# ME 651 Continuum Mechanics 3(3+0)
# Hamad F. Alharbi, PhD

**Instructor Contact Information:**

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**Office Hours:**

Monday and Wednesday: 1:00 pm-3:00 pm (Also by appointment)

**Prerequisites:**

Introduction to partial differential equations and vector mathematics.

**Course Description:**

ME 651 Continuum Mechanics: An introduction to the foundations of continuum mechanics; Vectors and tensors; Kinematics of deformation: Eulerian and Lagrangian descriptions of motion; Stress in a continuum; Conservation laws: mass and momentum balance; Thermodynamics: energy balance and entropy; Constitutive equations; Fluids and solids; Viscous and elastic response; The Navier-Stokes equations; Finite elasticity; Linear elasticity.

**Course Topics:**

- **Introduction to the Concept of a Continuum**
- **Math Preliminaries** *(Vector Space, Linear Operators on Vector Space, Indicial and Direct Notation, Essential of Tensor Math, Eigenvalue Problem, Derivatives of Tensor Fields, Integral Theorem)*
- **Strain and Deformation** *(Lagrangian and Eulerian Coordinates, Deformation Gradient Tensor, Measures of Strain, Polar Decomposition Theorem, Material Time Derivatives, Velocity Gradient Tensor, Strain Rate and Spin Tensors)*
- **Stress** *(Cauchy Stress Tensor, Nominal or Piola-Kirchhoff Stresses, Conjugate Stress-Strain Variables, Deviatoric and Hydrostatic Stress)*
- **Governing Equations** *(Conservation of Mass (Continuity), Balance of Linear and Angular Momentums, Energy Balance ($1^{st}$ Law of Thermodynamics), Clausius-Duhem Inequality and $2^{nd}$ Law of Thermodynamics, Helmholtz and Gibb Free Energy Functions, Principle of Virtual Work, Restrictions on Constitutive Laws, Material Frame Indifference (Objectivity))*
- **Introduction to Elastic Behavior of Solids** *(Hooke's Law for Isothermal, Infinitesimal Linear Elasticity, Hyperelasticity, Minimum Potential Energy, Isotropic Linear Thermoelastic Relations)*
- **Introduction to Fluids** *(Stokesian Fluid, Newtonian Fluid, Navier-Stokes Equations, Incompressible and Inviscid Fluids, Irrotational Flow and Bernoulli Equation, Ideal and Rotational Flow, Classical Incompressible Flows (Couette and Laminar Flows)*

**Course Meeting Times and Duration:**

Meeting one day a week in the ME conference room from 6:00 pm to 9:00 pm.

## Course Outcomes

By the end of this course, students should be able to

- Demonstrate an understanding of the mathematical relations written in compact indicial notations, which are commonly used in many scientific journal papers and engineering textbooks.
- Describe the basic principles in continuum mechanics applicable to all continuous media including conservation of mass, continuity equation, momentum principles, equation of motion and equilibrium, energy balance, first and second law of thermodynamics.
- Differentiate between the general principles applicable to all continuous media and the specialized constitutive equations characterizing an individual material system.
- Identify the necessity and limitations of constitutive equations
- Explain the basic concepts and mathematical descriptions of stress and deformation in different reference frames.
- Write the main constitutive equations in both elastic and plastic deformations of solid materials.
- Describe the basic field equations of Newtonian fluids.

## Reference Texts:

- G. E. Mase & T. Mase, Continuum Mechanics for Engineers, CRC Press, 1999.L.
- J. N. Reedy, An Introduction to Continuum Mechanics, Cambridge University Press, 2007.
- E. Malvern, Introduction to the Mechanics of a Continuous Medium, Prentice-Hall, Inc., 1969.
- Y. C. Fung, A First Course in Continuum Mechanics, Prentice-Hall, Inc. 1994.
- M. E. Gurtin, E. Fried, & L. Anand, The Mechanics and Thermodynamics of Continua, Cambridge University Press, 2010.

## Checking for Announcements:

All course materials, including syllabus, lecture slides, handout, video lectures, homework assignments, and exams, will be posted on LMS system (https://lms.ksu.edu.sa). You are also expected to check your email frequently for any additional announcements.

## Expectations

All students are expected to

- View video lectures in advance of class coverage of related topics
- Download lecture slides in advance of class time of related topics
- Select a topic for the term project before the 5$^{th}$ week and submit a progress report by week 11$^{th}$.

## Grading Policy

Homework (5 problem sets) ---------------------------------------------------------------- 25
Two Major Exams --------------------------------------------------------------------------- 30
Project -------------------------------------------------------------------------------------- 15
Final Exam ----------------------------------------------------------------------------------- 30

## Course Evaluation and Feedback

All students are strongly encouraged to provide anonymous feedback about the course and our conduct of the course. Please feel comfortable to provide feedback at any time.

## Course Schedule

The table below shows a tentative schedule for the topics, homework, and examinations in this course.

| Week | Date | Topics | Reading | Assignment |
|---|---|---|---|---|
| 1 | Jan 25, 2015 | **Part 1: Introduction to the Concept of a Continuum** | | |
| 2 | Feb 1, 2015 | **Part 2: Math Preliminaries**<br>• Vector Space<br>• Linear Operators on Vector Space<br>• Indicial and Direct Notation**<br>• Essential of Tensor Math**<br>• Eigenvalue Problem<br>• Derivatives of Tensor Fields<br>• Integral Theorem | | Problem Set 1 (Due: March 1) |
| 3 | Feb 8, 2015 | | | |
| 4 | Feb 15, 2015 | | | |
| 5 | Feb 22, 2015 | **Part 3: Strain and Deformation**<br>• Lagrangian and Eulerian Coordinates<br>• Deformation Gradient Tensor<br>• Measures of Strain<br>• Polar Decomposition Theorem<br>• Decomposition of the Deformation Gradient<br>• Material Time Derivatives<br>• Rate of Deformation Tensor<br>• Velocity Gradient Tensor<br>• Decomposition of the Velocity Gradient<br>• Spin Tensor | | Problem Set 2 (Due: March 29) |
| 6 | Mar 1, 2015 | | | |
| 7 | Mar 8, 2015 | | | |
| 8 | Mar 15, 2015 | | | |
| ** | **Mar 17th** | **Major Exam I** | | |
| 9 | **Mar 22nd** | **Semester Break** | | |
| 10 | Mar 29, 2015 | **Part 4: Stress**<br>• Cauchy Stress Tensor<br>• Nominal or Piola-Kirchhoff Stresses<br>• Conjugate Stress-Strain Variables<br>• Deviatoric and Hydrostatic Stress | | Problem Set 4 (Due: April 12) |
| 11 | Apr 5, 2015 | | | |
| 12 | Apr 12, 2015 | **Part 5: Governing Equations**<br>• Conservation of Mass (Continuity)<br>• Balance of Linear and Angular Momentums<br>• Energy Balance (1st Law of Thermodynamics)<br>• Clausius-Duhem Inequality (2nd Law of Thermodynamics)<br>• Principle of Virtual Work<br>• Restrictions on Constitutive Laws<br>• Material Frame Indifference (Objectivity) | | Problem Set 5 (Due: May 3) |
| 13 | Apr 19, 2015 | | | |
| 14 | Apr 26, 2015 | | | |
| ** | **Apr 28th** | **Major Exam II** | | |
| 15 | May 3, 2015 | **Part 6: Introduction to Elastic Behavior of Solids**<br>• Hooke's Law for Linear Elasticity<br>• Hyperelasticity<br>• Minimum Potential Energy<br>• Isotropic Linear Thermoelastic Relations | | |
| 16 | May 10, 2015 | **Part 7: Introduction to Fluids**<br>• Stokesian and Newtonian Fluids<br>• Navier-Stokes Equations<br>• Incompressible and Inviscid Fluids<br>• Irrotational Flow and Bernoulli Equation<br>• Classical Incompressible Flows | | |
| | **May 17th** | **Final Exam** | | |

***Prepared by*** *Dr. Hamad F. Alharbi [harbihf@ksu.edu.sa]* *January 24, 2015*