Advanced Metallurgy – Infos on Exam and Main Study Goals

General information and rules

- The exam will take place on **Wednesday, 22.01.2025, 09h15-10h45**, in room **CE11**
- The exam is NOT open book, i.e. lecture slides, course notes, textbooks etc. are not allowed.
- You may use **two handwritten A4 sheets of paper** (double sided) with the information from the lectures you find relevant.
- Computers, tablets, mobile phones etc. may not be used; mobile phones have to be switched off during the exam.
- You may use a pocket calculator for the exam.
- Do not forget to bring your student card and your ID.

In the following, the main goals of the course and what the students are expected to know for the exam are summarized. It should help the students to prepare for the final exam.

Fundamentals (thermodynamics, phase diagrams, phase transformations, kinetics, mechanical properties, strengthening mechanisms at low/high temperatures)

- Chapter 2 summarizes the materials science fundamentals that are relevant for understanding the **structure, properties and processing** of modern high-performance structural alloys.
- These topics have been introduced in BSc level courses at EPFL and are usually part of the undergraduate studies in materials science at other universities. Fundamentals were repeated and applied also in other chapters and in the exercises.
- It is essential that the students **have understood** these fundamentals and **can apply them** for the different alloy classes.
- In particular, the students must be able
    - to explain the fundamental thermodynamic quantities for alloy systems
    - to explain and provide the thermodynamic expressions for ideal/regular solutions
    - to derive phase diagrams based on the Gibbs Free Energy expression of two phases
    - to read binary and ternary phase diagrams and to find relevant points (e.g. eutectic compositions, peritectic reactions etc.)
    - to explain the basic mechanisms of plastic deformation at low/high temperatures
    - to explain the role of slip systems in bcc, fcc and hcp crystals for the plastic deformation
    - to read and explain stress-strain curves
    - to read and explain creep curves (including Larson-Miller representation)
    - to read and explain S,N-curves

The course gives an overview of the modern high-performance structural alloys

- The students should have learned that, despite different main elements and chemical compositions, these alloys have many things in common and that there are some general rules for the design of high-performance alloys.
- Independent of the class of alloys, the students must know
  - The **most important alloying** elements for the different alloy classes and their main roles
  - The **main phases and crystal structures** of the alloys
  - The **classification** of Fe, Ni, Ti, Al, Mg alloys and their **nomenclature**
  - Some typical microstructures (examples were given in the lecture slides) and how to explain them.
  - The **strengthening mechanisms** at room temperature and at elevated temperatures
  - The **basic heat treatments** (if applicable) for the different alloys, CCT and TTT diagrams
  - The **main properties and applications** of the alloys
- The students are NOT expected to memorize tables with compositions or mechanical properties, draw specific phase diagrams or stress-strain curves etc. given in the lecture slides.

In the following, some more specific study goals are given for the different alloy systems

Advanced Steels

- Fe-Fe_3C diagram and main phases in steel
- Stainless steels
  - Sub-classification of stainless steels
  - Main alloying elements and rough compositions
  - Why are stainless steels "stainless"?
- Steels for elevated temperature applications
  - Sub-classification of these steels
  - Main alloying elements and rough compositions
  - How do the steels get their high-temperature strength?
- AHSS/TRIP/TWIP steels
  - Sub-classification of AHSS/TRIP/TWIP steels
  - Main alloying elements and rough compositions
  - Explanation of the TRIP/TWIP effect; what determines the TRIP/TWIP effect?
  - Formation of stacking faults and role of Mn on SFE

Ni alloys

- Difference between wrought and cast Ni alloys (conventional, directional, single crystal)
- The γ'-Ni_3Al phase (structure, composition) and its role for HT-strengthening of Ni alloys
- Fabrication of directionally solidified/single crystal alloys incl. main casting defects
- Microstructural changes after high-T exposure/heat treatments

Ti alloys

- Main properties of α, β and α+β Ti alloys
- Surfaces on Ti alloys & reactivity
- Plasticity in hex crystals, implications on deformation behavior and notch sensitivity

Al and Mg alloys

- Main properties of Al and Mg alloys
- Surfaces on Al alloys & reactivity
- Plasticity in hex crystals, implications on deformation behavior and notch sensitivity (for Mg alloys)

Structural Intermetallics

- Hume-Rothery rules for substitutional/interstitial phases
- The different types of IM phases and their main characteristics
- The advantages/disadvantages and fundamental properties of the structural intermetallic alloys from the Ti-Al, Ni-Al and Fe-Al systems

High Entropy Alloys and Bulk Metallic Glasses

- Definitions of HEAs and BMGs
- Criteria for finding HEAs and BMGs
- Fundamental thermodynamic principles of HEAs
- Classes of HEAs and general properties of HEAs
- General properties of BMGs
- Plastic deformation of BMGs and differences to crystalline materials

Precious Metals

- Basic metallurgy of Au, Ag and Pt alloys (main alloying elements)
- Color formation in Au alloys
- Main applicati

Thermodynamic Modeling

- The main goal of this chapter is to explain what is behind the thermodynamic models that are used in Thermo-Calc, which is important for using the software in the correct way (case study 2)
- The students know/can explain
  - that the CALPHAD approach is based on the thermodynamic modeling of the Gibbs free energies of the solution phases and stoichiometric compounds
    $G = G^0 + G_m^{ideal} + G_m^{ex} + G_m^{phys}$
  - the ideal and regular solution model (incl. expressions for G)
  - the sub(n)-regular solution model for a 2-component system and the role of the interaction parameters (incl. expressions for G)

- Detailed knowledge of out-of-equilibrium solidification models, kinetic modeling and simulation, precipitate formation **are not relevant** for the exam.

Primary Metallurgy of steel and Al alloys

- Read/explain Ellingham diagrams and application for metal oxide systems
- The students can explain
  - The fundamentals of the steelmaking process (blast furnace, oxygen converter process, electric arc furnace)
  - The role of scrap
  - The basics of secondary steel metallurgy
  - The basics and advantages/disadvantages of direct reduction processes
- The students have an understanding of the environmental impact of the steelmaking process
- The students can explain the fundamentals of the Al making process
- The students have an understanding of the environmental impact of the Al making process
- The students can explain possible approaches for improving the environmental efficiency of the Al making process