

3.032 Quiz 2  
Fall 2006

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***DO NOT TURN THIS PAGE OVER AND START THE QUIZ UNTIL YOU  
ARE ASKED TO DO SO.***

Guidelines:

1. Show all your work on the sheets included in this stapled document.
  2. Use partial credit to your advantage. If you're running short on time, solve algebraically and then solve numerically (plugging in numbers) later.
  3. If there is not much space given for you to provide an answer, we want you to be brief.
  4. You may not need to use all the information given (e.g., dimensions) to reach your conclusions.
  5. Enjoy your dark chocolate before getting started! It lowers blood pressure (*JAMA*, 2003), contains antioxidants (*Nature*, 2003), and supposedly helps neural synapses responsible for memory to fire faster (*Nature Health*, 2003).
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NAME (PRINTED):

I agree that this document represents my own independent work on this quiz, using only my own brain, my allowed crib sheet of equations and notes, and my pen / pencil / calculator / protractor / compass / ruler / sliderule.

SIGNATURE:

GOOD LUCK!

1. You and your labmate have been given a joint project by your UROP advisor. He has asked you both to measure all the elements of the stiffness tensor  $C_{ijkl}$  of two new proteins he has crystallized and is considering for use in a flexible, organic integrated circuit that must withstand mechanical bending.

Another student has already used x-ray diffraction to determine the crystal structure of the proteins: protein A exhibits a tetragonal unit cell, whereas protein B exhibits an orthorhombic unit cell. Your labmate says, "Let's each measure the elastic constants  $C_{ijkl}$  of one protein. Which one do you want to do, A or B?"

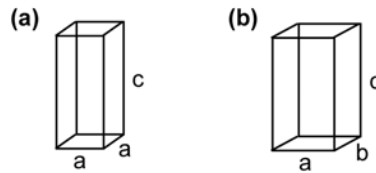


Figure 1: (a) Tetragonal; (b) Orthorhombic unit cells.

Under the assumption that you'd like to spend as little time as possible on this project, what is your answer? Explain concisely, but as fully and accurately as possible, using the concepts discussed in 3.032.

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2. Poly(dimethylsiloxane) or PDMS is a crosslinked elastomer that is commonly used to build optical/electronic/biomedical devices via soft lithography (borrowing from microelectronics processing approaches to make flexible, patterned surfaces). The glass transition temperature of pure PDMS is  $-120^{\circ}\text{C}$ , and crosslinking can be induced by exposure to UV light.

At molecular weights on the order of  $10^6$  g/mol or degree of polymerization (DP)  $\approx 60$ , PDMS is said to exhibit a viscoelastic response with Young's elastic modulus  $E$  reported to be about 2 MPa for short times / high strain rates. At very low molecular weights ( $\sim 10^2$  g/mol) or DP, PDMS acts as a Newtonian fluid.

- (a) Briefly discuss why it is confusing that PDMS is widely described as a rubber elastic polymer, but is also widely reported to exhibit measurable elastic moduli  $E$ .

- (b) Propose an experiment you would try to assess whether PDMS is best described as a hyperelastic or a linear viscoelastic material.

3. A jewelry maker has created a die that she is using to form a new cufflink made of stainless steel. From matweb.com, she knows that the yield strength of this particular stainless steel (AISI 304)  $\sigma_y$  is about 200 MPa, the elastic modulus  $E$  is about 200 GPa, and the Poisson's ratio  $\nu$  is about 0.33. She needs to know how much stress to apply to the metal slab to reduce the thickness to 3 mm, the cufflink thickness.

The die is a simple channel that does not constrain the metal in the  $x$ -direction, and the channel is well lubricated so that all frictional forces and stresses along the channel walls can be ignored.

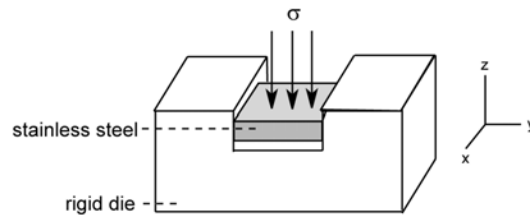


Figure 2: Die in which stainless steel slab of initial thickness 6 mm will be subjected to a normal stress  $\sigma_{zz}$ .

- (a) State all the components of the stress tensor  $\sigma_{ij}$  that exist in the stainless steel slab under that applied stress. Be sure to note components that are identically zero.

- (b) Which normal strain components  $\epsilon_{ii}$  are zero, and why?

(c) Treating the stainless steel as an isotropic continuum, use your answers in (a) and (b) to express the nonzero stresses in terms of elastic constants and  $\sigma$ . Assume the applied stress in the z-direction  $\sigma_{zz} = \sigma$ , some constant value.

(d) What is the magnitude (value in [Pa]) of the stress required to permanently deform the stainless steel according to the Tresca criterion of yielding?

(e) What is the magnitude (value in [Pa]) of the stress required to permanently deform the stainless steel according to the von Mises criterion of yielding?

(f) If you were her, which criterion would you use to make your decision about how much stress to apply, and *why*?

- (g) She has tacitly assumed that the yield criterion that tells her the stress required to initiate plastic deformation is the same stress she'll need to compress the stainless steel to the desired thickness of 3 mm.

Draw a uniaxial stress-strain response that shows how she thinks stainless steel deforms both before and after yielding, as quantitatively and as accurately as possible.

- (h) Her available instruments are not capable of applying the required stress  $\sigma$  that you computed above. Describe one way you would modify the material or the process in order to reduce the stress  $\sigma$  required to initiate plastic deformation, and *why* that mechanism is likely to be successful.

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END OF QUIZ 2

USE THIS PAGE FOR EXTRA PROBLEM SOLVING AS REQUIRED.