

TEXT: The assigned text for this course is the set of notes posted by the instructor. The notes should be used during lecture to reduce note-taking; each page reproduces the lecture screen image and includes detailed derivations. A full set of course notes provides a useful future reference. These books supplement the lecture and notes presentation.

Fracture Mechanics: Fundamentals and Applications, T.L. Anderson, CRC Press, 2nd edition, 1995. *Solid mechanics emphasis.*

Deformation and Fracture Mechanics of Engineering Materials, R.W. Hertzberg, Wiley, 4th edition, 1996. *Materials Science emphasis.*

These textbooks are recommended but not required, and are on 2-hour reserve in Prof. Gangloff's office. Interested students can special-order each text from the UVa bookstore.

CLASS TIME: 4:00 to 5:15 pm; Tuesday and Thursday.

CLASS LOCATION: MSE Classroom 125.

ATTENDANCE: Class participation, including attendance and real-time/electronic discussion, are important to effective learning and recognized in the grading.

ASSIGNMENT: Problem sets are assigned throughout the course. Read the pertinent notes prior to each lecture and review the notes after each lecture. Optional reading in Anderson and Hertzberg is cited at the beginning of each chapter for an alternate perspective on the topic.

SYLLABUS

1. Jan. 20 Course introduction.

MECHANICS OF FRACTURE

Overview: Damage tolerant fracture mechanics; Modes and micromechanisms of catastrophic fracture and subcritical crack growth; Methods of fracture control. Chapter 2 in Course Notes.

Review: Stress and strain. Chapter 2a: pages 1-10. [Each student is responsible for concepts of stress, strain and yielding theory, as presented in MSE 532/731 or courses on strength of materials. Hertzberg (1996): pp. 3-31, 45-51, and Dieter (1986): pp.18-60.]

2. Jan. 25 Notches and elastic stress concentration. Chapter 2a: 11-18, 24-30.
Cracks and elastic stress concentration. Chapter 3: 1-14.

3. Jan. 27 Elastic analysis of the crack tip stress field: Airy stress function; Westergaard analysis; Irwin stress intensity concept. Chapter 3: 15-31; Chapter 4: 1-12b.

4. Feb. 1 Westergaard and Irwin stress intensity examples; Boundary effects; Linear superposition; CTOD. Chapter 4: 13-29.
Stress intensity solutions for common 2-D geometries. Chapter 5: 1-14.
(Note special time for class; 9:00 am.)

Feb. 3 *Class cancelled.*

5. Feb. 7 Stress intensity solutions for 3-D crack geometries. Chapter 5: 15-23, 27-33.
K solutions for complex geometries; Handbook sources; PC software. Chapter 6: 1-21.
(Note special time for make-up class; 5:30 pm.)

6. Feb. 8 K solutions, continued; Experimental and analytical methods. Chapter 6: 22-31.
Cracked-body stress state; Crack tip plasticity, plane stress: Irwin and Dugdale models.
Chapter 7: 1-22.
7. Feb. 10 Plane strain crack tip plasticity. Chapter 7: 23-27.
Mohr's circle analysis of plastic zone shape. Chapter 8: 1-11.
Crack tip deformation and stress: Plane stress vs plane strain; Thickness effects on stress
state/magnitude; Estimates and finite element model results. Chapter 8: 12-25.
8. Feb. 15 Crack tip deformation and stress: Finite element model results. Chapter 8: 25-35.
Advanced topics in crack tip stress and strain: Strain gradient plasticity; Single crystal
deformation; Discrete dislocation modeling. Chapter 8a.
9. Feb. 17 Crack-body size requirements. Chapter 9: 1-6.
Exam/Homework Review Discussion
- Exam 1:** Take home (80 points): Out-5:15 pm Feb. 17th. Return-4:00 pm Feb. 22nd.
10. Feb. 22 Fracture Similitude; Review: Plane strain fracture toughness-concept and experiment.
Chapter 9: 7-25.
Plane stress crack growth resistance, the R-curve. Chapter 11: 1-20.
11. Feb. 24 Plane stress crack growth resistance, the R-curve. Chapter 11: 21-33.
Experimental characterization of fracture toughness for alloy/process development and
quality control. Chapter 11a: 1, 12-36.
12. Mar. 1 Review: Energy analysis of fracture; Griffith, Orowan and Irwin. Chapter 10: 1-14.
Review: Compliance; $G(K)$ relationship. Chapter 10: 15-31
Elastic-Plastic fracture mechanics; J-integral. Chapter 12a: 1-6.
13. Mar. 3 J-integral. Chapter 12a: 7-17; Chapter 12b.

March 5 – March 13: Spring Break
14. Mar. 15 Advanced fracture mechanics experimental methods. Chapter 12c; Chapter 12d: 1-13.
Crack Tip Opening Angle and stable crack growth. Chapter 12d: 14-30.

MICROSCOPIC MECHANISMS OF FRACTURE

MICROVOID FRACTURE

15. Mar. 17 Review of the failure mode; Importance of 2nd phase particles, yield strength, and stress
triaxiality. Chapter 17: 1-6, 9, 12-21, 24; Chapter 18: 1-5.
Case study: Ductile fracture in precipitation hardened aluminum alloys. Chapter 18: 6-21.
Quantitative metallographic studies of microvoid processes. Chapter 18: 27-33; Chapter
19: 1-4.
- Mar. 22 *Class cancelled.*
- Mar. 24 *Class cancelled.*
16. Mar. 29 Continuum mechanics modeling of microvoid processes. Chapter 19: 5-13.
Micromechanical modeling of K_{IC} for void rupture at crack tip. Chapter 19: 14-32.

17. Mar. 31 Effect of temperature on ductile fracture resistance of Al alloys: Temperature dependent ϵ_F and K_{IC} by micromechanical modeling; Next generation modeling. Chapter 18: 7-8; Chapter 19a: 1-15.

INTERGRANULAR FRACTURE

18. Apr. 5 Review of the failure mode and causes. Case studies: effects of boundary precipitation, and slip localization. Modeling to predict ϵ_F and K_{IC} . Chapter 30.
19. Apr. 6 Intergranular embrittlement by alloyed hydrogen; Fracture mechanics characterization of subcritical crack propagation; Effects of yield strength, H content, temperature, boundary composition and loading rate on fracture mechanics properties; H-damage mechanisms. Chapter 32. *(Note special time for make-up class; 5:30 pm.)*

Exam 2: Take home (100 points): Out-5:15 pm April 6th. Return-4:00 pm April 12th

20. Apr. 7 Decohesion and micromechanical modeling of fracture mechanics properties for intergranular H embrittlement. Chapter 33.
21. Apr. 12 Transgranular hydrogen embrittlement, definition of the failure mode and fracture mechanics properties; Hydride formation; Micromechanical modeling of subcritical crack growth. Chapter 34.

ENVIRONMENT ASSISTED (STRESS CORROSION) CRACKING

22. Apr. 14 Definition of environmental fracture mode; Critical characteristics and occurrences; Methods of characterization; Fracture mechanics approach to environmental crack propagation. Chapter 26: 1-17; Chapter 27.
23. Apr. 19 Damage mechanisms. Chapter 26: 18-38.
Environment chemistry effects for steels. Chapter 28: 1-10.
Microstructure effects for high strength aluminum alloys. Chapter 28a.
24. Apr. 21 *Class Cancelled*
25. Apr. 26 Modeling environmental cracking kinetics: Film rupture. Chapter 29: 8-19.
Rate-limiting step concept in H environment assisted cracking; Chapter 29a.

DEFORMATION AND FRACTURE OF AMORPHOUS AND NANOSCALE MATERIALS

26. Apr. 28 Submicron grain size nano-crystalline and amorphous alloys; Structure-flow strength properties relationships; Plastic flow localization and instability. Chapter 35.
27. May 3 Structure-toughness/ductility properties relationships; Fracture micromechanisms and modeling; Alloy toughening. Chapter 36.
- Project Due at UVa*
28. May 5 Fracture of functionally graded materials and/or MEMS structures.
(Note special time for make-up class; 5:30 pm.)

May 6-14 **Exam 3:** In class (70 points): 2 hours (Date to be finalized)