MATSCEN 6XXX

Constitutive Modeling of Materials

Thermodynamics, electromagnetics, and mechanics of materials

Mon & Wed, 9:10-10:05, Bolz Hall 311

CARMEN: https://osu.instructure.com/courses/XXXX

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Overall Course Description: A constitutive theory or constitutive model is a relation between two physical quantities that is specific to a material and approximates the response of that material to external stimuli, such as applied electromagnetic fields or forces. Constitutive models are formulated at the continuum length scale and are often a link between the atomistic description of intrinsic material properties and the properties of heterogeneous materials at the meso or macroscale. Real physical problems often contain too many degrees of freedom to be uniquely solved by fundamental physical balance laws (conservation of energy and momentum).These laws must be combined with experimental observation and thermodynamic principles to develop a physically meaningful solution.

As a more specific example (from Wikipedia article on Maxwell's Equations): *The microscopic Maxwell equations have universal applicability, but are unwieldy for common calculations. They relate the electric and magnetic fields to total charge and total current, including the complicated charges and currents in materials at the atomic scale. The "macroscopic" Maxwell equations define two new auxiliary fields that describe the large-scale behaviour of matter without having to consider atomic scale charges and quantum phenomena like spins. However, their use requires experimentally determined parameters for a phenomenological description of the electromagnetic response of materials....In order to apply "Maxwell's macroscopic equations", it is necessary to specify the relations between displacement field and the electric field, as well as the magnetizing field and the magnetic field. Equivalently, we have to specify the dependence of the polarization (hence the bound charge) and the magnetization (hence the bound current) on the applied electric and magnetic field. The equations specifying this response are called constitutive relations. For real-world materials, the constitutive relations are rarely simple, except approximately, and usually determined by experiment.* In mechanics the primary relationship is between stress and deformation or deformation rate. Real problems where constitutive theory must be applied include the response of a polycrystalline piezoelectric material to an applied electric field or related problems in anisotropic dielectrics, or the relationship between applied deformation rate and stress in a mechanical test.

While constitutive models can be phenomenological or empirical they cannot simple be chosen arbitrarily. Care must be taken to ensure that the model does not violate the fundamental balance laws of physics or the second law of thermodynamics. Also the theory must also be consistent with any symmetry (e.g. crystallographic) present in the material and also follow several mathematical principles as well.

The goal is to develop skills and understanding in the following specific areas:

1. Understanding the limits of continuum vs atomistic systems
2. Thermodynamics of Electromagnetic and Mechanical systems
3. Fundamental mechanical and electromagnetic theory
4. What is a constitutive theory?
5. Basic requirements for developing a physically meaningful constitutive theory
6. Dissipation potentials and thermodynamic consistency
7. Coleman-Noll process for identifying constraints on a constitute model
8. Free-energy in coupled thermo-mechanical-electromagnetic systyems
9. Examples of commonly used theories that violate the above principles (e.g. hypoelasticity)

Existing constitutive theories from the scientific literature will be studied to explore these ideas, including:

1. Mechanical and Thermodynamical Laws at a Shock Wave
2. Rigid body heat conductors
3. The mechanical theory of compressible and incompressible Fluids
4. Thermoelasticity
5. Dffusion in elastic fields
6. Thermo-electromagetic coupling
7. Piezoelectric systems
8. Magnetic hysteresis

Prerequisite(s): Grad standing in MatSc&En or permission of instructor. MSE 6765 or a graduate level continuum mechanics class or tensor analysis. At the very least the student should have a working knowledge of tensor algebra, derivatives, and coordinate transformations.
Note(s): Students should also have some basic programing skills and passing familiarity with MATLAB's basic plotting functions or some other scientific plotting software such as ORIGIN, Kaleidagraph etc.
Credit Hours: 3

Course Format: I have tried every conceivable method for delivering this course material. It is difficult to balance the course content with the workload expected from a 2 credit-hour course. I have tried live lectures, flipped classroom, pre-recorded lectures with classtime being reserved for problem solving etc. By far the best feedback (from SEI) has been for lectures. So the format will be as follows:

- In-class lectures punctuated with numerous example problems
- Lectures will be recorded and links to lectures will be posted to CARMEN
- There will be weekly homework.
- There will be an approximately weekly quiz which will largely be derived from the homework exercise.
- There will be a set of project problems, assigned at the end of the first half of the course, which are a little more in-depth and will effectively count as 1 exam.

Text(s): There is no assigned textbook for the course. Assigned reading material will be posted to CARMEN or will be available in ebook format from the OSU library. Readings will extracted from the following texts and supplemented with review papers and classic papers from the scientific literature. General references for the course will be :

Fabrizio, M. and Morro, A., 2003. Electromagnetism of continuous media: mathematical modelling and applications. Oxford University Press.

Gurtin, M.E., Fried, E. and Anand, L., 2010. The mechanics and thermodynamics of continua. Cambridge University Press.

Grade Distribution for first half of course:

Homework	15%
Weekly Quizzes	10%
Project Problems	25%
Mideterm	25%
Final Exam	25%

Course Policies:

- **Exams**
  - Exams are closed notes.
  - **No makeup exams will be given without prior permission of instructor.**
  - Exams will be a mix of long answer, short concepts, and problems.
- **Quizzes**
  - Weekly quiz will be closed notes.
  - Quiz will be 10 minutes in duration
  - Lowest quiz scores will be dropped.
  - Missing quiz counts as zero (0) and will be elegible for dropping

- Make-ups for additional quizzes beyond the two automatic drops may be made at the discretion of the instructor. Permission for a makeup will only be given if the instructor is notified **PRIOR** to class. This can include for illness, conference travel, personal emergencies etc.

- **Homework and Project Problems**
  - Students are encouraged to work together. There is no better way to understand the material than to explain it to each other.
  - However keep in mind that Project Problems are not group assignments. You are expected to turn in your own individual work.
  - **No late assignments will be accepted under any circumstances**.

Academic Honesty Policy Summary: Ohio State University has a Code of Student Conduct and a Committee on Academic Misconduct with frequently asked questions. In general,

- Any work you submit for grading must be your work and it must include appropriate references to outside sources of information, including oral or written communication. You are encouraged to discuss course concepts and principles with others, but you must calculate/derive answers and write up course material on your own and in your own words. If you have difficulty making progress on homework or other material, please see the instructor.

Tentative Course Outline: Still under development. See course objectives.