Lecture on Materials Science - Material Testing

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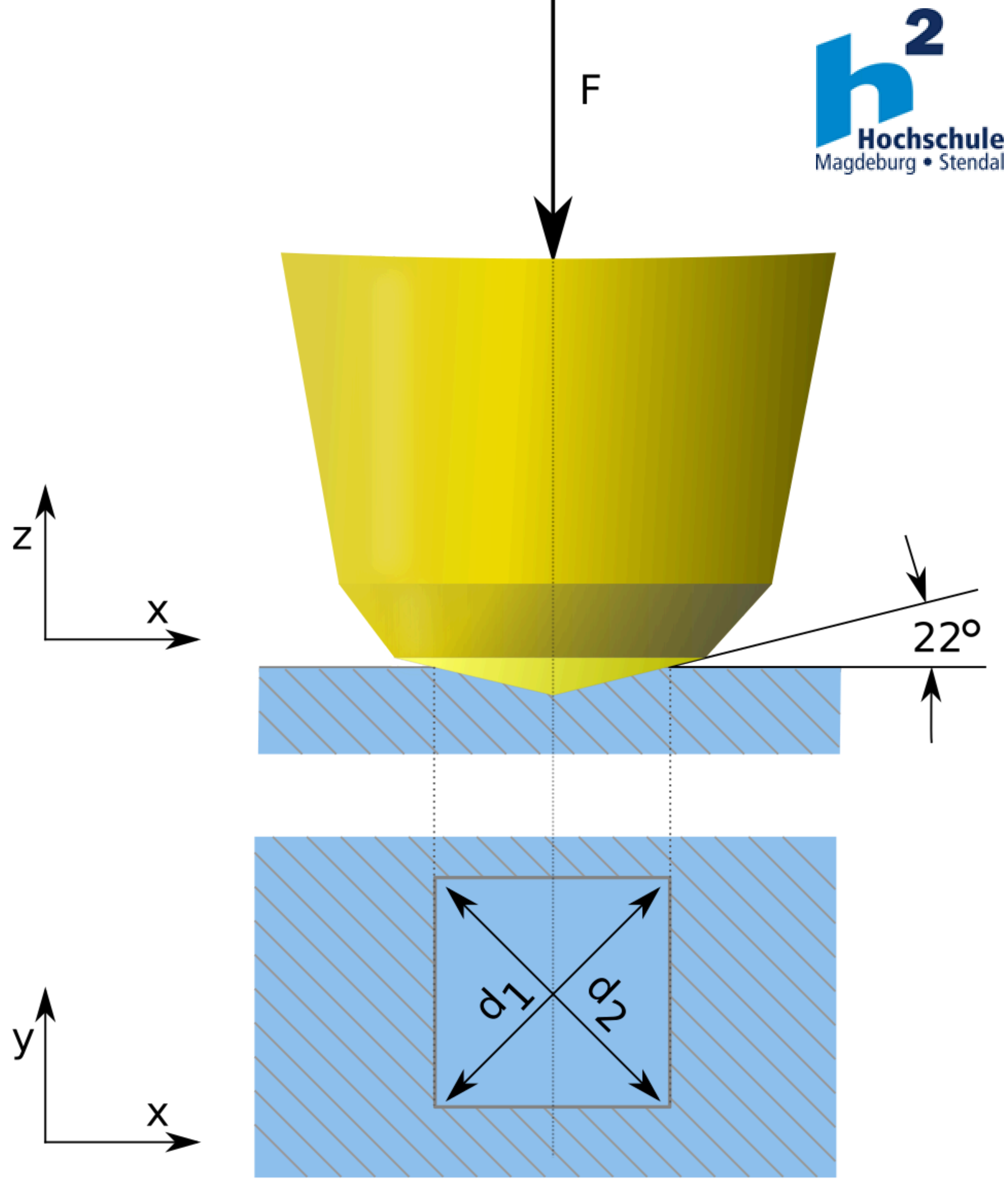
Parts of the script are adopted from Prof. Dr.-Ing. Jürgen Häberle



Contents

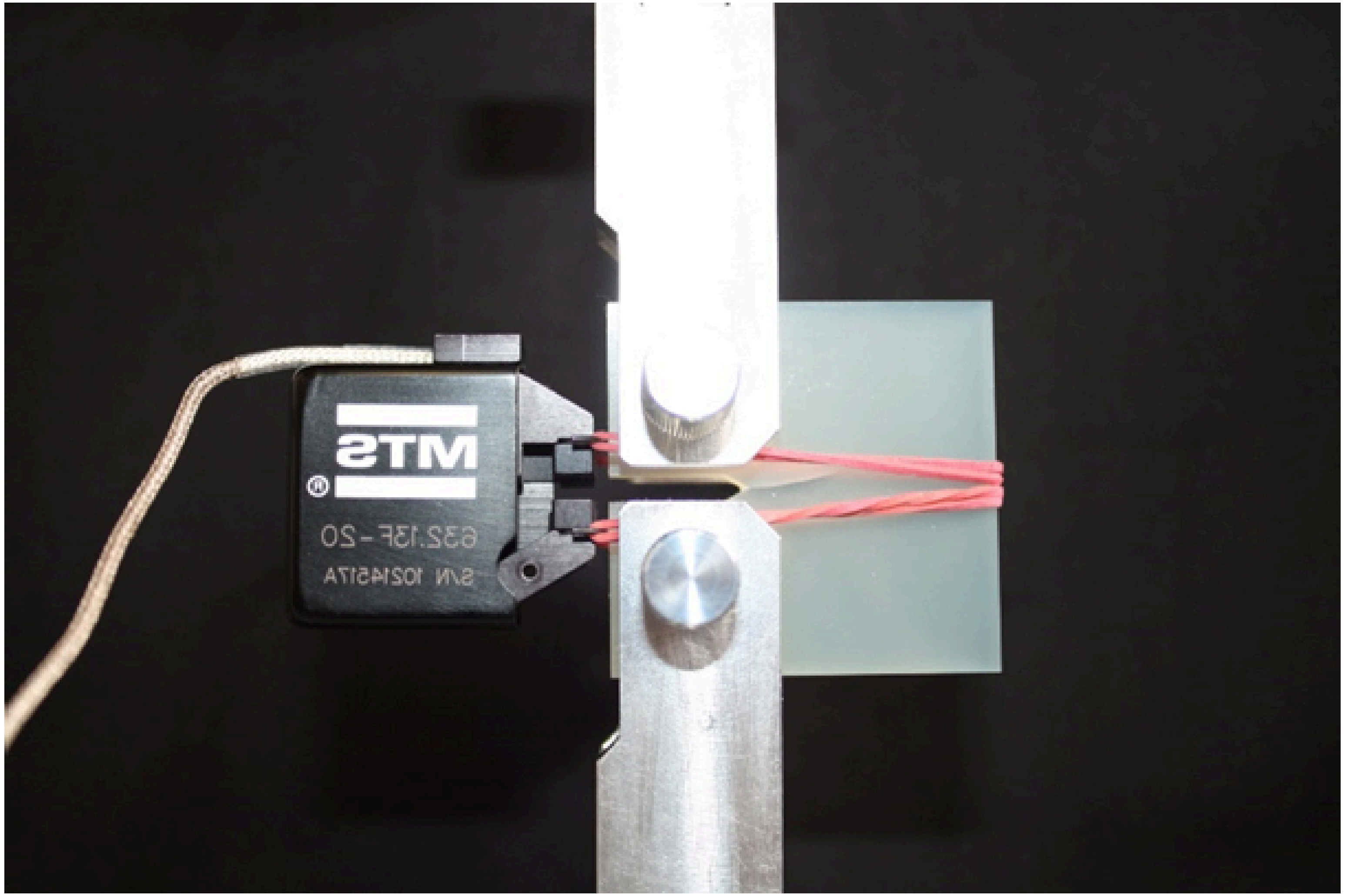
Characterization

Mathematical models are used in engineering to predict the behavior of components and structures. Determining the parameters required for the model is known as characterization.

Models

What are models, and why do we need them?


VOLVO
Safety Centre
142019
64 KPH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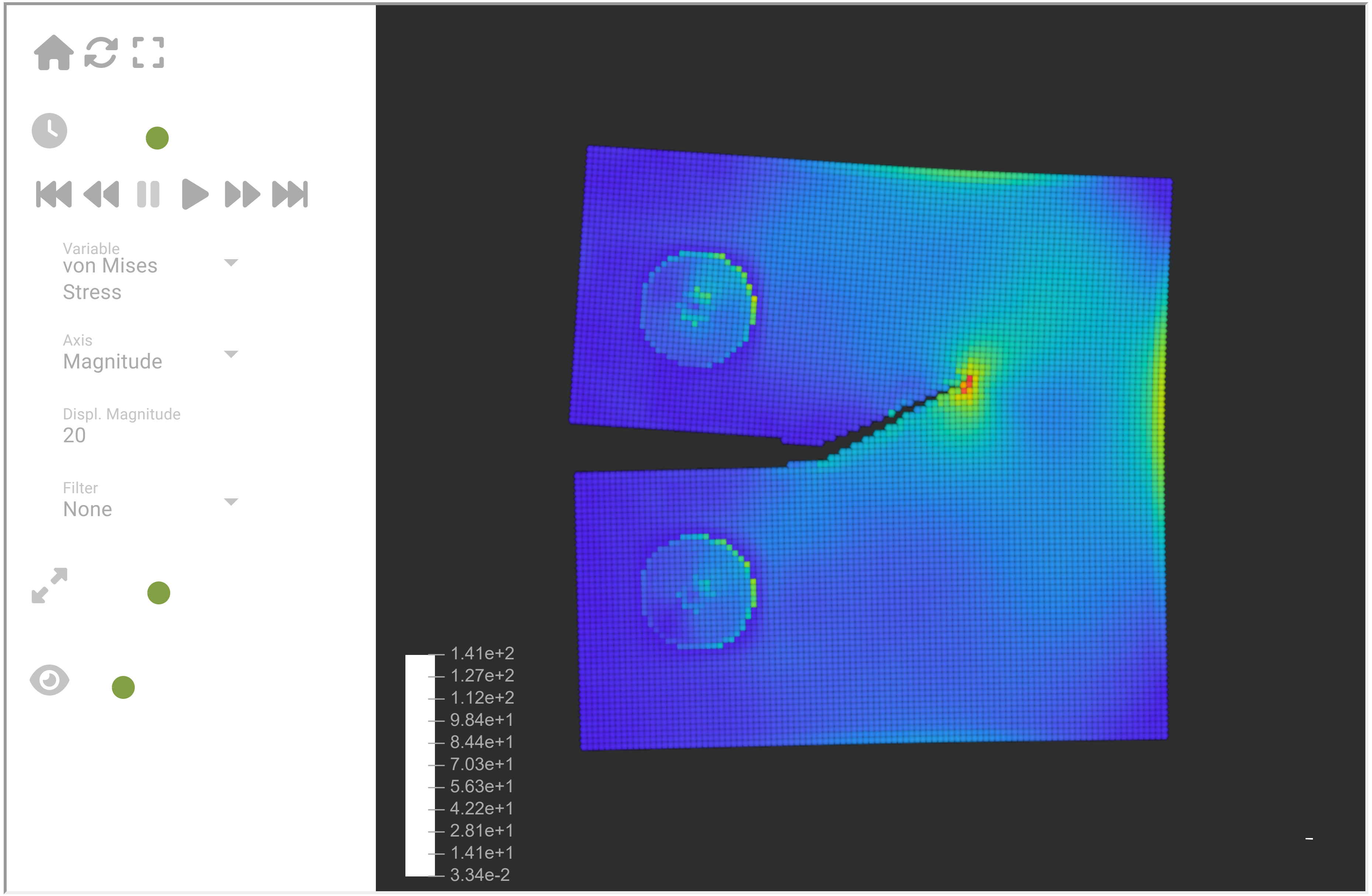
Variable
von Mises Stress
Axis
Magnitude
Displ. Magnitude
20
Filter
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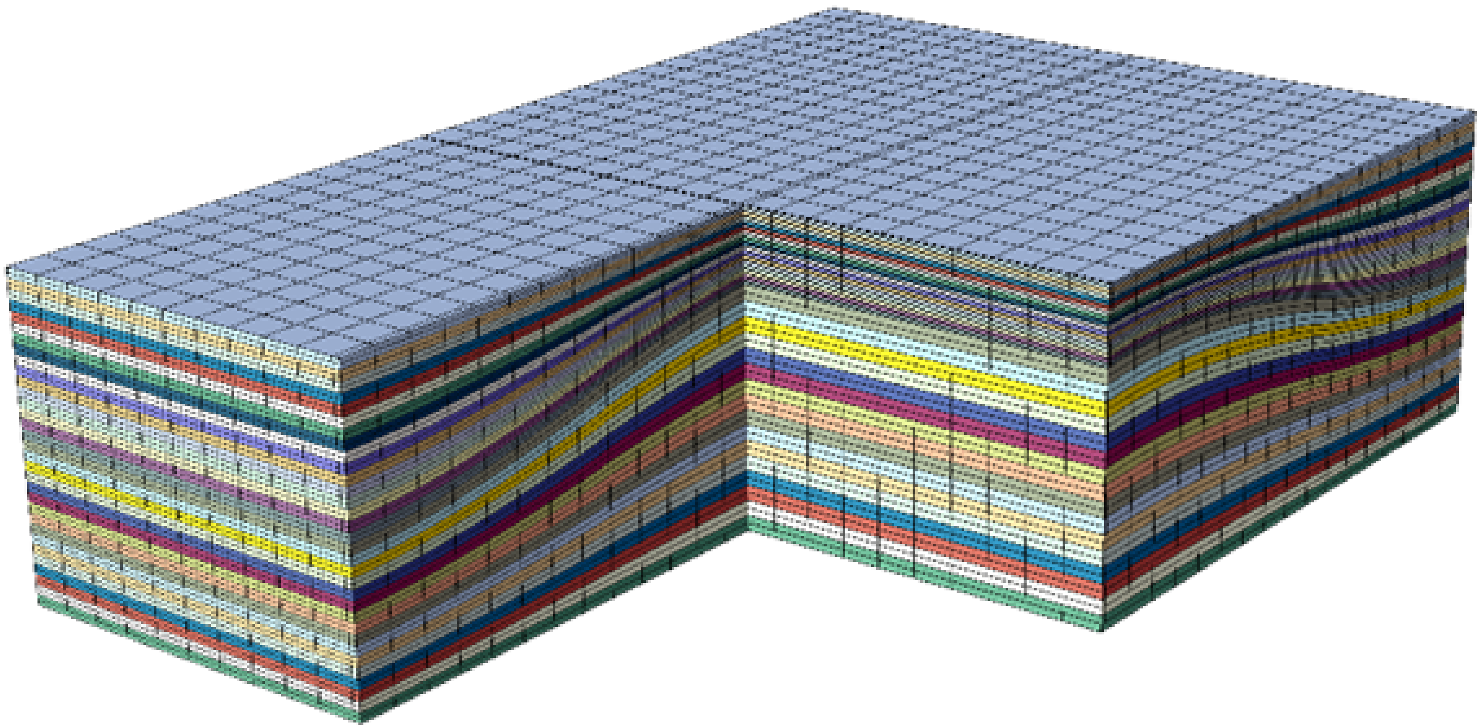
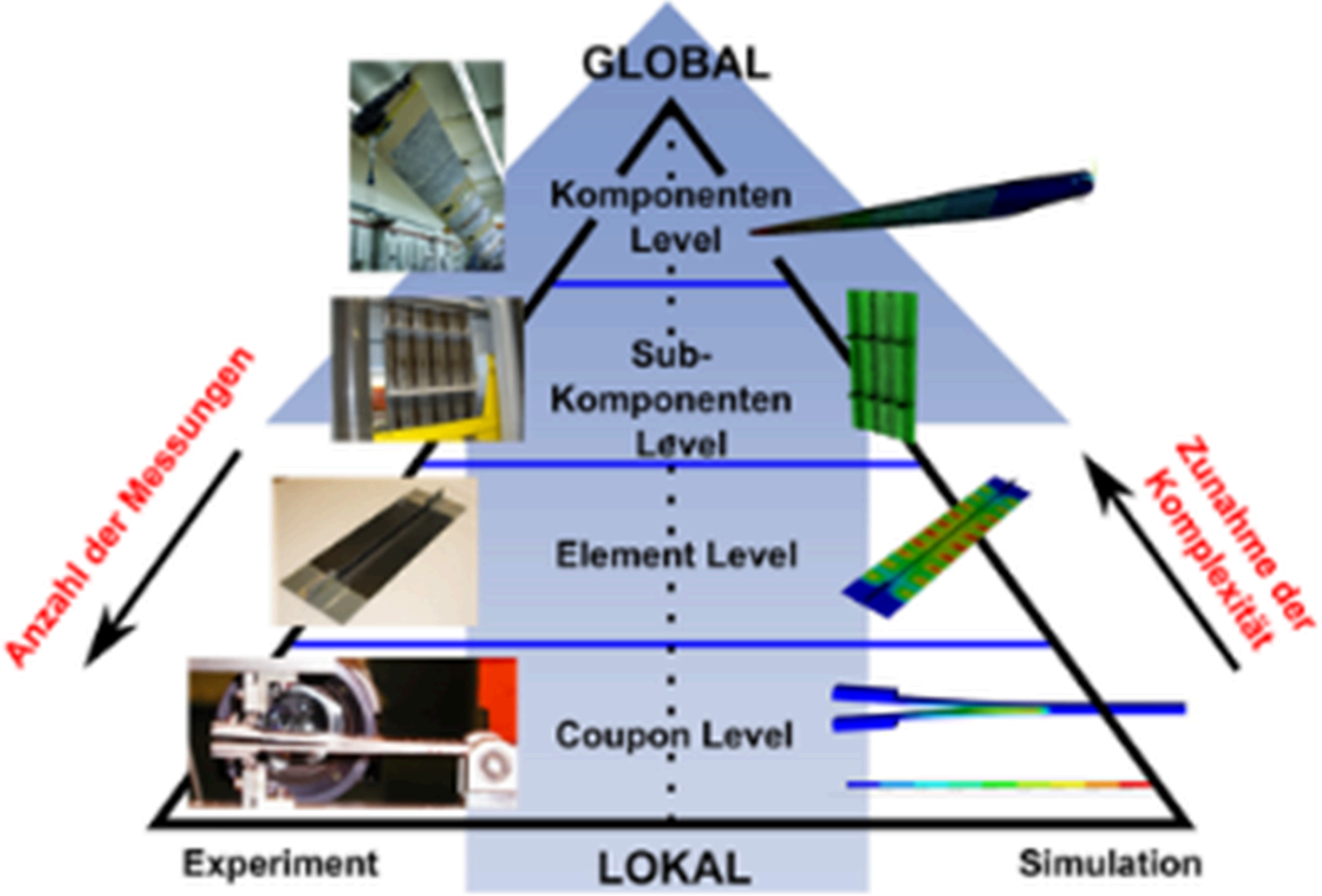
1.27e+2
1.12e+2
9.84e+1
8.44e+1
7.03e+1
5.63e+1
4.22e+1
2.81e+1
1.41e+1
3.34e-2




GLOBAL
Komponenten Level
Sub-Komponenten Level
Element Level
Coupon Level
Experiment
LOKAL
Simulation
Anzahl der Messungen
Zunahme der Komplexität

Examples

- Determination of E and ν in an isotropic material
- Sketching different methods
- Discussing challenges

Note

- There are relationships between the shear modulus G and E and ν

Data Acquisition

Typical sensors:

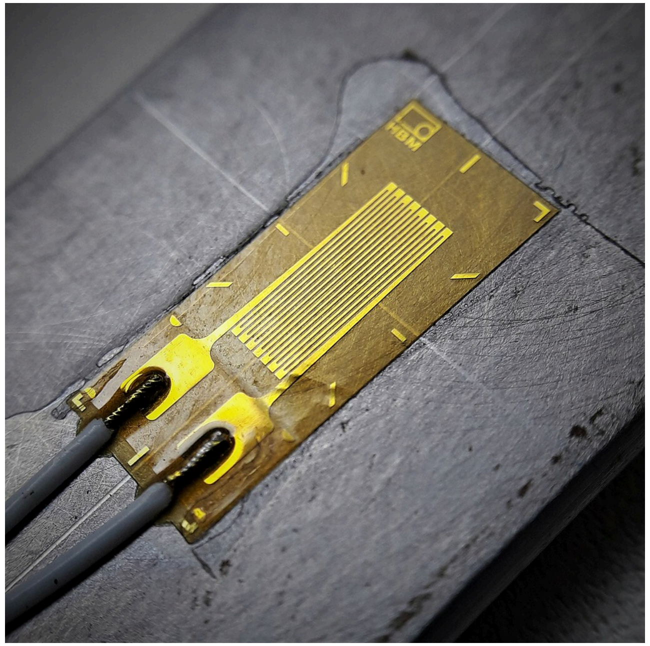
- Strain sensors:
  - Strain gauges (SG)
  - Fiber Bragg
  - Camera systems
- Displacement sensors:
  - Laser triangulation
  - Tape measure
  - Time-of-flight measurement
- Force transducers

Strain Gauges (SG)

- Working principle
- Electrical resistance

$$R = \rho \frac{l}{A} = \frac{U}{I}$$

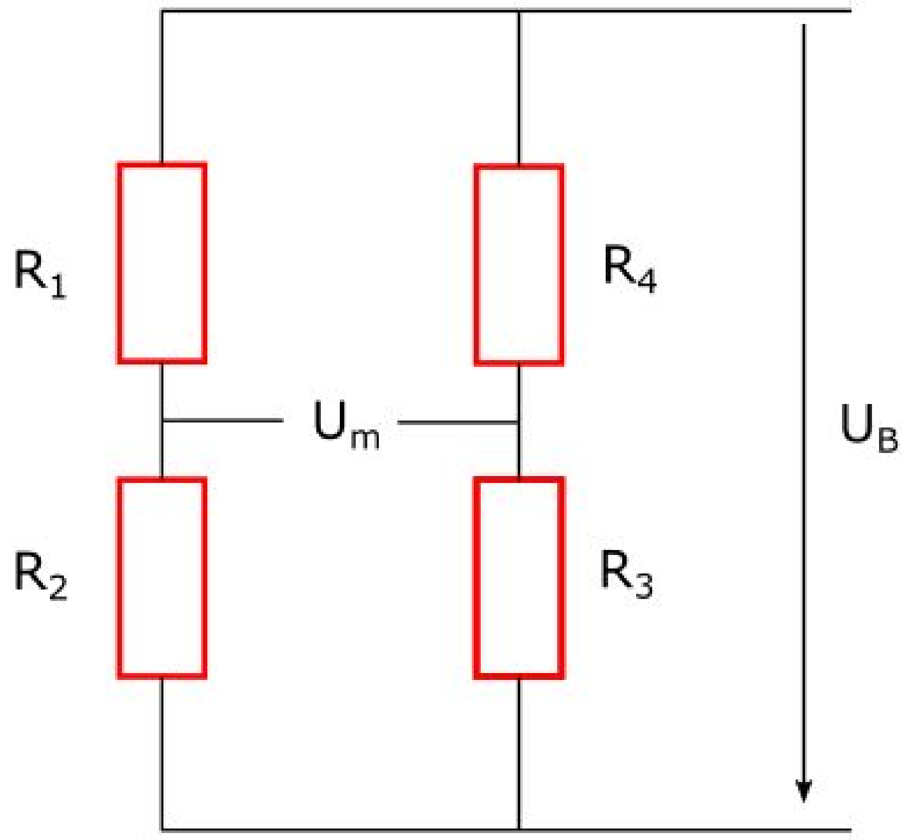
$$\frac{\Delta R}{R} = k\varepsilon$$



Compensation

- Temperature compensation:
  - Measure on an unloaded component
  - Utilize a bridge circuit of strain gauges
- Normal strain compensation:
  - Utilize a bridge circuit of strain gauges

$$\frac{U_m}{U_B} = \frac{k}{4}(\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4)$$



Analog-to-Digital Conversion

- Analog signals
- Digital signals
- A-D converter

$$dt < \frac{1}{2f_{max}}$$

- If not adhered to, information loss occurs

Example

Data Analysis - Basics

Variations

- Measurement uncertainties
- Material uncertainties
- Manufacturing uncertainties

Special case:

- Model uncertainties -> Cannot be reduced by more measurements

Dealing with Variations

Mean

$$sample_{mean} = \sum_{i=1}^{n} \frac{samples_i}{n}$$

Median

50% of the values are above and 50% below this value; more robust against outliers

Standard Deviation

Measures the spread of the data

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (samples_i - sample_{mean})^2}$$

Correlation Coefficient

Describes the linear relationship between data (-1 to +1)

Fitting

Least squares method

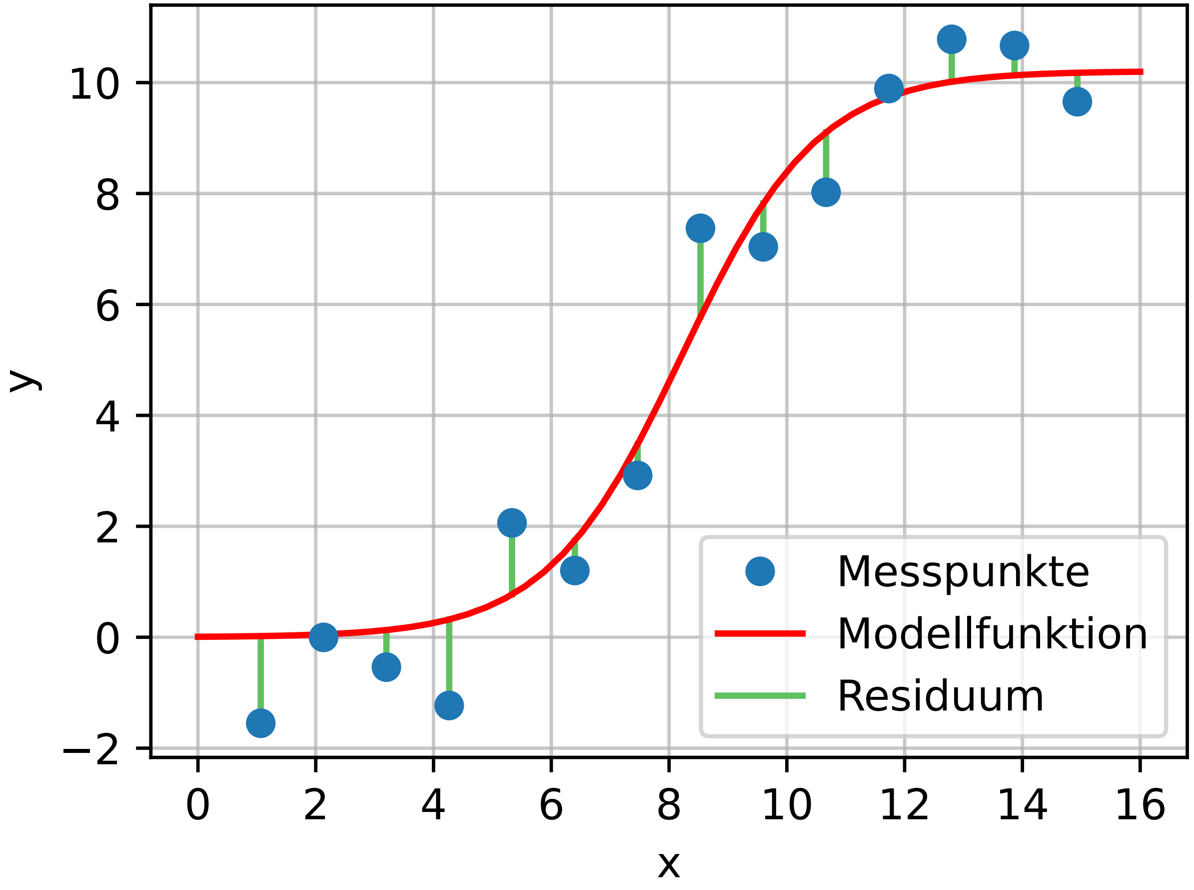
$$\min||\mathbf{y}_m(\mathbf{x}) - \mathbf{y}||^2$$

to determine an arbitrary fitting function.

Choosing the function:

Polynomials - High-degree polynomials may cause oscillations

Splines, B-Splines - More complex

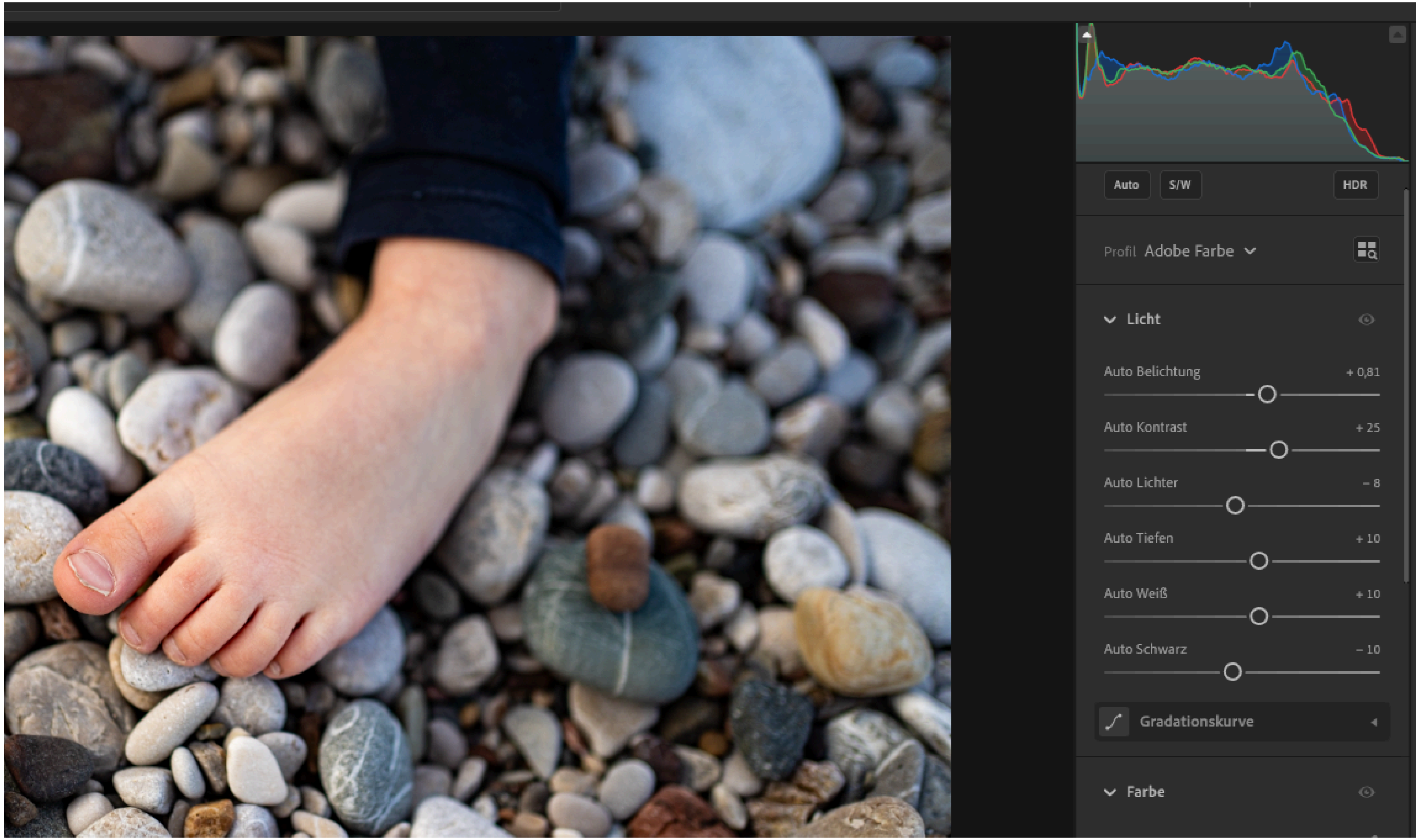


Fourier Transformation

- Any signal/function can be decomposed into a sum of sine curves
- Time functions -> Frequency representations

Filters

- Low-pass:
  - Allows signals below a defined frequency
- High-pass:
  - Allows signals above a defined frequency
- Band-pass:
  - Allows signals between two defined frequencies
- Band-stop:
  - Allows signals outside two defined frequencies


Auto
S/W
HDR
Profil Adobe Farbe
Licht
Auto Belichtung + 0,81
Auto Kontrast + 25
Auto Lichter – 8
Auto Tiefen + 10
Auto Weiß + 10
Auto Schwarz – 10
Gradationskurve
Farbe

Exercise

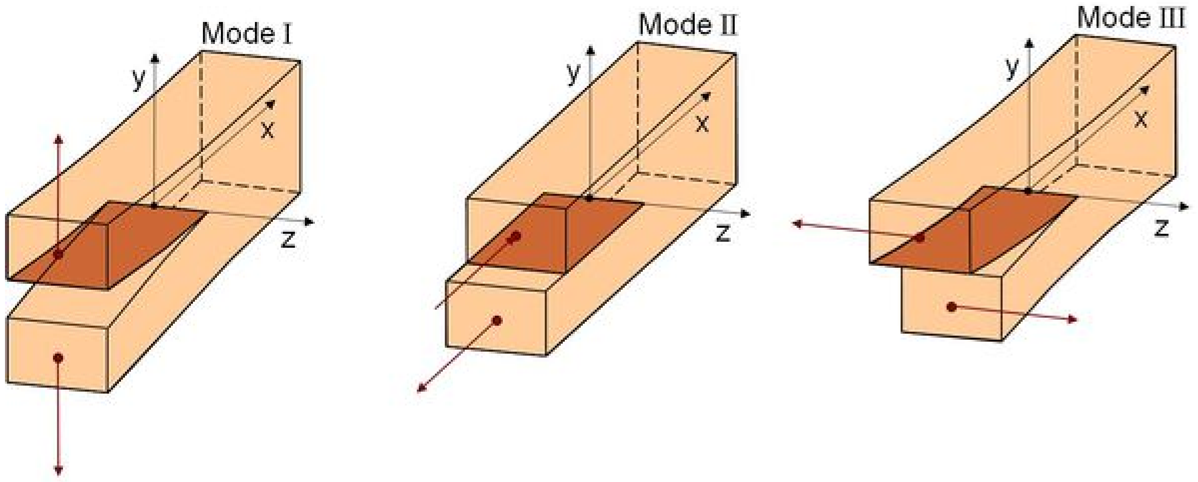
- Create a dataset
- Plot the dataset
- Fitting
- Statistical evaluation of data
- Signal oscillations
- FFTs
- Gradient determination

Destructive Testing

Certain properties or statements about a material or component can only be made if loaded until failure.

Fracture Mechanics Basics

- Fractures can be categorized into these modes
- Specific energy release rates exist



Experiments for determining these energies

Toughness Determination

- Material's resistance to fracture or crack propagation
- Ability to absorb mechanical energy through plastic deformation

$$Z = \int_0^{\varepsilon_B} \sigma d\varepsilon$$

- Energy release rate $G = \frac{Z}{A_{fracture}}$
- Effect of loading speed

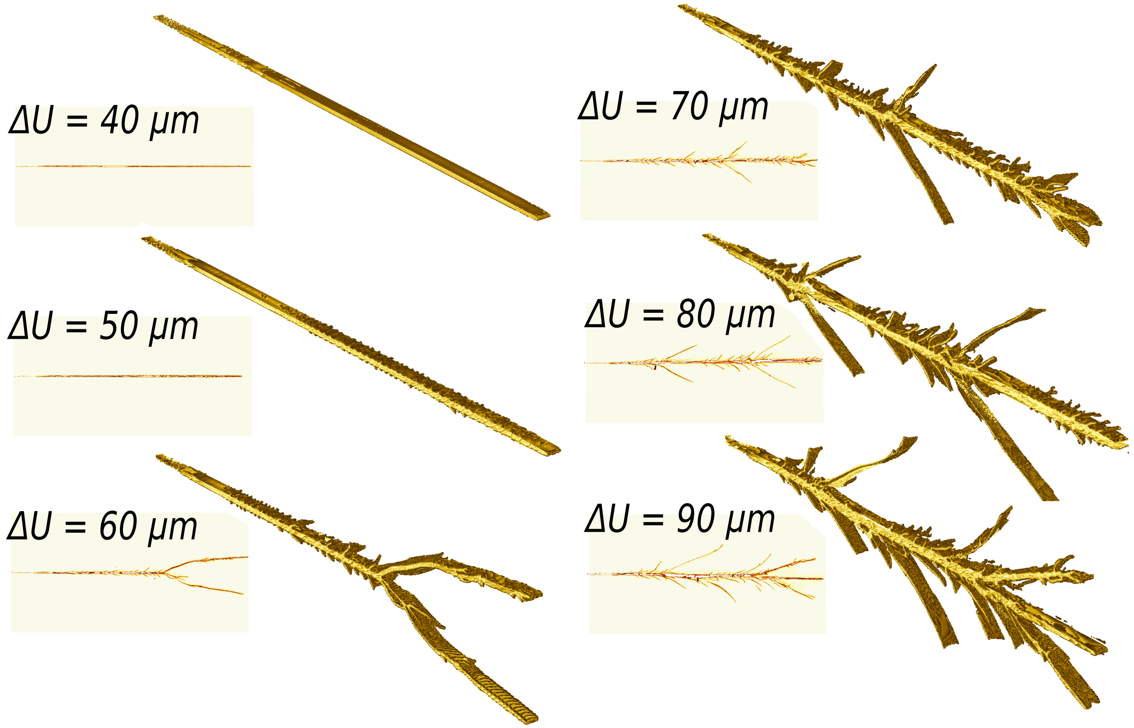
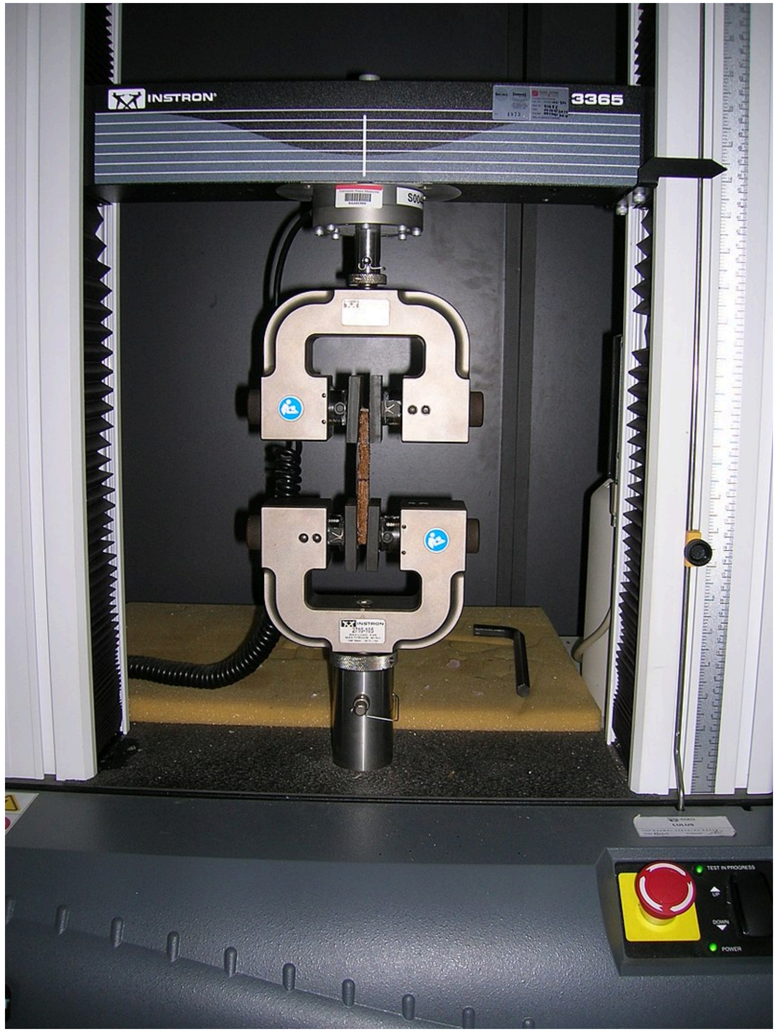


Image Reference

Tensile Test

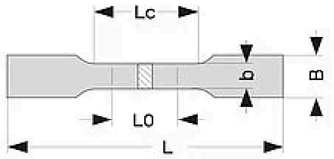
- Determination of:
    - Elastic stiffness
    - Strength
    - Yield strength
    - In one direction
- Constant stress across the cross-section is assumed

$$\sigma = \frac{F}{A} = E\varepsilon = E\frac{\Delta l}{l}$$
$$F = \frac{\Delta l E A}{l}$$



Sample Geometry

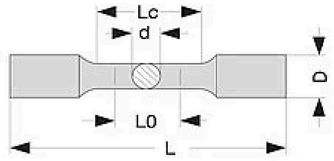
Flat specimen



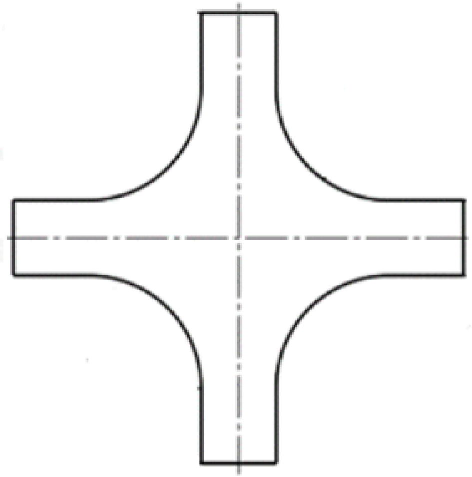
Dimension, mm

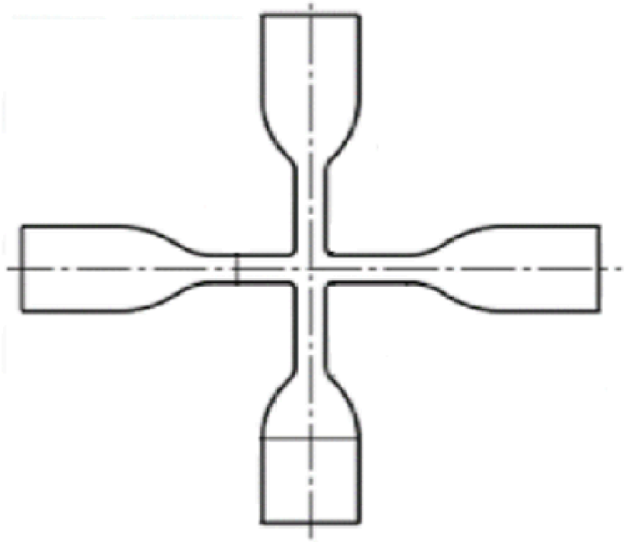
b	L_0	B	L_c	L	Δb
12,5	50	20	60	≥200	0,05
40	200	50	225	≥450	0,1

Round specimen



d	L_0	L_c
12,5	50	60
8,75	35	45





Video 1

Parameter Compression

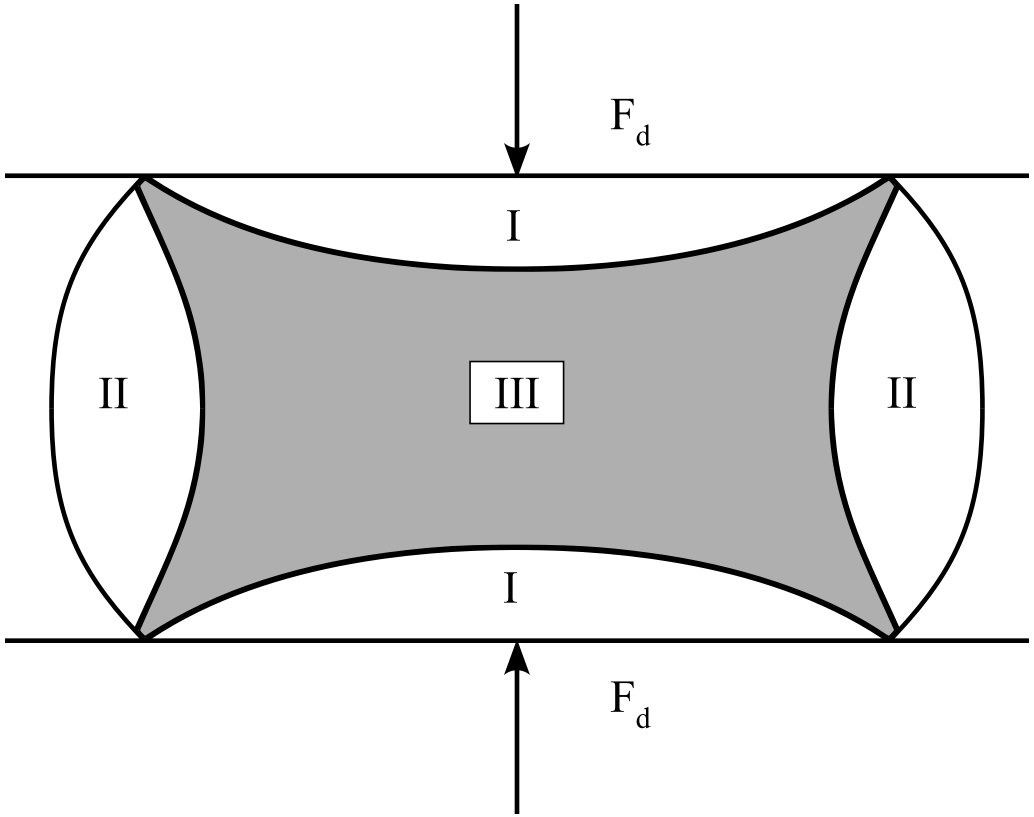
Crushing Limit

- Beyond this limit, plastic deformation occurs (ductile material)
- Brittle materials develop cracks and then fracture

Stability

- Buckling
- Bulging

  Deformation zones of a compressed sample (Fig. 3.16)



Compression Deformation

I - Minor deformation (friction hindrance)

II - Moderate tensile deformation

III - High shear deformation

Anisotropic Measurements

Anisotropy

- Measurements under different angles

Influencing factors

- Slip at clamping
- Temperature
- Geometry
- Sample clamping

Bending Test

- Typically flat samples with rectangular profiles
- Preferable for brittle materials
- Assumptions of Bernoulli beam theory must hold
- Suitable for brittle materials

$l > 20 \cdot h$

F - test force

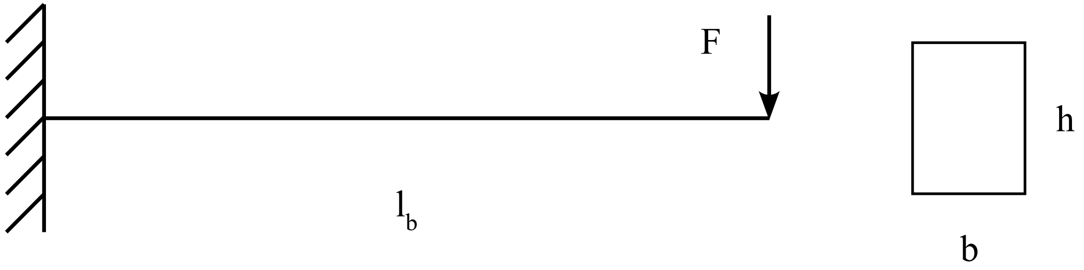
u - resulting displacement

a - height of the rectangular profile

b - width of the rectangular profile

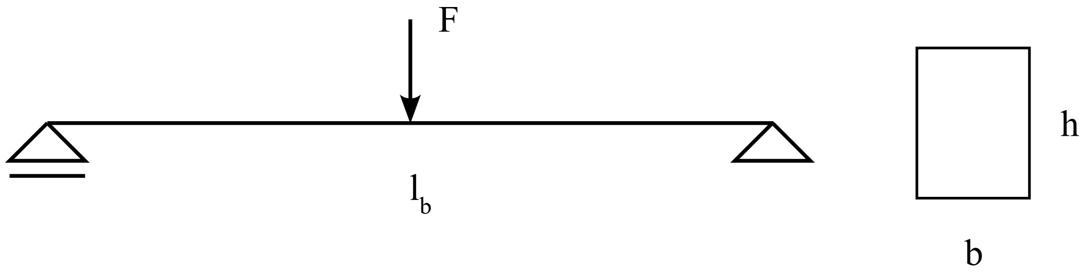
l_b - length of the sample

2-Point Bending Test



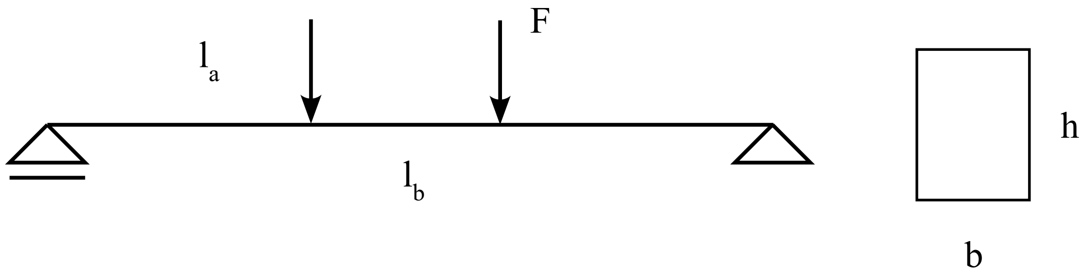
$$E = \frac{4 l_b^2 F}{u b h^3}$$

3-Point Bending Test



$$E = \frac{l_b^3 F}{4ubh^3}$$

4-Point Bending Test



Objective: A shear-free region resulting in a constant bending moment.

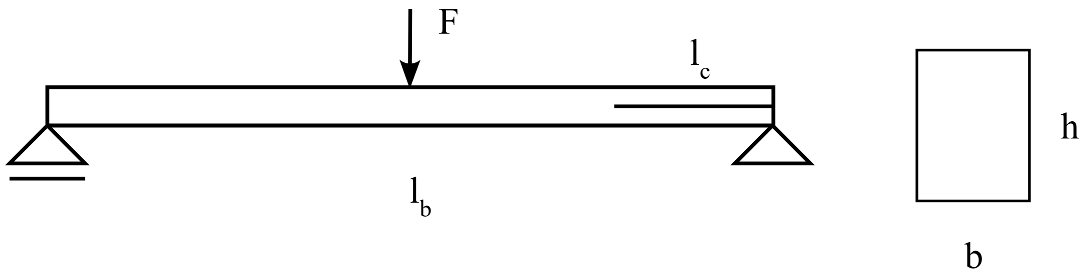
$$E = \frac{l_a^2(2l_a+3l_b)F}{ubh^3};$$

l_a - distance between support point and closer pressure point of the test stamp

Stress Profiles

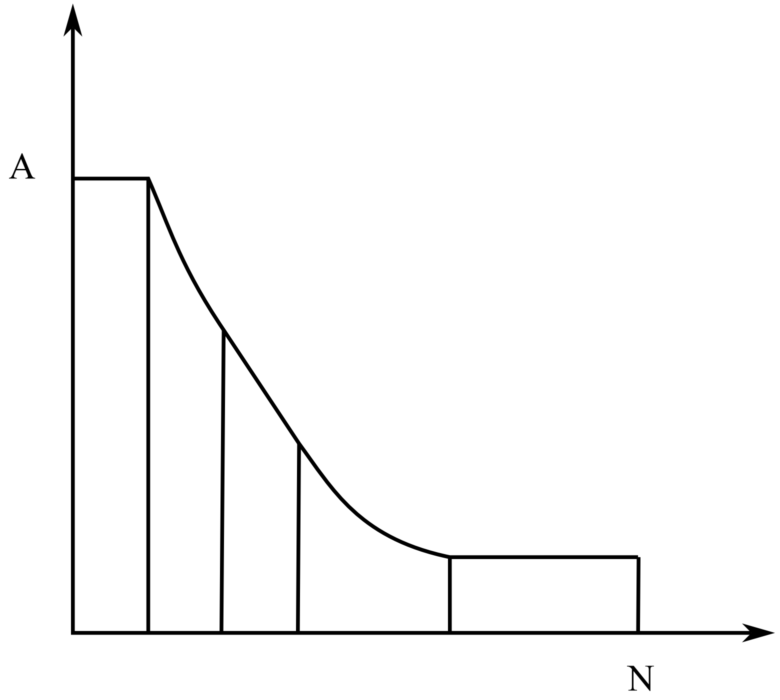
Video

- Bending stress
  - $\sigma_b = \frac{M_b}{I_{xx} y}$
  - Neutral stress line
- ENF (End-Notched Flexure) test uses the neutral stress line strategically



Fatigue Test According to Wöhler

- Test setup
  - Bending test
  - Torsion test
  - Tension/compression test



Fatigue Test According to Wöhler

Influencing factors:

- Temperature
- Corrosive environments
- Notches
- Surface condition
    - Smooth surfaces are favorable
- Heat treatment

Structural Fatigue Test

Video

Challenges?

- Representative loads
- Heating due to rapid loading
- Load sequence influences lifespan

Charpy Impact Test

- Determines the impact energy and impact toughness $\frac{E}{A_{nominal}}$
  - No longer has technical significance
- Energy is sufficient for determining material quality
- Divides into high-level (ductile), low-level (brittle fractures), and the transition region (mixed fractures)
- Not suitable for determining strength properties

Test

Explanation video

Additional Tests

- Burst tests
- Shear tests
- Pull-out tests
- Corrosion tests
- Burn tests

Hardness Testing

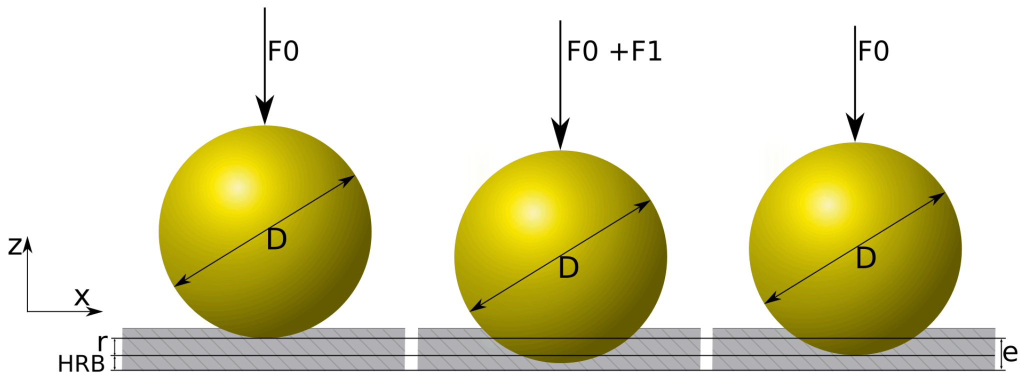
- Sample or component is not fully destroyed
- Partially destructive material testing
- Most common: Rockwell (HR), Brinell, Vickers, and Shore
- Hardness properties of the component surface affect fatigue and wear

Rockwell

- Measures penetration depth t with various standardized test bodies
- Measurement procedure is defined

$$\text{Rockwell Hardness} = a - \frac{t}{d}$$

- Scales A, C, D; $a = 100$, $d = 0.002mm$
- Scales B, E-H, K; $a = 130$, $d = 0.002mm$
- Scales N, T; $a = 100$, $d = 0.001mm$

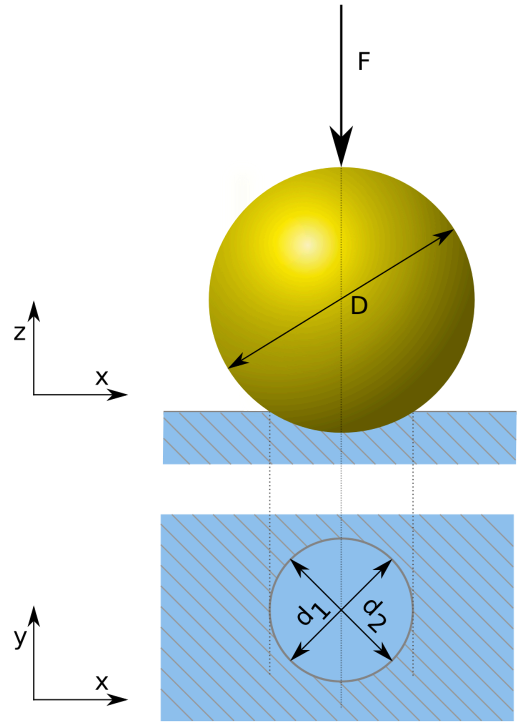


Brinell

- A hardened steel ball is pressed with a defined force onto the surface.
- Average diameter is determined.

$$\text{Brinell Hardness} = \frac{0.204F}{\pi D\sqrt{D-\sqrt{D^2-d^2}}}$$

with $d = \frac{d_1+d_2}{2}$



Vickers

- Similar to Brinell, but uses an equilateral diamond pyramid instead of a ball
- Requires smaller areas compared to Brinell

$$\text{Vickers Hardness} = \frac{0.204F\cos 22^\circ}{d^2}$$

with $d = \frac{d_1+d_2}{2}$