



Graduate course

Continuum Thermodynamics

April 8th - 9th 2019

**Faculty of Aerospace Engineering
Delft University of Technology**

General

In a variety of technologically-important applications, materials are subjected to large plastic deformations, experience damage or undergo phase transformations. In such cases, the analysis should be carried out using a thermodynamically-consistent model. This topical course is intended to provide a comprehensive overview of the balance principles (mass, linear and angular momentum, energy) within the context of continuum mechanics, which is often referred to as continuum thermodynamics. Special attention will be given to the use of the second law of thermodynamics (entropy inequality) in the derivation of various constitutive theories in terms of affinities and fluxes (Onsager's approach). In particular, an overview will be given for thermo-elasticity, elasto-plasticity, martensitic phase transformations and damage mechanics. The purpose is to provide the participants of this course a unified understanding of all thermodynamically-consistent material models.

Local organization

The course is organized by the Aerospace Structures and Computational Mechanics chair of the Faculty of Aerospace Engineering of Delft University of Technology in collaboration with the Mechanics of Materials chair of the Department of Mechanical Engineering of Eindhoven University of Technology and the Applied Mechanics and Design chair of the Department of the Built Environment of Eindhoven University of Technology. The course is hosted by Delft University of Technology. Local information may be obtained from

- Dr. Sergio Turteltaub (for course content)
- Laura Chant (L.Chant@tudelft.nl) (for other local information)

Lecturers

- Dr. Sergio Turteltaub (TUD)
- Prof. dr.ir. Akke Suiker (TU/e)
- Dr. Varvara Kouznetsova (TU/e)

Lecture notes

Lecture notes and course material will be distributed at the start of the course.

Prerequisites

Prerequisites for this topical course are undergraduate courses in solid and fluid mechanics and thermodynamics. A course in continuum mechanics is recommended.

Contents

- 1 General introduction
 - Objectives and scope
 - Notation and summary of tensor algebra and analysis
- 2 Thermodynamics of continuum media
 - 2.1 Basic mechanical and thermal concepts
 - Reference and current configurations
 - Mechanical concepts
 - Thermal concepts
 - Energy of a continuum
 - Intensive and extensive quantities in the reference and current configurations
 - 2.2 Thermomechanical principles
 - Principles in global form (integral relations)
 - Principles in local form (differential relations)
 - 2.3 Constitutive theory
 - Field equations and constitutive models
 - Thermoelasticity
 - Theories with internal variables
 - Dissipation and kinetic relations: Onsager's framework
- 3 Thermoelasticity
 - 3.1 Introduction
 - 3.2 Thermodynamical laws
 - 3.3 General equations of a thermoelastic material
 - 3.4 Thermodynamical equilibrium
 - 3.5 Linear thermoelastic material
 - 3.6 Isotropic linear thermoelastic material
 - 3.7 Isothermal and adiabatic conditions
- 4 Elastoplasticity
 - 4.1 Introduction
 - 4.2 Inelastic materials and internal variables
 - 4.3 Constitutive laws and dissipation inequality
 - 4.4 Elastoplastic material
 - 4.5 Approach based on postulate of maximum dissipation
 - 4.6 Approach based on dissipation potential
 - 4.7 Von Mises plasticity with isotropic hardening

- 4.8 Von Mises plasticity with kinematic hardening
- 4.9 Drucker-Prager plasticity with isotropic hardening
- 5 Martensitic phase transformations and damage
 - 5.1 Introduction
 - 5.2 Martensitic phase transformations
 - Transformation kinematics and stress-strain response
 - Formulation in terms of the Helmholtz and Gibbs energy densities
 - Thermomechanical constitutive model
 - Kinetic relation for transformation
 - Heat conduction and latent heat
 - Summary of main model equations
 - 5.3 Phase transformations with damage
 - Derivation of model equations from Helmholtz energy density
 - Driving forces for transformation and damage
 - Stress and conservative entropy
 - Kinetic law for damage

Although the emphasis in the present course is on solid materials, the general thermodynamical principles are valid for continuum media, including fluids (liquid and gases).

Fee/Registration

The course is free for registered members of the graduate school Engineering Mechanics and for the research members of the contributing research groups. The course fee for non EM members is € 100 for students and € 400 for other participants. They will receive an invoice after accepted registration. Participants need to register by completing the registration form, which can be found at <http://www.em.tue.nl/events/index.php/2/2018> and returning it before **27 March, 2019** to the Secretariat of the Graduate School Engineering Mechanics, Eindhoven University of Technology. Members of the Graduate School Engineering Mechanics receive priority in case of over-subscription.

Further information

Arrangements regarding dinners and accommodation will be communicated to the course participants by email prior to the course.

For more information on the contents of the course, contact:

Dr. Sergio Turteltaub
E-mail: s.r.turteltaub@tudelft.nl

Further information about the educational programme and other activities of the Graduate School on Engineering Mechanics can be found at: www.em.tue.nl.