if use d for area then zero

- (d) **The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist marking this question.**

Level 3

Correct materials selected for **each** application (B/C for lift and D for bungee). One reason for choices given for **each** application and explanation why at least one other material would be rejected for **each** application.

6

Correct materials selected for **each** application (B/C for lift and D for bungee). One reason for choices given for **each** application and explanation why at least one other material would be rejected for **one** application.

5

The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.

Level 2

Correct material selected for **one** application (B/C for lift and D for bungee). **One** reason for choice given for one application and explanation why at least one other material would be rejected for **one** application.

4

Correct material selected for **one** application (B/C for lift and D for bungee). **One** reason for choices given application.

OR

Correct materials selected for **each** application (B/C for lift and D for bungee). One reason for choices given for **each** application

3

The student presents relevant information and in a way which assists the communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.

Level 1

No correct material selected but at least **two** properties necessary for an application given.

2

No correct material selected but at least **one** property necessary for an application given.

1

The student presents some relevant information in a simple form. The text is usually legible. Sp&g allow meaning to be derived although errors are sometimes obstructive.

Level 0

No correct material selected and no properties necessary for an application given

The student's presentation, spelling and grammar seriously obstruct understanding.

0

*The following statements may be present for cable supporting a lift
material B/C is used for the lift because it has a high breaking
stress and a high Young modulus*

material A not chosen because lower breaking stress

material A not chosen because fails without warning

material C not chosen because has a lower breaking stress

*material D not chosen as larger increase in strain for a given
increase in stress*

material D not chosen as low breaking stress.

*material D a given stress produces a large strain meaning large
extension*

*The following statements may be present for rope or cable used for
bungee jump*

*material D chosen as due large strain for given stress
time taken to come to rest lengthens*

*material D is chosen because D can store a large amount of energy
before failure*

*not A ,B or C because high Young Modulus so sudden stop
resulting in large forces*

not A as brittle and therefore limited strain and sudden failure

not C because requires a large strain before plastic behaviour

not C because if behaves plastically will not return to original length

[13]

3

(a)

breaking stress	✓
stiffness constant, k	
tensile strain	
tensile stress	
Young modulus	✓

1

(b) (i) elastic limit ✓

only one attempt at the answer is allowed

1

(ii) ($E = 300 \times 10^6 / 4 \times 10^{-2} = 7.5 \times 10^9$)

7.5 (Pa) ✓ allow 7.4 to 7.6 (Pa)

$\times 10^9$ ✓

*first mark is for most significant digits ignoring the power of 10. E.g.
7500 gains mark*

2

- (c) straight line beginning on existing line at a strain of 0.10 and hitting the strain axis at a lower non-zero value ✓
line that ends on the x-axis with strain between 0.045 and 0.055 ✓ (only allow if first mark is given)

ie accuracy required $\pm$ one division

2

- (d) $8.99 \times 10^{-3} \text{ (m}^3\text{)}$ ✓ condone 1 sig fig

allow 9.00×10^{-3}

1

- (e) $0.9872 \times 8.99 \times 10^{-3}$ or $= 8.8749 \times 10^{-3} \text{ (m}^3\text{)}$ ✓

allow CE from 4d

$$(m = \rho V) = 2700 \times 8.8749 \times 10^{-3} = 24 \text{ (kg)} \quad \checkmark \quad (23.962 \text{ kg})$$

allow CE from first part, e.g. if 1.28% was used gives 0.311 kg

$$V = 0.9872 \times (d)$$

$$m = 2.665 \times (d)$$

$$1.28\% \text{ of vol} = 1.15 \times 10^{-4} \text{ m}^3$$

2

[9]

4

- (a) extension divided by its **original** length ✓

do not allow symbols unless defined ✓

1

- (b) $1.9 \times 10^8 \text{ (Pa)}$ ✓

1

- (c) point on line **marked 'A'** between a strain of 1.0×10^{-3} and 3.5×10^{-3} ✓

1

- (d) clear evidence of gradient calculation for **straight section**

$$\text{eg } 1.18 \text{ (1.2)} \times 10^8 / 1.0 \times 10^{-3} \quad \checkmark$$

$$= 120 \text{ GPa and stress used } \geq 0.6 \times 10^8 \text{ Pa} \quad \checkmark \quad \text{allow range 116 – 120 GPa}$$

$$\text{Pa or Nm}^{-2} \text{ or N/m}^2 \quad \checkmark$$

3

- (e) (i) clear attempt to calculate correct area (evidence on graph is sufficient) ✓

$$(32 \text{ whole squares} + 12 \text{ part}/2 = 38 \text{ squares})$$

$$(38 \times 10000 =) 380000 \text{ (J m}^{-3}\text{)} \quad \checkmark \quad \text{allow range 375000 to 400000}$$

2

- (ii) $V = m/\rho$ or $0.015/8960$ or $1.674 \times 10^{-6} \text{ (m}^3\text{)}$ ✓

$$380\,000 \times 1.674 \times 10^{-6} = 0.64 \text{ (0.6362 J)} \quad \checkmark \quad \text{ecf from ei}$$

2

- (f) straight line passing through origin (small curvature to the right only above 160 MPa is acceptable) end at 176 MPa ✓ (allow 174 to 178)

straight section to the left of the line for copper (steeper gradient) ✓

2

[12]

5

- (a) tensile stress: force/tension per unit cross-sectional area or $\frac{F}{A}$

with F and A defined (1)

tensile strain: extension per unit length or $\frac{\Delta L}{l}$ with e and l defined (1)

the Young modulus: $\frac{\text{tensile stress}}{\text{tensile strain}}$ (1)

3

- (b) (i) $E_S = \frac{F_S}{A} \frac{l}{\Delta L}$ (1) and $E_B = \frac{F_B}{A} \frac{l}{\Delta L}$ (1) hence $\frac{E_S}{E_B} = \frac{F_S}{F_B}$

(ii) $\frac{E_S}{E_B} = 2$ (1)

$\therefore F = 2F_B$ (1)

$F_S + F_B = 15 \text{ N}$ (1) gives $F_S = 10 \text{ N}$

[or any alternative method]

(iii) $\left(E = \frac{F}{A} \frac{l}{\Delta L} \text{ gives } \right) e = \left(\frac{F}{A} \frac{l}{E} \right) = \frac{10 \times 1.5}{1.4 \times 10^{-6} \times 2.0 \times 10^{11}}$ (1)

$= 5.36 \times 10^{-5} \text{ m}$ (1)

6

[9]

6

- (a) (i) X (1)
stress (force) $\propto$ strain (extension) for the whole length (1)

- (ii) Y (1)
has lower breaking stress (or force/unit area is less) (1)

- (iii) Y (1)
exhibits plastic behaviour (1)

- (iv) Y (1)
for given stress, Y has greater extension
[or greater area under graph] (1)

8

QWC 2

- (b) (i) (use of $E = \frac{F}{A} \times \frac{l}{\Delta L}$ gives)

$$F \left(= \frac{EA\Delta L}{l} \right) = \frac{2.0 \times 10^7 \times 0.64 \times 10^{-6} \times 30 \times 10^{-3}}{160 \times 10^{-3}} \quad (1)$$

(1) for data into correct equation, (1) for correct area

$$= 2.4 \text{ N} \quad (1)$$

(allow C.E. for incorrect area conversion)

- (ii) (use of energy stored = $\frac{1}{2}Fe$ gives) energy = $\frac{2.4 \times 30 \times 10^{-3}}{2} \quad (1)$

$$= 36 \times 10^{-3} \text{ J} \quad (1)$$

(allow C.E. for value of F from (i))

5

[13]

7

- (a) below yield stress material behaves elastically
or returns to original length when forces are removed

B1

above the yield stress: (condone 'at the yield stress')

material behaves plastically/is permanently deformed / is ductile

B1

extends considerably / has large strain / extension

B1

for very small increases in stress / force

B1

Max 2

- (b) (i) Strain = 3.33×10^{-4} or $\frac{1.5 \times 10^{-3}}{4.5}$ seen

C1

$E = \text{stress} / \text{strain}$ and $\text{stress} = F / A$;

or $E = Fl / A\Delta l$

C1

$$A = 2.8 \times 10^{-4} \text{ m}^2 \text{ or } \frac{\pi(0.0019)^2}{4} \text{ or } \pi(9.5 \times 10^{-3})^2 \text{ seen}$$

C1

$$\text{Stress} = 7.0 \times 10^7 \text{ Pa}$$

C1

2 max for C marks

$$\text{Force} = 19.6 \text{ to } 19.8 \text{ (20) kN}$$

A1

(3)

(ii) Strain energy = $\frac{1}{2}F\Delta l$ or $\frac{1}{2}$ their (b)(i) $\times (1.5 \times 10^{-3})$

C1

condone incorrect power or no 10^{-3} for C mark

or $\frac{1}{2} \sigma \epsilon \times \text{volume}$

14.6 to 14.9 (15) J (e.c.f.)

A1

(2)

[7]

8

(a) The force per unit area

B1

at which the material extends considerably / a lot / plastically /

or strain increases considerably etc

NOT doesn't return to its original shape / permanently deformed

B1

for no (or a small) increase in) force / stress

B1

(3)

(b) (i) strain = 8.4×10^{-4} (1.3×10^{-3} / 1.55 seen) (allow if in $E = FL / A\Delta L$)

B1

or area of cross section = 2.54×10^{-6}

or $\pi (0.9 \times 10^{-3})^2$

stress = $E \times \text{strain}$ (explicit or numerically) and

stress = F / A or $E = FL / AL$

C1

force = 440 – 450 N(cao)

A1

(3)

(ii) Energy = $\frac{1}{2} F \Delta l$ or $\frac{1}{2}$ stress $\times$ strain $\times$ volume

C1

0.29 J ecf for F from (b)(i)

A1

(2)

[8]

9

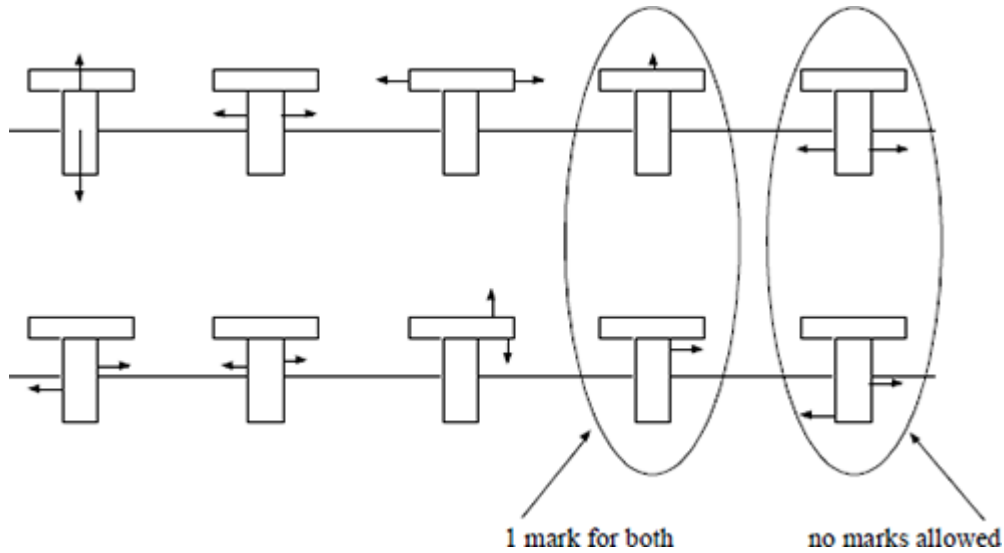
C

[1]

10

- (a) two forces shown producing tension (see examples below)

B1



(2)

- (b) (i) tension / area

or force / area (perpendicular to the surface on which the force acts)

or F / A with terms defined (condone loose definition of area)

B1

(2)

- (ii) extension / original length

or extension per unit length

B1

(2)

- (iii) the point / stress / strain / force or extension up to which

either all energy supplied in stretching is returned when (deforming) forces are removed

or the object returns to its original shape when (deforming forces) are removed

or beyond which further stress causes plastic deformation or permanent deformation

B1

(2)

- (c) (i) force on each bolt = 0.56 MN (ie total force divided by 8)

or

cross-sectional area each bolt = πr^2 plus correct substitution $6.4 \times 10^{-3} \text{ m}^2$

C1

$$\text{stress} = 8.8 \times 10^7 \text{ or } \frac{0.56}{6.4 \times 10^{-3}}$$

stress / strain = Young modulus

C1

$$\text{strain} = 4.4 \times 10^{-4}$$

A1

(4)

- (ii) area of steel needed = maximum force / UTS

or maximum force / elastic limit

C1

$$4.5 \times 10^6 / 5.0 \times 10^8 = 9.0 \times 10^{-3} \text{ m}^2$$

$$\text{or } 4.5 \times 10^6 / 2.5 \times 10^8 = 18.0 \times 10^{-3} \text{ m}^2$$

C1

number of bolts = 9.0×10^{-3} / area of a bolt (allow e.c.f.)

= 1.4 bolts

or = 2.8 bolts

A1

answer = 2 bolts (c.a.o.)

or answer = 3 bolts (c.a.o.)

B1

(3)

[11]

11

- (a) maximum force (from graph) = 1840 (N) (± 100 N) **(1)**

$$\text{max stress} \left(= \frac{\text{force}}{\text{contact area}} \right) = \frac{1840(\text{N})}{550 \times 10^{-6}(\text{m}^2)} \text{ **(1)**}$$

(for correct denominator) **(1)**

$$= 3.3 \times 10^6 \text{ N m}^{-2} \text{ **(1)**}$$

- (b) using shoes without cushioning:
impact time would be less **(1)**
maximum impact force would be greater **(1)**
area under the curve the same **(1)**