MS/ME116. Mechanical Behavior of Materials

General Scope. Introduction to the mechanical behavior of solids, emphasizing the relationships between microstructure, architecture, defects, and mechanical properties. Elastic, inelastic, and plastic properties of crystalline and amorphous materials. Polymer and glass properties: viscoelasticity, flow, and strain rate dependence. Relations between stress, strain, strain rate, and temperature for deformable solids. Introduction to dislocation theory, motion and forces on dislocations, strengthening mechanisms in crystalline solids. The phenomena of creep, yielding, and fracture, and their controlling mechanisms. Mechanical properties relevant to modern day: photovoltaic devices, thin films, biomedical devices, and cellular solids.

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Lectures. TR 2:30 PM - 3:55 PM in **Arms 155**

Sub Lectures. David Chen (highlighted dates)

Recitation. TBD time in Keck 142 (doodle poll will be sent out)

Office Hours. Thursdays at 5-6pm in Steele 223

Website. http://jrgreer.caltech.edu/teaching.php. Find the "MS162" tab and download your homework assignments, lecture notes, solutions, and handouts from this website.

Homework. There will be weekly problem sets to be turned in on Fridays NO LATER than **5pm**. There will be no problem set due the week after midterm and the week before final. NO LATE HOMEWORKS WILL BE ACCEPTED. Collaborative work is encouraged, but homework has to represent everyone's own individual solutions.

Exams. There will be 1 take-home midterm exam and 1 final project or exam. You are welcome to use any of your notes (no books) during these exams. You **may not** collaborate with others on any of the problems and you **may not** work past the allotted amount of time. The midterm exam will last 3 hours; final project (if given) can be worked on for the entire study period and handed in on Tuesday, March 15th.

Class Schedule (subject to change).

Week/Date	Section	Topic
Wk 1/Jan 5 Wk 1/Jan 7	**C** Ch. 1	**Introduction** to Mechanical Properties of Materials: Microstructure, mechanical fundamentals, stresses and strains, Mohr Circle, coordinate conversion
Wk 2/Jan 12 Wk 2/Jan 14	**C** 2.1-2.5	**Elasticity:** isotropy, stresses and strains, elasticity and bonding, effects of temperature and composition on elastic constants, rubber elasticity **HW1 due 01/15**

Wk 3/Jan 19 Wk 3/Jan 21	**C** 2.6-2.8	**Viscoelasticity and Damping**: Maxwell, Voigt, and Standard Linear (SLS) solids, damping and phase angle, mechanisms **HW2 due 01/22**
Wk 4/Jan 26 Wk 4/Jan 28	Dislocations: **C** 3.1-3.4, **W&W** Ch. 1-3, **B&H** Ch. 1-4; Tensile test: **M&A**, Ch. 8	**Dislocations and Yielding in crystalline solids:** Schmid's law, slip systems, twinning, deformation of single crystals. Mechanical testing, stress-strain curves, instabilities, yield criteria, ductility. **HW3 due 01/29**
Wk 5/Feb 2 Wk 5/Feb 4	Same as above +**C** 3.5-3.10, **C** 4.1-4.4, **W&W** Ch. 4-6, **H&B** Ch. 5-8	**Dislocations/Yield cont'd:** crystallographic slip, motion, geometry of dislocations: forces, interactions and properties, mechanics of testing, three stages of yielding, dislocation mobilities, kinetic and structure evolution laws **Midterm NO HW!**
Wk 6/Feb 9 Wk 6/Feb 11	J.R. Greer and J. th. De Hosson ***Progress in Mat Science*** Vol. 56 Issue 6 (2011) pg. 654-724 and refs therein	**Mechanical Properties of Nanomaterials:** size effects, intrinsic lattice resistance, hardening mechanisms, Hall-Petch strengthening, intrinsic vs. extrinsic size effects as a function of microstructure.
Wk 7/Feb 16 Wk 7/Feb 18	**C** 9.1-9.5, 10.1-10.11	**Fracture in Brittle Materials:** Griffith's fracture theory, crack propagation modes, stress intensity factor, fracture toughness, ductile vs. brittle fracture, fracture in specific crystals. **HW4 due 02/19**
Wk 8/Feb 23 Wk 8/Feb 25	Cellular Solids: **C** 14.1-14.4, **G&A** Ch. 1-8, but basically entire book ;)	**Architected materials:** energy absorption as a function of geometry, density, and material properties. **HW5 due 02/26**
Wk 9/March 1 Wk 9/March 3	Entire Ch. 6 in **C;** Launey, Buehler, and Ritchie "On the Mechanistic Origins of Toughness in Bone" ***Annu. Rev. Mater. Res.*** 2010. 40:25–53	**Hard Biomaterials and Composites:** fiber and platelet composites, discontinuous fibers, statistical failure, structure and properties of nacre and bone. **HW6 due 03/04**
Wk 10/Mar 8		**Special Project or Final Exam**

Lecture Topic Outline.

1. Mechanical Fundamentals
   - Force, moment, stress, equilibrium
   - Coordinate transformations
   - Mohr's circle
   - Principal Stress Axes
   - Displacements and strain
   - Infinitesimal Strains

2. Elastic Behavior of Materials
   - General formulation of Hooke's law
   - Strain energy

- Elastic anisotropy: properties in particular directions and planes
- Average elastic constants, composites
- Atomic bonding basis for elastic behavior
- Rubber elasticity

3. Time-dependent Behavior: Viscoelasticity and Damping
    - Simple models for solids: Maxwell, Voigt, and Standard Linear Solid (SLS)
    - Viscoelasticity: mechanical models, damping and relaxation
    - Mechanisms of viscoelasticity and damping

4. Yielding and Plasticity
    - Tensile test for metals
    - Generalized yield criteria
    - Strain rate sensitivity
    - Plastic instability
    - Ductility

5. Defects and imperfections in Crystalline Solids (DISLOCATIONS)
    - Crystallographic slip
    - Dislocation properties, interactions, and motion
    - Taylor hardening
    - Yielding from crystalline solids perspective
    - Single crystals – polycrystals deformation relation

6. Deformation in Specific Crystals
    - Independent slip systems and plasticity
    - Hexagonal Close-Packed (hcp)
        i. Twinning
    - Face-centered cubics (fcc)
        i. Stress-strain curve
        ii. Deformation mechanisms
        iii. Kinetic and structure evolution laws
        iv. Theory of yielding and hardening
        v. Dislocation density, mobility, and multiplication
    - Body-centered cubic (bcc) and others
    - Strain hardening

7. Mechanical Properties of Nanomaterials
    - Size-dependent strength
    - Size Effects in Crystals: smaller is stronger
    - Global Size Effects as function of microstructure
    - Hall-Petch Strengthening
    - Extrinsic vs. Intrinsic Size Effects

8. Composites and Some Hard Biological materials
    - Reinforcement with particles and fibers
    - Continuous vs. discontinuous fibers: shear lag model

- Statistical failure
- Microstructural effects
- Structure of nacre (shells) and bone and its effect on deformation and failure

9. Cellular Solids
    - Properties of cellular solids, cell size and geometry
    - Deformation mechanisms in honeycombs
    - Mechanics of foams: stress-strain curves
    - Bending vs. stretching dominated deformation
    - Relationship between stress, stiffness, and relative density
    - Energy absorption

10. Fracture of Brittle Materials
    - Types of fracture
    - Stress concentration, stress intensity factor
    - Linear Elastic Fracture Mechanics (LEFM)
    - Plastic zones and small-scale yielding
    - Fracture toughness and resistance curves
    - Physical basis for fracture and toughening concepts

Books. Required class text: T.H. Courtney "Mechanical Behavior of Materials" (McGraw-Hill, 2nd edition, 2000) (**C**)

Additional Recommended Texts

1. F.A. McClintock and A.S. Argon "*Mechanical Behavior of Materials*" Addison-Wesley (1966) – a REALLY good fundamentals book! (**M&A**)
2. A.S. Argon "Strengthening Mechanisms in Crystal Plasticity" Oxford University Press (2008) (**A**)
3. T. L. Anderson "*Fracture Mechanics- Fundamentals and Applications"* CRC Press (1991)
4. L.B. Freund and S. Suresh "Thin Films Materials," Cambridge University Press (2003) (we will not have time to cover this material as much, but it is a terrific book specifically for the mechanical properties of thin films) (**F&S**)
5. J. Weertman and J.R. Weertman "Elementary Dislocations Theory" Oxford University Press (1992) (**W&W**)
6. D. Hull and D.J. Bacon "Introduction to Dislocations" 3rd Ed. Pergamon Press, New York (1984) (**H&B**)
7. "Dislocations bible": J.P. Hirth and J. Lothe "Theory of Dislocations" 3rd Ed., John Wiley, New York (1982).
8. L.J. Gibson and M.F. Ashby "Cellular Solids: Structure and Properties" 2nd Ed., Cambridge University Press (1997) (**G&A**)
9. J.R. Greer and J. Th. De Hosson "Plasticity in Small-Sized Metallic Systems: Intrinsic vs. Extrinsic Size Effect" (a long review paper on size effects)