Fatigue and Wear

Prof. Dr.-Ing. Christian Willberg
University of Applied Sciences
Magdeburg-Stendal

Contact: christian.willberg@h2.de

Parts of this script are adapted from
Prof. Dr.-Ing. Jürgen Häberle

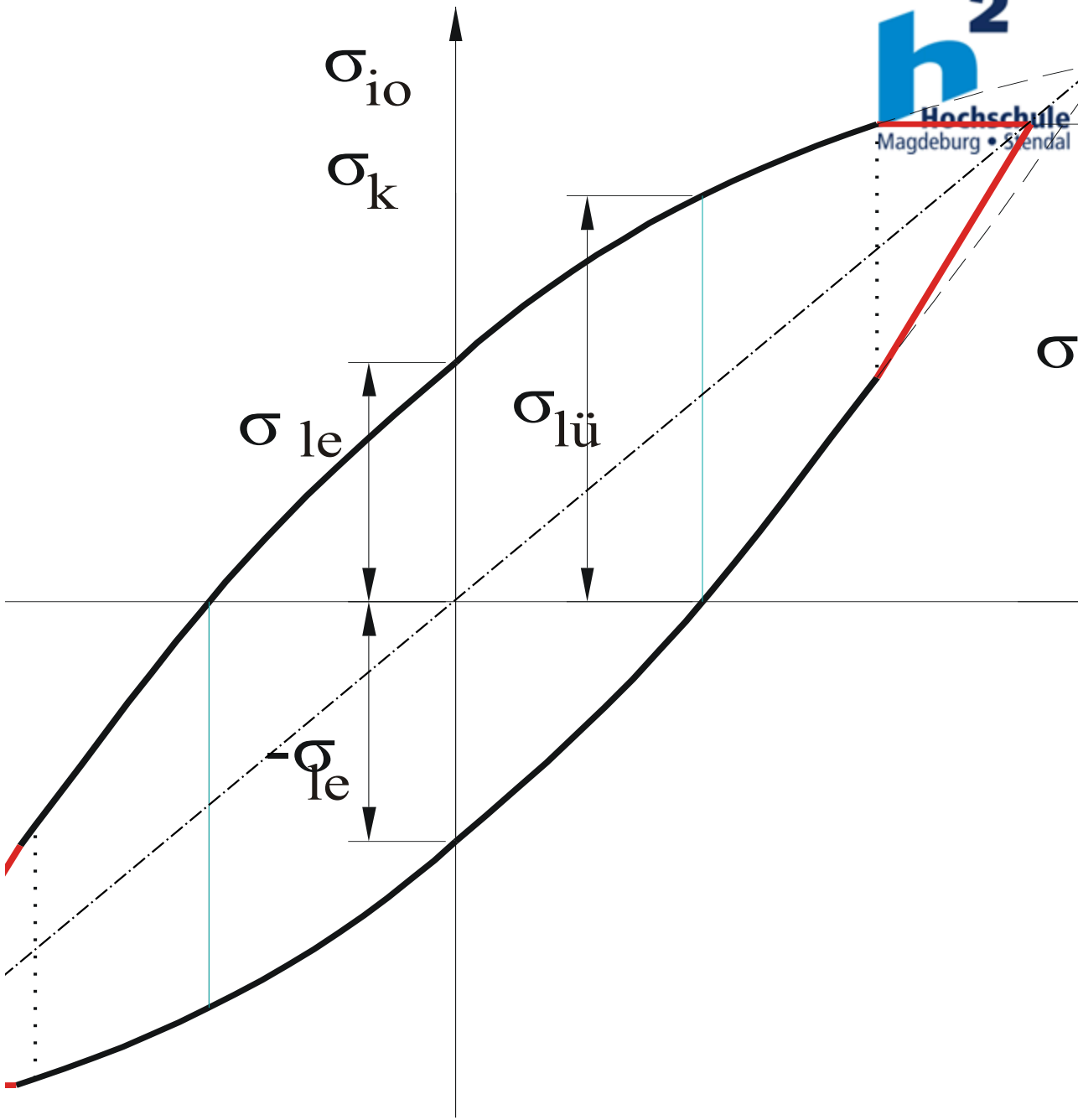
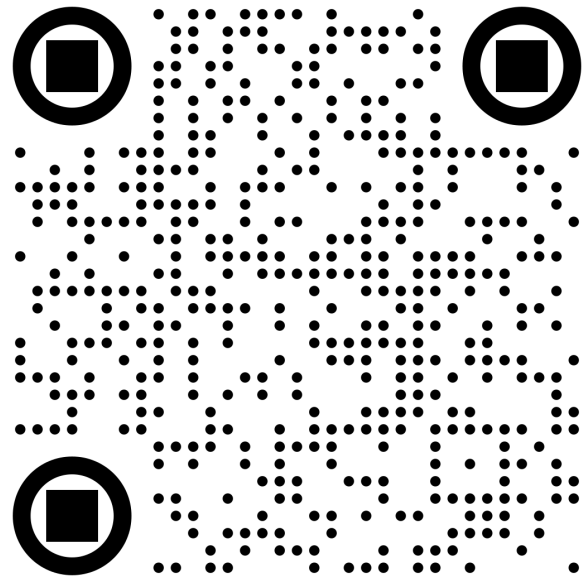


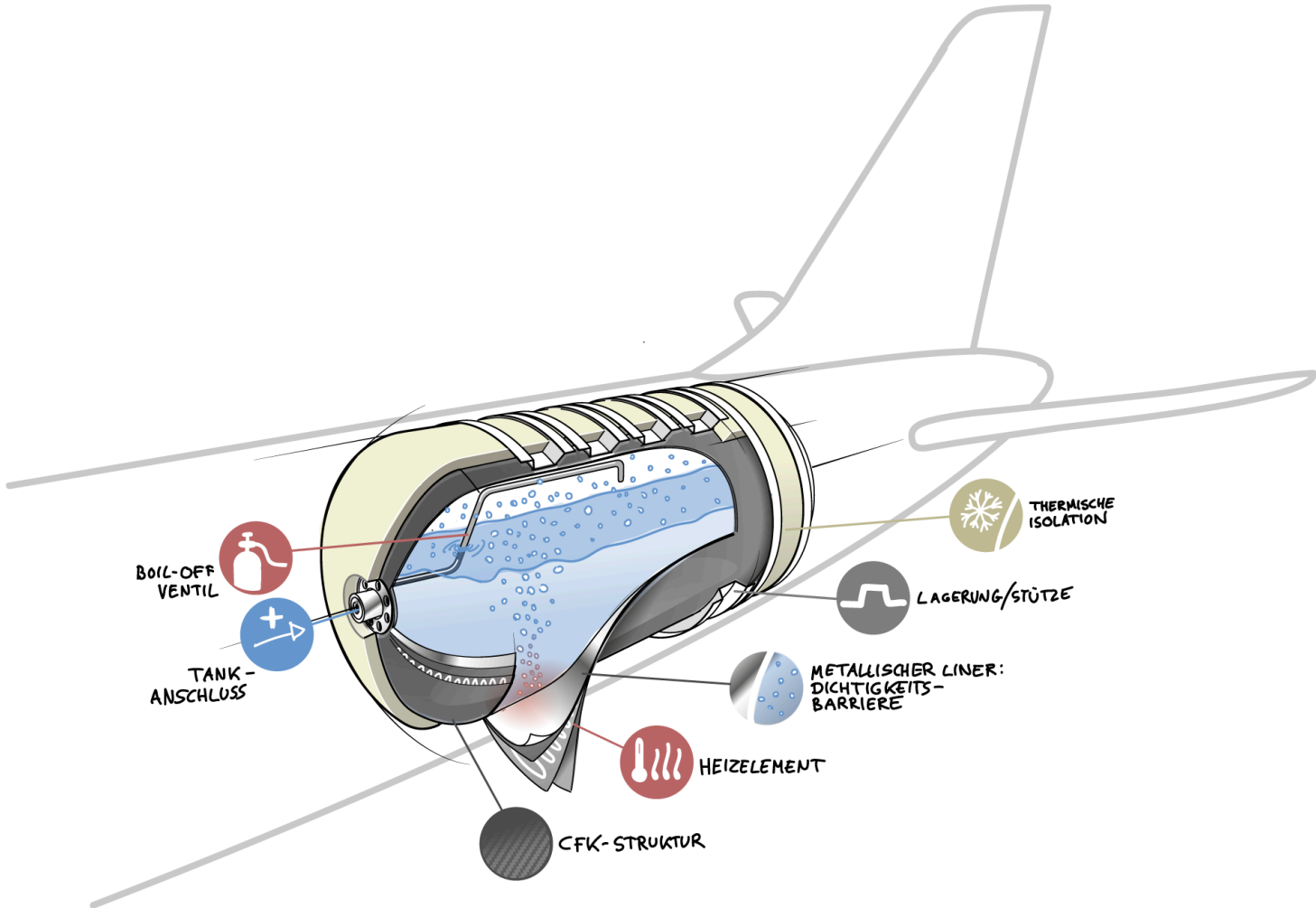
Image reference



Fatigue

- What is Fatigue?

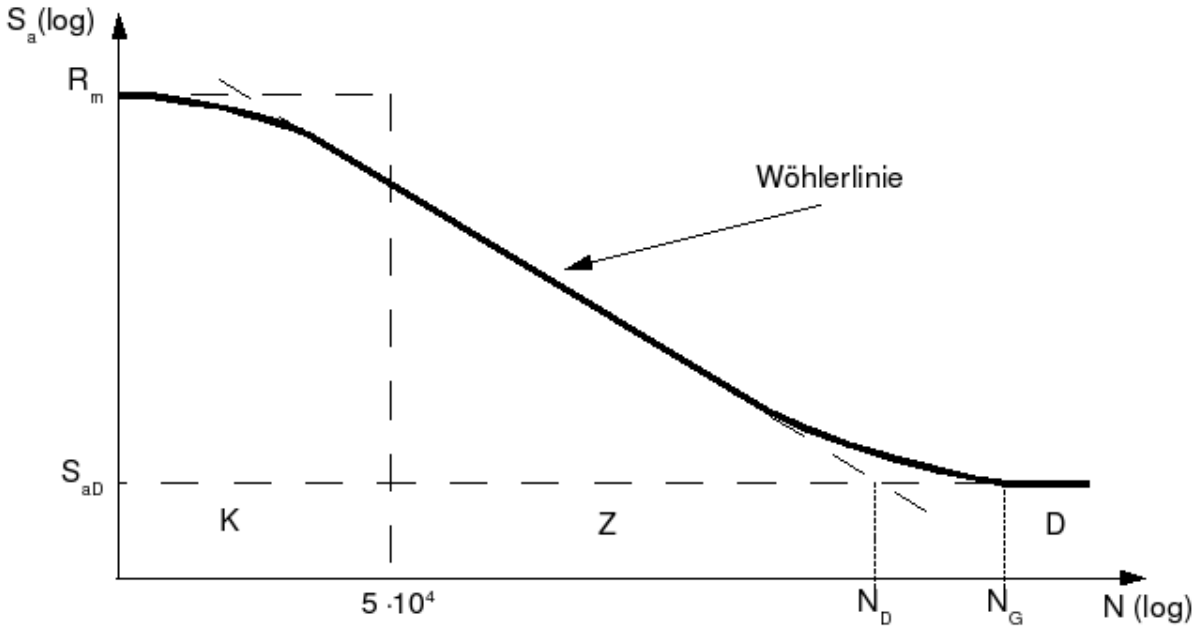
- Typically occurs under cyclic loading
  - Isothermal mechanical fatigue
    - Oscillating load
    - Aircraft fuselages (pressure buildup and release)
  - Thermal fatigue
    - Ovens, heating elements
  - Thermomechanical fatigue
    - High-pressure containers
  - Electrothermal fatigue
    - Current conductors (filaments)

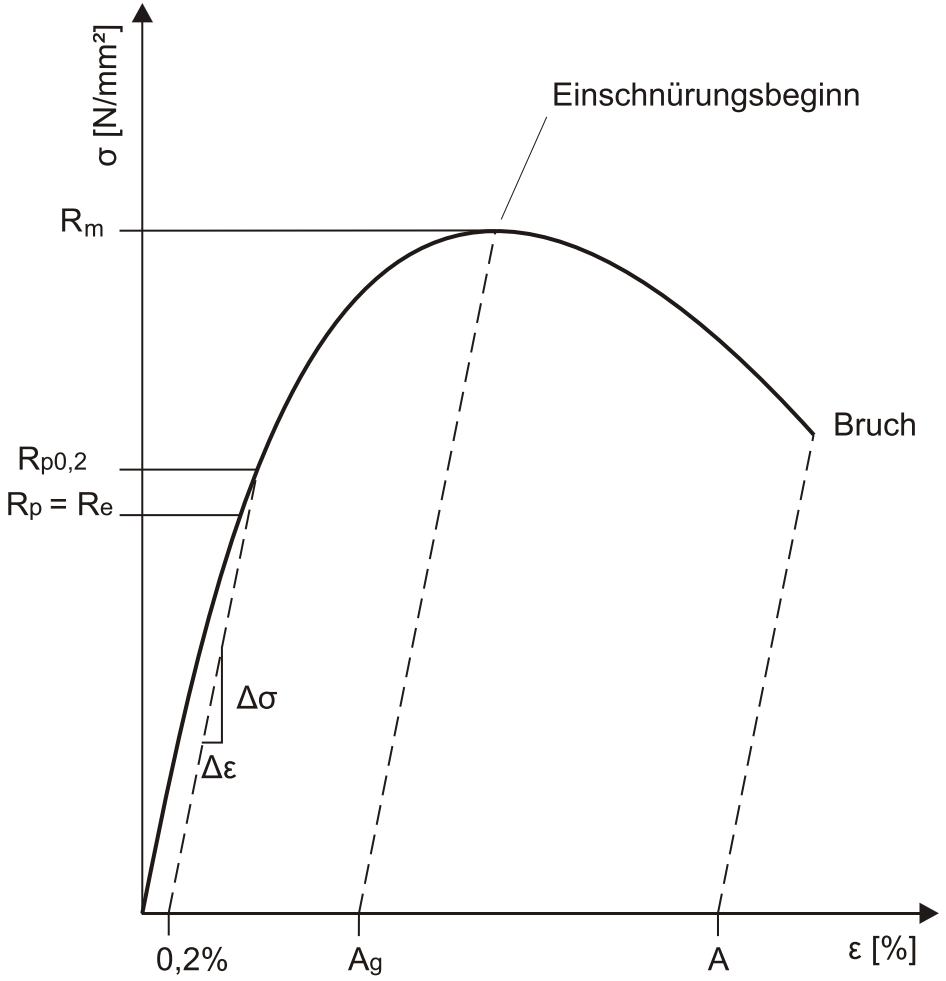

BOIL-OFF VENTIL
TANK-ANSCHLUSS
THERMISCHE ISOLATION
LAGERUNG/STÜTZE
METALLISCHER LINER: DICHTIGKEITS-BARRIERE
HEIZELEMENT
CFK-STRUKTUR

Fatigue

- Load is below the yield strength $R_{p0,2}$
  - > *Reminder: What does $R_{p0,2}$ mean?*
- Stress concentrations occur at material defects (pores, microcracks) or in the crystal (dislocations, defects)
- Initially, random local areas of plastic deformation form under alternating load
- These points represent stress concentration areas that increase over time and can lead to fracture

Explanation video


S_a(log)
R_m
Wöhlerlinie
S_aD
K
Z
D
5 ·10⁴
N_D
N_G
N (log)


σ [N/mm²]
Einschnürungsbeginn
R_m
Bruch
R_p0,2
R_p = R_e
Δσ
Δε
0,2%
A_g
A
ε [%]

Stress Ratio

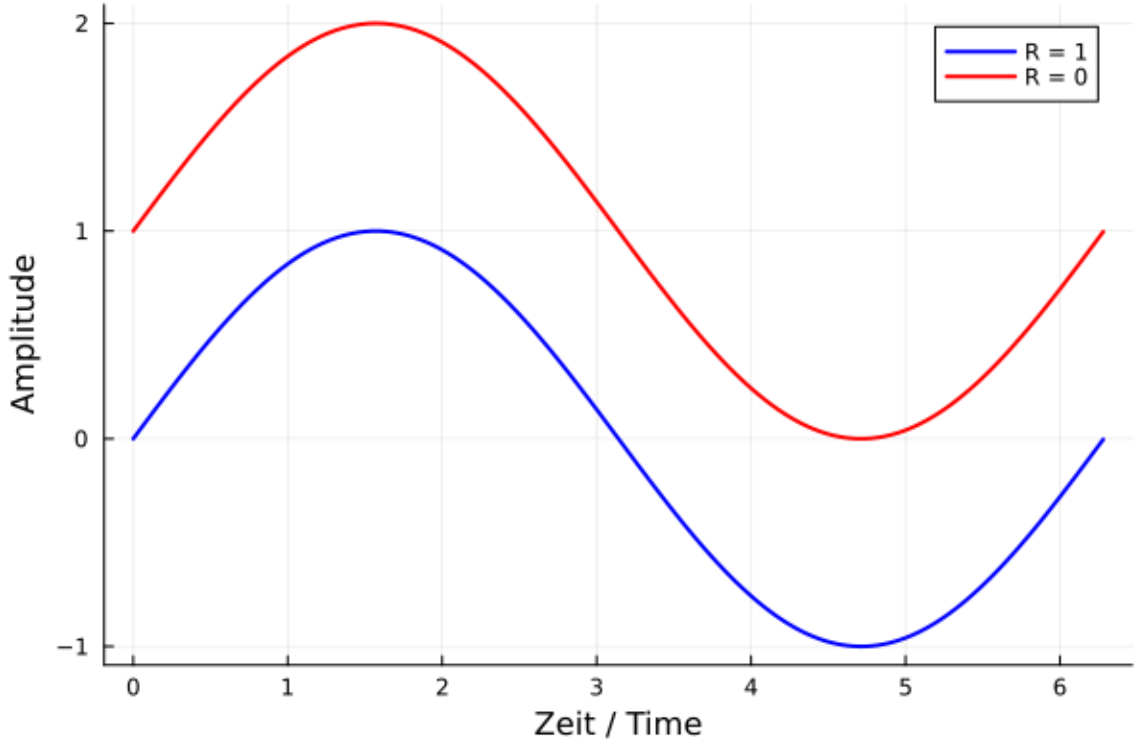
$$R = \frac{\sigma_l}{\sigma_u}$$

Mean Stress

$$\sigma_m = \frac{\sigma_l + \sigma_u}{2}$$

σ_u - Upper stress

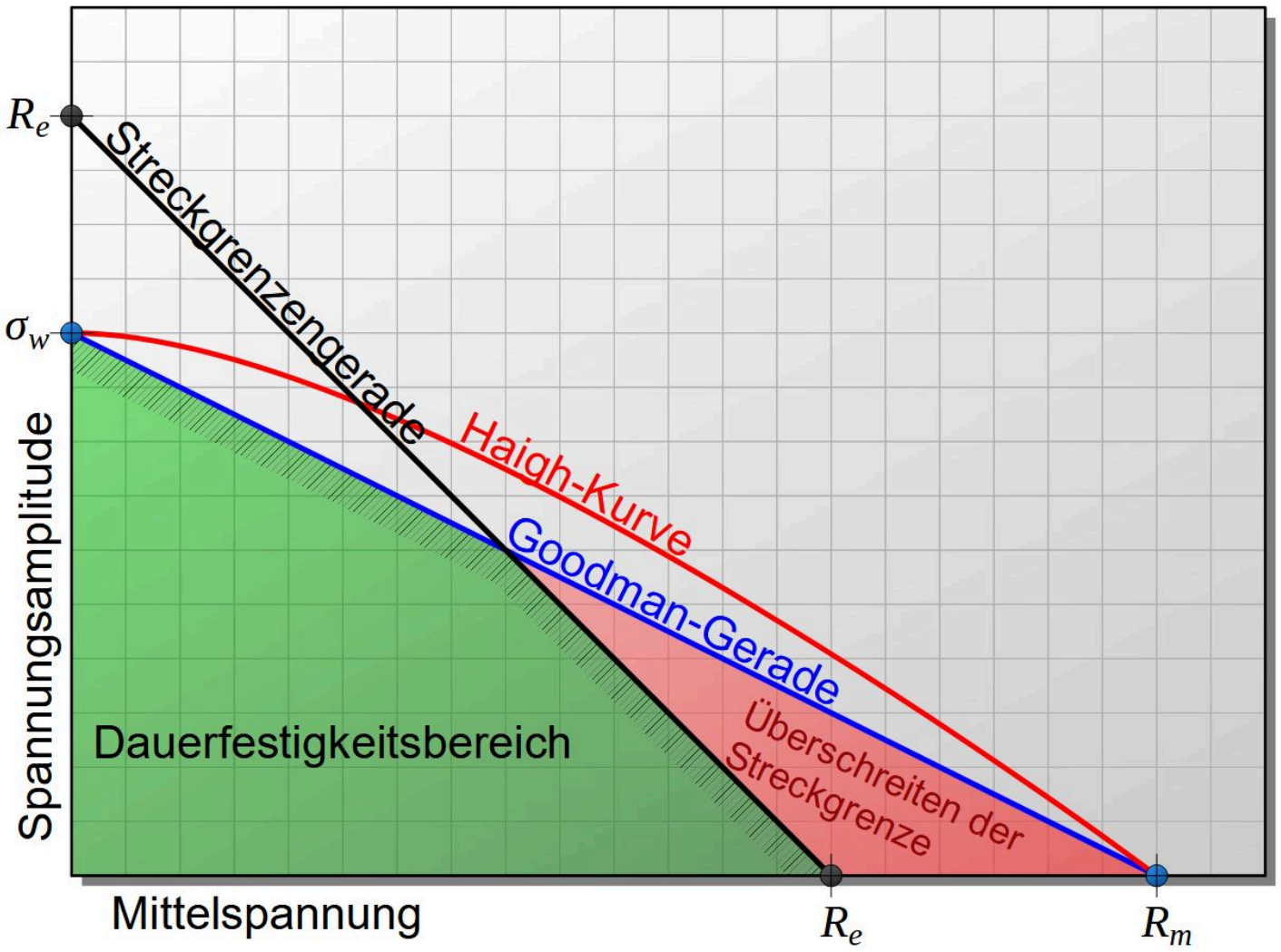
σ_l - Lower stress

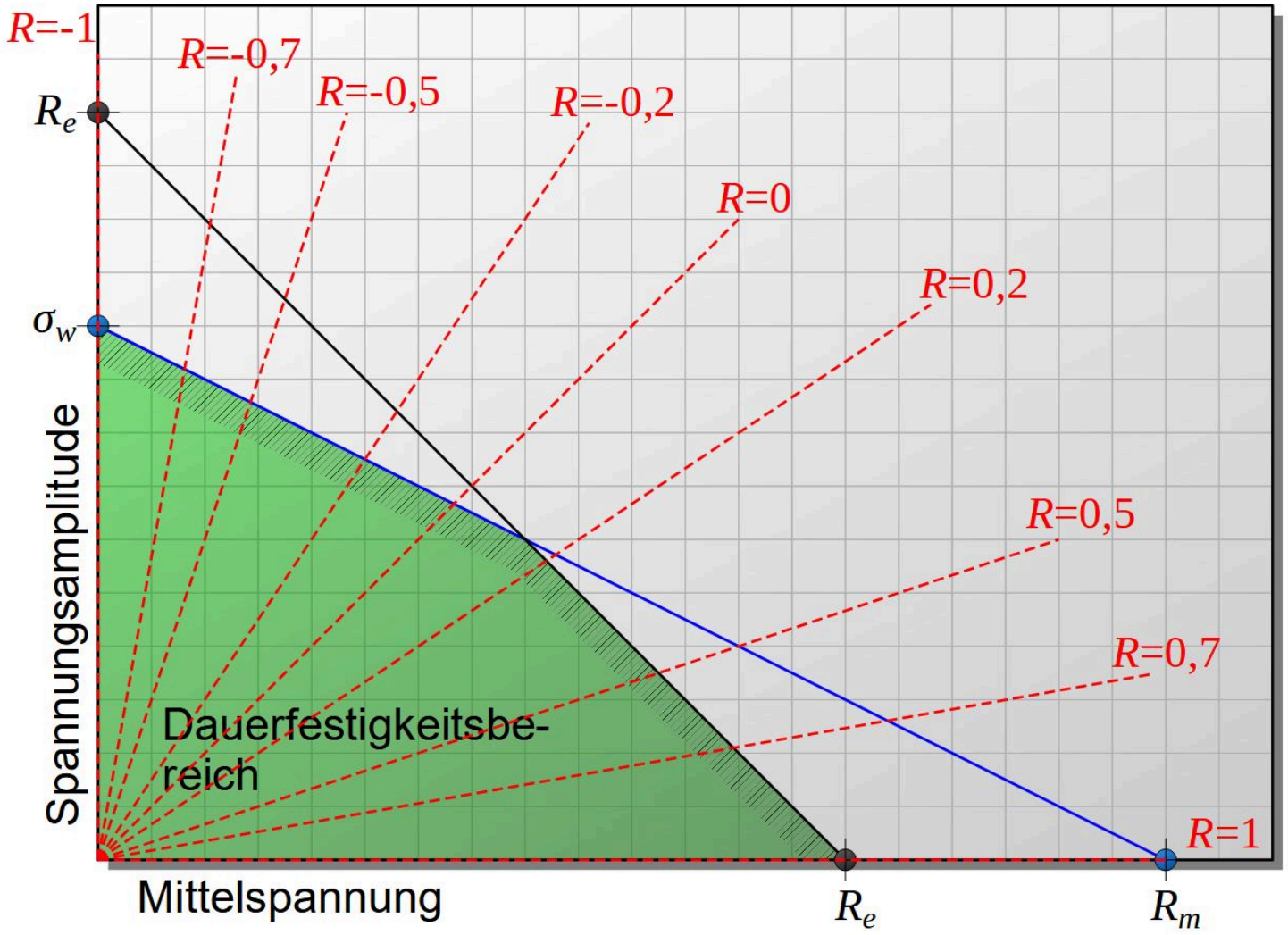


Endurance Limit Diagrams

- Haigh diagram and Smith diagram recommended according to DIN 50100

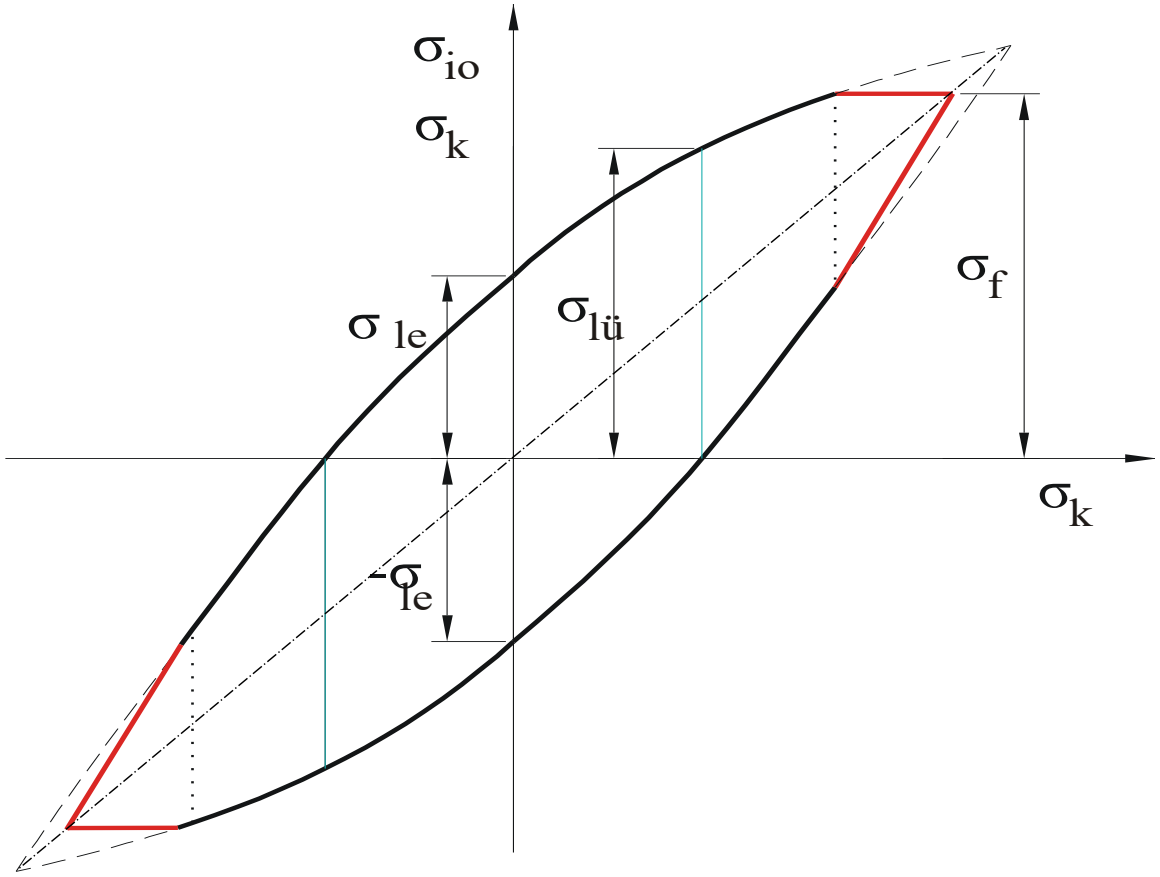
Haigh Diagram




R=-1
R=-0,7
R=-0,5
R=-0,2
R=0
R=0,2
R=0,5
R=0,7
R=1
R_e
σ_w
Spannungsamplitude
Dauerfestigkeitsbe-
reich
Mittelspannung
R_e
R_m

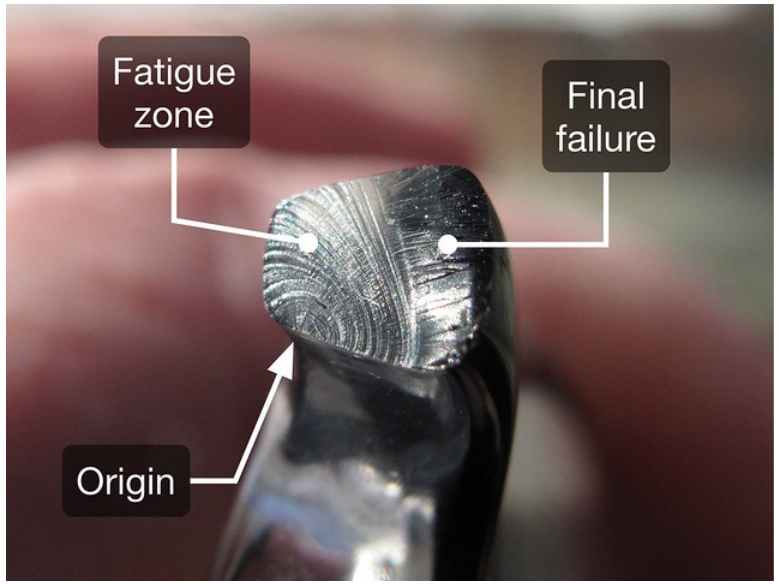
Smith Diagram

- Draw angle bisector
- Top and bottom (parallel lines) -> static tensile and compressive strength
- Curves are determined from Wöhler experiments with different R values



Terms

- Lifetime
- Fatigue crack
- Fatigue fracture
- Low-cycle fatigue (LCF) $< 10^5$ cycles
- High-cycle fatigue (HCF) $10^4 < 10^6$ cycles
- Very high-cycle fatigue (VHCF) $> 10^6$ cycles



Countermeasures

- Reduce notch effect
- Material adaptation
- Adjust design so that local stress does not exceed allowable limits
- Regular inspections

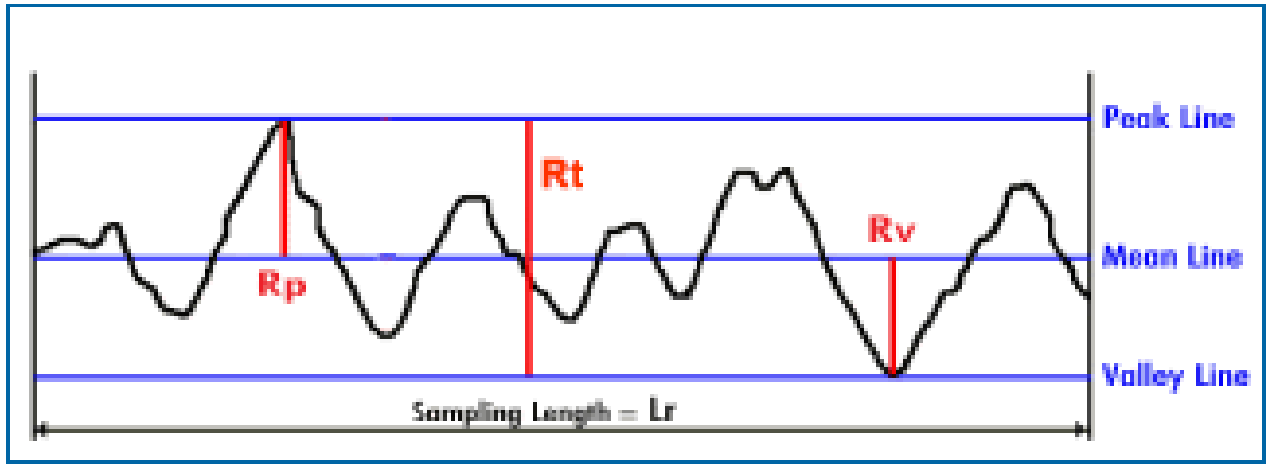
Wear

- Permanent shape and material changes on the surface of solid bodies due to friction
- Not intended technologically and can represent or result in functional failure
- Influenced by
  - Friction pair combination
  - Condition of boundary layers and intermediate substances
  - Type of movement
  - Magnitude of load

- Adhesive Wear
- Abrasive Wear
- Surface Fatigue
- Triboxidation

Adhesive Wear

- Adhesive wear occurs with insufficient lubrication
- High surface pressure causes surfaces to stick together
- When sliding occurs, boundary layer particles transfer
- Results in holes and flaky material particles, often adhering to the sliding surface of the harder counterpart

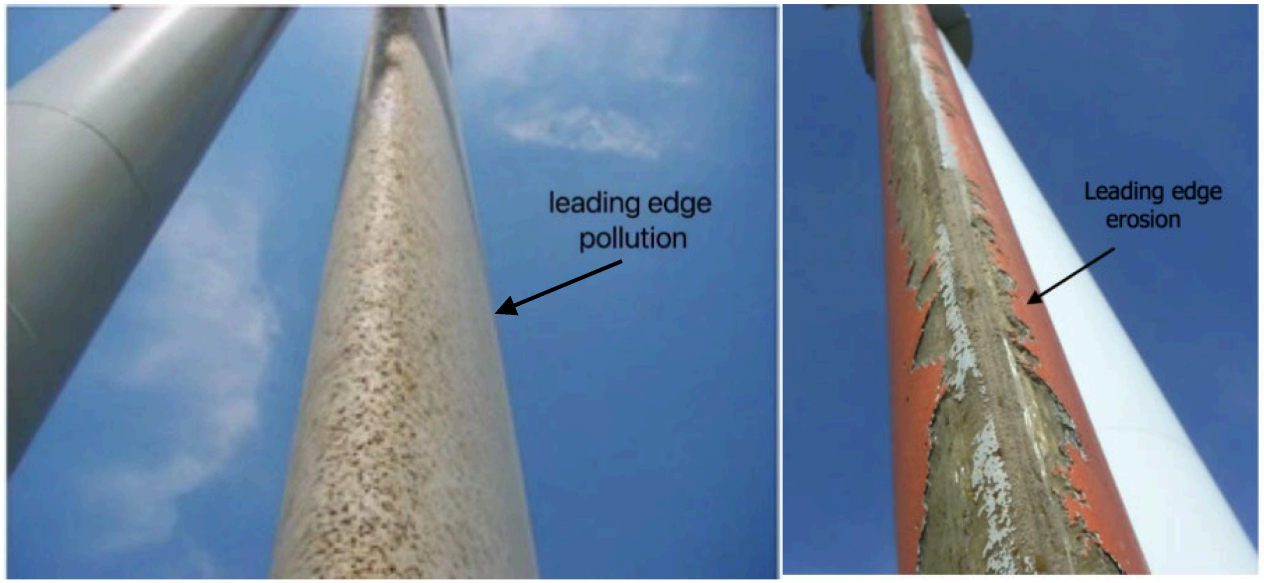

Peak Line
Rt
Rv
Rp
Mean Line
Valley Line
Sampling Length = Lr

Abrasive Wear

- Hard particles in a lubricant or roughness peaks of a friction partner penetrate the boundary layer
  -> results in scratching and micro-cutting
    - Groove wear or erosion wear
- Correct choice of material pairing; metal-plastic or metal-ceramic pairings

Example Wind Energy:

- Sand in the wind "grinds" down the surface
- Efficiency decreases



Surface Fatigue

- Alternating or swelling mechanical stresses on the surface
- Fatigue or creep of the material on the surface

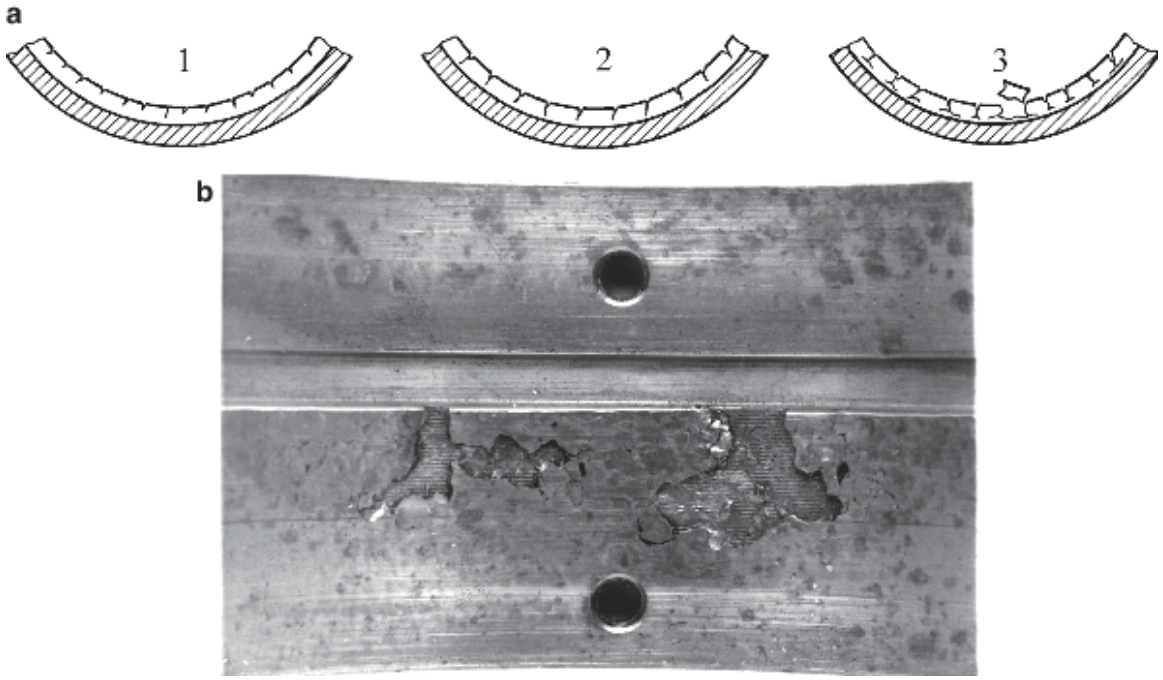
Triboxidation

- Triboxidation (fit corrosion) on a steel shaft
- Formation of intermediate layers, e.g., oxide layers, due to chemical reaction and their mechanical destruction due to movement of parts
- Almost always occurs together with adhesive wear

Type of Wear	Appearance	Primary Occurrence
Sliding Wear	Grooves or scratches due to abrasion, material transfer, or local melting	Non-lubricated bearings, clutches, brakes
Rolling Wear	Flaking due to fatigue cracks	Wheel/rail, rolling bearings
Pitting	Formation of pits: pitting	Rolling elements, especially gears
Abrasive Wear	Plastic deformation, erosion	Excavators, bulk material transport, particle impact
Cavitation	Surface damage due to impact of vapor bubbles	Water turbines, pumps

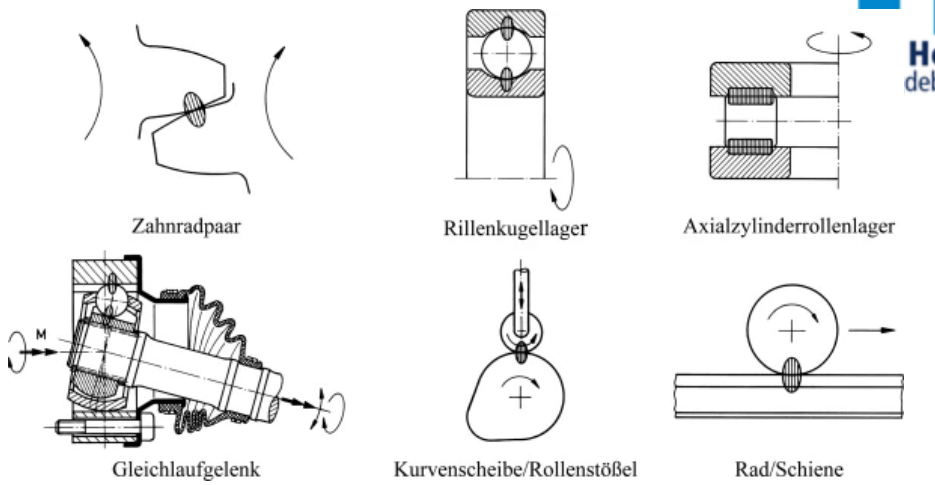
Sliding Wear

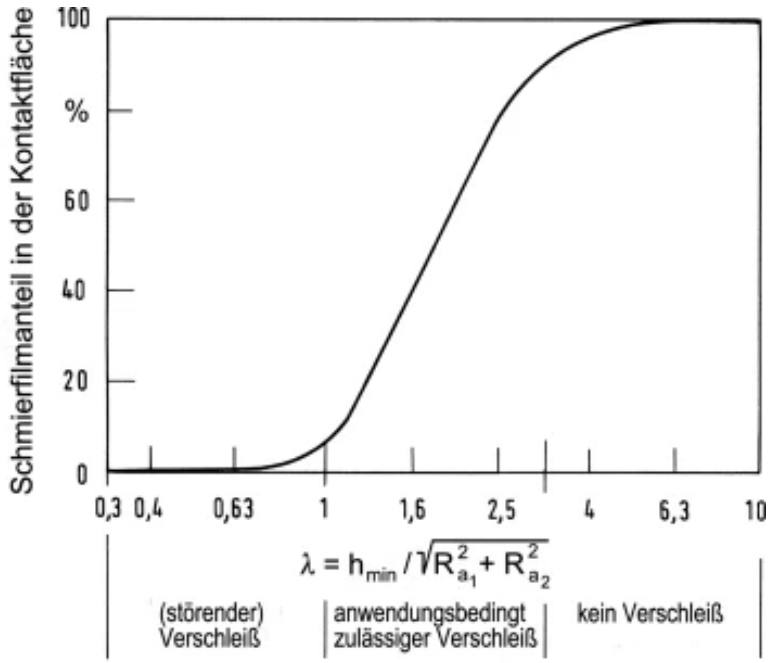
- Influenced by
  - Mean roughness depth R_z
  - Contact pressure
  - Wear path ratio $W = k\frac{F_N}{A}10^6$
  - k in $\left[\frac{mm^3}{Nm}\right]$ specific wear coefficient (load-independent)



Rolling Wear

- Rolling is a type of stress in which sliding components (slip) superimpose the pure rolling process
- Small contact area; high surface pressure
- Surface fatigue (plastic deformation, structural changes, etc.)
- Significantly reducible through lubrication $\rightarrow$ specific lubricant film thickness λ



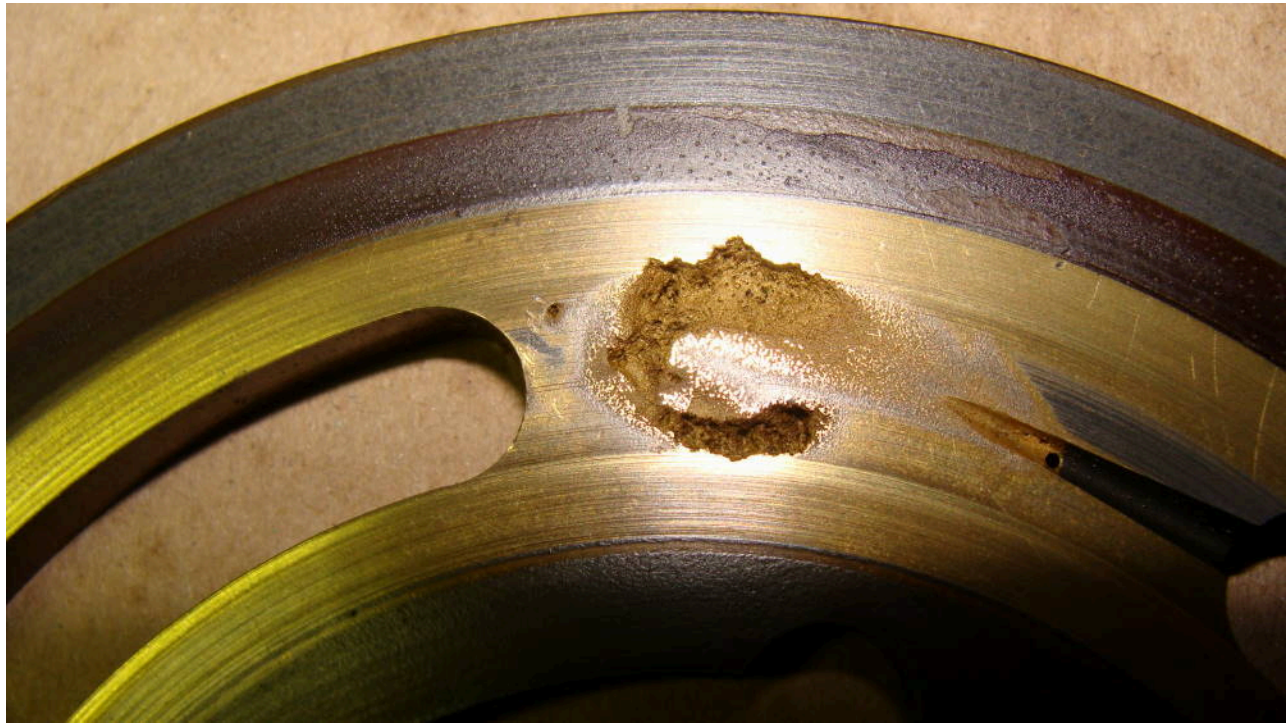


Cavitation

Video

- Physical Cause?

- Local stress on the surface
- These areas fatigue and flake off
- Impacts the surface
  - Efficiency reduction
  - Corrosion
  - Areas where cracks can initiate



Friction Corrosion

- Sliding movements between two highly loaded components
- Often occurs when there is insufficient clearance $\rightarrow$ fits