FS 2025/26

MSE-422 – Advanced Metallurgy

1-Introduction

Christian Leinenbach

Zoom-Link for quizzes etc.

- https://epfl.zoom.us/j/69365527653?pwd=hzKzFvgbQSr4jc6jDdhrv1DyvAga75.1
- Meeting-ID: 693 6552 7653
  Code: 070632

About myself – MER Dr. Christian Leinenbach

- My main working place: Empa Dübendorf & Thun (since 2005)
- Head Advanced Processing and Additive Manufacturing of Metals
- Education
  - MSc Materials Science and Engineering, Universities Saarbrücken (DE) and Luleå (SE)
  - PhD Materials Science and Engineering, University of Kaiserslautern (DE)
- Research focus (with ~25 years experience):
  - Design and characterization of advanced structural alloys and composites
  - Additive manufacturing: materials & process optimization
  - Advanced joining technologies
- MER/Lecturer at EPFL since 2018
  - Advanced Metallurgy (MSE-422)
  - Assembly Technologies (MSE-464, with C. Plummer – not given anymore)
  - AM of Metals and alloys (PhD course, MSE-666, with R. Logé)
  - Laser Materials Processing (PhD course, MSE-662, with P. Hoffmann)
- Lecturer at University of Kaiserslautern (2005-2014), Empa Academy, CCMX Winter Schools

About myself

EPFL

- Contact at EPFL (on Wednesdays):

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christian.leinenbach@epfl.ch

- Contact at Empa (other days):

Head Advanced Processing & Additive Manufacturing of Metals
Empa-Swiss Federal Laboratories for Materials Science and Technology
Dübendorf & Thun
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- Topics for Internships / Semester Projects / PDM on alloy development, metals processing and additive manufacturing available upon discussion

Teaching assistants

Exercises / case studies /exam

Abdullah Aydemir
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PhD student
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Why studying the course MSE-422?

Some sentences I heard throughout my career

«Metallurgy is the science of the 19th century»

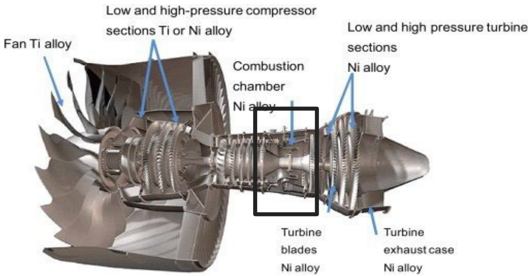
«Metallurgy is a workshop technology and does not belong to a university»

«We know everything about metals and there is no need for further research»

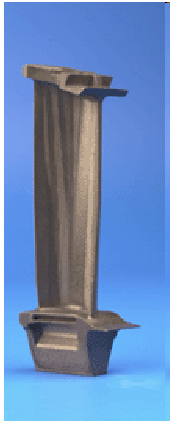
Well, really???

Materials in a modern aero-engine

/www.airbus.com/, /www.geae.com/



/www.volvo.com/



- Ni superalloy CM247LC – directionally solidified

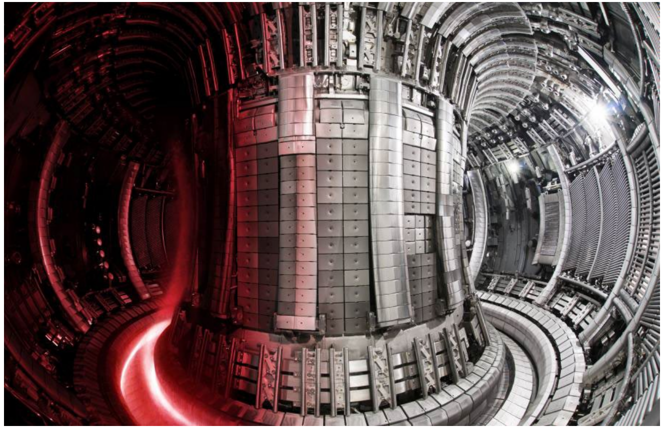
	C	Si	Mn	Cr	Mo	Ni	Ta	Ti	W	Co	Fe	Al	Hf	V	Zr
CM 247	0.074	< 0.03	< 0.03	8.16	0.43	Bal.	3.21	0.68	9.55	9.364	0.03	5.63	1.42	< 0.03	0.015
	Cu	B	P	S	Pb	Ag	Bi	Te	Tl	Sb	Sn	Zn	Cd		
	< 0.03	0.0155	< 0.005	6 ppm	< 2 ppm	< 2 ppm	< 0.3 ppm	< 1 ppm	< 1 ppm	< 3 ppm	< 3 ppm	< 2 ppm	< 0.5 ppm		

Typical chemical composition in wt.%

- Why Ni as base material?
- Why so many alloying elements and what do they do?
- Why this special grain structure?
- How do we produce such a turbine blade?
- What are the properties of the turbine blade?

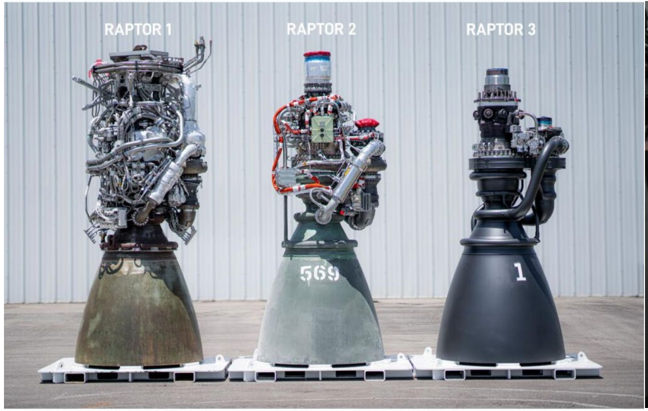
Materials for extreme environments

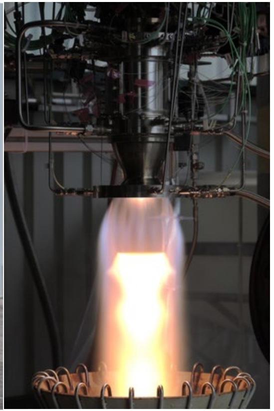
Fusion reactor



//www.iter.org/

Re-usable rocket engines



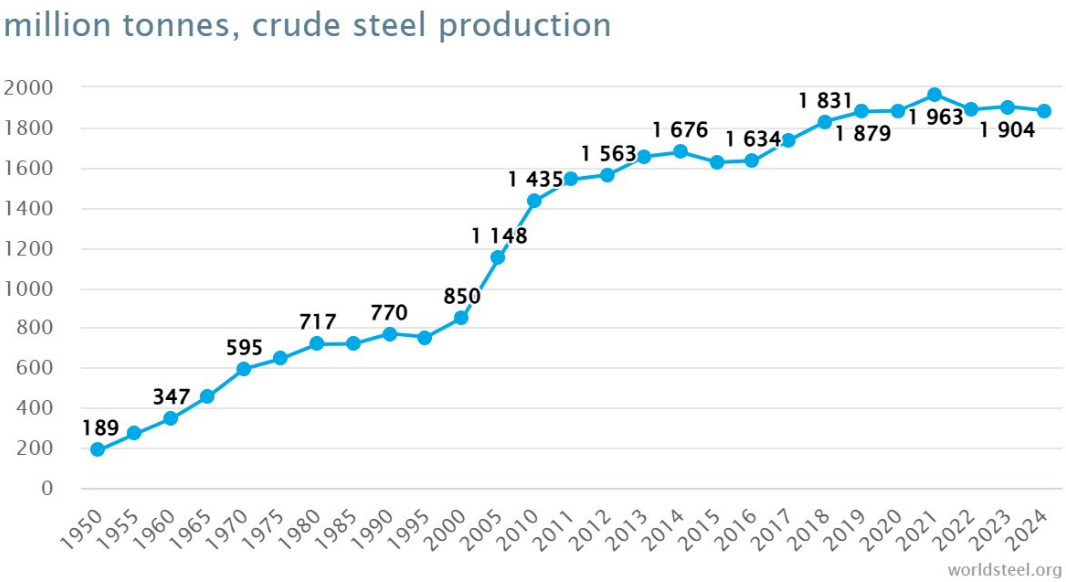


- How can we select/design alloys that can withstand extreme environments?
  - Alloys for fusion reactors (plasma, T=10^8 K, combined with neutron irradiation)
  - Re-usable, 3D-printable and cost-efficient rocket engines (O_2-rich fuels, >20 launches)

Materials in a modern car body structure

- Why do we still use that much steel for a car body and not e.g. Al or Mg?
- What requirements do we have for steels to be used in a car body structure?
- Car bodies consist of different types of steels: Dual Phase (DP), Complex-Phase (CP), Ferritic-Bainitic (FB), Martensitic (MS), Transformation-Induced Plasticity (TRIP), and Twinning-Induced Plasticity (TWIP). What do all these terms mean?
- How are these steels made?

The problems with steel making



- For very ton of steel produced in 2023
  - ~21.3 GJ (5917 kWh) of energy were used
  - ~1.92 tons of carbon dioxide were emitted, equating to about 8 percent of global carbon dioxide emissions.
- Are there ways for a more sustainable steel production?
- What is the picture for other metals?

Course structure

- 4 ECTS point
  - 2/4h lectures per week (Wednesday 11-13 and 14-16)
  - 2h exercises every second week (beginning 17.09.25)
- The exercises will include
  - Problems/calculations
  - Case studies and examples from ongoing research
  - Software demonstration (Thermo-Calc) and hands-on software training
- Assessment
  - A larger case study for groups of 3-4 students during the semester including (50%)
    - Literature review
    - A Thermo-Calc case study
    - Summary of results in a course paper and a poster presentation at the end of the course
  - Final written exam 90 mins (50%)

General remarks

- As the course name "Advanced Metallurgy" implies, the students are expected to have some basic background in metallurgy.
- We will assume that you are already familiar with the topics covered in the EPFL Bachelor's courses in Materials Science, especially from the classes on Metals and Alloys, Phase Transformations, and Deformation of Materials…
  - I will give a short reminder of the most important points, but it is up to you to make yourself familiar with these fundamentals!
- For those coming from other universities or those having a B.S. in another subject, either from EPFL or another university, additional work in personal reading might be necessary.
  - Ask your course mates from EPFL for their old course material!

Course outline

- Introduction
- Reminder
  - Thermodynamics and phase diagrams
  - Kinetics and phase transformations
  - Mechanical properties (quasistatic, cyclic, creep); strengthening mechanisms in alloys for RT and HT
- Introduction into alloy design

  → how can we design multi-component alloys with specific properties?
  - Integrated computational materials engineering
  - Thermodynamic/kinetic modeling using Thermo-Calc
  - Case studies - alloy development cycle, processing, behaviour in service

Course outline

- Modern high performance metallic materials → in each chapter, I will talk about compositions & microstructures, potential heat treatments, properties, and fields of application.
  - Advanced steels: austenitic steels, HT resistant steels, AHSS
  - Ni alloys
  - Ti alloys
  - Mg alloys
  - Structural intermetallics (TiAl, NiAl,)
  - High entropy alloys and bulk metallic glasses
  - Precious metals (Au, Pt alloys)

Course outline

- "Green" (sustainable) metallurgy and metals recycling
  - Primary and secondary metallurgy of steels and Al alloys
  - Problems with energy consumption and CO_2 emission
  - Sustainable metallurgy approaches
  - Recyclability of the main alloy classes