



EM Graduate course

Continuum Thermodynamics

17-18 April 2023

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

General

In many 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.

- Dr. Sergio Turteltaub (for course content)
- Annejet Stegeman (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

Participants need to register via our website <https://engineeringmechanics.nl/courses> before **April 3rd, 2023**

Location/date

The course will be provided at the University of Technology Delft. The course language is English. Further details about the online setup of this course will be communicated to the registered participants in due time before the start of the course

Further information

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

On the contents of the course:

Dr. Sergio Turteltaub

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On the organization of the course:

Mrs. Rachel van Outvorst, TU/e,

E-mail: Engineering.Mechanics@tue.nl

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