COURSE SYLLABUS

ME 524

Fracture Mechanics

FACULTY CONTACT INFORMATION:
Instructor: Reza Abedi
Office Location: Room B203
Phone: (931) 393-7334 **E-mail**: rabedi@utsi.edu
Web page: http://www.rezaabedi.info/

I. **COURSE DESCRIPTION**: Mechanisms of fracture and crack growth; stress analysis; crack tip plastic zone; energy principles in fracture mechanics; fatigue-crack initiation and propagation; fracture mechanic design and fatigue life prediction. Analytical, numerical, and experimental methods for determination of stress intensity factors. Current topics in fracture mechanics.

Registration Permission: Consent of instructor.

II. **COURSE OBJECTIVE**: The objective of the course is to prepare students to develop theoretical background in linear elastic and plastic fracture mechanics. This will include energy approaches, stress intensity factors, plastic zones, and J-integral. Subsequently, we employ various models in computational fracture mechanics. Through a term project with commercial finite element software and paper reviews on modern fracture mechanics topics students are expected to develop necessary background to conduct research in the field.

III. **STUDENT LEARNING OUTCOMES**: Students will be able to:

- Discern the connections between stress and energy approaches, and between elastic and plastic fracture mechanics methods for crack tip mechanical fields.
- Understand notions such as stress intensity factor and J integrals and solve for those using commercial finite element software.
- Get familiar with recent research directions in fracture mechanics.
- Employ or formulate appropriate fracture models for various applications.

IV. **SELECTED BIBLIOGRAPHY:**

- Course textbook:
    1. T. L. Anderson, Fracture Mechanics: Fundamentals and Applications, 3rd Edition, CRC Press, USA, 2004 (main textbook).

  Some reference textbooks for fracture mechanics

    2. D. Broek, Elementary Engineering Fracture Mechanics, 4th Revised Edition, Springer, 1982 (or reprint 2013).
    3. B. Broek, The Practical Use of Fracture Mechanics, Springer, 1998.
    4. S. Murakami, Continuum Damage Mechanics: A Continuum Mechanics Approach to the Analysis of Damage and Fracture, Springer Netherlands, Dordrecht, 2012.
    5. Suresh, S. Fatigue of Materials. 2nd ed. Cambridge University Press,

1998.
6. L.B. Freund, Dynamic Fracture Mechanics, Cambridge University Press, 1998.
7. B. Lawn, Fracture of Brittle Solids, Cambridge University Press, 1993.
8. M.F. Kanninen and C.H. Popelar, Advanced Fracture Mechanics, Oxford Press, 1985.
9. R.W. Hertzberg, Deformation and Fracture Mechanics of Engineering Materials. 5th ed. John Wiley & Sons, Inc., 2012 (materials focus).
10. S Al Laham, Stress Intensity Factor and Limit Load Handbook, British Energy Generation Limited, 1998.

V. **COURSE REQUIREMENTS, ASSESSMENT AND EVALUATION METHODS:**

- Assignments(35%+5%): Extra 5% is for challenge problems.
- Term project (20%): We use commercial software for application of several computational tools such as cohesive and damage models, and for computation of FM crack tip fields.
- 4-page report & presentation on a topic on fracture mechanics (20%): The topic and sources for the study will be chosen based on student's interest and available topics. Each student will have a 10 minute presentation at the end of the semester.
- Midterm and final exam (25%)

VI. **UNIVERSITY POLICIES:** The students should abide by the UTK honor statement included on the Campus Syllabus available on the Provost and TennTLC websites, and the online UT catalog. The honor statement includes information about discrimination, scholastic dishonesty, cheating, and plagiarism policies. All the homework assignments and exams are individual assignments unless otherwise noted by the instructor.

Fracture Mechanics Topics & References

Color Code: Covered, Brief Discussion, Not Covered

1. Preliminaries: Tensors; Kinematics (displacement, strain); Stress; Balance laws; Constitutive equations
   Saouma 5.1-5.4; Anderson A2.1
2. History
   Anderson 1.2.1-1.2.5
3. Fracture modes
   3.1. Classification
   Murakami 1.1.1, 1.1.2, **1.1.3**; Saouma **4.1-4.4** (buckling, fracture, yielding, etc.); Schreurs 2.1.
   3.2. Ductile fracture
   3.2.1. Dislocation dynamics
   Hertzberg 2 (theory), 3 (slip and twinning)
   3.2.2. Void nucleation, growth, and coalescence
   Anderson **5.1**
   3.3. Brittle fracture
   Anderson 5.2; Lawn
   3.4. Ductile-brittle transition
   3.4.1. Temperature
   Anderson 5.3
   3.4.2. Radiation embrittlement
   Anderson 7.8; Hertzberg 10.6.3

3.4.3. Hydrogen embrittlement
Anderson 11.4; Hertzbeg 11.1
3.4.4. Strain rate
Anderson 4.1.1; Hertzbeg 5.2
3.4.5. Size effect
Samoua 16.2.3 (Bazant), 16.2.4 (Carpintieri)

4. Linear Elastic Fracture Mechanics (LEFM)
 4.1. Griffith energy approach
  4.1.1. Atomic view of fracture; mismatch with experiments
  Anderson 2.1; Saouma 8.1.1
  4.1.2. Effect of flaws, Griffith experiment
  Anderson 2.1; Saouma 8.2
  4.1.3. Energy equation, Fracture Resistance (R)
  Anderson 2.3; Saouma 9.1
  4.1.4. Energy Release Rate (G)
  Anderson 2.4
  4.1.5. Crack Stability, R and Π curve
  Anderson 2.5; Saouma 9.1.2, **9.3**
 4.2. Stress solutions, Stress Intensity Factor K (SIF)
  4.2.1. Airy stress functions
  Anderson A2.1; Saouma 5.6; Schreurs 5.8 (general indicial expressions)
  4.2.2. Complex variables and cylindrical coordinate
  Sauoma 5.7, 5.8; Zender 2.4
  4.2.3. Stress solutions, stress concentration
  Saouma 6.1, 6.3, **6.5**; Anderson A2.3; Schreurs 6.2
  4.2.4. Crack tip stress fields, SIF
  Saouma 6.4; Schreurs 6.3-6.6; Anderson A2.3
  4.2.5. Relation between K & R (SIF & Resistance)
  Saouma **9.2**; Anderson 2.7;
  4.2.6. SIF Handbooks, design
  Saouma **7.2**; Schreurs **6.7**; Anderson 2.6.3; Laham
 4.3. Mixed mode fracture
  4.3.1. Crack propagation criteria
  Saouma **10.1**; Schreurs **7.3**; Lawn **2.8**
  4.3.2. Nucleation criteria
 4.4. Crack interactions
 Anderson 2.12

5. Elastoplastic fracture mechanics
 5.1. Introduction to plasticity
 Saouma **2**; Schreurs 9.1-9.4
 5.2. Plastic zone models
  5.2.1. 1D models: Irwin, Dugdale, and Barenbolt models
  Saouma **11.1**; Anderson 2.8
  5.2.2. 2D models: plane stress versus plane strain plastic zones
  Anderson 2.8.4; 2.10.1-2.10.3; Saouma 11.2-11.3; Schreurs 9.1, 9.3-6
 5.3. J Integral

5.3.1. Path independence
Schreurs 10.2.1-10.2.2; Saouma 13.2; Anderson 3.2.2 (Saouma 13.11-13.12 generalizations for dynamic, crack surface loading, body force, etc loading)
5.3.2. Relation between J and G
Saouma **13.3**, 13.4; Anderson 3.2.1
5.3.3. Relation between J and K
Schreurs 10.2.3; Saouma **13.10**; Anderson 3.2.3
5.3.4. Energy Release Rate, crack growth and R curves
Anderson 3.2.1, 3.2.5, 3.4, **3.5**; Saouma 13.6, 13.7
5.3.5. Plastic crack tip fields; Hutchinson, Rice and Rosengren (HRR) solution
Saouma **13.8**; Schreurs 10.3.1-10.3.2
5.3.6. Small scale yielding (SSY) versus large scale yielding (LSY)
Schreurs 9.9 (SSY); Anderson 3.6.1 (LSY T-stress effect), 3.6.2 (J-Q theory)
5.3.7. Fracture mechanics versus material (plastic) strength
5.4. Crack tip opening displacement (CTOD), relations with J and G
Anderson 3.1, **3.3**; Saouma 12
6. Computational fracture mechanics
6.1. Fracture mechanics in Finite Element Methods (FEM)
6.1.1. Introduction to Finite Element method
6.1.2. Singular stress finite elements
Saouma **19.2-19.6**; Schreurs 11.1-11.4
6.1.3. Extraction of K (SIF), G
K: Anderson **12.2.1;** Saouma **19.7.1**
G: Anderson 12.2.2-12.2.4; Saouma **20.2** (Mixed mode)
6.1.4. J integral
Anderson 12.3; Saouma 21.1, 21.3.1.1; Schreurs 11.7
6.1.5. Finite Element mesh design for fracture mechanics
Anderson 12.4, 12.5
6.1.6. Computational crack growth
6.1.7. Extended Finite Element Method (XFEM)
6.2. Traction Separation Relations (TSRs)
7. Bulk damage models
7.1. Representative Volume Element (RVE) and damage representation
Murakami 1.2, 2.1
7.2. Continuum models based on thermodynamics
7.2.1. Thermodynamic laws, Thermodynamic and dissipation potentials
Murakami 3.1-3.2.2
7.2.2. Damage evolution with plasticity
Murakami 4.1 (1D), **4.2.1-4.2.5** (3D)
7.3. Micromechanics based damage models
7.3.1. Ductile void evolution models
Murakami 6.5.1 (Gurson) & 6.5.2 GTN (Tvergaard & Needleman)
8. Fatigue
Suresh
8.1. Fatigue regimes
8.2. S-N, P-S-N curves
Schreurs 12.3

8.3. Fatigue crack growth models (Paris law)
   Anderson 10.2, 10.4 (fatigue threshold); Schreurs 12.5
8.4. Variable and random load
   Anderson 10.5; Schreurs 12.6

9. Dynamic fracture mechanics and rate effects
   9.1. LEFM solution fields
      Freund; Anderson A4.1
   9.2. Dynamics of moving crack tip, process zone size, crack speed
      Freund; Anderson 4.1.2.2-4.1.2.3
   9.3. Crack path instabilities
   9.4. Rate effects, viscoelastic and viscoplastic
      Anderson 4.3; Kanniwen 2.5, 2.7
   9.5. Creep
      Kanniwen 7
10. Statistical fracture
   10.1. Flaws
      Lawn 9 Introduction, 9.1 microcontacts, 9.2 dislocation pile up, 9.3 Chemical, thermal, and radiation source
   10.2. Weakest link, Weibull distribution
      Anderson **A5.1**; Lawn 10.1.1
   10.3. Probabilistic fracture analysis
      Anderson A5.2, Lawn 10.2
11. Experimental fracture
   11.1. SIF (K)
      Zender 5.5.1-5.5.3
   11.2. Fracture toughness
      Zender 6
   11.3. J
      Anderson 3.2.5
12. Material specific fracture analysis
   12.1. Metals
      Anderson 7
   12.2. Ceramics
      Anderson 6.2, 8.3 (experimental); Lawn 7.6, 9.4
   12.3. Polymers
      Anderson 6.1; 8.1 (experimental)