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Properties of Matter

Basics You Should Know

Elasticity. Young modulus

1. **Hooke's law**. Extension α tension (force or load) if the proportional (or elastic approximately) limit not exceeded.

2. **Tensile Stress σ** = $\underline{\text{F}}$ (Force)   Unit: Pa or N m^{-2}
                    A   (Area)

                                            .

3. **Tensile strain ε** = $\underline{\text{extension e}}$ Unit: none
                    original length *I*.

4. **Young modulus** *E* = $\underline{\text{tensile stress}}$ **σ**   Unit: Pa or N m^{-2}
                    tensile strain. **ε**

$$E = \frac{F/A}{e/L} = \frac{F\,L}{A\,e}$$

5. To find Young modulus value *E* from load (F) against extension (e) straight line graph, use

$$E = (L/A) \times (F/e) = L/A \times \text{gradient of line.}$$

6. Energy in stretched wire is due to work done against molecular forces.

Within proportional or elastic limit,
Energy or Strain Energy = ½ *Force* x E*xtension*
AND
Energy per unit volume = ½ Stress x Strain

7. Polymers are organic compounds. Their long chains of molecules are made from a basic unit called a "monomer'.

(a) Polymer molecules may be linear, branched or cross-linked. Thermoset polymers such as bakelite are cross-linked and can not be re-moulded after heating. Thermoplastic polymers such as nylon are not cross linked and can be re-moulded after heating.
(b) Plastics have low Young modulus, large elongation and do not obey Hooke's Laws

8. Rubber
(a) Molecules are coiled. With increased tension, molecules uncoil and high strain obtained.
   After all molecules uncoiled, low strain obtained.
(b) When rubber heated, molecules coil up and rubber contracts. Young modulus then increases.
(c) On loading and then unloading, rubber does not fully recover.

Hysteresis is shown by loop in stress-strain graph. Energy lost as heat is proportional to area of loop.
Synthetic rubber used for car tyres have low hysteresis.

Force F (N)

Loading

Unloading
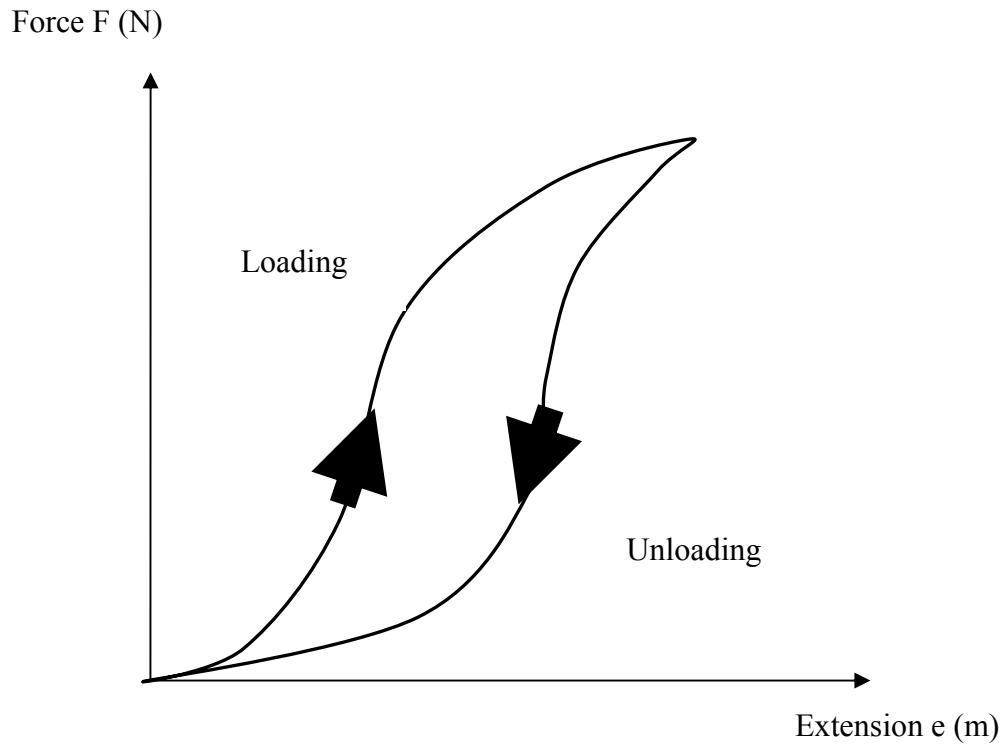
Extension e (m)

Questions

(Assume $g = 10Nkg^{-1}$)

1 (i) State *Hooke's law,* (ii) define *tensile stress, tensile strain, Young modulus* and state the units of each quantity.

2. A load of 20N on a wire of cross-section area 8×10^{-7} m^2 produces an extension of 0.1mm.

   Calculate

   (i)   the tensile stress and strain,
   (ii)   the Young modulus for the metal if its length is 3.0 m.

   Answers: i. 2.5 X 10^7 Pa, 3.3 X 10^{-5}.
   ii. 7.5 X 10^{11} Pa.

3   The Figure A below shows the force *(F)-extension (e)* graphs for two materials X and Y. The cross-section area of X is twice that of Y and the length of X is three times that of Y.

   From the graphs OP and OQ, calculate the ratios of

   (i)   the Young modulus values of X and Y,
   (ii)   the energies stored in X and Y for extensions of 1 mm and 1.5 mm respectively as shown.

   Answers i. 2.81
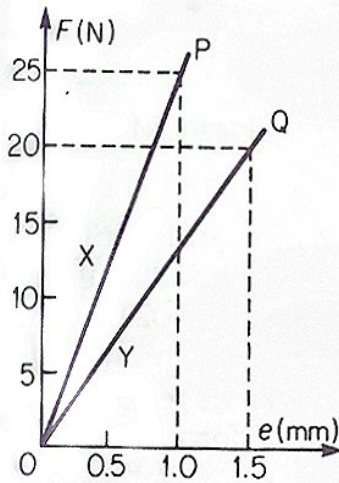   **ii. 0.83**

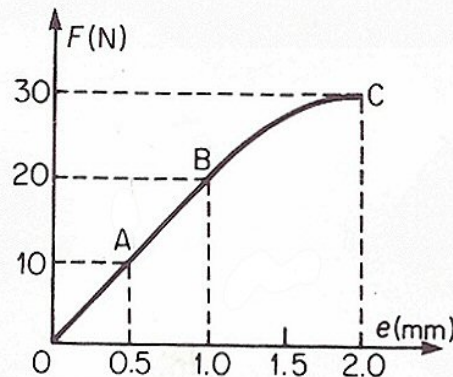Figure A   Figure B

4 In Figure B, OABC is the force *(F)-extension (e)* graph obtained for a length of wire.

(i) Over what range of load is Hooke's law obeyed?
(ii) Calculate the energy stored in the wire for an extension
(a) from 0 to 0.5mm,
(b) from 0.5 mm to l.0 mm.
In each case, can the energy be recovered?

(iii) If the 30N load is taken off, what would be the extension of the wire approximately? Give a reason for your answer.

Answers: ii. (a) 2.5 X 10^{-3}J
(b) 7.5 X 10^{-3}J

5. What force will produce an extension of 0.3 mm in a steel wire 4 m long and area of cross-section of 2 x 10^{-6} m^2 ?
Calculate the energy stored in the stretched wire.
(Young modulus for steel = 2 x 10^{11} Pa (Nm^{-2}).

Answers: 30N
4.5 X 10^{-3}J

6. A load of 15 N produces an extension of 0.1 mm in a wire 10m long. If the Young modulus is 1.8 x 10^{11} N m^{-2} or Pa, find the cross-sectional area and diameter of the wire.

Answers: 8.3 X 10^{-6} m^2
3.3 X 10^{-3}m

7. A steel rod of cross-section 0.2 cm^2 is fixed at both ends. The rod is heated from 12°C to 100°C. Calculate the force required to prevent the rod expanding.
(Young modulus of steel = 2 x 10^{11} N m^{-2}; linear expansivity = 1.1 x 10^{-5}K^{-1}.)

8. Define the terms *proportional limit, elastic limit, elasticity, yield point.* Draw a graph showing how the extension of a wire varies with the applied force, and mark the elastic limit and yield point on it. Explain how the magnitude of the Young modulus is obtained from the graph.

9. Draw a labelled diagram of the apparatus to measure the Young modulus for a wire, and describe the experiment. Show how the Young modulus is calculated after a graph of load *F* against extension *e* is plotted.

10. What is meant by the *stiffness* and the *tensile strength* of glass and steel?
Illustrate your answer with a graph of stress against strain for each and state their differences in stiffness and tensile strength.

11. What is the difference between (i) *elastic deformation* and *plastic deformation,* (ii) *ductile* and *brittle* materials? Give examples in your answer.

12. Rubber shows *hysteresis.* Explain, with the help of diagrams, what this means.
Synthetic rubbers, which have a small hysteresis loop, are used for car tyres. Explain the advantage of the synthetic rubber.

13. A steel wire AB, length 1.000m and cross-section area 8×10^{-7} m^2, is joined to an iron wire BC, length 1.500 m and cross-section area 6×10^{-7}m^2.
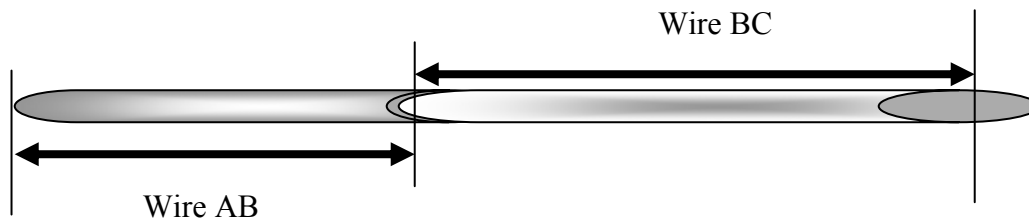
The total length increases by 0.020m when a tensile force is applied along ABC.

If Young modulus of steel is 2.0×10^{11} Pa and that of Iron is 1.2×10^{11} Pa, find:

(i)   the extensions of AB and of BC,
(ii)   the *common* tensile force applied.

Answers: i. 4.6 X 10 -3m, 1.5 X 10-2m
ii. 738N