MSE 532 DEFORMATION AND FRACTURE OF MATERIALS DURING PROCESSING AND SERVICE

Department of Materials Science and Engineering Fall, 2004

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OFFICE HOURS: 12:00 to 1:30 pm; Wednesday 12:00 to 1:30 pm; Friday

OBJECTIVE: The objective of this course is to develop broad understanding of deformation and fracture phenomena for crystalline materials in the contexts of material processing and in-service performance. Mechanical behavior is approached through integration of materials science microstructure and continuum mechanics principles over a range of length scales. After introduction to elasticity, plastic deformation is reviewed based on dislocation concepts. Fatigue and fracture are characterized using fracture mechanics and understood based on microstructural damage mechanisms. Time-temperature-dependent plastic deformation is introduced, and used to understand mechanical processing and microstructure evolution. The principles of mechanical behavior are illustrated for metals, semiconductors, and ceramics; and structure-property relationships are emphasized. Special topics reinforce concepts and show next generation challenges involving mechanical behavior. Breadth is achieved at the expense of depth to provide a foundation for advanced courses. The student will be equipped to participate in material development and design, as well as in scientific research to combat deformation, fracture, and fatigue.

PREREQUISITES: Strength of Materials plus MSE 304 and/or 306 for 4th year undergraduates in the materials minor or engineering science/materials option programs.

Graduate status in MSE, or permission of the instructor for SEAS graduate students in Applied Mechanics, Civil Engineering, and MAE.

CLASS INTERNET SITE: Homework assignments, solution sets, a volume of course notes, exams, and newsgroup archiving of questions and answers will be posted on the class homepage at http://toolkit.virginia.edu/MSE532-1.

CLASS TIME: 6:30-7:45 pm Tuesday and Thursday

CLASS LOCATION: Room A119, Thornton Hall

TEXTBOOK: None

REFERENCE: Optional---*Deformation and Fracture Mechanics of Engineering Materials,* R.W. Hertzberg, John Wiley, 4th edition, 1996. All receive sites were asked to place this book on library reserve.

NOTES: Each student will be provided with a set of course notes that are available for downloading as .PDF files from the UVa class internet site. These notes will reproduce projected images and constitute the course text.

ASSIGNMENT: Download and read each set of notes prior to the associated lecture. Pages in Hertzberg are cited with each lecture to provide an alternate perspective, but these readings are optional. Four problem sets will be assigned during the course. Exams will be given on the dates noted in the syllabus.

GRADING: 3 Quizzes - 240 points Final Exam - 100 points
4 Problem Sets - 100 points
Class Participation/Extra Credit - 30 points Attendance - Factor in borderline final grade elevation.

All undergraduates and graduate students outside of MSE will replace the lowest quiz score with the average of the two highest grades and will be given a *pass* on 1 homework set. MSE graduate students will replace the lowest quiz score with the average of the 3 exams.

SYLLABUS:

Date Lecture #

Introduction

9/2 1. Course procedures; Great Failures in Materials Engineering. (Optional reading---Hertzberg: pp. 261-263; 521; 699-702; 711-716; Cases 3, 4, 5, 8, 9, 10; pp. v-vi. Read for overview perspective. You are not expected to understand the calculations or details.)

Elastic-Plastic Deformation: Continuum Mechanics

Stress/Strain Definition; Tensile Test; Linear-Elastic Constitutive Behavior. (H: pp. 3-5.)

9/7 2. Linear-Elastic Constitutive Behavior, continued. (H: pp. 6-16; 31-33.)
Elastic-Plastic Constitutive Behavior; Plastic Instabilities; Applied Stress Equations; Stress State and Yield Criteria. (H: pp. 16-25; 28-31; 42-51.)

9/9 3. Stress Concentration; Notch Strengthening *vs* Notch Weakening; Broken Chalk and Strong Joints. (H: pp. 273-278.)

Plastic Deformation: Time-independent Microscopic Mechanisms

Review of Properties of Dislocations in Crystalline Lattices. (H: pp. 57-70.)

9/14 4. Review of Properties of Dislocations, continued. (H: pp. 70-87.)
Crystallography and Geometry of Slip; Single *vs* Polycrystal Slip-Schmid and Taylor. (H: pp. 89-102.)

9/16 5. Single Crystal Stress-Strain Curve; LEDS; Strengthening---Work Hardening. (H: pp. 123-129.)
Strengthening of Polycrystalline, Multi-phase Metals---Grain Boundary/Size. (H: pp. 129-130.)

9/21 Class Cancelled

9/22 6. Strengthening of Polycrystalline, Multi-phase Metals---Solute. (H: pp. 131-134.)
Strain Aging and Discontinuous Yielding. (H: pp. 134-137.)
Strengthening of Polycrystalline, Multi-phase Metals---Precipitation and Dispersion Hardening; Dislocation-Particle Interactions. (H: pp. 137-144.) *Taped Lecture*

9/28 7. Dislocation-Particle Interactions, continued.
Slip Localization and Role of Deformation in Fracture.

9/30 Catchup, Review, Questions and Answers.
Exam #1; 2.0 h (download and take out of class; due on site, 10/5 at 6:30 pm).

Elementary Fracture Mechanics

10/5 8. The Crack Problem: Elastic Griffith Theory and $\mathcal{G}$. (H: pp. 315-321.)
Crack Tip Stress/Strain Fields; Stress Intensity Factor, K. (H: pp. 321-333.)

10/7 9. Stress Intensity Factor, continued. (H: pp. 757-758.)
Elastic Compliance; Relation of $\mathcal{G}$ to K; Plastic Zone. (H: pp. 335-342.)

10/12 No Class; Reading Holiday

10/13 10. Make-up Class: Catastrophic Fracture and Stress State Constraint. (H: pp. 342-345.)
Fracture Mechanics Similitude and Design. (H: pp. 332-335; 381-383.)
Fracture Toughness Data and Test Methods. (H: pp. 345-354; 358-359; 375-379.)

Tensile Fracture

10/14 11. Fracture Toughness Tests, continued. (H: pp. 385-396; 471-474.)
Macromodes and Micromechanisms of Fracture; Microvoid Fracture---Microscopic Mechanisms; Structure-Property Relations. (H: pp. 290-297; 405-407; 418-435.)

10/19 12. Cleavage Fracture and Dislocation Mechanisms. (H: pp. 263-266; 297-298; 460-471.)
Cleavage Fracture---Alloy Microstructure *vs* Properties. (H: pp. 452-457.)
Intergranular Fracture. (H: p. 298.)

10/21 13. Fracture of High Performance Ceramics: Crack Tip Shielding and Weibull Statistics. (H: pp. 267-273; 350; 407-409; 435-445; 472-474.)

10/26 Catchup, Review, Questions and Answers.
Exam #2; 3.0 h (download and take out of class; due on site, 11/2 at 6:30 pm).

Fatigue Deformation and Fracture

11/2 14. Multiple Stages of Cumulative Fatigue Damage; SN Approach; Surface Effects on SN Properties. (H: pp. 521-534; 542-548.)
Cyclic Stress *vs.* Strain Response. (H: pp. 556-566.)

11/4 15. Plastic Strain and LCF Approach. (H: pp. 566-567.)
Method of Universal Slopes and Transition Fatigue Life. (H: pp. 567-570.)
Fracture Mechanics, Cyclic Plastic Zone and Crack Propagation. (H: pp. 591-598.)

11/9 16. Fatigue Crack Propagation, continued. (H: pp. 604-606.)
Near-threshold Fatigue Crack Growth. (H: pp. 620-628.)

11/11 17. Make-up class: Fatigue Life Prediction and Design; Safe-Life *vs* Damage Tolerance; Data Sources and PC Software. (H: pp. 598-604; 663.) *Taped or Live Lecture*

11/16 18. Defect-Sensitive Fatigue and Surface Engineering.
Fatigue Crack Closure (H: pp. 613-617.) *or* Case Study: Aging Aircraft

Plastic Deformation: Time-dependent

11/18 19. Elevated Temperature Creep. (H: pp. 157- 170.)
Creep Deformation Mechanisms. (H: pp. 170-178.)

11/23 20. Deformation-Mechanism Maps. (H: pp. 178-185.)

Elevated Temperature Cracking

Stress Rupture. (H: pp. 187-193.)
Microscopic Damage Mechanisms. (H: pp. 201-204.)

11/25 No Class; Holiday Break.

Special Topics

11/30 In class Exam #3; 2.0 h.

12/2 21. Environmental Cracking; Embrittlement Mechanisms. (H: pp. 485-495.) Hydrogen Embrittlement.

12/7 22. Environmental Cracking; Laboratory Tests and Microstructure-Property Relations. (H: pp. 495-507; 513-514.)

12/9 23. Deformation and Fracture of Submicrometer, Nanoscale and Amorphous Metals.
Nanomechanics: Indention and Strain Gradient Plasticity.

12/13 Extra Class: Review; Questions and Answers.

Final Exam: 12/13/04 through 12/21/04.