Materials-and-Production-Engineering-Lecture Materials Science - Lecture on Real Structures and Properties

Prof. Dr.-Ing. Christian Willberg
Hochschule Magdeburg-Stendal

Contact: christian.willberg@h2.de

Parts of the script are taken from
Prof. Dr.-Ing. Jürgen Häberle

Objectives

- Defects in crystals
- Plasticity
- Basics of mechanical properties

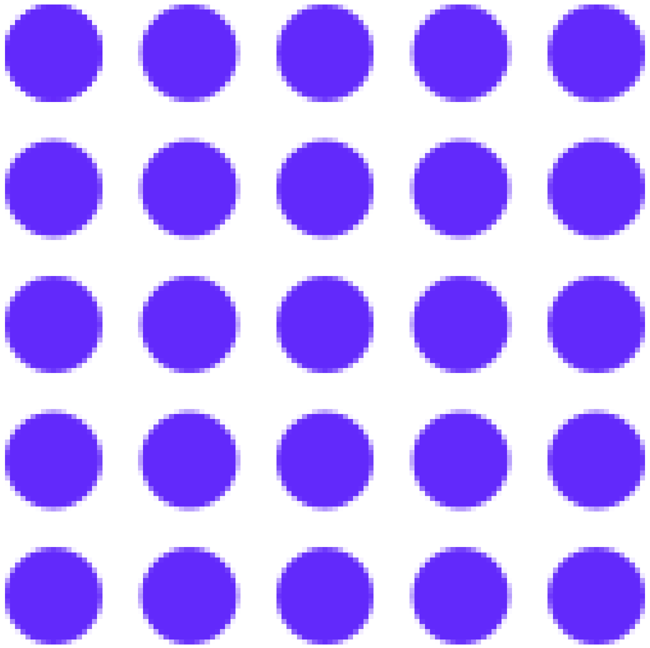
Real Structure of Crystals

Lattice Defects

- Zero-dimensional defects (point defects): vacancies, interstitial atoms, interstitial foreign atoms, substitutional foreign atom
- One-dimensional defects (line defects): dislocations
- Two-dimensional defects (surface defects): stacking faults, grain boundaries, subgrain boundaries, phase boundaries

Zero-dimensional Defects

- What are the possible variants?



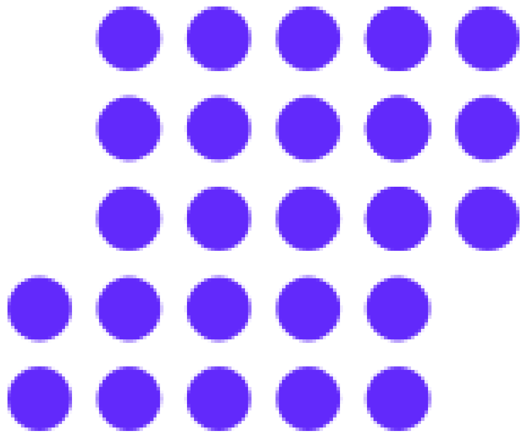
Foreign Atoms

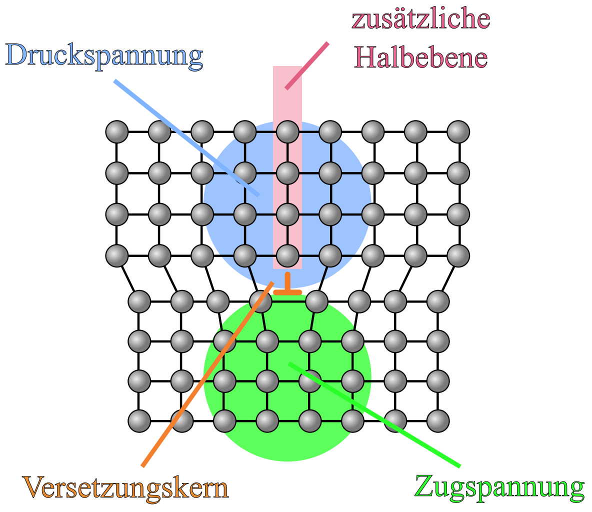
- How can foreign atoms be used?

Dislocations

Dislocations occur

- during crystal growth
- due to residual stresses
- through plastic deformation

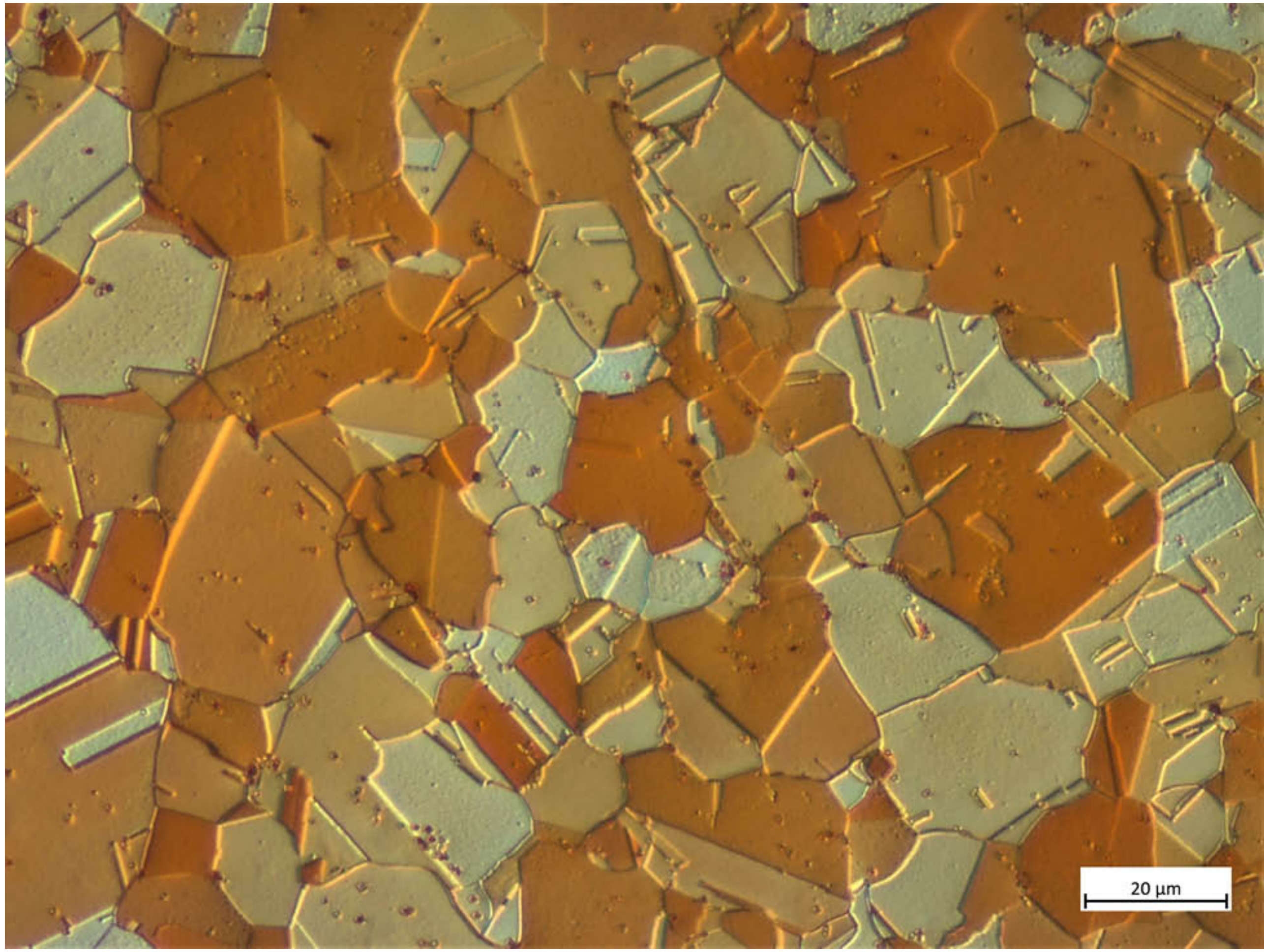




Two-dimensional Defects - Grain Boundaries

- Grain boundaries
- Phase boundaries
- Subgrain boundaries

Script



Plasticity

Good or Bad?

Examples

High plasticity:

- Modeling clay
- Wet clay
- Metals and metal alloys with a suitable atomic lattice:
  - glowing steel in forging
  - cold forming of sheets

Low plasticity:

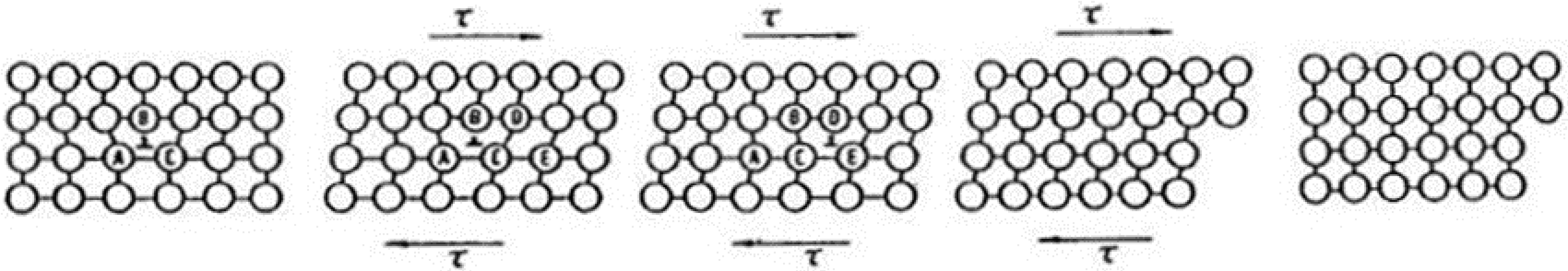
- Rubber
- Ceramics
- Fiber-reinforced composites (epoxy-glass fiber or epoxy-carbon fiber)

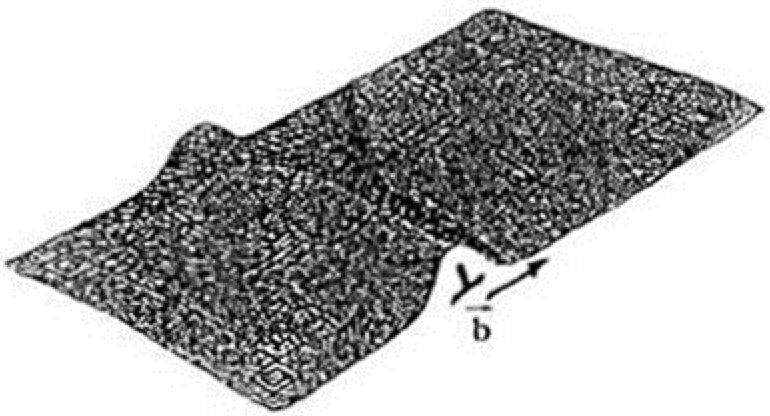
Plasticity - Single Crystal

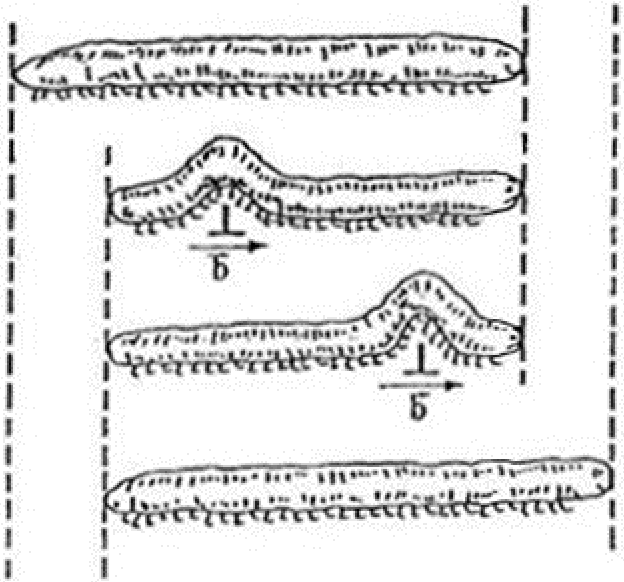
The plastic deformation of a crystal mainly occurs through the sliding of atomic layers along certain crystallographic planes and directions under the influence of shear stress.

- The slip system consists of a slip plane and a slip direction.
- Critical shear stress ($\tau_{Cr} \approx G/10$ - estimate or theoretical shear strength)
- Reality is ~100 times lower due to dislocations

Image



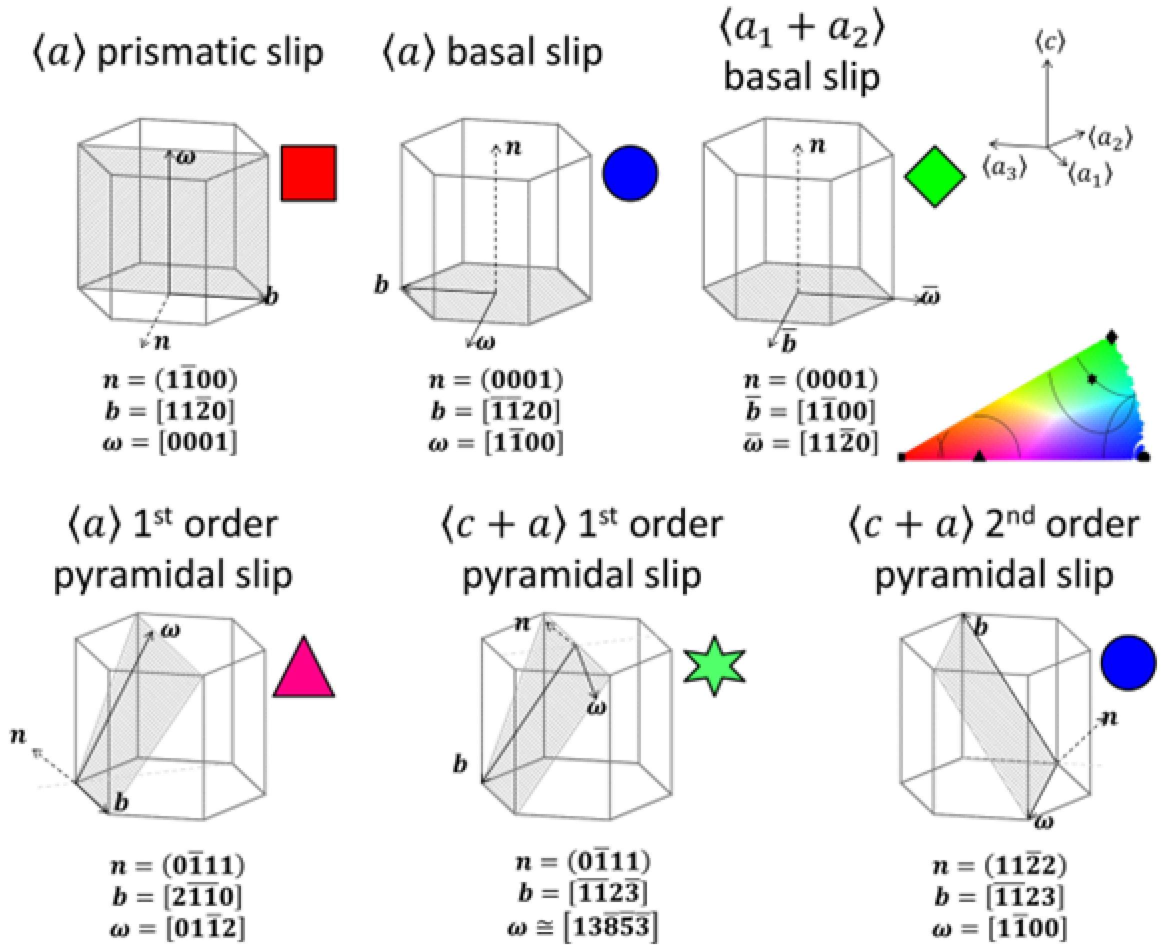




Plastic Deformation of Polycrystalline Material

- Micro- and macroplasticity
  - Plastic deformation starts at "unfavorable" orientations
- Grain boundaries
  - Barrier to dislocation motion
  - At high temperatures, grain boundaries can slide (creep)
  - Targeted manufacturing can increase toughness through grain boundaries
- Heterogeneity
  - Multiphase materials
  - Inhomogeneous distribution of stresses and deformations
- Anisotropy

Slip Systems



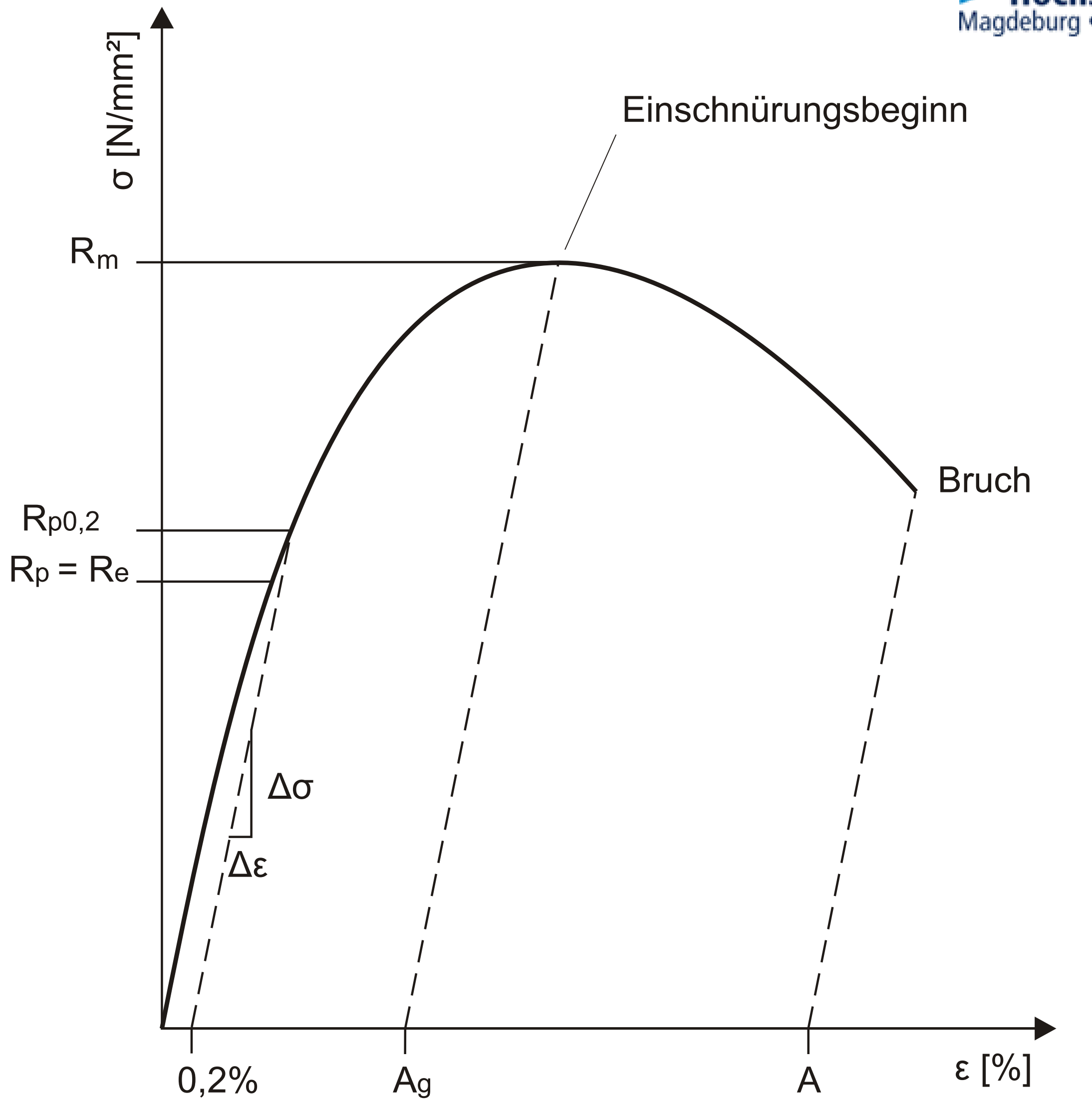
Polycrystal Plasticity

Example from a simulation

Shear bands

Yield Strength

- R_m - tensile strength
- R_e - yield strength
- Offset yield strength or elastic limit $R_{p0.2}$
  - After loading and unloading, 0.2% strain remains
- Offset yield strength is used as a substitute for yield strength

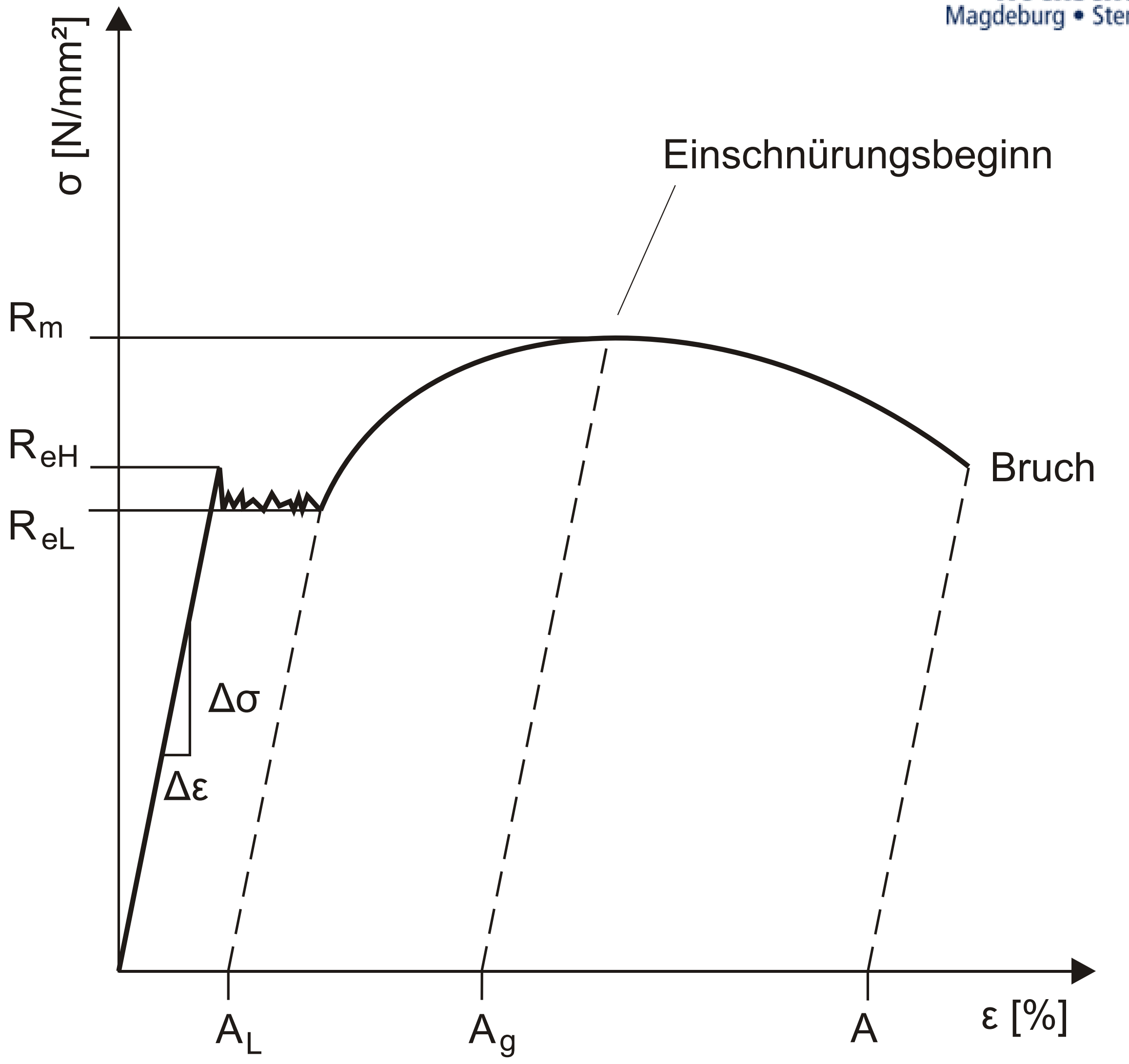


Yield Strength

- Upper yield strength R_{eH}
- Lower yield strength R_{eL}

> Jagged area: Lüders region

Example video

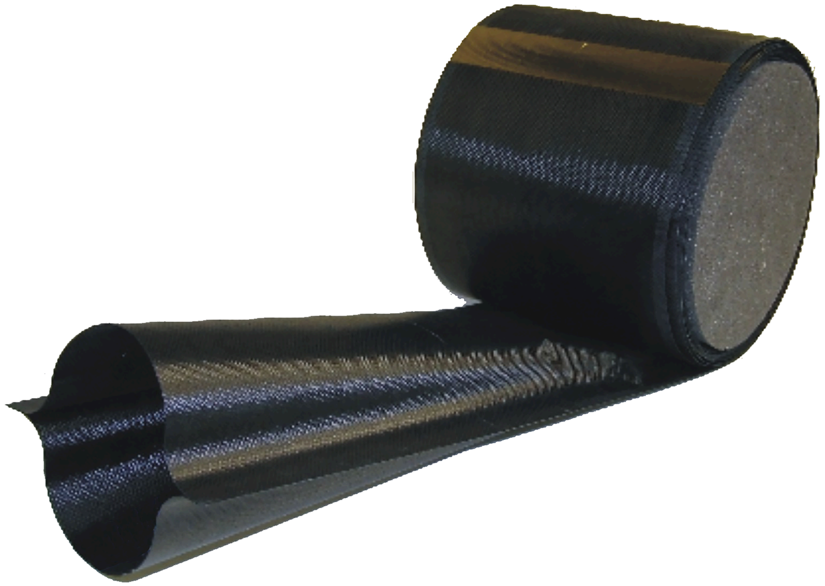


Plasticity - Forming

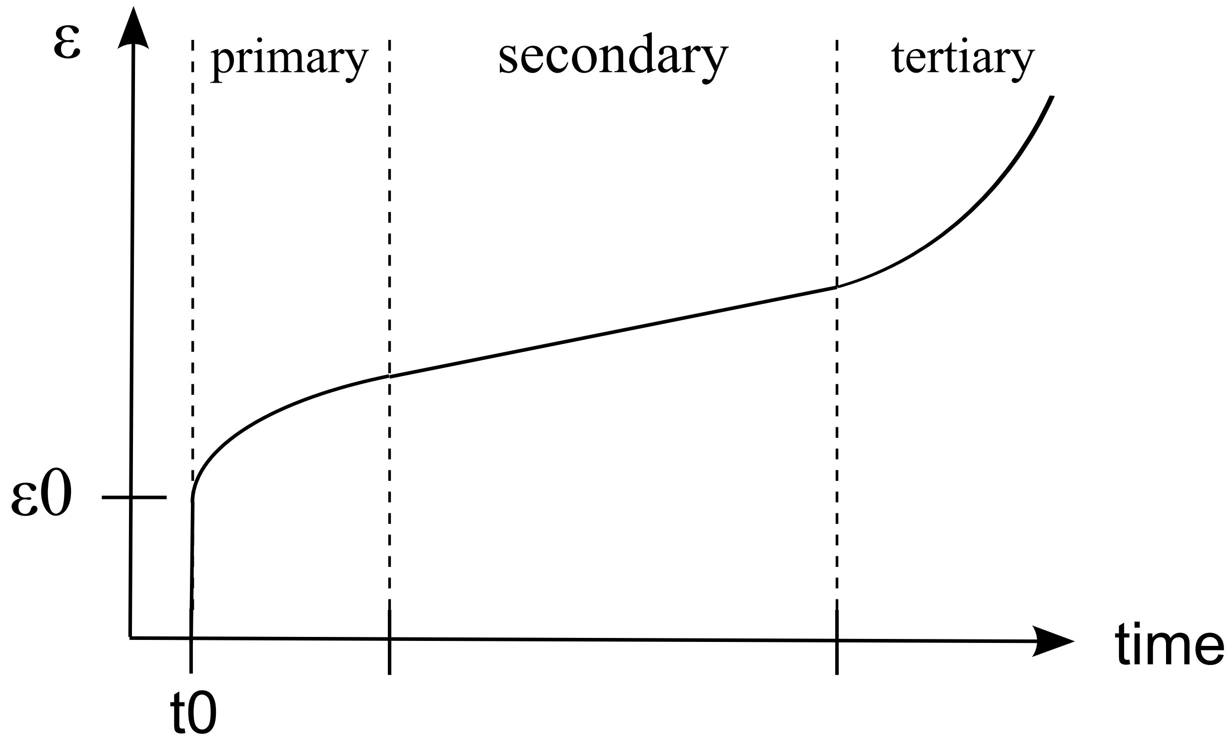
- Deep drawing principle
- Deep drawing in reality

Creeping

- Time-dependent deformation under constant load
- **Example**: Deployable Space Structures



- **Occurs in metals above a transition temperature:** $T > 0.3\text{–}0.4 \cdot T_S$
- **Irreversible plastic deformation** takes place even at low mechanical stresses, **below the yield strength** R_e:
    - Slow but continuous progress



Creep Characteristics in Metals

- **Dependent on**: temperature, stress, time, material
- **Causes**:
  - Dislocation movements
  - Vacancy diffusion
  - Grain boundary sliding
  - Grain boundary diffusion