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

Spring 2015

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 *Campus*: Rm. 324 Hearst Mining Memorial Bldg., *LBL*: Materials Sciences Division, Bldg. 62, Rm. 239, 486-5798 *e-mail:* roritchie@lbl.gov
WEB PAGE:	http://www2.lbl.gov/ritchie/teaching.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 topic. At the end of the semester, a three-page 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, A. S. Argon: *Mechanical Behavior of Materials* (Addison-Wesley, 1966)

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

R. W. Hertzberg, R. P. Vinci, J. L. Hertzberg: *Deformation and Fracture Mechanics of Engineering Materials* (Wiley, 2012, 5th ed.)

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

H. L. Ewalds, 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, 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 & Life Prediction (Chapman & Hall, 1997)

4) Environmentally-Influenced Failure:

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

5) Biomaterials:

M. A. Meyers, P-Y. Chen: Biological Materials Science (Cambridge, 2014)

6) Mechanical Testing:

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

7) Failure Analysis/Fractography:

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

8) Continuum Mechanics/Elasticity (simple treatments):

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

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

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DEFORMATION AND FRACTURE OF ENGINEERING MATERIALS

MSE C212 –ME C225 (TU, TH: 9:00 – 11:00 AM) Prof. R. O. Ritchie

COURSE OUTLINE (SP 2015)

PART I: DEFORMATION

Jan.	T	20	Introduction. Continuum Mechanics: stress, strain
	Th	22	Linear Elasticity: beam theory, invariants, etc.
	T	27	constitutive laws
	Th	29	Plasticity: yield criteria, deformation and flow theories
Feb.	T	3	constitutive laws, Prandtl-Reuss equation
	Th	5	limit analysis (lower bounds)
	T	10	limit analysis (upper bounds)
	Th	12	deformation processing
	T	17	Rate-Dependent Plasticity: creep deformation & rupture

PART II: FRACTURE MECHANICS

	Th	19	Linear Elastic Fracture Mechanics: K_I singularity
	T	24	plasticity considerations, K_{Ic}, CTOD
	Th	26	resistance curves, plane-stress analyses
Mar.	T	3	Nonlinear Elastic Fracture Mechanics: HRR singularity
	Th	5	J_{Ic}, $J_R(\Delta a)$ resistance curves, T_R, CTOA
	T	10	Non-stationary crack-growth analysis

PART III: SUBCRITICAL CRACK GROWTH

	Th	12	Environmentally-Assisted Fracture: stress corrosion
	T	17	hydrogen embrittlement
	Th	19	Deformation and Fracture of Polymers (Prof. Pruitt)
	T	31	Cyclic Fatigue Failure: mechanistic aspects
Apr.	Th	2	crack propagation, damage-tolerant analysis
	T	7	variable-amplitude loading, small cracks & closure
	Th	9	stress-strain/life analysis
	T	14	ceramics, intermetallics
	Th	16	biological materials, e.g., bone

PART IV: MODELING, ETC

	T	21	Physical Basis of Toughness: intrinsic toughening – metals
	Th	23	extrinsic toughening – ceramics, composites
	T	28	****** *Presentation of project reports* ******
	Th	30	****** *Presentation of project reports* ******

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DEFORMATION AND FRACTURE OF ENGINEERING MATERIALS

MSE 212 - ME 225 Prof. R. O. Ritchie

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, $\mathcal{G}$	
Linear elastic crack-tip fields	Airy stress function, biharmonic equation
	Williams solution, Westergaard σ function
K singularity	Modes I, II, III
	notch solution
Stress-intensity factor, K	K solutions, superposition
	equivalence of $\mathcal{G}$ and K
Crack-tip plasticity	plastic-zone size solutions
	effective stress-intensity factor
	crack-tip opening displacement
	plane stress v. plane strain
K as a failure criterion	plane-strain fracture toughness, K_{Ic}
Mixed-mode fracture	crack-deflection equations
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
Large strain analyses	crack-tip fields, blunting solutions
Crack-tip opening displacement, δ	measurement
Relationship between J and δ	
J and δ as failure criteria	Measurement of J_{Ic}, δ_{i}
J-contolled crack growth	$J_{\mathrm{R}}(\Delta a)$ resistance curve, tearing modulus
Non-stationary cracks	Rice-Drugan-Sham analysis
T stress	crack stability

3. PHYSICAL BASIS FOR FRACTURE TOUGHNESS

Intrinsic and extrinsic toughening	metals, ceramics, polymers, composites
Intrinsic toughening in metals	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
	$\mathcal{G}_{\mathrm{max}}$, $K_{\mathrm{II}}=0$ 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_{Iscc}, 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