

UNIVERSITY OF CALIFORNIA AT BERKELEY
College of Engineering
Departments of Materials Science & Engineering and Mechanical Engineering

Spring 2012

COURSE: **MSE C212 - ME C225**

TITLE: **DEFORMATION & FRACTURE OF ENGINEERING MATERIALS**

UNITS: 4

LECTURES: Tuesday, Thursday 9 - 11 am, 348 HMMB

OFFICE HOURS: Tuesday, Thursday 11 - 12 noon, 324 HMMB

LECTURER: Professor R. O. Ritchie, MSE & ME Departments
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WEB PAGE: <http://www.lbl.gov/Ritchie/Teaching/MSE212/mse212.html>

COURSE DESCRIPTION:

A survey course of the mechanics and microstructural aspects of deformation and fracture in structural metallic, ceramic and composite materials, including linear elastic, nonlinear elastic/plastic and creep deformation from a continuum viewpoint, fracture mechanics of linear elastic, nonlinear elastic and creeping materials, physical basis of intrinsic and extrinsic toughening, environmentally-assisted fracture, cyclic fatigue failure, fatigue-crack propagation, stress-strain/life and damage-tolerant design, creep-crack growth, and fracture statistics.

PREREQUISITES:

Undergraduate level understanding of mechanics; MSE 113, ME 108 or equivalent

PROJECT:

Students will be selected into groups of three and chose, or be assigned, an individual project on a topic *distinct from his or her research work*; the topic could be based on a published paper or a series of papers, or be an in-depth study of a particular top. At the end of the semester, a full write-up on each project will be required, plus a 10-minute oral presentation by each group to the class.

REFERENCE TEXTS:

1) Mechanical Behavior of Materials:

F. A. McClintock and A. S. Argon: *Mechanical Behavior of Materials* (Addison-Wesley, 1966)

M. A. Meyers and K. K. Chawla: *Mechanical Metallurgy: Principles and Applications* (Prentice-Hall, 1984)

2) Fracture Mechanics:

D. Broek: *Elementary Engineering Fracture Mechanics* (3rd ed., Sijthoff Noordhoff, 1982)

J. F. Knott: *Fundamentals of Fracture Mechanics* (Halstead Press, 1973)

S. T. Rolfe and J. M. Barson: *Fracture and Fatigue Control in Structures* (2nd ed., Prentice-Hall, 1987)

H. L. Ewalds and R. J. Wanhill: *Fracture Mechanics* (Arnold, 1984)

T. L. Anderson: *Fracture Mechanics: Fundamentals and Applications* (3rd ed., CRC Press, 2005)

B. R. Lawn: *Fracture of Brittle Solids* (2nd ed., Cambridge Univ. Press, 1993)

3) Handbooks on K and J Solutions:

Akram Zahoor: *Ductile Fracture Handbook* (Electric Power Research Inst., 1989)

H. Tada, P. C. Paris, and G. R. Irwin: *Stress Analysis of Cracks Handbook* (Del/Paris Publ., 1985)

3) Fatigue:

S. Suresh: *Fatigue of Materials* (Cambridge, 1998, 2nd ed.)

F. Ellyin: *Fatigue Damage, Crack Growth and Life Prediction* (Chapman&Hall, 1997)

4) Environmentally-Influenced Failure:

J. C. Scully: *Fundamentals of Corrosion* (Pergamon, 1975, 2nd ed.)

5) Mechanical Testing:

Metals Handbook, 9th ed., vol. 8 (American Society for Metals)

6) Failure Analysis/Fractography:

Metals Handbook, 9th ed., vol. 12 (American Society for Metals)

7) Continuum Mechanics/Elasticity (simple treatments):

E. P. Popov: *Introduction to Mechanics of Solids* (Prentice-Hall, 1968)

S. H. Crandall, N. C. Dahl and T. J. Lardner: *An Introduction to the Mechanics of Solids* (2nd ed., McGraw-Hill, 1978)

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Prof. R. O. Ritchie

COURSE OUTLINE

PART I: DEFORMATION

Jan.	T 17	Introduction. Continuum Mechanics: stress, strain
	Th 19	Linear Elasticity: beam theory, invariants, etc.
	T 24	constitutive laws
	Th 26	Plasticity: yield criteria, deformation and flow theories
	T 31	constitutive laws, Prandtl-Reuss equations
Feb.	Th 2	limit analysis (lower bounds)
	T 7	limit analysis upper bounds)
	Th 9	deformation processing
	T 14	Rate-Dependent Plasticity: creep deformation, creep rupture

PART II: FRACTURE MECHANICS

	Th 16	Linear Elastic Fracture Mechanics: K_I singularity
	T 21	plasticity considerations, K_{Ic} , CTOD
	Th 23	resistance curves, plane-stress analyses
	T 28	Nonlinear Elastic Fracture Mechanics: HRR singularity
Mar	Th 1	J_{Ic} , $J_R(\Delta a)$ resistance curves, T_R , CTOA
	T 6	Non-stationary crack-growth analysis

PART III: SUBCRITICAL CRACK GROWTH

	Th 8	Environmentally-Assisted Fracture: stress corrosion
	T 13	hydrogen embrittlement
	Th 15	corrosion fatigue
	T 20	Cyclic Fatigue Failure: mechanistic aspects
	Th 22	crack propagation, damage-tolerant analysis
Apr.	T 3	variable-amplitude loading, small cracks, crack closure
	Th 5	stress-strain/life analysis
	T 10	ceramics, intermetallics
	Th 12	biological materials, e.g., bone

PART IV: MODELING, STATISTICS, ETC

	T 17	Physical Basis of Toughness: intrinsic toughening - metals
	Th 19	extrinsic toughening – ceramics, composites
	T 24	fracture statistics
	Th 26	***** <i>Presentation of project reports</i> *****

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MSE 212 - ME 225

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PART I: DEFORMATION
(CONTINUUM ASPECTS)

1. CONTINUUM MECHANICS/ LINEAR ELASTICITY

Linear elastic beam in bending	equilibrium of stresses elastic strain energy
Composite beam in bending	superposition principle
Transformation of stresses, strains	Mohr's circle
Invariants	principal stresses and strains hydrostatic stress, dilation equivalent stress and strain
Geometric compatibility	
Phenomenological description of elasticity	
Elastic constitutive relationships	Hooke's law
Pressurized cylinders, spheres	
Torsion of cylinders, tubes	
Castigliano's theorem	
Stress concentration	
Elastic instabilities	buckling

2. PLASTICITY

Phenomenological description	
Uniaxial tensile test	true stress, incremental strain deviatoric stresses and strains
Plastic constitutive relationships	Ramberg-Osgood
Criteria for initial yielding	Tresca, Mises criteria
Plastic flow under multiaxial loading	Prandtl-Reuss equations
Plastic instabilities	necking
Limit load analysis	upper and lower bounds

3. RATE-DEPENDENT INELASTICITY

Phenomenological description of creep
Creep constitutive equations
Evaluation of creep data in design
Correlation of creep-rupture data
Creep under multiaxial stress states

PART II: FRACTURE MECHANICS

1. LINEAR ELASTIC FRACTURE MECHANICS

Atomically brittle fracture	theoretical cohesive strength Orowan (stress concentration) approach Griffith (energy balance) approach Griffith multiaxial stress criterion
Strain energy release rate, G Linear elastic crack-tip fields	Airy stress function, biharmonic equation Williams soln., Westergaard σ function
K singularity	Modes I, II, III notch solution
Stress-intensity factor, K	K solutions, superposition equivalence of G and K
Crack-tip plasticity	plastic-zone size solutions effective stress-intensity factor crack-tip opening displacement plane stress v. plane strain plane-strain fracture toughness, K_{Ic} crack-deflection equations
K as a failure criterion Mixed-mode fracture Plane-stress resistance curves	

2. NONLINEAR ELASTIC FRACTURE MECHANICS

Fully plastic (slip-line) fields J contour integral	HRR singularity, path-independent integral nonlinear energy “release” rate crack-tip fields, blunting solutions measurement
Large strain analyses Crack-tip opening displacement, δ Relationship between J and δ J and δ as failure criteria J -controlled crack growth Non-stationary cracks T stress	Measurement of J_{Ic} , δ_i $J_R(\Delta a)$ resistance curve, tearing modulus Rice-Drugan-Sham analysis crack stability

3. PHYSICAL BASIS FOR FRACTURE TOUGHNESS

Intrinsic and extrinsic toughening Intrinsic toughening in metals	metals, ceramics, polymers, composites RKR critical- σ criterion for cleavage stress-modified critical-strain criterion statistical considerations
Extrinsic toughening in ceramics	transformation/microcrack toughening fiber/ligament toughening

4. INTERFACIAL FRACTURE MECHANICS

Crack-tip fields	interfacial and near-interfacial cracks Dundurs parameters, phase angle
Crack-path analysis	crack deflection at interfaces G_{max} , $K_{II}=0$ criteria, crack-path diagrams
Crack stability	role of T stress
Interfacial toughness	test specimens, toughening strategies
Subcritical crack growth	stress corrosion, cyclic fatigue

PART III: SUBCRITICAL CRACK GROWTH

1. ENVIRONMENTALLY-ASSISTED FRACTURE

Introduction	mechanisms
Active-path corrosion	stress-corrosion cracking
Hydrogen-assisted cracking	hydrogen embrittlement, hydrogen attack
Liquid-metal embrittlement	
Test techniques	test specimens
	v - K curves, $da/dt = AK^n$
	K_{Isc} , K_{TH} thresholds
	Mode I vs. Mode III behavior
Corrosion fatigue	Superposition models

2. (CYCLIC) FATIGUE FAILURE

Mechanistic aspects	
Crack initiation	models, $\Delta K/\sqrt{\rho}$ approach
Crack propagation	Paris law ($da/dN = C\Delta K^m$)
	cyclic plastic-zone size
	load-ratio effects, ΔK_{TH} thresholds
Damage-tolerant design	life prediction
Models for crack growth	striation growth
Crack closure	plasticity-, oxide- and roughness-induced
Variable-amplitude loading	Wheeler, Willenborg, closure models
Small cracks	Continuum, LEFM, shielding limitations
Cyclic fatigue of ceramics	mechanisms
Stress-strain/life analysis	role of mean stress, notches, etc.
	Miner's rule
Multiaxial fatigue	equivalent stress models
	mixed-mode crack growth

3. CREEP CRACK GROWTH

Crack-tip fields	$C(t)$ integral, transition time
	steady-state creep parameter C^*
	v - C (v - K) curves