3.22 Mechanical Properties of Materials
Spring 2008

3.22 Mechanical Behavior of Materials
Spring 2008

Quiz 3

- Show all your work on the sheets included in this stapled document.
- Use partial credit to your advantage. If you're running short on time, solve algebraically and then solve numerically (plugging in numbers) later.
- If there is not much space given for you to provide an answer, I want you to be brief.
- You may not need to use all the information given (e.g., dimensions) to reach your conclusions.
- Enjoy your fruit/nut mixture before getting started! Nuts and dried fruits reduce low-density lipoprotein cholesterol, decrease oxidative damage to tissues, and improve indices of cardiovascular disease associated with stress.

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:

1. In addition to predicting the mechanical responses of linear viscoelastic materials like amorphous polymers, springs and dashpots can be used to created models of creep and recovery in crystalline materials.

(a) Although springs and dashpots are used to predict the behavior of amorphous polymers and crystalline materials in response to mechanical loading, they are predicting two very different ways of dissipating mechanical energy. Explain the difference, precisely but concisely, in terms of elasticity, plasticity, and atomic / molecular mechanisms.

(b) Below is a model that accurately captures the creep and recovery response of several microcrystalline materials. For a step-stress applied at t=0 and removed after a long time $t=t_1 >> 0$, draw how strain in the microcrystalline material evolves as a function of time, up to times much greater than t_1 (i.e., tending toward infinity).

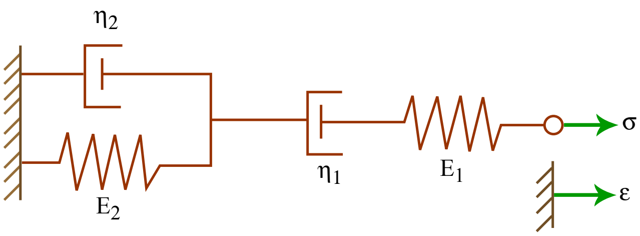


Fig 1: Phenomenological model that is predictive of creep in microcrystalline materials.

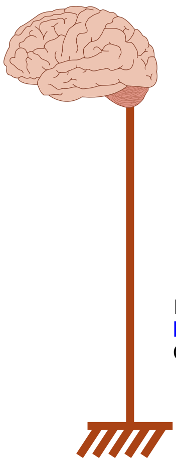
Figure by MIT OpenCourseWare.

Your answer must be in terms of the model's spring and dashpot values E_i and η_i, and you must indicate the magnitude of strain at:

- t = 0+ (i.e., just after the stress is applied);
- $t = t_1-$ (i.e., right before the stress is removed),
- $t = t_1+$ (i.e., just after the stress is removed), and
- t = 1.

2. I am often reminded, and with good reason, that MIT students should not be treated like “brains on sticks”. Fair enough, but let’s consider for a moment the mechanical consequences of this mental picture:

My first impulse is to wonder what such a stick should be made of, so that it should not buckle under the weight of a human brain (mass = 1.4 kg). Let’s assume the stick is stuck firmly in the ground, is 180 cm in height (approximately 6’), and is cylindrical in cross-section with the radius of a rat femur (1.9 mm; Horcajada et al., J. Endocrin. 165: 2000. Strangely, much easier to find documented rat femur radii than human femur radii.)



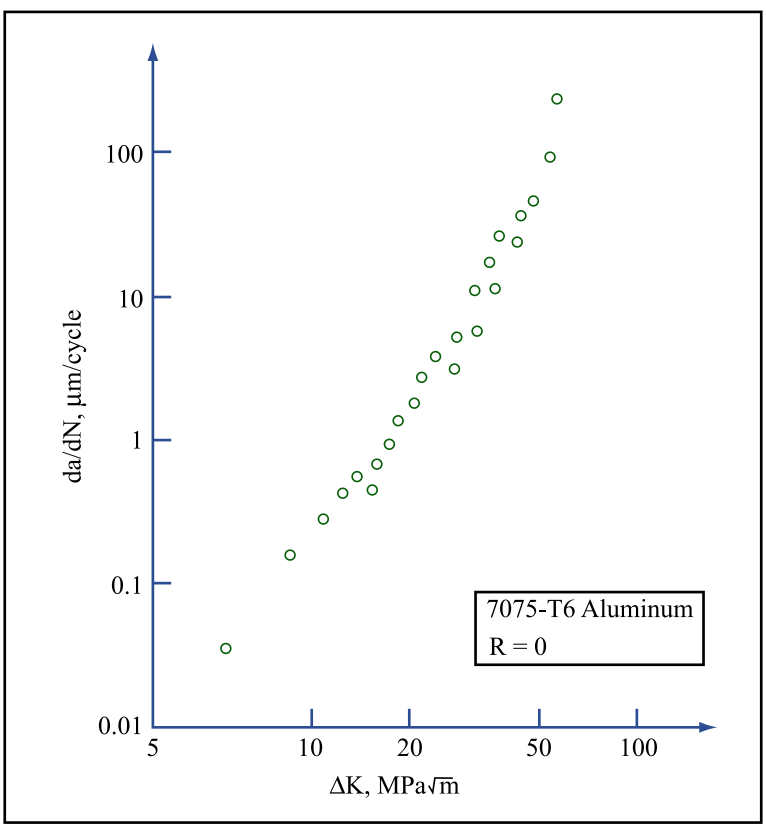
(a) Motivated by the aesthetics of the human body, I decide to make these sticks of solid 7075 T6 aluminum alloy rod with a radius of 6 mm (about that of the human spinal cord). Show whether the rod will buckle or not, noting the rod boundary conditions.

Figure by MIT OpenCourseWare. Adapted from http://upload.wikimedia.org/wikipedia/commons/6/6d/Brain_stem_normal_human.svg. Courtesy of Patrick J. Lynch, medical illustrator and C. Carl Jaffe, MD, cardiologist.

(b) I then realize that, because I can only fit so many brain-sticks in a lecture hall, I’ll probably be making cyclic use of these sturdy brain-sticks, taking off a tired brain and putting on a fresh brain once per week. Luckily, I know the steady-state crack growth behavior of this alloy under these conditions, as indicated in the graph below.

What is the value of R for this cyclic loading?

Fig 2: Brain on a stick.



(c) What are the values of C and m that characterize the steady-state crack growth for this 7075 Al under this R? Be sure to include units!

Figure by MIT OpenCourseWare.

Fig 3: Crack growth rate as a function of ΔK for aluminum alloy.

(d) I decide I can visually inspect each brain-stick to detect cracks on the surface that are about a = 100 μm in length. For the cyclic stress involving the stress of one brain per brain-stick, am I in the steady-state crack growth regime? In other words, is my ΔK sufficient to enter the Paris law regime?

(e) Since I did not acquire these da/dN vs. ΔK data myself, I decide to figure out if I need a safety factor by measuring the fatigue life of one such aluminum brain-stick for a stress range of 1000 MPa. Show exactly how I would determine how many lecture weeks can I use each brain-stick under this loading scheme before I should retire it for fear of fatigue failure. State any additional, needed data about the material required for the calculation, and how I would obtain/calculate these data. You do not have to complete the calculation to obtain N_f or t_f.

(f) As the brain-stick is made of 7075 Al and is under cyclic axial loading, sketch how you expect the fatigue failure surface to appear.

(i) This material is already an alloy, but I want to further extend the fatigue lifetime of the brain-stick. Briefly but completely describe one option to increase the *fatigue life* of this specific alloy (i.e., further alloying is not an option).

3. Choose 2 of the following 3 special topics to address briefly. Neither can be from the special topic you considered during the semester.

(a) In Li-based materials used for battery electrodes, mechanical failure results from cyclic stresses generated via repeated delithiation (phase transformation). This team estimated the failure stress from lattice mismatch strain and an elastically isotropic Hooke's law. If the phases were cubic (which they are not), this prediction of critical stresses would be a bit more complicated due to reduced symmetry. Show how lattice mismatch strain would be used to compute the effective (von Mises) stress in a battery material for which both the lithiated and nonlithiated phases are body centered cubic.

(b) In semiconductor materials used for III-V device applications, cyclic stresses result from thermal cycling during microelectronic device application. Given a difference between a III-V thin film and its substrate to differ by 10%, compute the temperature required for homogeneous nucleation of a dislocation in the III-V semiconducting film. Estimate and justify any required physical and mechanical properties, based on knowledge of similar materials.

(c) In amorphous oxide glasses used for fiber optics, a model was suggested that showed water reacting with Si-O-Si bonds to produce 2SiOH. From models of interatomic interactions, show how uniaxial tensile stress on a defect-free SiO_2 glass could reduce the energetic barrier to hydrolysis (water breaking of Si-O bonds).

ENJOY YOUR WEEK & SUMMER! SOLUTIONS WILL BE POSTED ONLINE BY END OF DAY.