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

Spring 2019

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.,
LBNL: Materials Sciences Division, Bldg. 62, Rm. 239, 486-5798
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WEB PAGE: https://bcourses.berkeley.edu/courses/1478515

COURSE DESCRIPTION:

A survey course of the mechanics and nano-/micro-structural aspects of deformation and fracture in structural metallic, ceramic, composite and biological materials, including linear elastic, nonlinear elastic/plastic and creep deformation from a continuum viewpoint, limit analysis, 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 and fracture statistics.

PREREQUISITES:

Undergraduate level understanding of mechanics; MSE 113, ME c85/CEE c30, 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* (2nd, 3rd or 4th ed., CRC Press, 2005-2017)

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)
348 HMMB Prof. R. O. Ritchie

CLASS SCHEDULE (SPRING 2019)

PART I: DEFORMATION

Jan.	T	22	*NO CLASS* (will be made up later)
	Th	24	*NO CLASS*
	T	29	Introduction. Continuum Mechanics: stress, strain
	Th	31	Linear Elasticity: beam theory, invariants
Feb.	T	5	constitutive laws, stress concentrations
	Th	7	Plasticity: yield criteria, deformation & flow theories
.	T	12	constitutive laws, Prandtl-Reuss equation
	Th	14	limit analysis (lower bounds)
	T	19	limit analysis (upper bounds)
	Th	21	deformation processing
	T	26	Rate-Dependent Plasticity: creep deformation & rupture
	Th	28	life-prediction

PART II: FRACTURE MECHANICS

Mar.	T	5	Linear Elastic Fracture Mechanics: K_I singularity
	Th	7	plasticity considerations, K_{Ic}, CTOD
	T	12	resistance curves, plane-stress analyses
	Th	14	Nonlinear Elastic Fracture Mechanics: HRR singularity J_{Ic}, $J_R(\Delta a)$ R-curves
	T	19	Non-stationary crack-growth analysis

PART III: SUBCRITICAL CRACK GROWTH

	Th	21	Environmentally-Assisted Fracture: stress corrosion
Apr.	T	2	hydrogen embrittlement
	Th	4	Cyclic Fatigue Failure: mechanistic aspects
	T	9	crack propagation, damage-tolerant analysis
	Th	11	Polymers: Deformation, fracture & fatigue
	T	16	Cyclic Fatigue: stress-strain/life analysis
	Th	18	ceramics, intermetallics
	T	23	Biological Materials: bone & teeth, skin, fishscales, seashells, *etc*.
	Th	25	Physical Basis of Toughness: metals, ceramics, composites
	T	30	****** *Presentation of project reports* ******
May	Th	2	****** *Presentation of project reports* ******

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DEFORMATION AND FRACTURE OF ENGINEERING MATERIALS

MSE C212 - ME C225 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	$J_R(\Delta a)$ 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
	$\mathcal{G}_{max}$, 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_{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