Paper 2: Materials

Examples Paper 6

Elementary exercises are marked †, problems of Tripos standard $*$.
Answers can be found at the back of the paper.

Friction and wear

1 (a) † Explain, with the help of a sketch, the details of what happens when the surfaces of two metals come into contact.

(b) The mild (medium carbon) steel body of a car weighing 200 kg has been compressed into a cube with a density half that of mild steel (the cube also contains some air). Calculate the nominal area of contact between the cube and the relatively hard metal chute that it sits on. Using the lower value of yield stress for medium carbon steel given in the data book, estimate the true area of contact between the surfaces.

(c) The cube is now tipped into a furnace. During sliding the asperity junctions grow, so that the true area of contact is twice that calculated in part (b). Calculate the friction coefficient between the surfaces if the shear strength of the oxide film separating the surfaces is about 100 MPa. Hence find the minimum angle of elevation of the chute required. Assume that the angle of elevation is small so that the normal reaction on the cube can be approximated by the weight of the cube.

(d) How would this minimum chute angle change with the weight of the car or the degree of compaction of the cube?

(e) How does the hardness of the chute prevent wear of the chute?

(f) Explain how boundary additives put onto the chute would reduce the friction coefficient between the cube and the chute.

(g) Explain why the friction coefficient is likely to increase significantly if the chute were made of rubber.

2 In a wear test, a medium carbon steel pin of hardness 240 HV (kgf/mm^2) is loaded against the surface of a hard steel disc rotating at 6 revolutions per second in air. The pin has a small cross-section, and the wear track has a diameter of 50 mm.

(a) Over a test duration of 1 hour at a normal load of 1 N, the mass of the pin falls by 0.4 mg and the wear debris is found to be oxide, assumed to have the same density as steel. Calculate the wear coefficient, K, for the pin.

(b) The test is then repeated with fresh specimens at a load of 10 N, and after only 1 minute, the pin has lost 10 mg. Discuss the observations and suggest reasons for them. The density of steel is 7.9 Mg m^{-3}.

Visco-elasticity

3 † Given a piece of unknown material, how would you assess if:

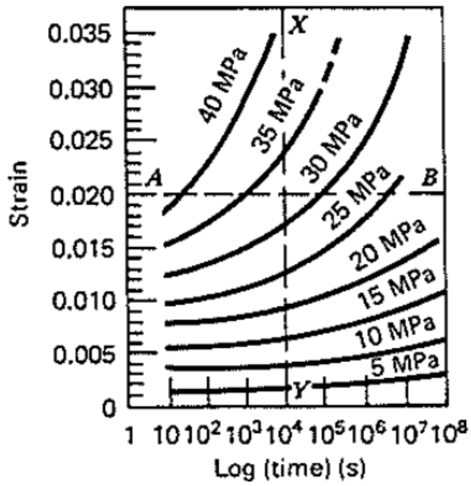
(a) the material's stiffness is isotropic?

(b) the material is non-linear elastic?

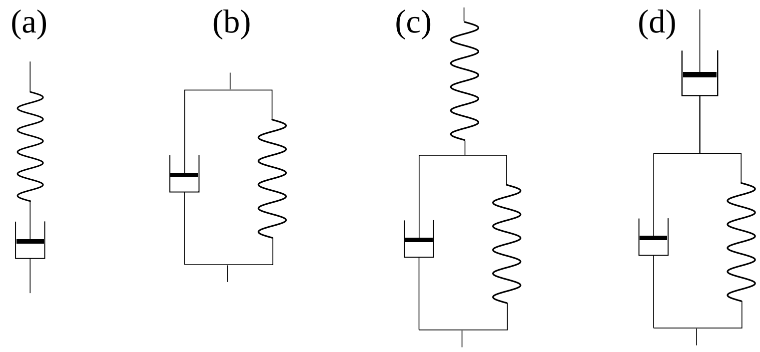
(c) the material has a time-dependent response?

(d) the material can be modelled as linear visco-elastic?

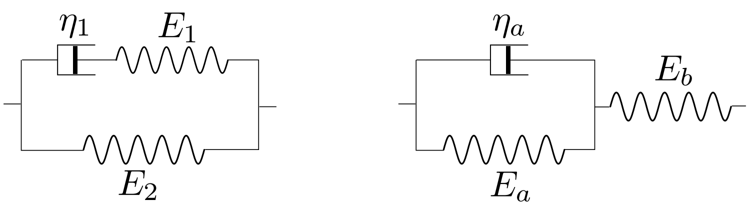
4 † Consider a PVC rod subjected to a steady tensile load of 500 N. A maximum strain of 1% after a year of service is acceptable. Using the data below (from lecture handouts), determine what the minimum rod diameter should be.



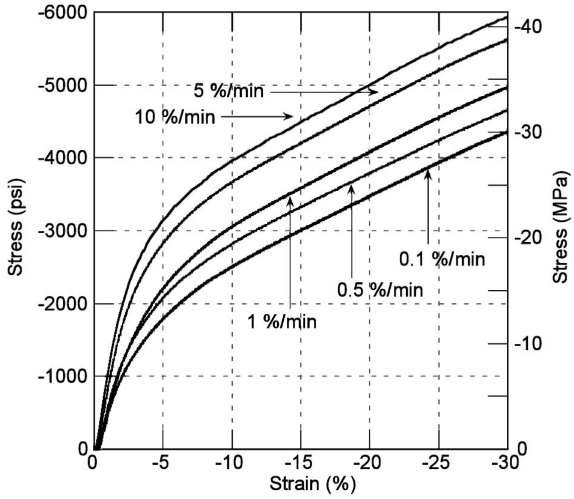
5 For the four spring-dashpot networks below, without any calculation, sketch the expected strain response to an applied step of stress. Briefly explain the reasoning behind your sketches. In each case, indicate the equivalent models at high and low frequency, or short and long time-scales.



6 Show that the two models below are equivalent. Express E_a, η_a and E_b as a function of E_1, η_1 and E_2.



7 $*$ Devise a suitable visco-elastic model to account for the stress-strain curves for the High Density Polyethylene below (extracted from handouts). Fit the data to estimate the relevant parameters. Is the data consistent with a linear model?



8 $*$ When a nylon guitar string is first fitted, strain is imposed via the tuning peg to achieve a suitable tension so that the string vibrates at the required frequency. It is a common experience that after a while the frequency has dropped, implying that the tension has fallen. This behaviour is known as "relaxation".

(a) Do either of the models analysed so far in this paper exhibit this behaviour, so that they might be a candidate constitutive model for a drawn nylon monofilament?

(b) Another familiar experience to guitarists is that if you tune a string down to a lower frequency by reducing the tension, the frequency goes back up again somewhat after a few minutes. Does the model predict this as well?

Suitable past Tripos questions

Friction and wear: 2017 Q11, 2012 Q7
Visco-elasticity: 2016 Q9, 2015 Q12. This material has recently been moved from Part IB so there are not many previous IA questions. Questions can also be found in Part IB Paper 3, but the format is a little different from IA papers.

Answers

1(b). Nominal area = 0.137 m^2, true area of contact = 2.14mm^2. Note the different units.

1(c). $\mu \approx$ 0.22, $\sin^{-1}$(0.22)=13°,

1(d). No change. μ is independent of the nominal area and the weight.

2(a). K = 3.5 10^{-5}.

2(b). When the load increases to 10 N, the wear rate is 1500 times higher. The oxide layer can no longer sustain the load resulting in severe wear.

4. 6.5 mm

6. $E_b = E_1 + E_2$, $E_a = (E_1 + E_2)\frac{E_2}{E_1}$, $\eta_a = \eta_1 \left(\frac{E_1+E_2}{E_1}\right)^2$

7. Notice that the data is obtained from ramping up the strain at constant rate. Think about the relationship between this curve and the relaxation/creep responses of the different models studied in the course.