ENME 684: Modeling Material Behavior

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Lecture Hours: TuTh 11:00am-12:15pm
Location: Online
Office Hours: TBD

Course Objective: Nonlinear mechanical behavior of solids (and their dependence on temperature and loading rates) is important, not only in classical engineering applications such as in metal forming and high-temperature superalloys, but also in a wide and diverse range of modern applications such as: microscale and nanoscale structures; soft materials such as biotissues; multi-physics tranaduction materials ('Smart materials') for sensing and actuation; Materials in electronic and photonic systems; Materials in energy systems; Nano-scale deformations.

The focus is on mathematical constitutive models that relate stress, strain, temperature, and other ambient parameters. Such models are also important in organizing and interpreting experimental results. Classical and emerging modeling methods at various length scales, ranging from nano to continuum length scales, are explored. These models must be relatively easy in order for them to be useful. Whenever possible, these modeling approaches will be illustrated via examples of loaded structures.

Outcomes: After taking this course, students should be able to model the nonlinear mechanical behavior of structures that consist of materials with:

- nonlinear, rate-dependent and history-dependent properties.
- cumulative damage.
- multi-physics behavior (eg. in transduction materials).
- multi-scale behavior caused by nanoscale phenomena (eg. crystal plasticity and strain-gradient plasticity).

References:

Malvern, *Continuum Mechanics*, Prentice Hall, 1969
Green & Adkins, *Large Elastic Deformations*, Oxford 1970
Kachanov, *Fundamentals of the Theory of Plasticity*, Dover, 2004
Mendelson, *Plasticity: Theory and Application*, 2nd ed., Krieger, 1983
Hill, *The Mathematical Theory of Plasticity*, Oxford, 1998
Lubliner, *Plasticity Theory*, Macmillan, 1990
Khan and Huang, *Continuum Theory of Plasticity*, Wiley, 1995
Hetnarski and Skrzypek, *Plasticity and Creep: Theory, Examples, and Problems,* Begell House, 1993
Betten, *Creep Mechanics,* Springer, 2002
Flugge, *Viscoelasticity*, Springer-Verlag, 1975
Christensen, *Theory of Viscoelasticity*, 2nd ed., Academic Press, 1982
Rabotnov, *Elements of Hereditary Solid Mechanics*, Mir, 1980
Eringen, *Nonlinear Theory of Continuous Media*, McGraw Hill, 1962

Recommended Prior Coursework:

Math (ENRE620, ENME700, ENME745):

- Advanced Calculus, Vectors/Tensors (Math 412)
- Differential Equations (MATH462)
- Matrices and Linear Algebra (MATH461)

Solid Mechanics, Continuum Mechanics and Materials:

- ENES221, ENME382, ENME670

Grading:

Homework	-	35%
Exam	-	30%
Project	-	35%
Total	-	100%

Course Outline:

A. Introduction and Review of Material Behavior, Math and Continuum Mechanics
1. Mechanical behavior of materials
2. Mathematical preliminaries
3. Displacement & Strain: Compatibility relations
4. Forces and Stress: Equilibrium relations
5. Constitutive Relations: Elasticity
6. *Finite Deformations: Finite rotation and material frame objectivity

B. Nonlinear Elastic behavior: Neo-Hookean and Mooney-Rivlin-Saunders model

C. Plasticity
1. Sources of plastic behavior and simple experimental observations
2. Yield criteria: Hencky-Mises, Tresca, Hill, Hershey; Burzynski;
   Drucker-Prager, Mohr, Coulomb
3. Incremental flow theory: Associated flow rule (Levy-Mises; Prandtl-Reuss)
4. Hardening rules: Isotropic, kinematic, mixed, anisotropic
5. Stability, convexity of yield surfaces, normality of plastic increments
   Drucker inequality, Ilyushin inequality
6. Deformation theory of plasticity: Hencky-Ilyushin, Nadai-Ilyushin
7. Relationship between incremental and deformation theories
8. *Finite strain plasticity
9. *Slip-Line Field: Velocity equations; applications
10. *Limit analysis: Lower and upper bound theorems; applications
11. *Shakedown analysis: Melan's theorem; Koiter's theorem; applications
12. Examples of elasto-plastic problems
    Spheres & cylinders; torsion of prismatic bars
13. *Endochronic theory of plasticity

D. Creep: Viscoelasticity and Viscoplasticity
1. Sources of creep behavior and simple experimental observations
   Dependence on stress, time, temperature
2. Uniaxial phenomenological modeling approaches
   Total strain model, time-hardening model, strain-hardening model

Hereditary integrals
Creep compliance and relaxation modulus

3. Uniaxial linear viscoelastic models
   - Maxwell, Kelvin-Voigt, 3-parameter standard linear solid, 4-paremeter Burger's solid, Wiechert series model, Prony series
   - Boltzman's time-temperature superposition principle
   - Shift function (thermo-rheologically simple materials): e.g. WLF model
   - Correspondence Principle
4. Multiaxial loading
   - Deformation model (total strain model)
   - creep potential and Incremental flow rule and hardening rules
5. Examples: Bending, Torsion, buckling
6. *Viscoplastic phenomenological models
   - Andrade's model, Odqvist's model, Bingham-Norton model, Bodner-Parton model, Weertman model, Garofalo model, Cowper-Symonds model, Johnson-Cooke model.
   - Isochoric steady-state creep
7. *Creep Rupture models: Larson-Miller, Manson-Haferd, Orr-Sherby-Dorn

E. *Damage Mechanics
1. Continuum Damage Mechanics (CDM) concepts
2. Local and non-local CDM models

F. *Multi-physics Behavior
1. Electroelastic coupling
2. Magnetoelastic coupling
3. Ferro-elastic shape-memory behavior
4. Meta-materials

G. *Special Topics: microscale and nanoscale material heterogeneity
1. Crystal plasticity and viscoplasticity
2. Nanoscale enriched continuum mechanics: strain-gradient and nonlocal models
3. Inelastic behavior of porous and composite materials

H. Summary

Course Related Policies:

Please note that this course will be conducted in accordance with UMD's course policies, available at this link: http://www.ugst.umd.edu/courserelatedpolicies.html.
These policies address important updates regarding:

- Academic Integrity and Plagiarism (also see: https://president.umd.edu/sites/president.umd.edu/files/documents/policies/III-100A.pdf)
- Accessibility & Disability Services (formerly Disability Support Services)
- Civil Rights & Sexual Misconduct (OCRSM)
- CourseEvalUM
- Excused Absence Policy

Please review this link carefully as you are responsible for adhering to these policies.