MFG-512 Mechanics of Solids

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Instructor: Eralp Demir
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Class hours/place:

Office Hours: After class, or by appointment

Main References:

- **Allan F. Bower, *Applied Mechanics of Solids*, CRC Press, 2009.**
- Robert D. Cook, David S. Malkus, Michael E. Plesha and Robert J.Witt, *Concepts and Applications of Finite Element Analysis*, John Wiley & Sons Inc., 2002.
- Fionn Dunne, Nik Petrinic *Introduction to Computational Plasticity*, Oxford University Press, 2006.
- Ever J. Barbero, *Introduction to Composite Materials Design*, CRC Press, 1999.

Objectives: This course is primarily designed for graduate students to gain understanding in the field of mechanics of solids. Course introduces concepts of continuum mechanics and governing physics of deformation of solids including large deformation theory. The finite element concepts will be explained at introductory level and the students will be asked to solve practical solid mechanics problems using a commercially available finite element software.

Prerequisites: -

Tentative Course Outline:

Week-1: Objectives and Applications of Solid Mechanics
Basic introduction of equilibrium equations, finite element applications, examples
Week-2: Review of Engineering Mechanics
Review of Engineering level Mechanics background: stress-strain relations, tension, compression, bending, torsion, complicated loading, beam deflections and buckling
Week-3: Introduction to Vector & Tensor Algebra
Vector and Tensor definition, Index (Summation) notation; Tensor operations; cross product, dyadic product, inner product, double contractions, transpose etc.; Kronecker Delta, Levi-Civita operators; 2nd, 3rd and 4th order tensors; Description of Physical Quantities (Eulerian or Lagrangian); Spatial derivatives: gradient, divergence, curl
Week-4: Deformation and Strain Measures
Reference and deformed configurations; Displacement and velocity fields; Displacement gradient and deformation gradient tensors; Jacobian of the deformation gradient; Lagrange strain tensor; Infinitesimal strain tensor; Engineering shear and normal strains; Decomposition of infinitesimal strain into volumetric and deviatoric parts; Infinitesimal rotation tensor; Principal values and directions of the infinitesimal strain tensor; Cauchy-Green deformation tensors; Principal stretches
Week-5: Alternate Stress Measures
Surface traction and body force; Traction acting on planes within a solid; Cauchy (true) stress tensor; Volume Mapping: Jacobian; Area Mapping: Nanson's relation; Other stress measures: Kirchhoff, 1st

Piola-Kirchoff, 2nd Piola-Kirckoff Stress Tensors; Nominal and Material Stress Tensors; Principal stresses and directions; Hydrostatic and Deviatoric stresses, and Von Mises stress
Week-6: Equations of motion and equilibrium for deformable solids
Linear momentum balance in terms of Cauchy stress; Angular momentum balance in terms of Cauchy stress; Equations of motion in terms of other stress measures; Principal of virtual work
Week-7: Constitutive Equations: Relations between Stress and Strain
Strain energy derivation of elasticity; Symmetry property of elasticity tensor; Isotropic elasticity tensor bulk, shear and Lame constants; Ortho-tropic elasticity tensor
Week-8-9: Composite Laminate Mechanics
Plate deformation theory, Laminae micro mechanical elastic properties; Laminate macro mechanical elastic properties; Transformation rules for elastic modulus; Stress-Strain relations for laminate (ply mechanics)
Week-10: Isotropic Plasticity (An Introduction)
Strain Decomposition; In-compressibility Condition; Effective stress and plastic strain rate; Yield Criterion; Normality Rule; Implicit Integration of Constitutive Equations; Material Jacobian
Week-11-12: Crystal Plasticity
Anisotropic Elasticity; Schmid-Rule (Sachs); Taylor Rule; Rate-Dependent Plastic Flow; Crystal Plasticity Deformation Kinematics; Single Crystal Phenomenological and Dislocation Density based plastic flow rules; Implicit Integration of Crystal Plasticity
Week-13: A Guide to Use a Finite Element Software
Finite element mesh; Nodes and Elements; Element Connectivity; Element Types; Material Behavior; Boundary conditions; Initial conditions; Constraints; Solution Procedures and Time Increments; Post-Processing
Week-14-15 Theory and Implementation of the Finite Element Method
Generalized FEA for static linear elasticity; Review of the principle of virtual work; Integral (weak) form of the governing equations of linear elasticity; Interpolation of displacement field and virtual velocity field; Finite element equations; Element Stiffness; Simple 1D Implementation of the finite element method; Summary of the 1D finite element procedure; Example FEM Code structure: mesh and material inputs, processor, assembly of equations, solution procedures etc.

Learning Outcomes:

- Mathematical background for solid mechanics problems
- Understanding of large deformation theory
- Ability to develop continuum elastic models for solid mechanics problems
- Understanding and application of composite ply mechanics
- Introductory level understanding of plasticity: isotropic plasticity and crystal plasticity
- Finite element skills with applications of 1D problems
- Ability to solve basic engineering problems with the use of a commercially available software

Computer Programming: Matlab, Fortran, MSC-MARC

Grading Policy: Assignments(40%), Project (10%), Midterm (20%), Final (30%).

Important Dates:

will be announced

Class Policy:

- Regular attendance is essential and expected.