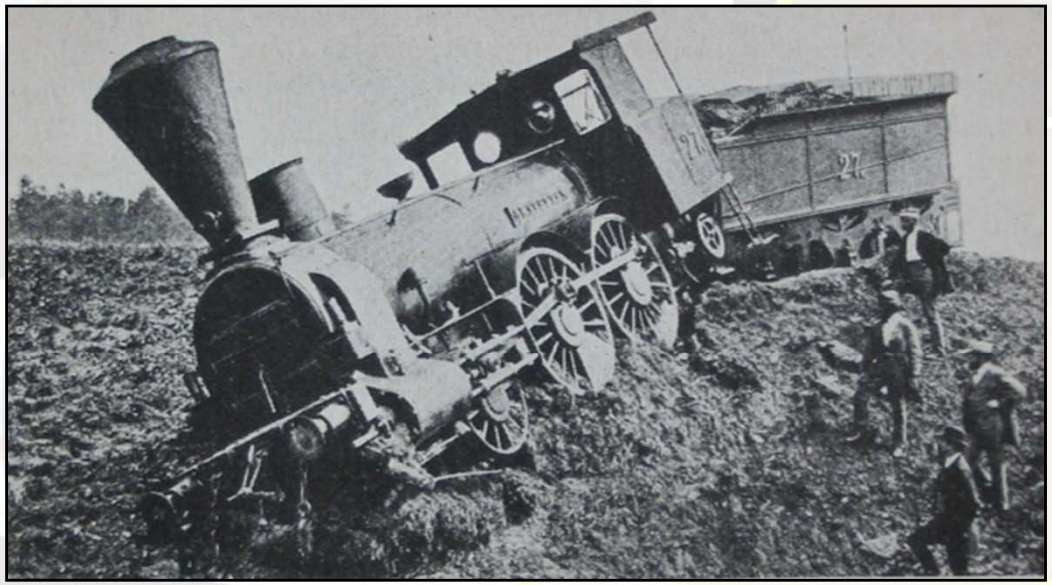
D. Eifler

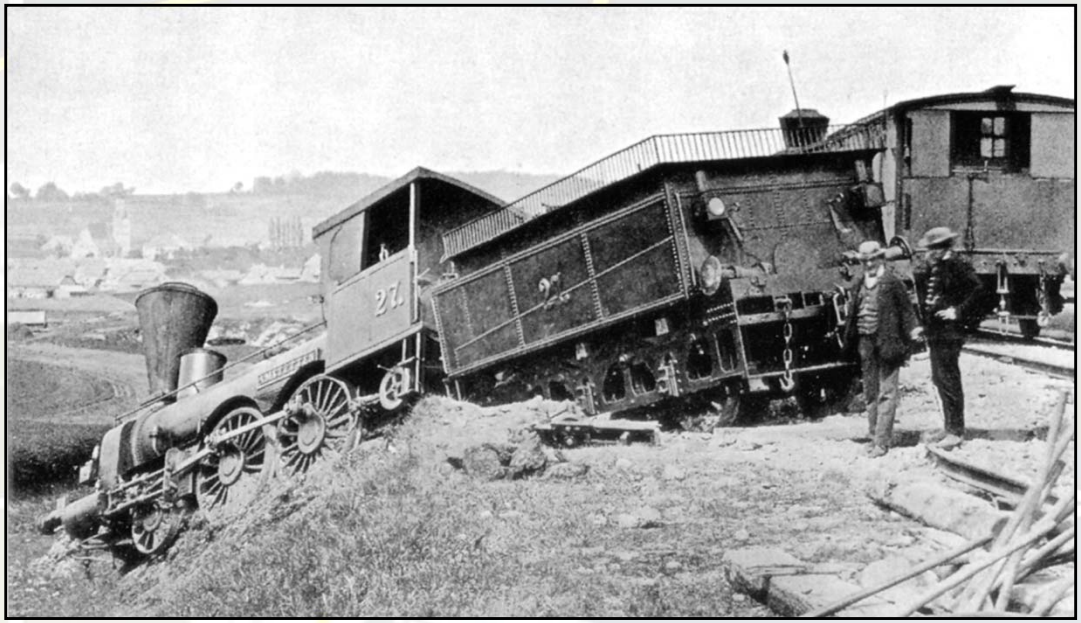
Herausforderung Radsatzstähle – Materialverhalten von hochbelasteten Eisenbahnradsätzen im VHCF-Bereich

TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

Prof. Dr. D. Eifler

www.uni-kl.de/WKK

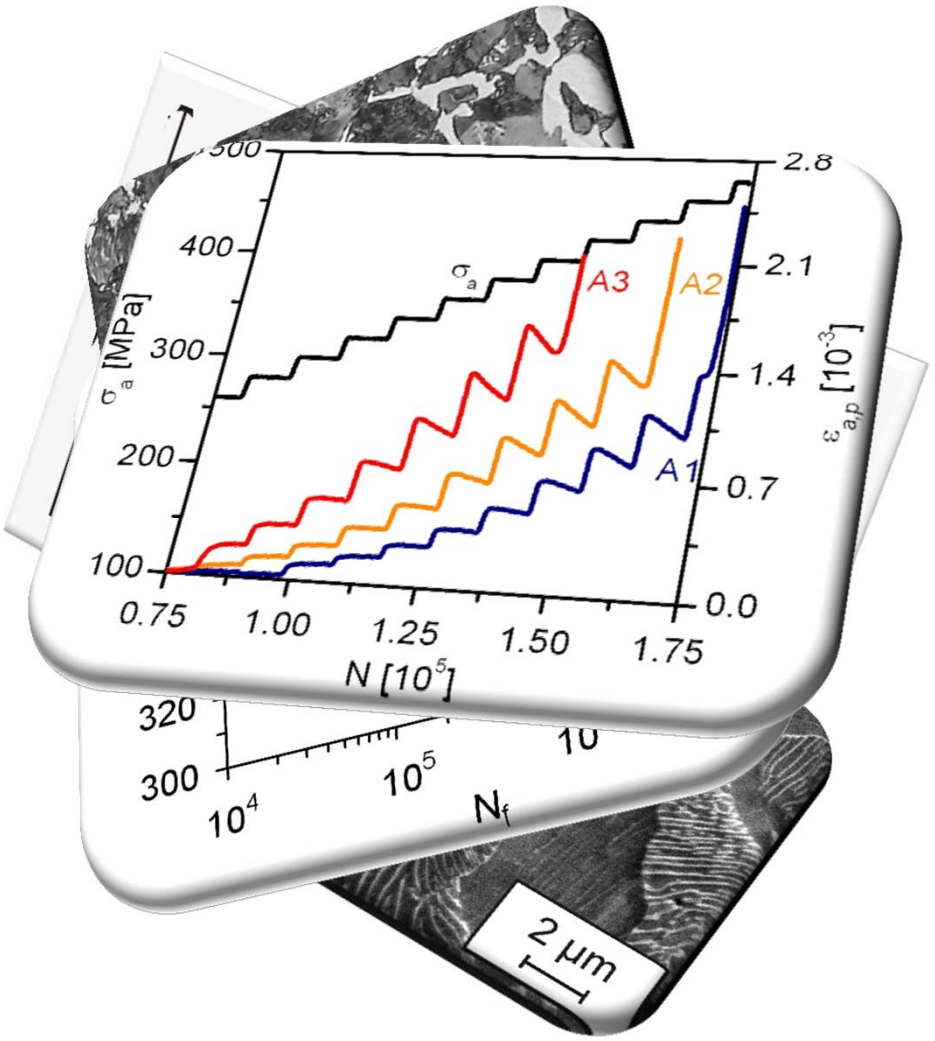




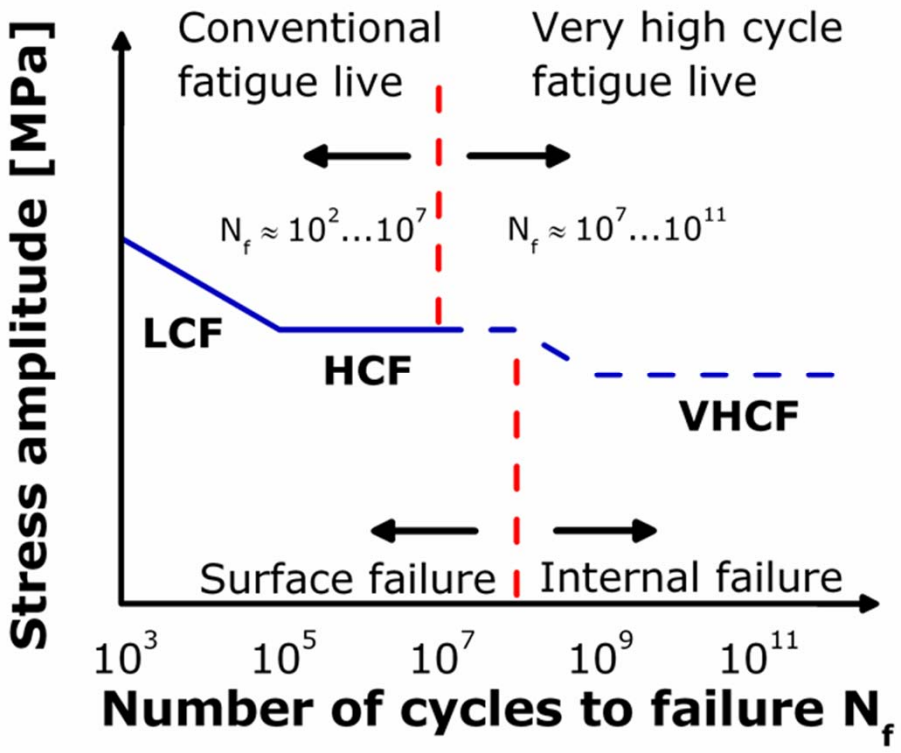
The locomotive “Amstetten” derailed on the railway line Salzburg-Linz (Austria). The accident was caused by a broken axle (1875).

Historical examples

- **Introduction**
- **Measurement techniques**
- **Material**
  - SAE1050 (R7)
- **Results**
  - Load increase tests
  - Constant amplitude tests
  - Ultrasonic VHCF tests
- **Conclusions**



Outline




[MTS]

Servo hydraulic fatigue testing machine (5 Hz)


[Rumul]

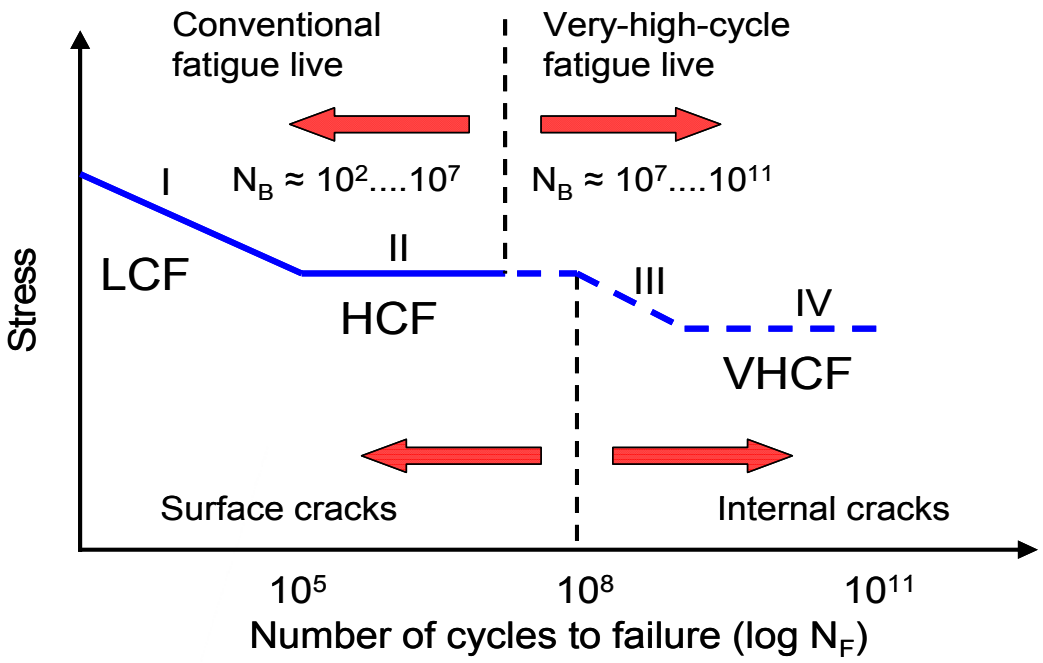
Resonant testing machine (150 Hz)

Test duration for $1 \cdot 10^{10}$ cycles

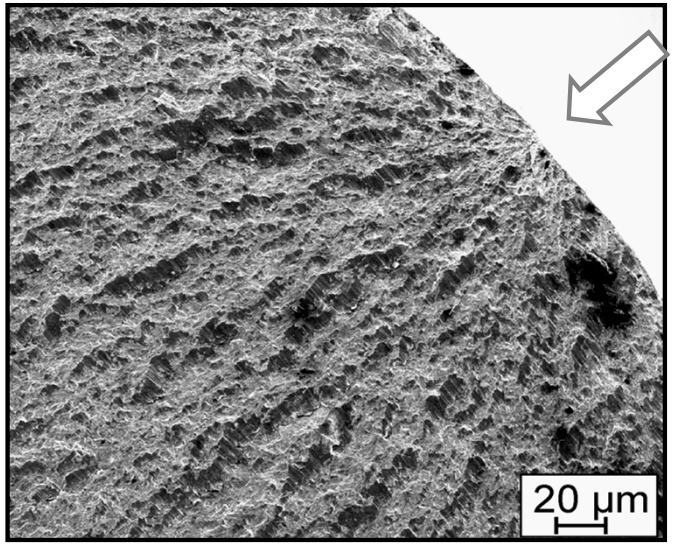
≈ 63 years

≈ 25 month

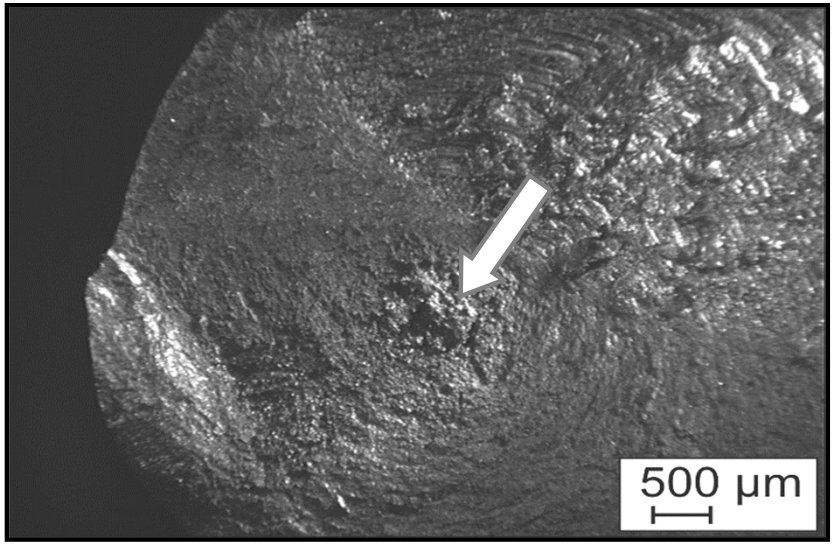
Fatigue tests in the VHCF-regime



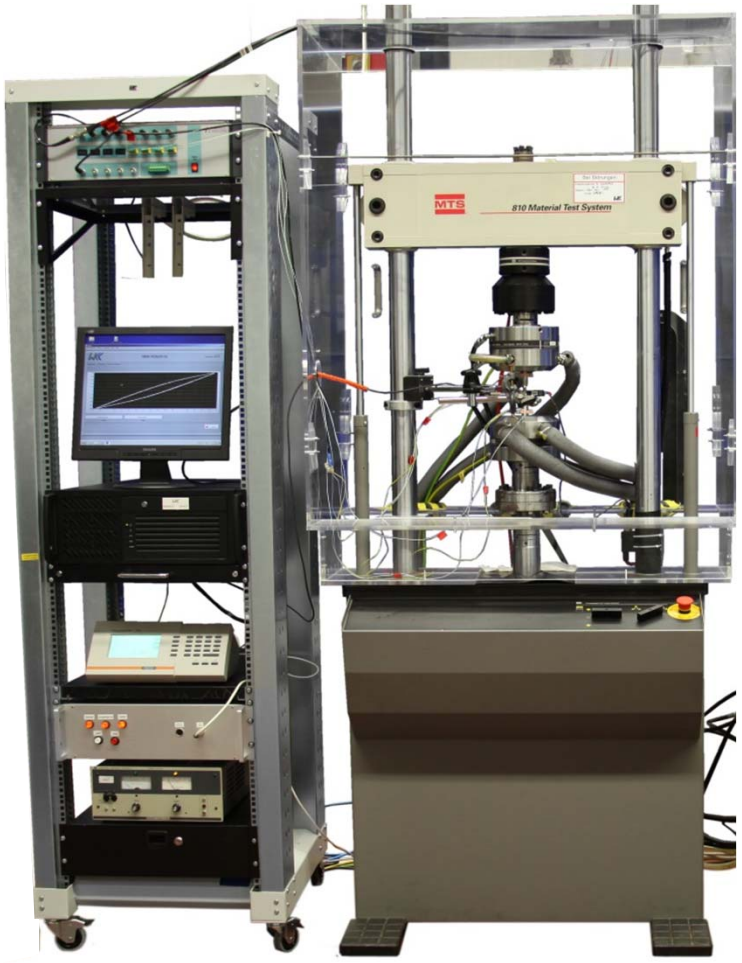
Surface crack



Subsurface crack



Schematic fatigue life diagram



LCF / HCF

(σ-ε) stress-strain

(ΔT) temperature

(ΔR) el. resistance

(P) generator power

SAE 1050 (R7)

VHCF

Measurement techniques and investigated material

LCF / HCF

(σ-ε) stress-strain

(ΔT) temperature

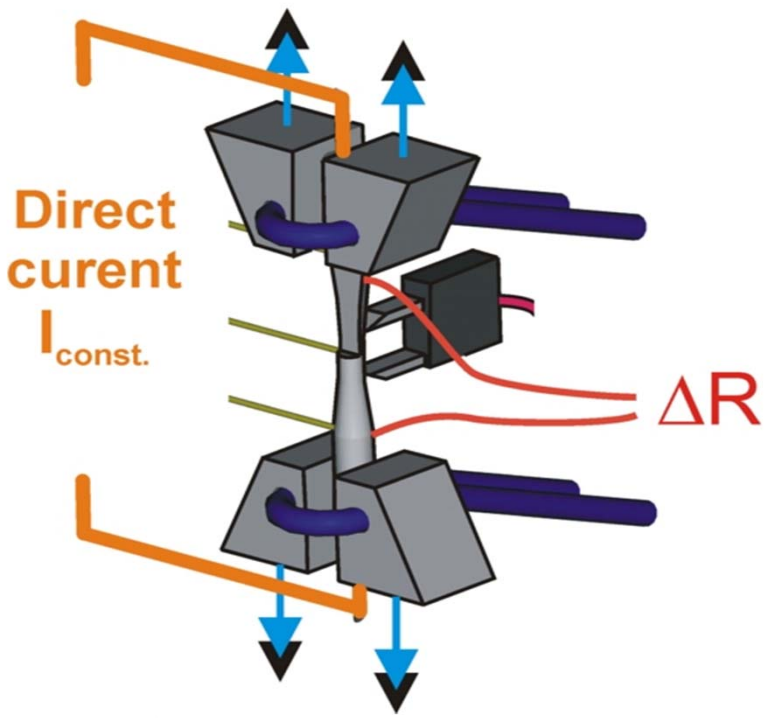
(ΔR) el. resistance

(P) generator power

SAE 1050 (R7)

VHCF

Measurement techniques and investigated material

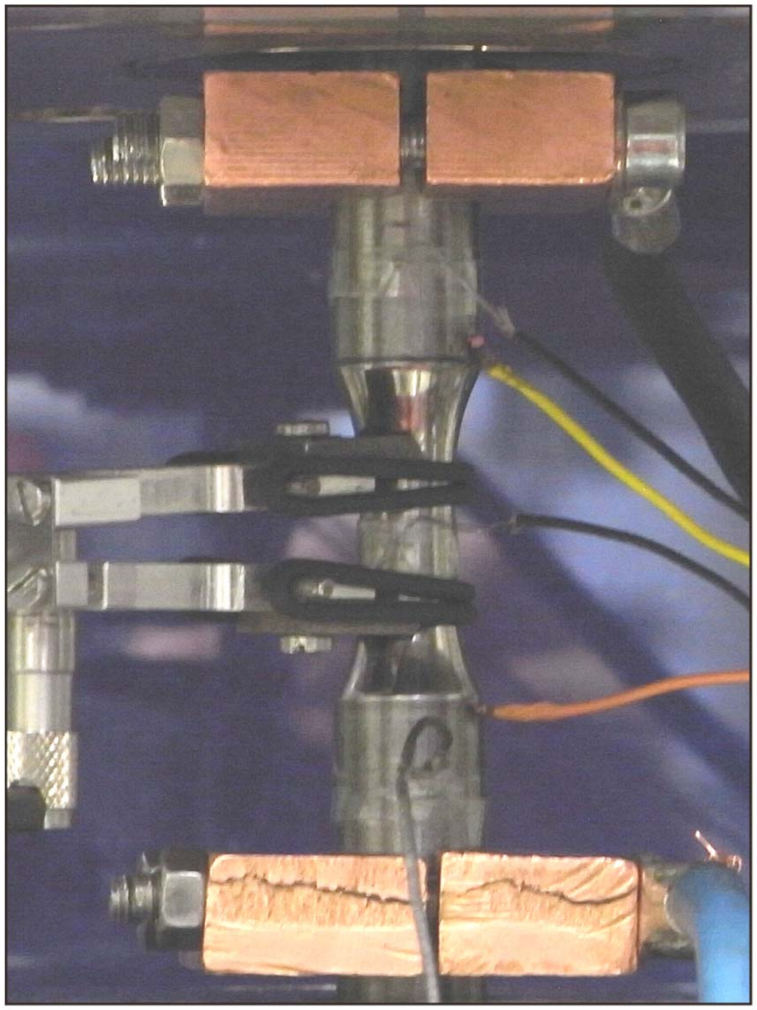


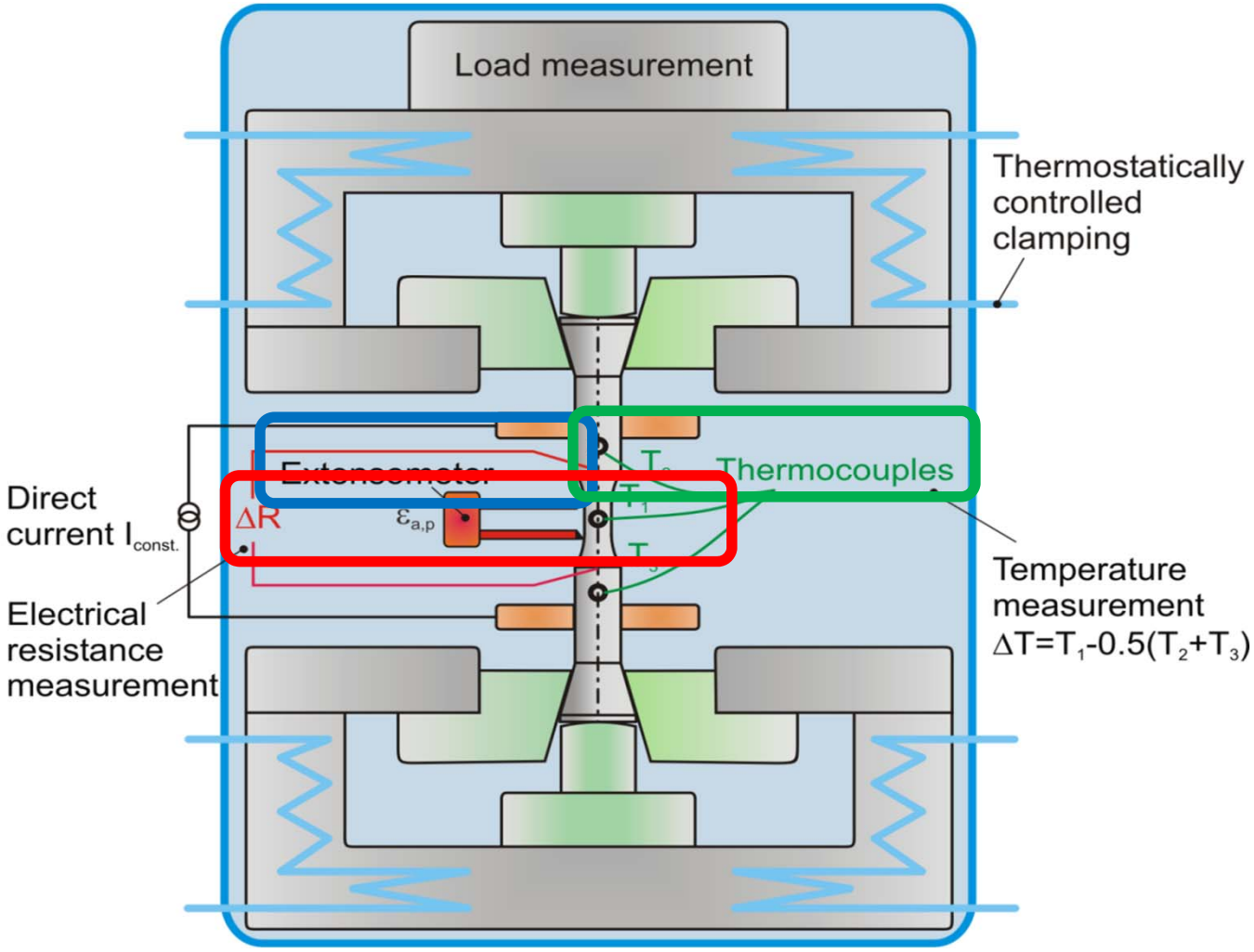
$$\Delta R = \rho^* \cdot \frac{L}{A}$$

The resistivity ρ^* is directly influenced by <u>deformation induced changes of the microstructure</u>

- ⇨ dislocation density
- ⇨ dislocation arrangement
- ⇨ vacancies
- ⇨ micro-shrinkage cavities
- ⇨ micro-pinholes and micro-cracks
- ⇨ ...

Change in electrical resistance ΔR

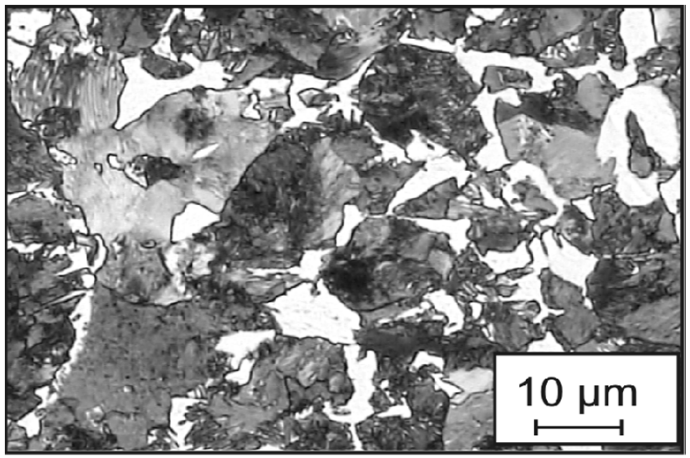




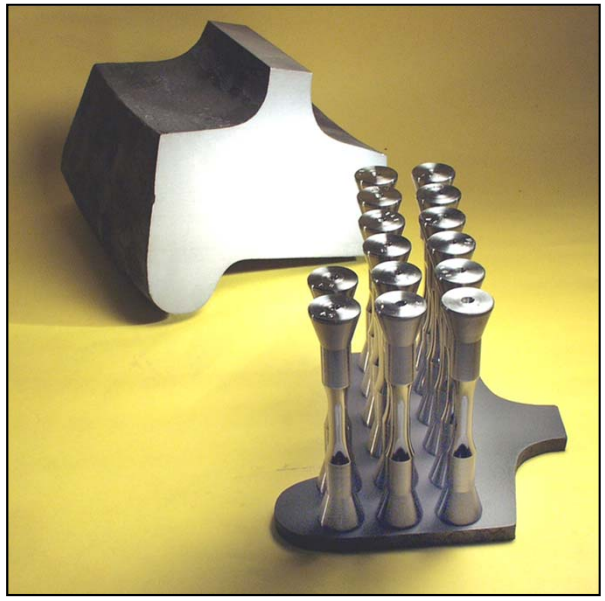
Measurement methods during fatigue tests

ICE 3

Microstructure



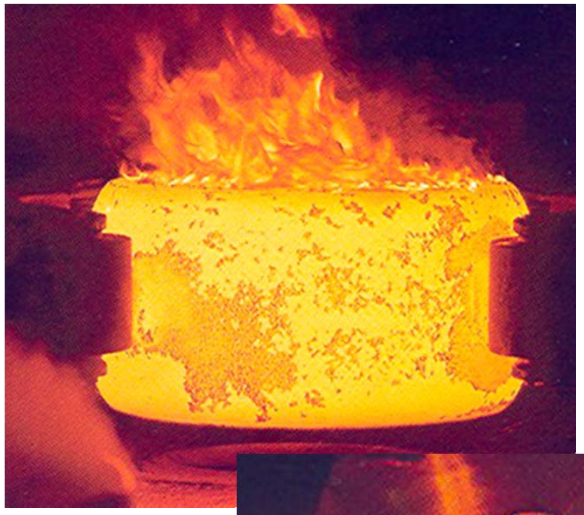
Specimen position



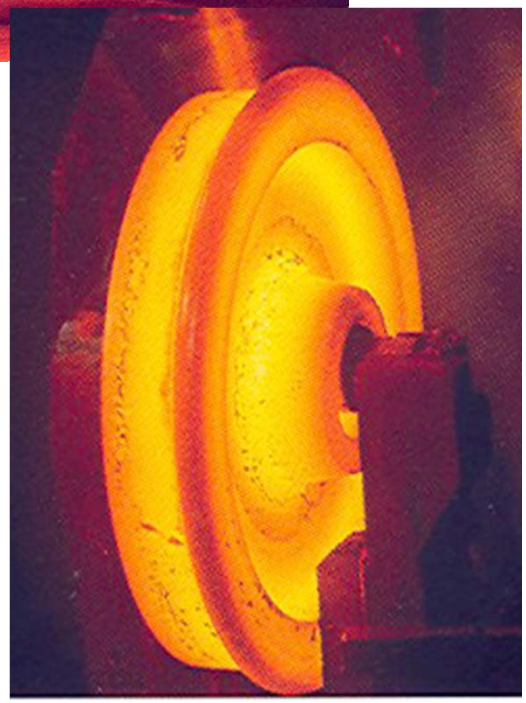
SAE 1050 (R7)

Elements	C	Si	Mn	Cr	Cu	Mo	Ni
[wt.-%]	0.50	0.31	0.75	0.23	0.02	0.01	0.14

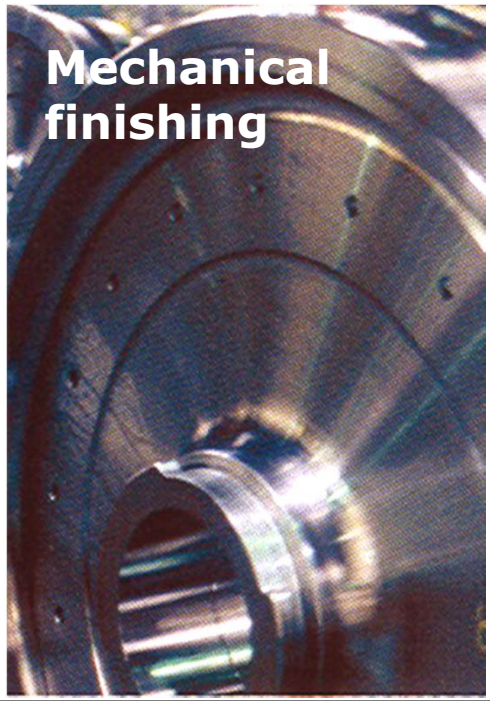
Chemical composition of SAE 1050 (R7) and specimen positions



Strand casting ingot 1300°C

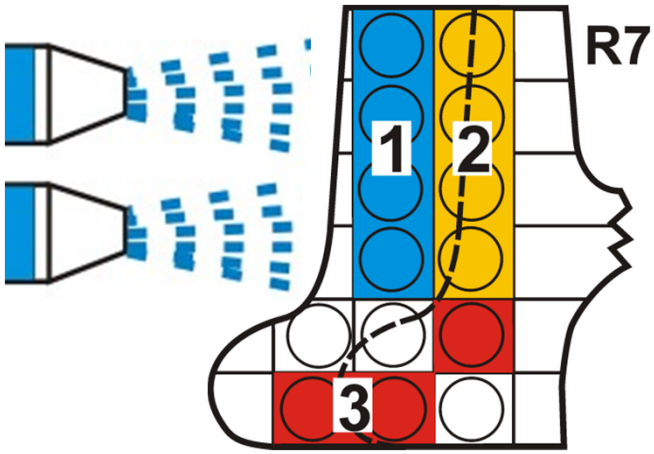


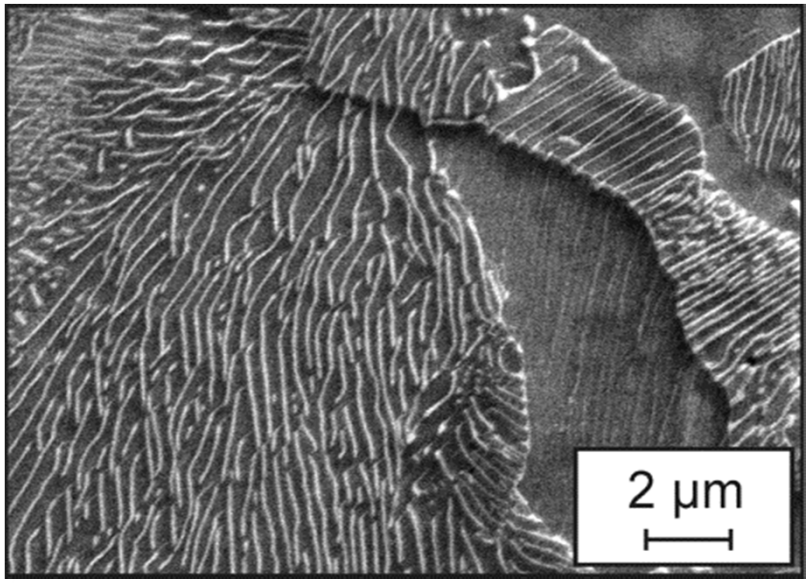
Flanging press



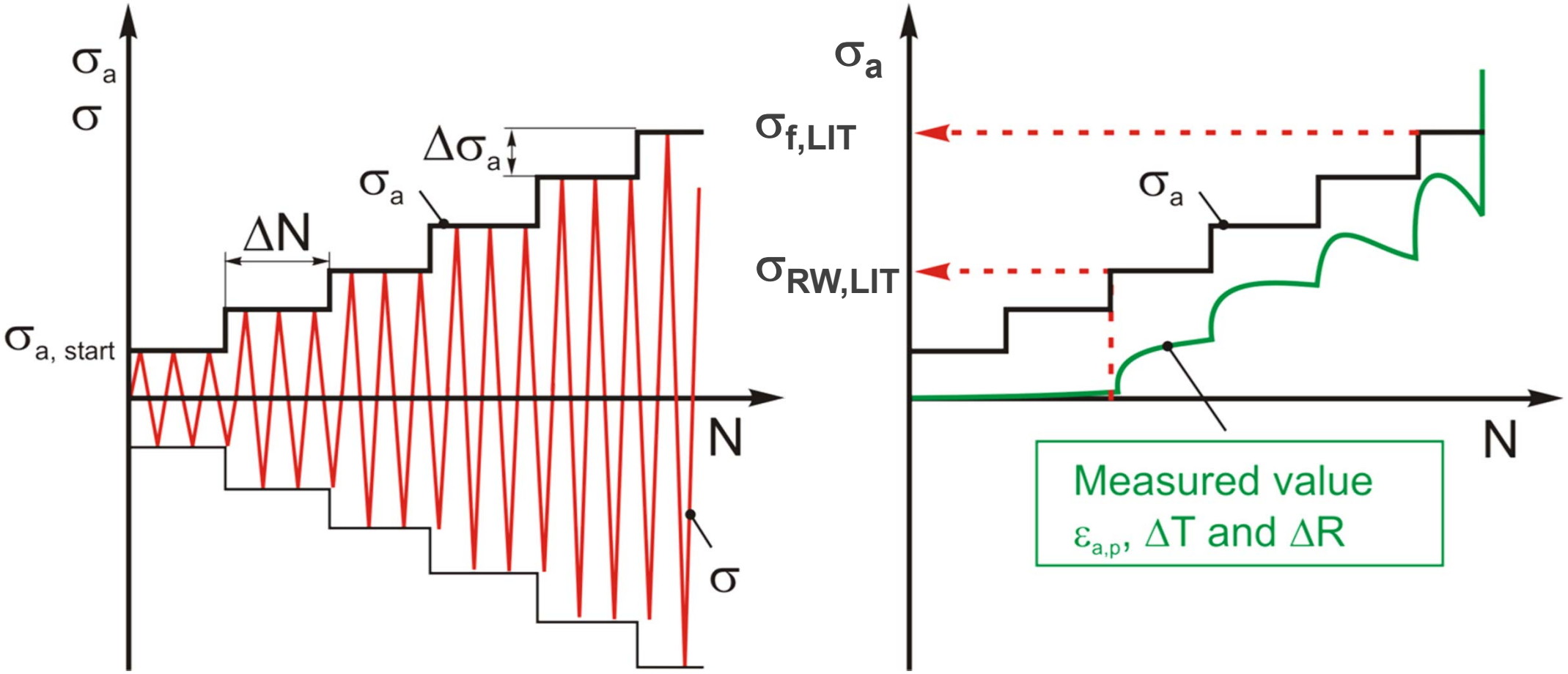
[Bochumer Verein, DB]

Manufacturing



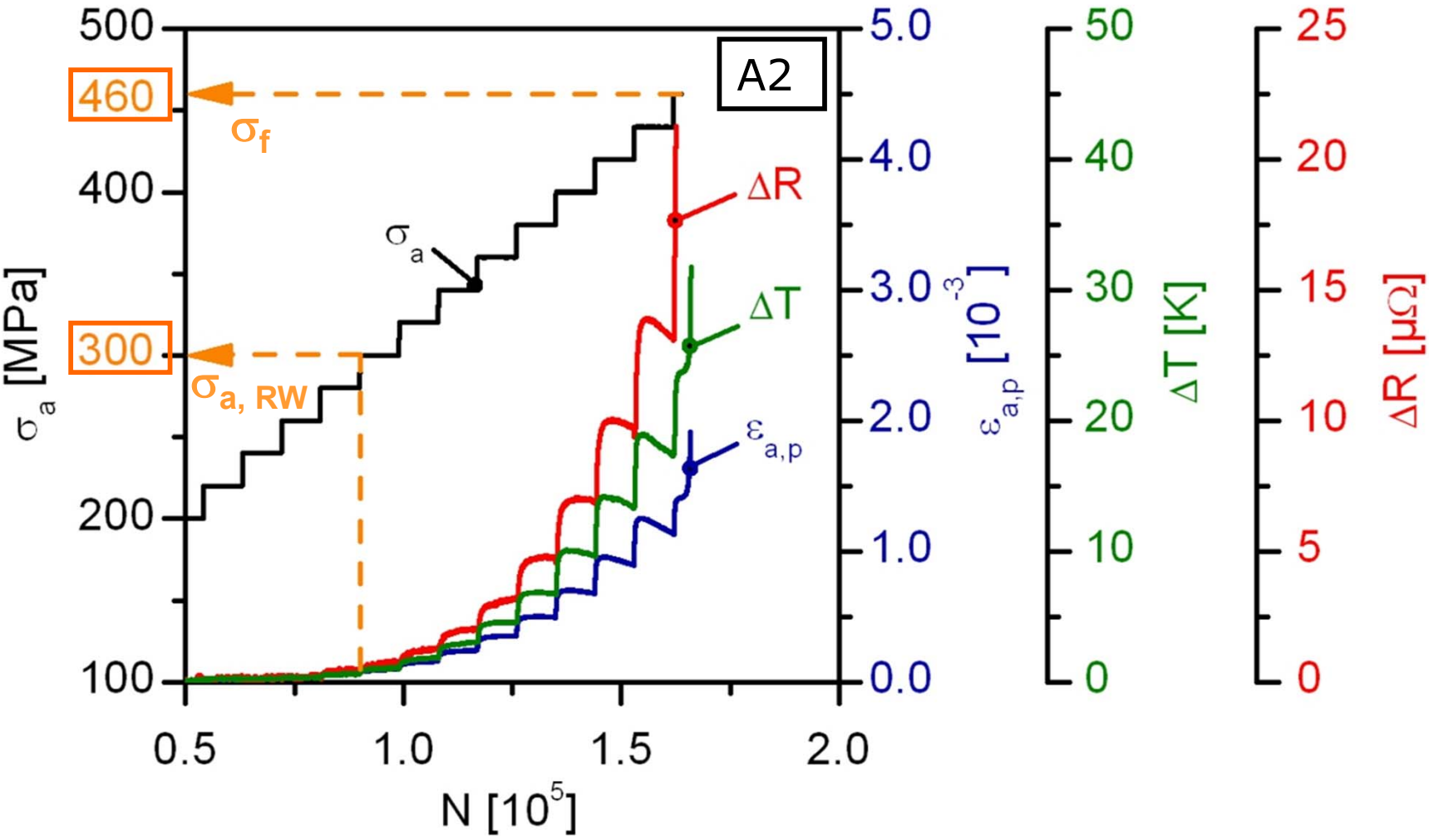


Specimen position

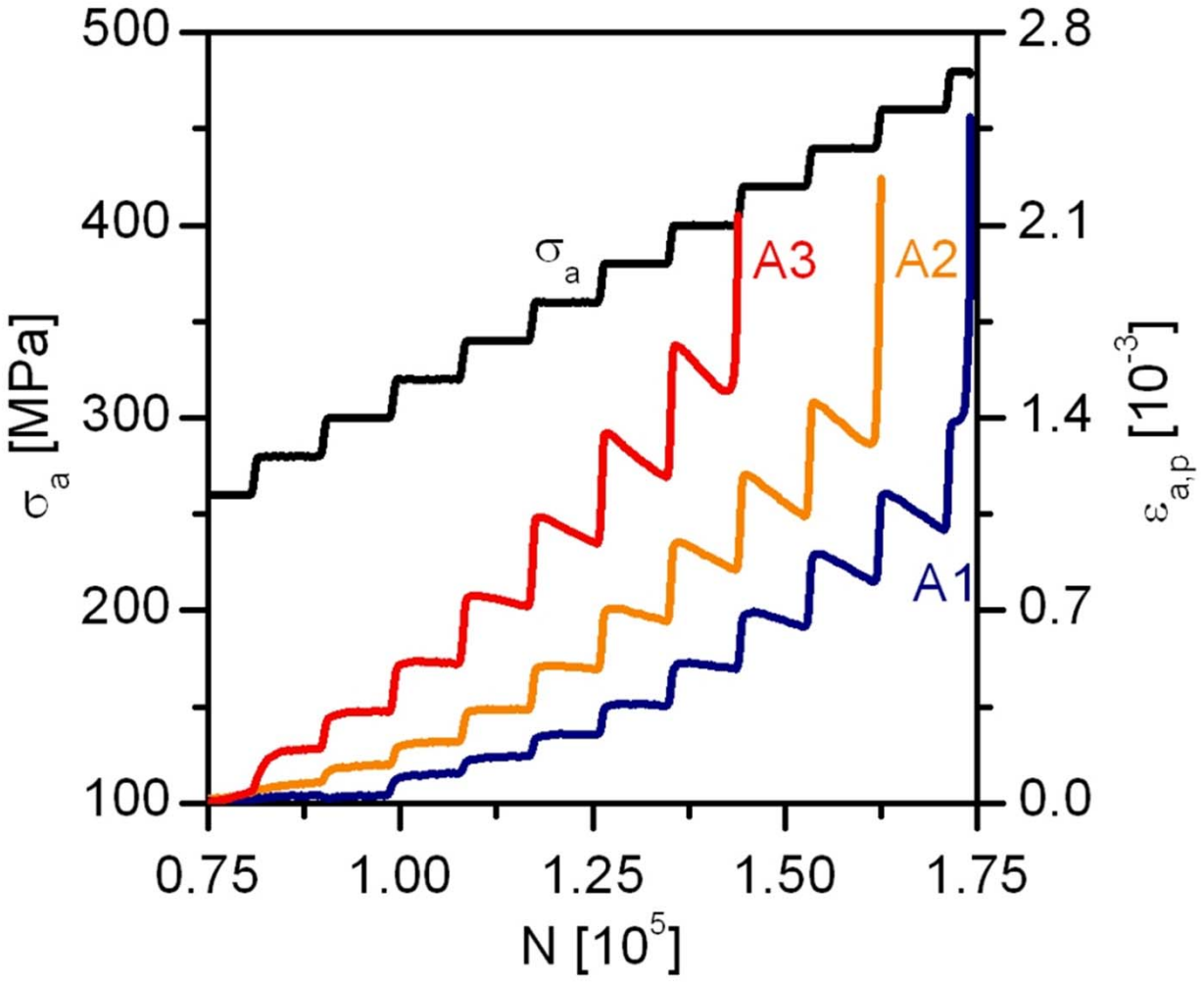


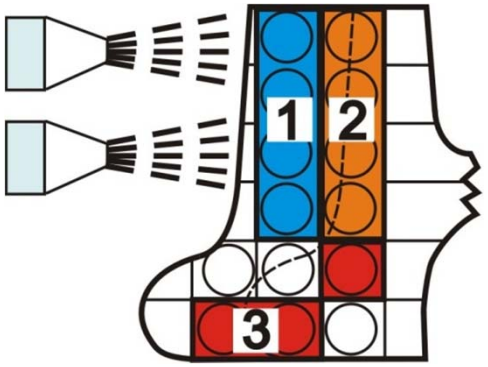
R_σ = -1, $\sigma_{a,\,start}$ = 100 MPa, $\Delta\sigma_a$ = 20 MPa, $\Delta N = 9 \cdot 10^3$, f = 5 Hz

Load increase test



Load increase test

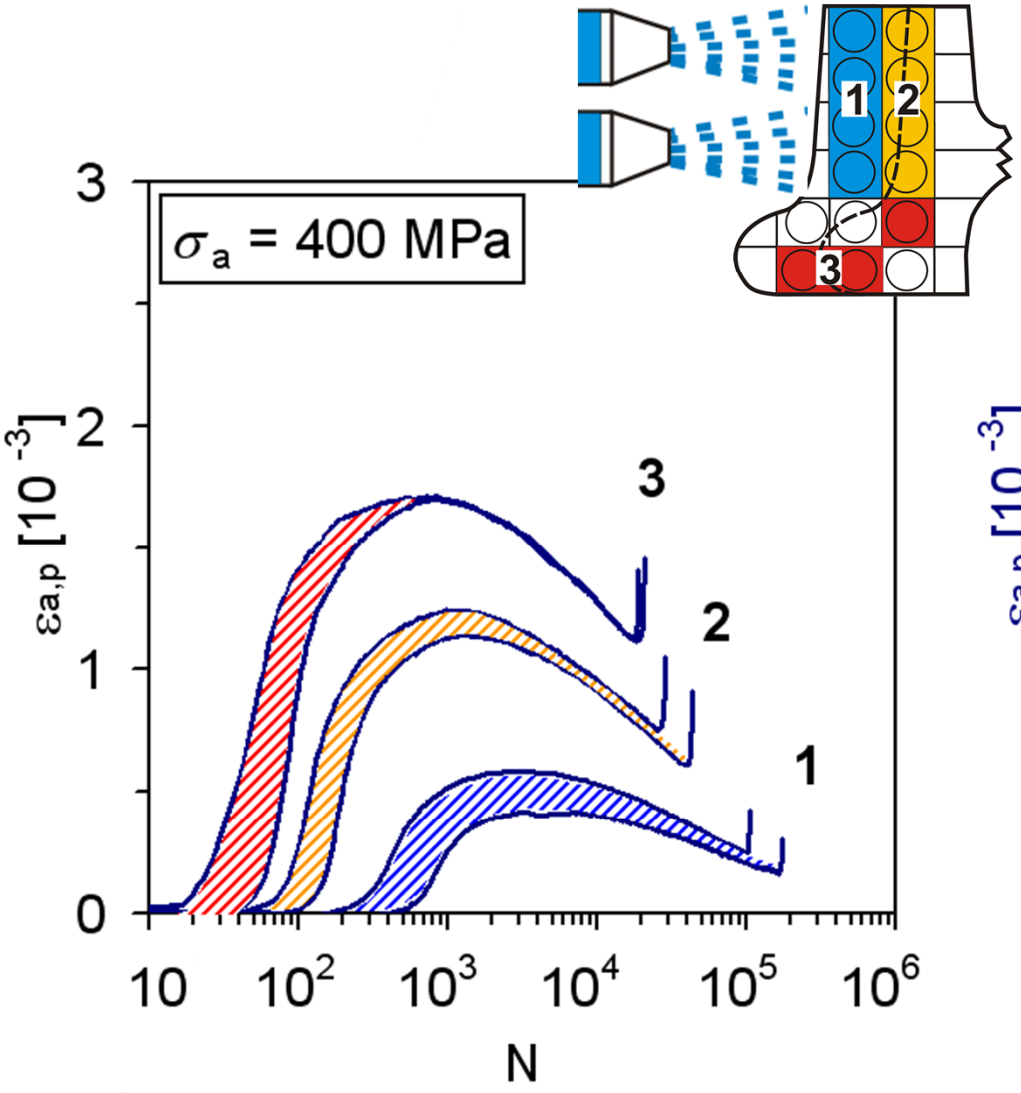


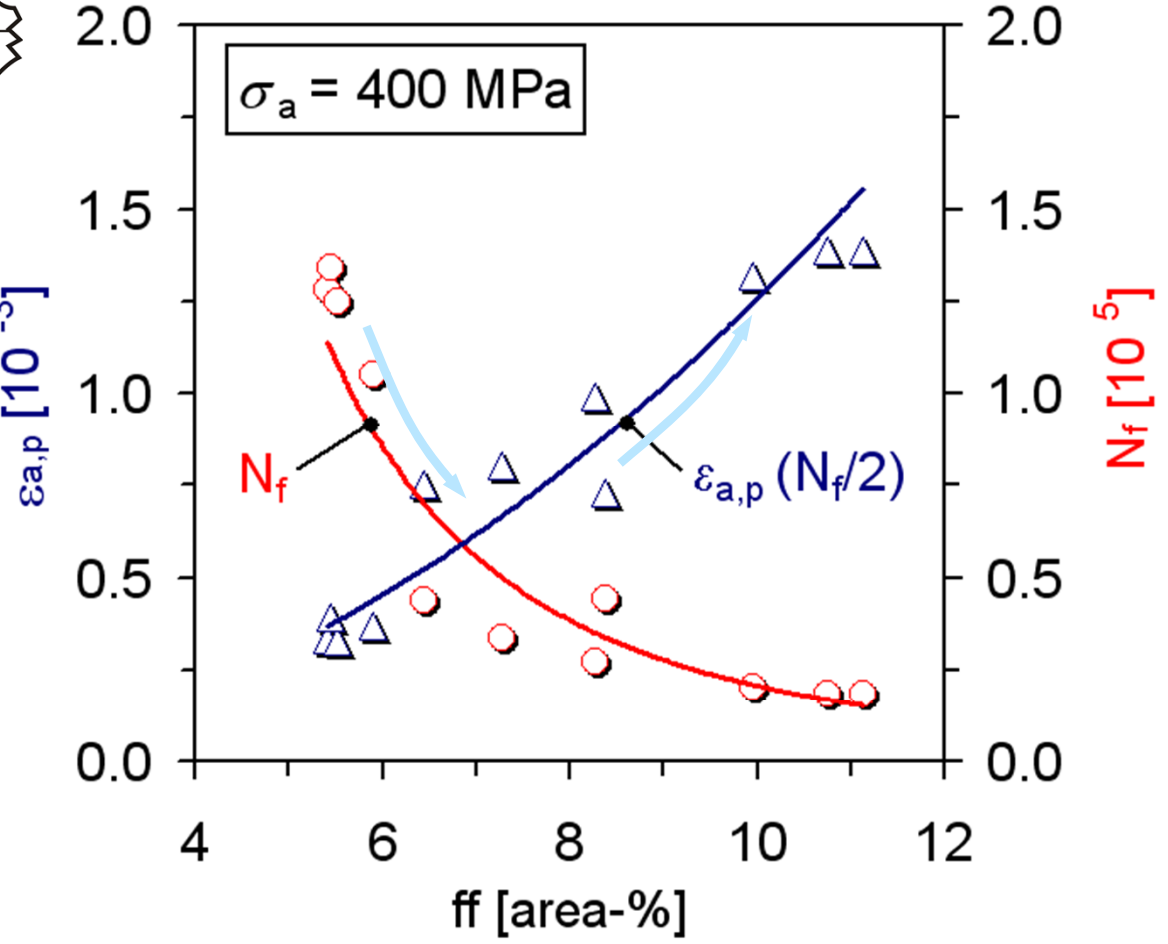


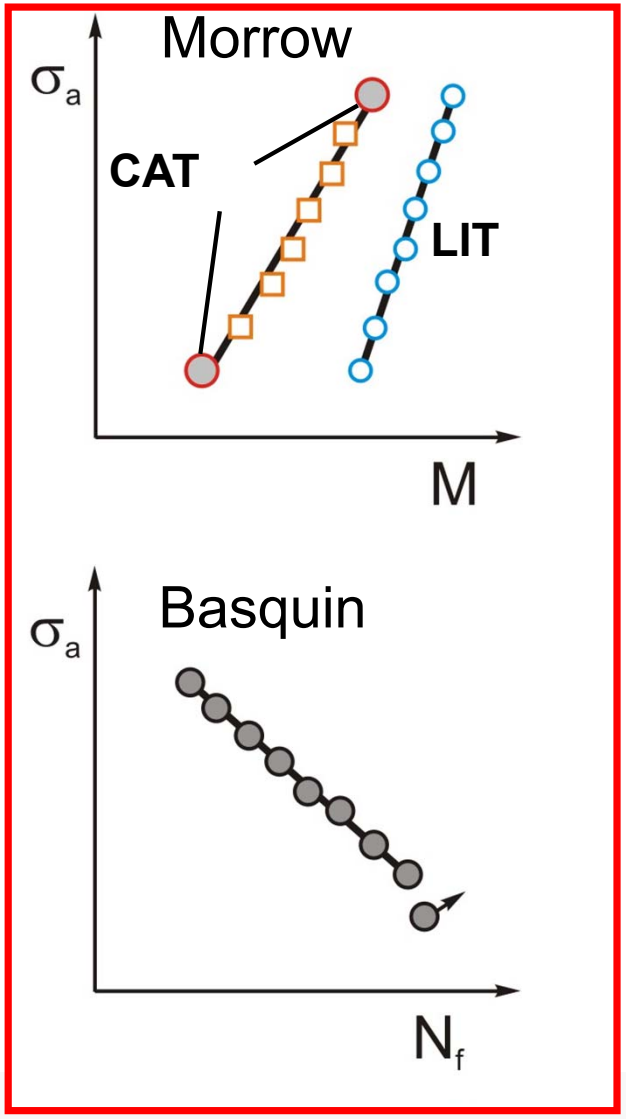
Area	A1	A2	A3
$\sigma_{RW,LIT}$ [MPa]	320	300	280
$\sigma_{f,LIT}$ [MPa]	460	440	420

R_σ = -1, $\sigma_{a,\,start}$ = 100 MPa, $\Delta\sigma_a$ = 20 MPa, $\Delta N = 9 \cdot 10^3$, f = 5 Hz

Load increase test


σa = 400 MPa
εa,p [10 -3]
N
1
2
3


σa = 400 MPa
εa,p [10 -3]
Nf [10 5]
ff [area-%]
Nf
εa,p (Nf/2)



$$\sigma_a = K' \cdot \left(\varepsilon_{a,p}\right)^{n'}$$

$$\sigma_a = K'_M \cdot \left(M\right)^{n'_M}$$

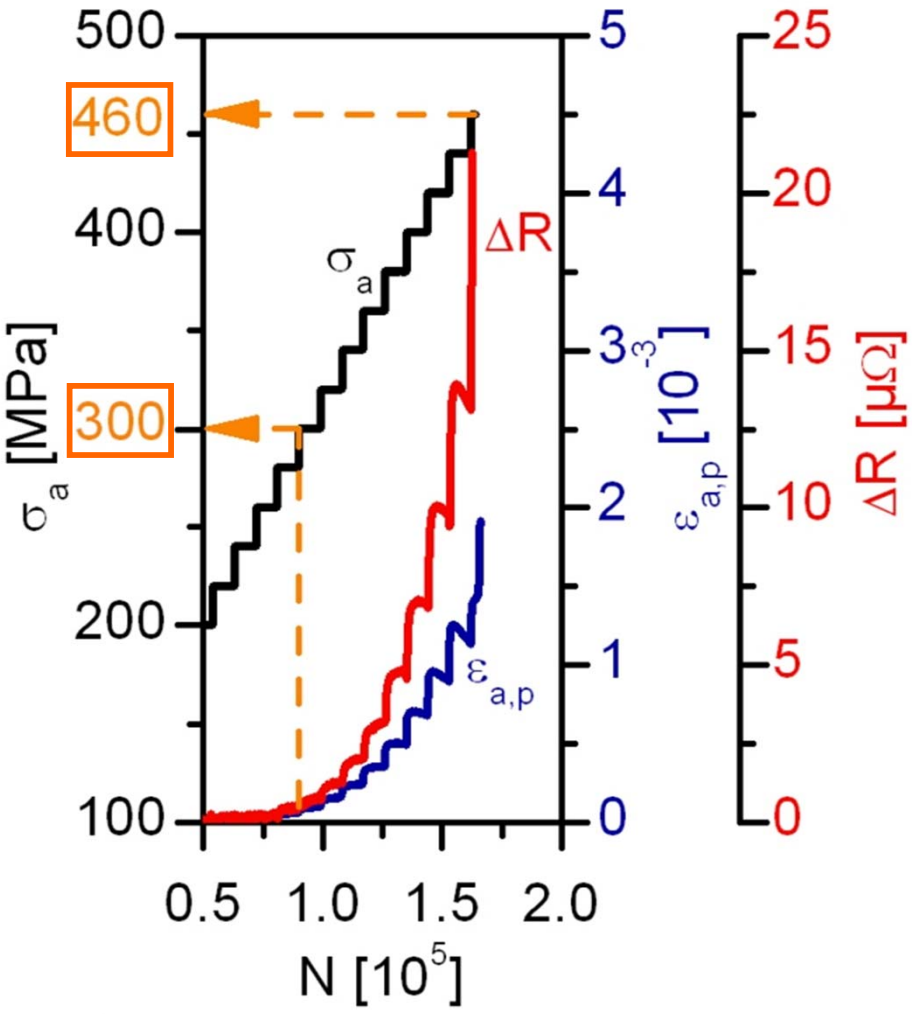
$$b_M = \frac{-n'_M}{5\,n'_M + 1}$$

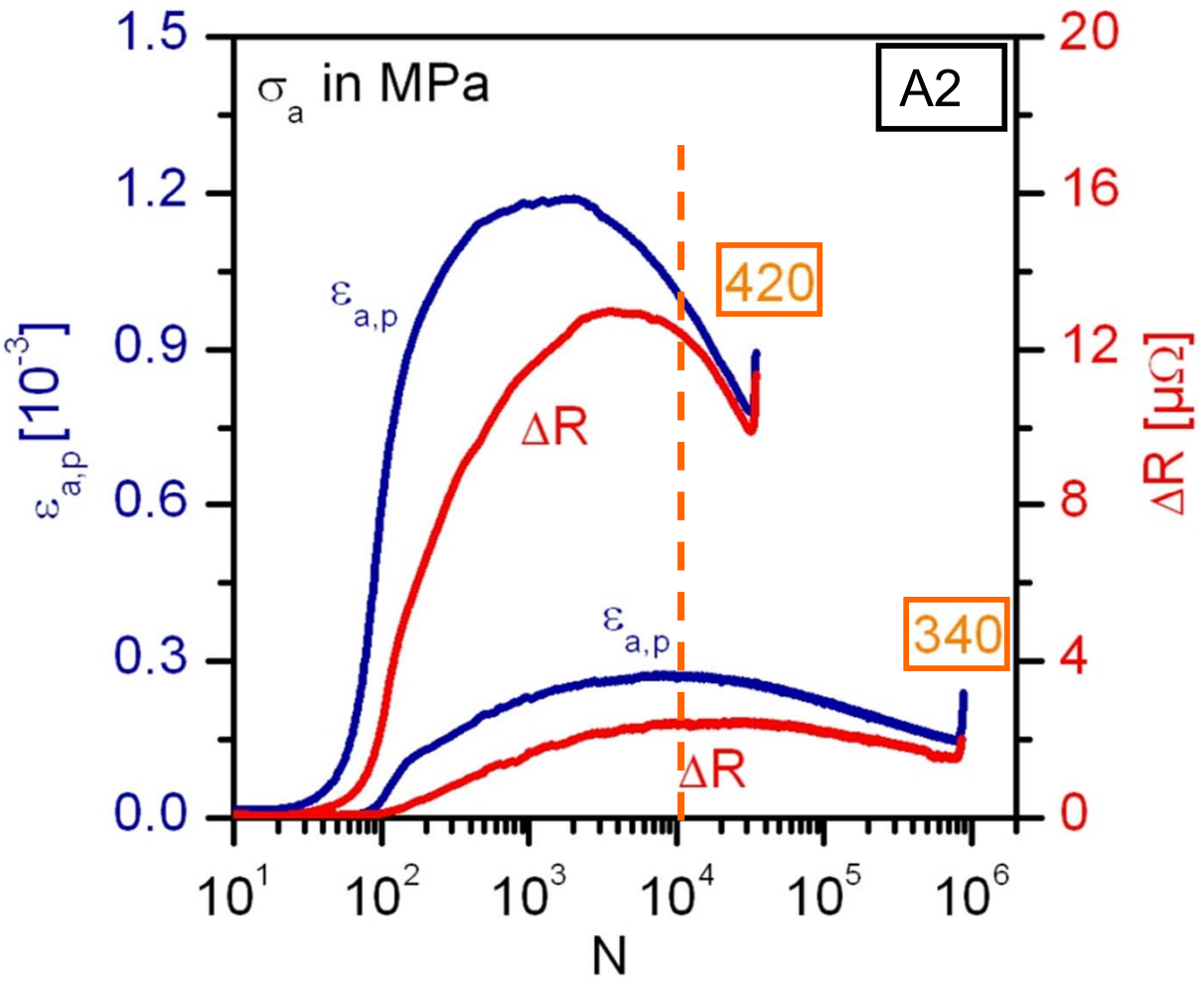
σ_a and N_f of one CAT

$$\sigma_a = \sigma'_{f,M} \cdot \left(2N_f\right)^{b_M}$$

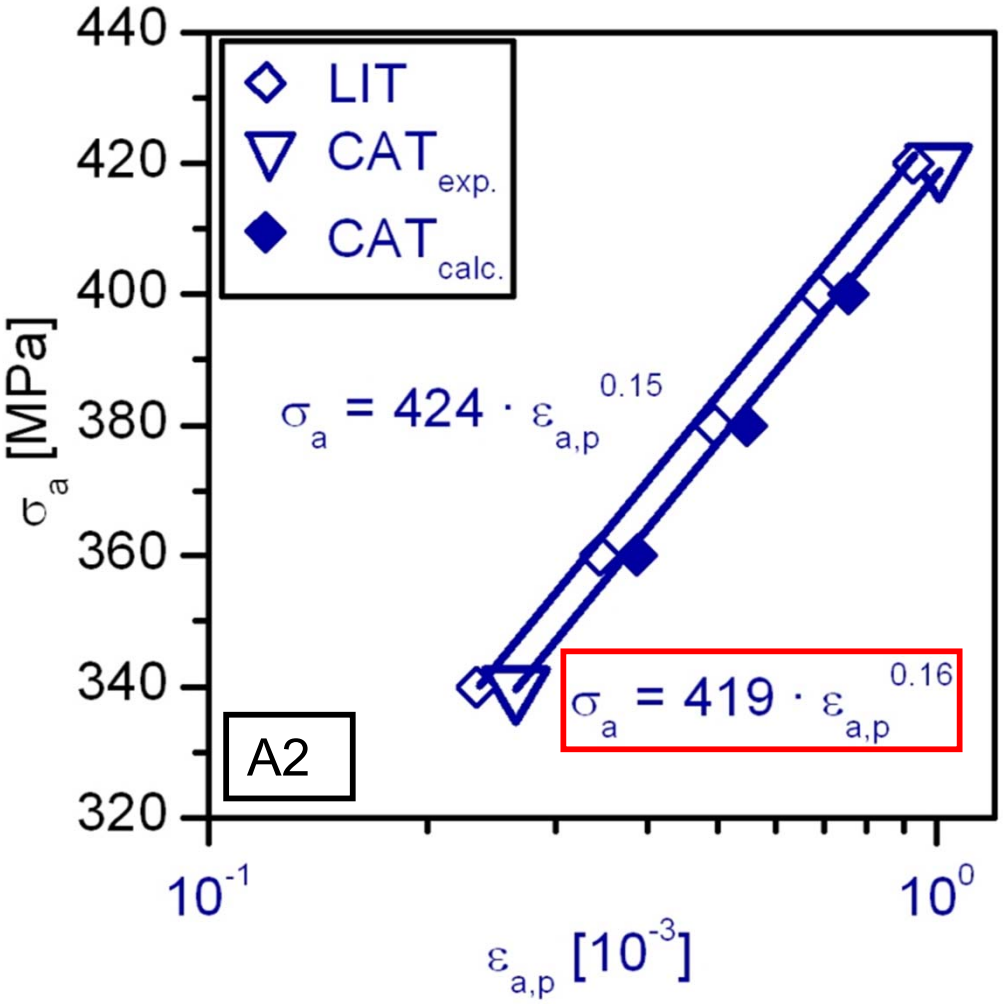
$$N_f = 0.5 \cdot \left(\frac{\sigma_a}{\sigma'_{f,M}}\right)^{\frac{1}{b_M}}$$

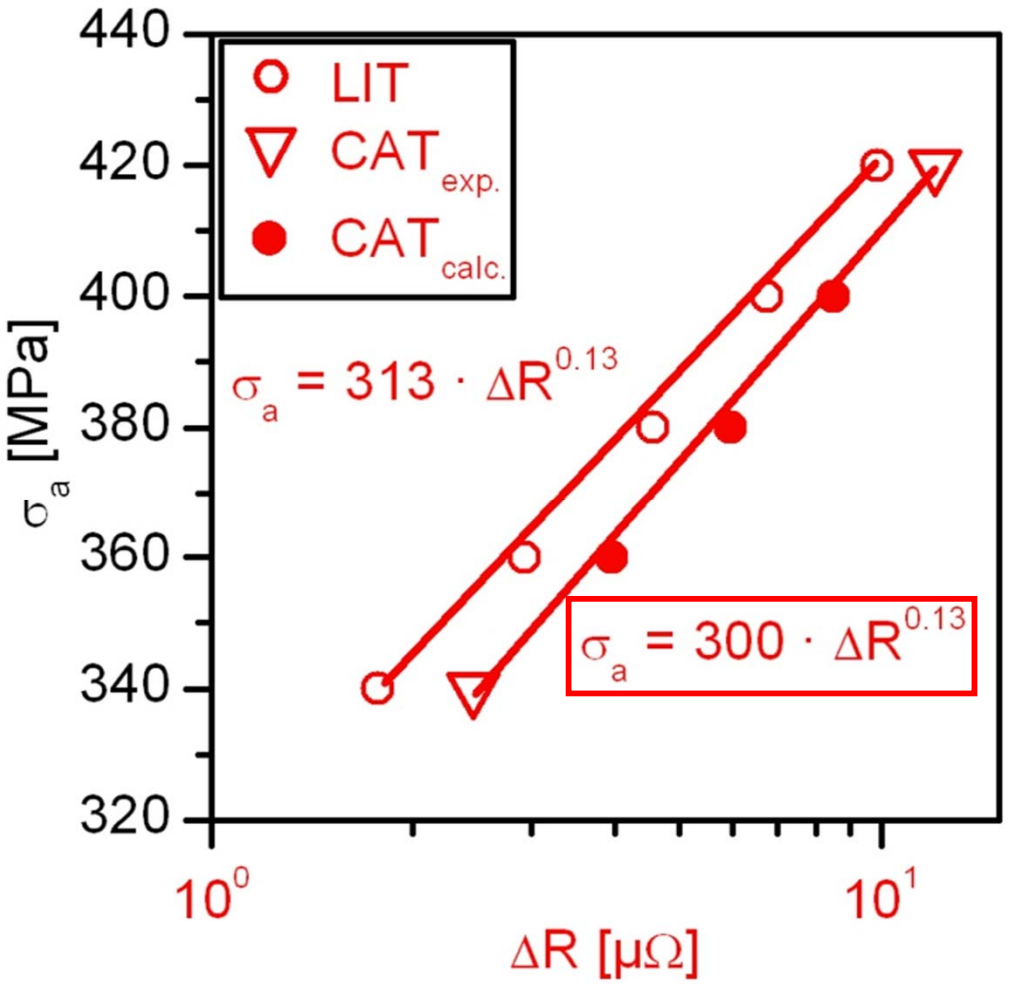
Fatigue life calculation "PHYBAL$_{LIT}$"



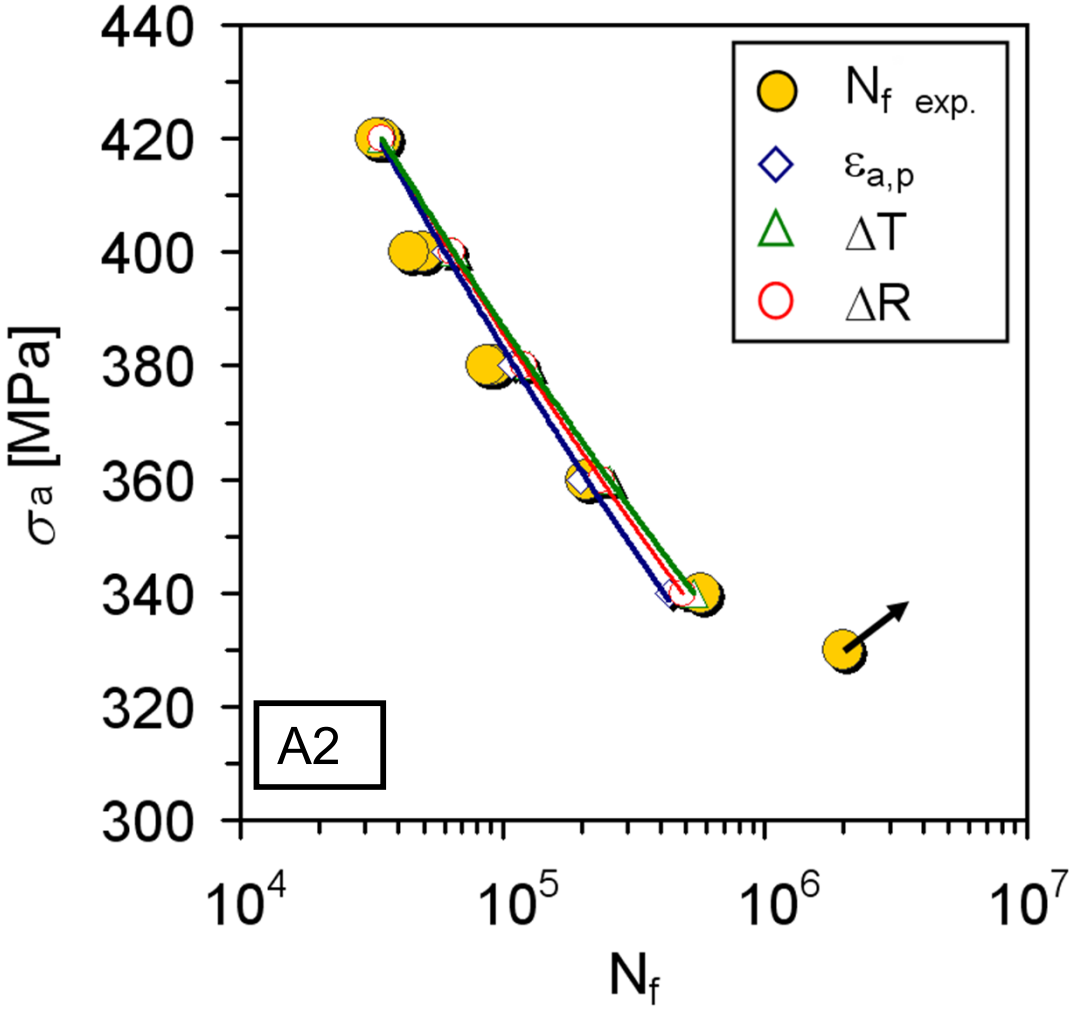


Load increase and constant amplitude tests





Fatigue life calculation method "PHYBAL$_{LIT}$"



Calculation of the S-N curve on the basis of one load increase and two constant amplitude tests

Fatigue life calculation method "PHYBAL$_{LIT}$"

- The plastic strain amplitude, the change in temperature and the change in resistance can be equivalently used for the detailed characterisation of the fatigue behaviour and the precise fatigue life calculation of metallic materials.

- On the basis of generalised Morrow and Basquin equations the physically based fatigue life calculation method "$PHYBAL_{LIT}$" was developed.

- This new short-time procedure allows the fast and accurate calculation of Woehler curves using cyclic deformation data of only three fatigue tests.

- With a total running time of about two days per material and heat treatment "$PHYBAL_{LIT}$" yields an enormous saving of time and costs compared to the conventional determination of Woehler curves with about 30 days for constant amplitude tests with f = 5 Hz until N = $2 \cdot 10^6$ cycles.

Conclusions

(σ-ε) stress-strain

(ΔT) temperature

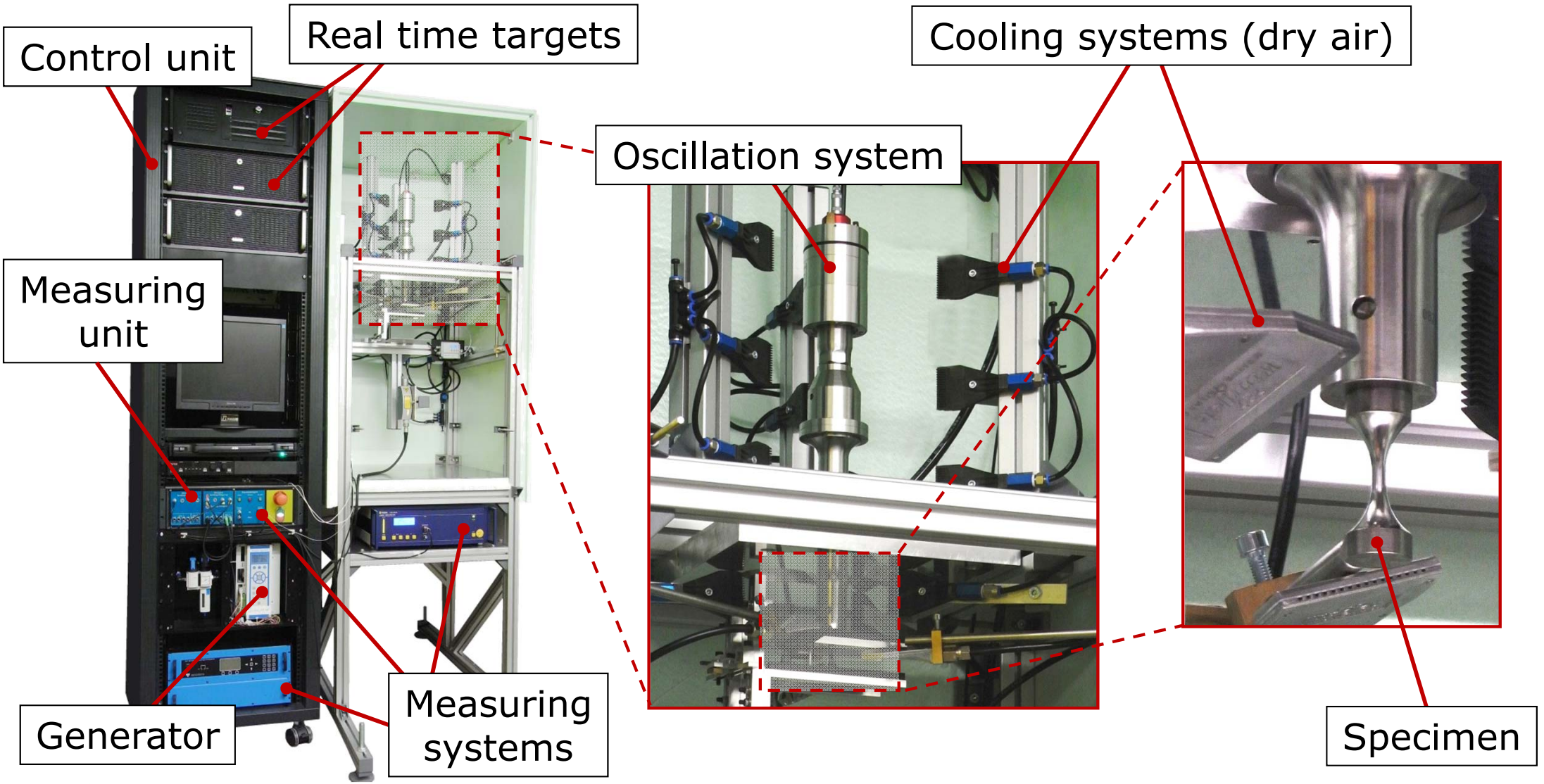
(ΔR) el. resistance

(P) generator power

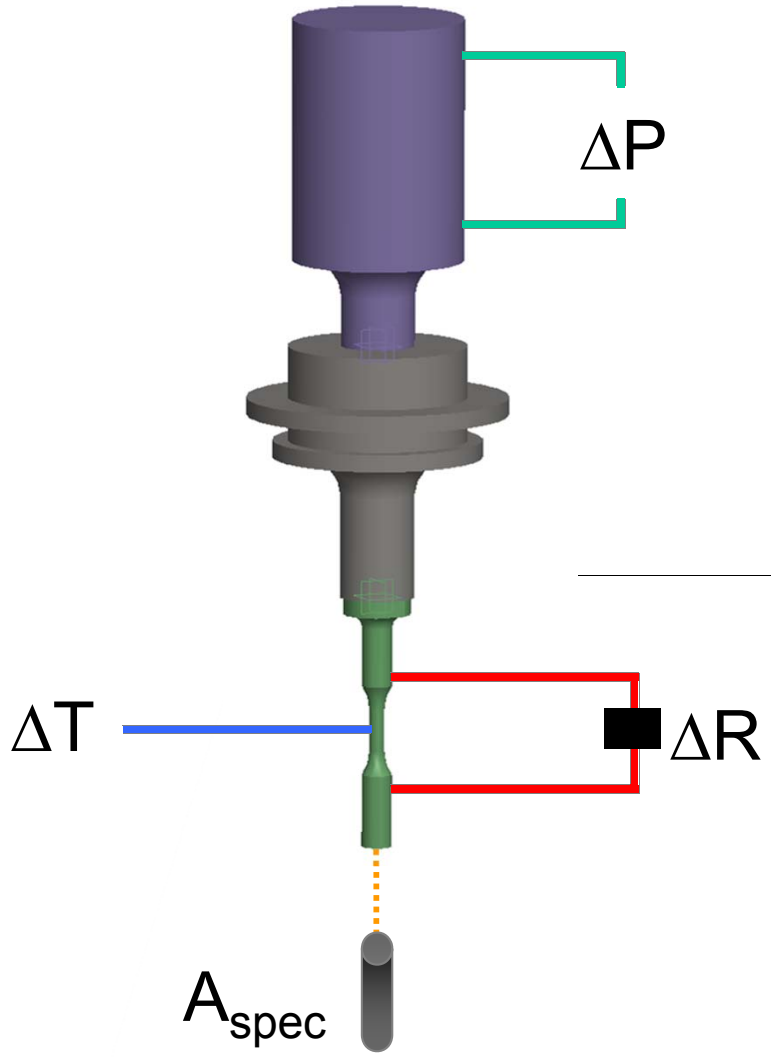
SAE 1050 (R7)

VHCF

Measurement techniques and investigated material



VHCF testing facility



Continuously measured data:

ΔP: generator power

ΔT: temperature

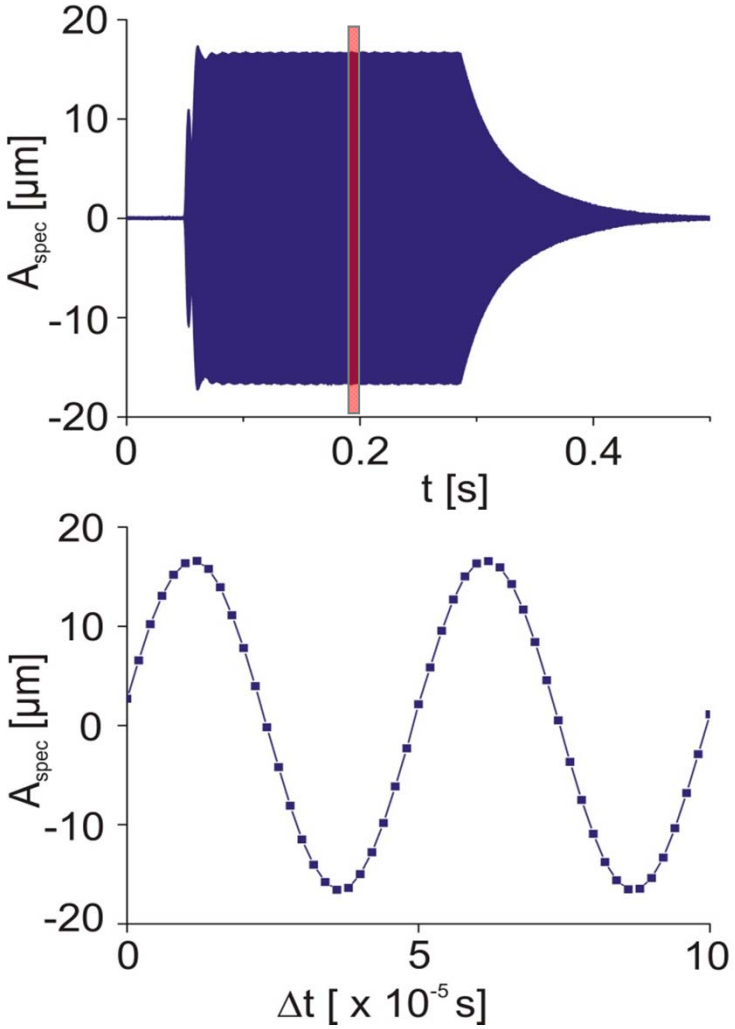
A_{spec}: mech. oscillation of the specimen (LDI)

Discontinuously measured data:

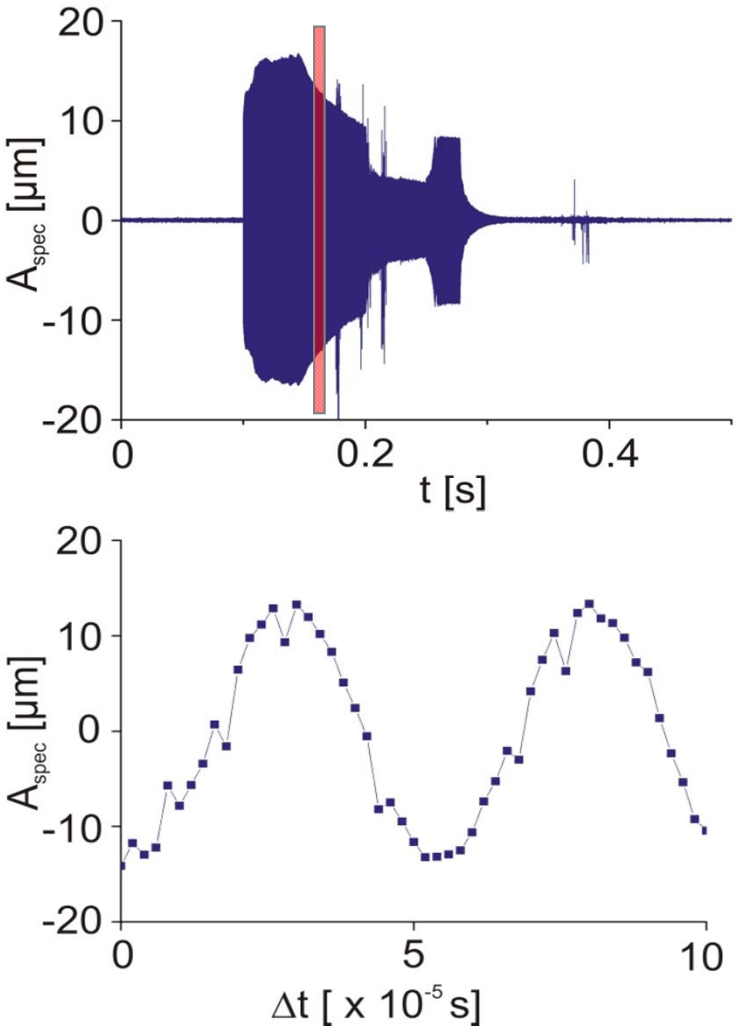
ΔR: electrical resistance

Data measured during the fatigue test

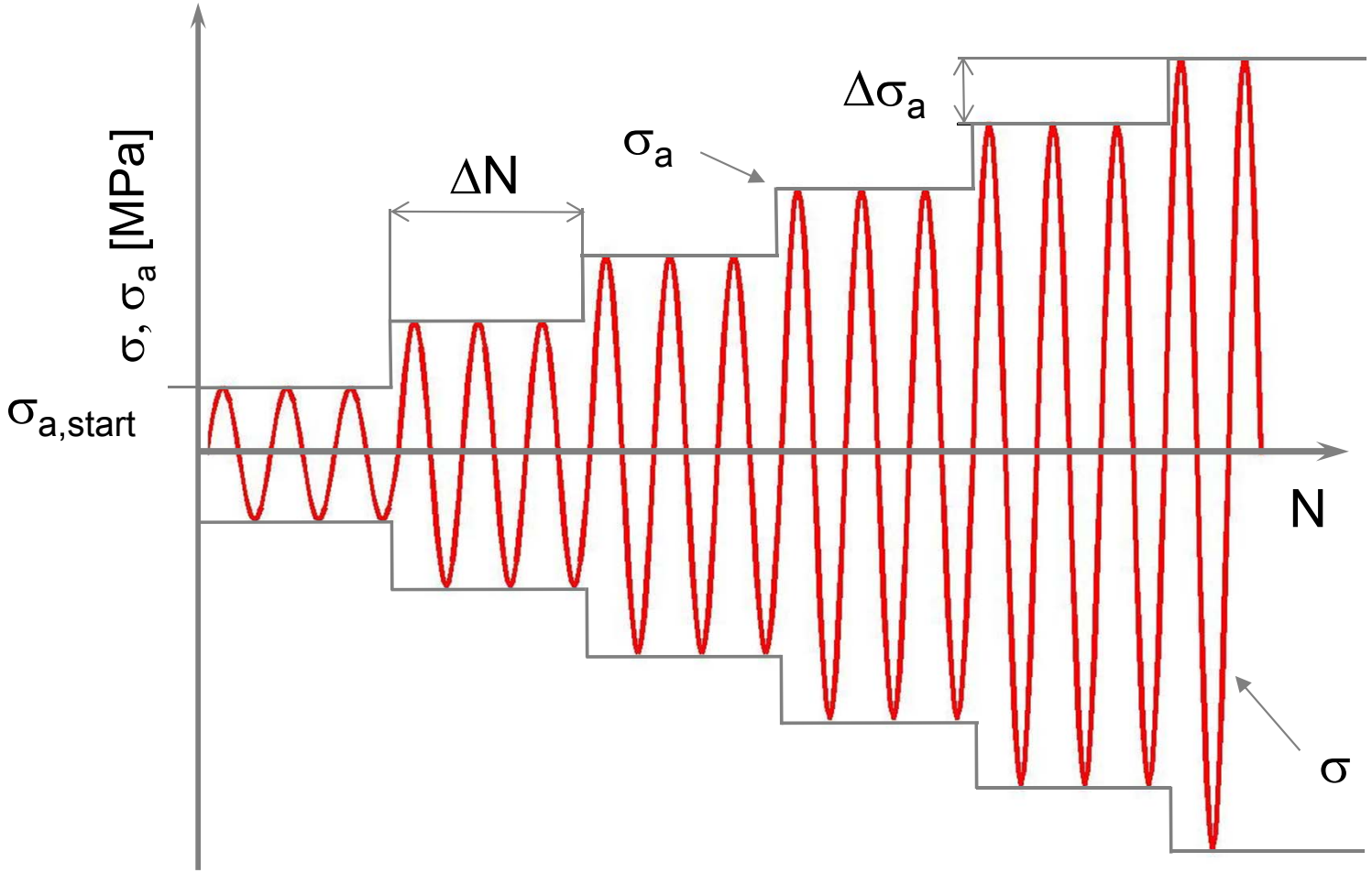
Specimen in the initial state



Specimen with macro-crack



Amplitude course



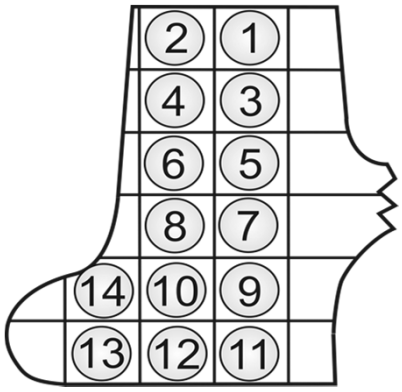
Test parameters:

$\Delta N = 10^6$

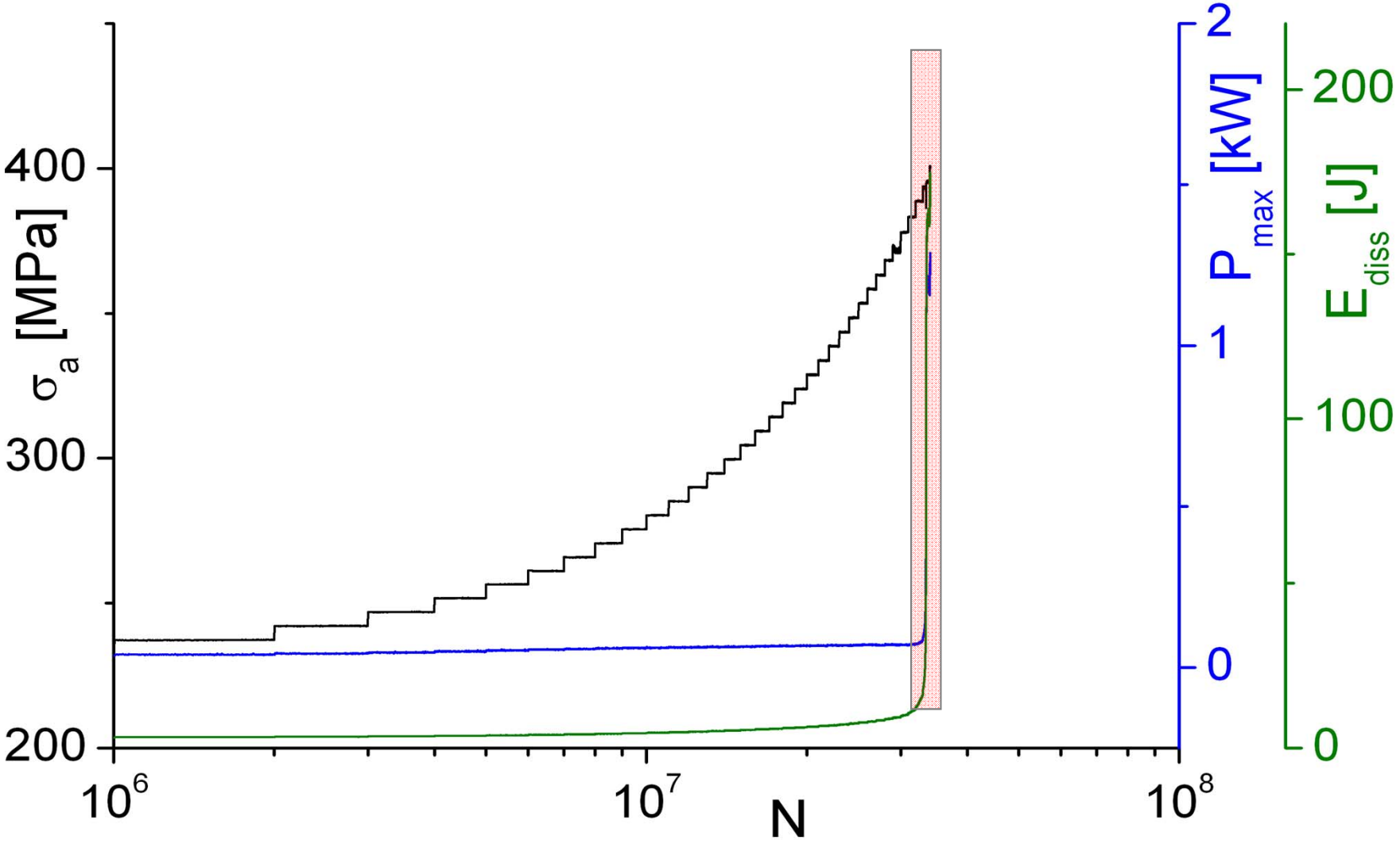
$\sigma_{a,start} = 220$ MPa

$\sigma_{a,end} = 455$ MPa

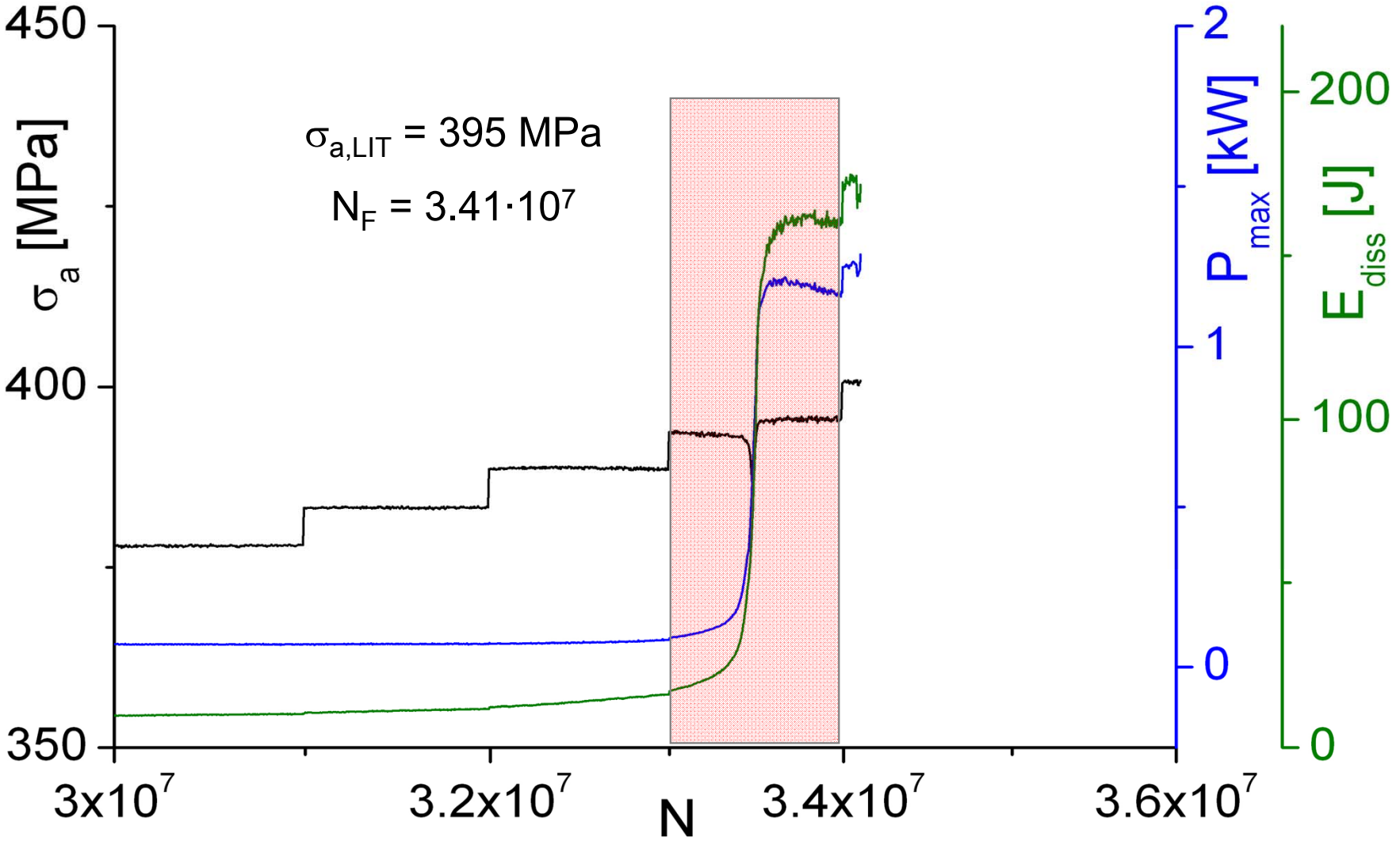
$\Delta \sigma_a = 5$ MPa



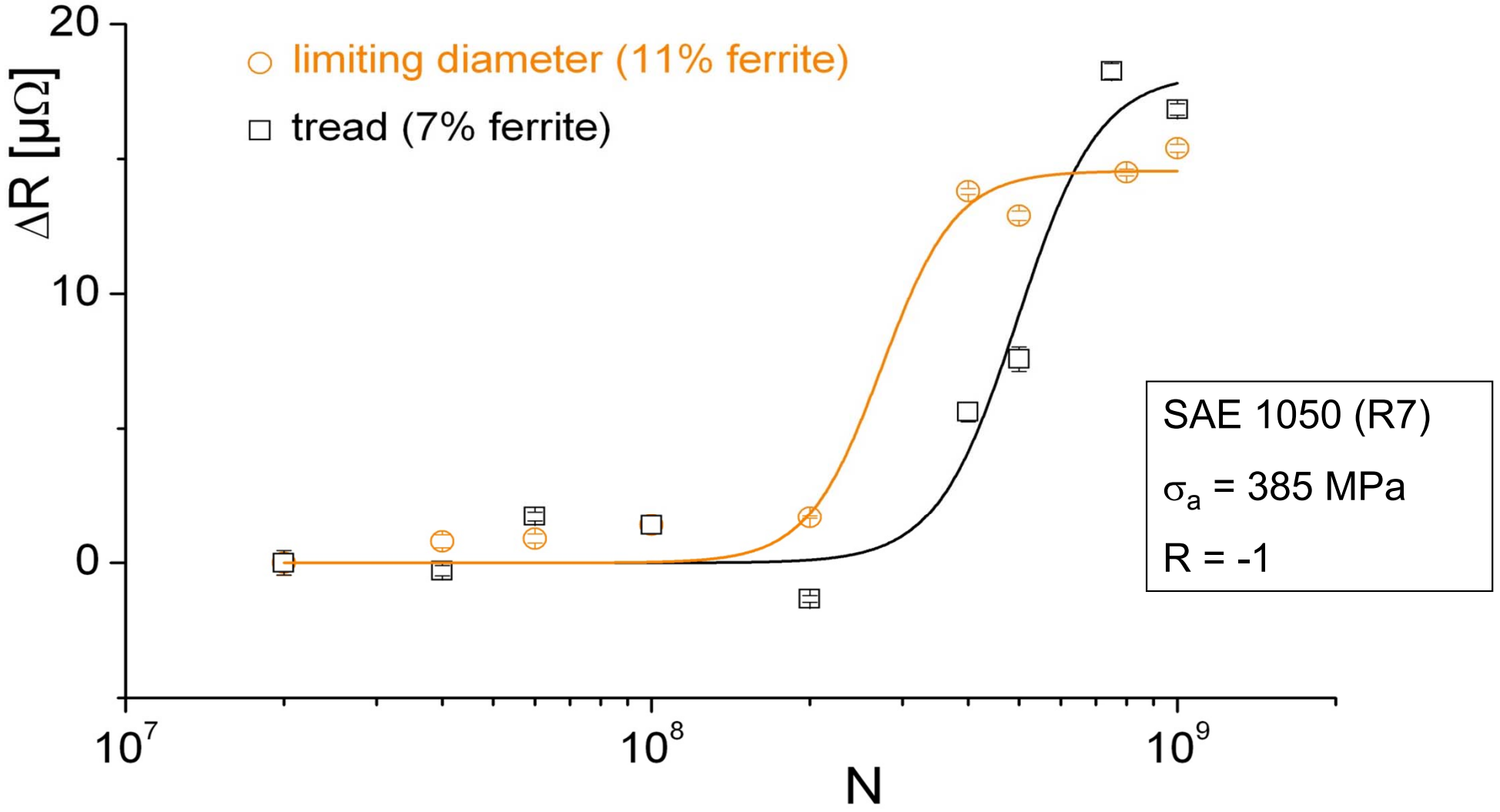
Load increase test (LIT) with an ultrasonic testing facility



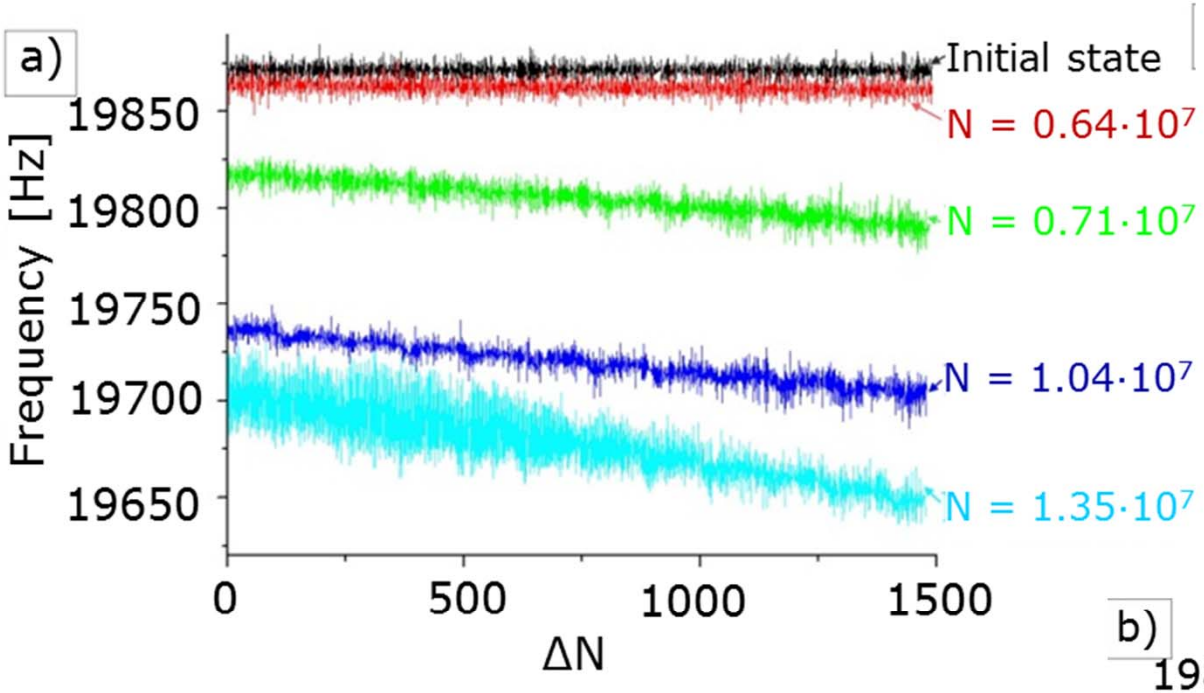
LIT: analysis of the power and energy course



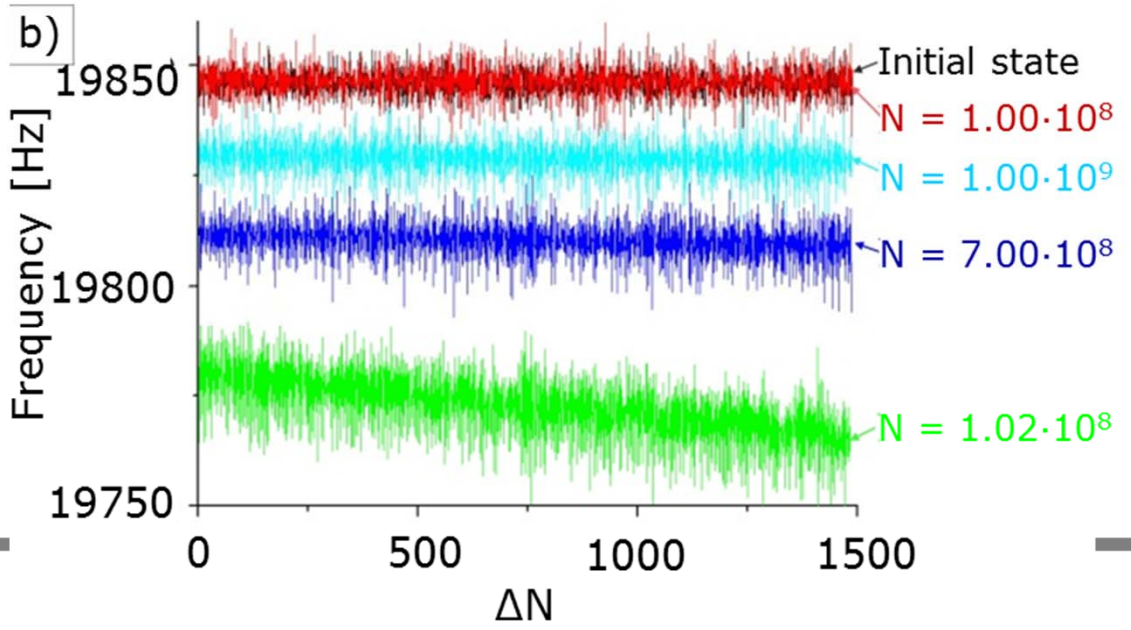
LIT: analysis of the power and energy course

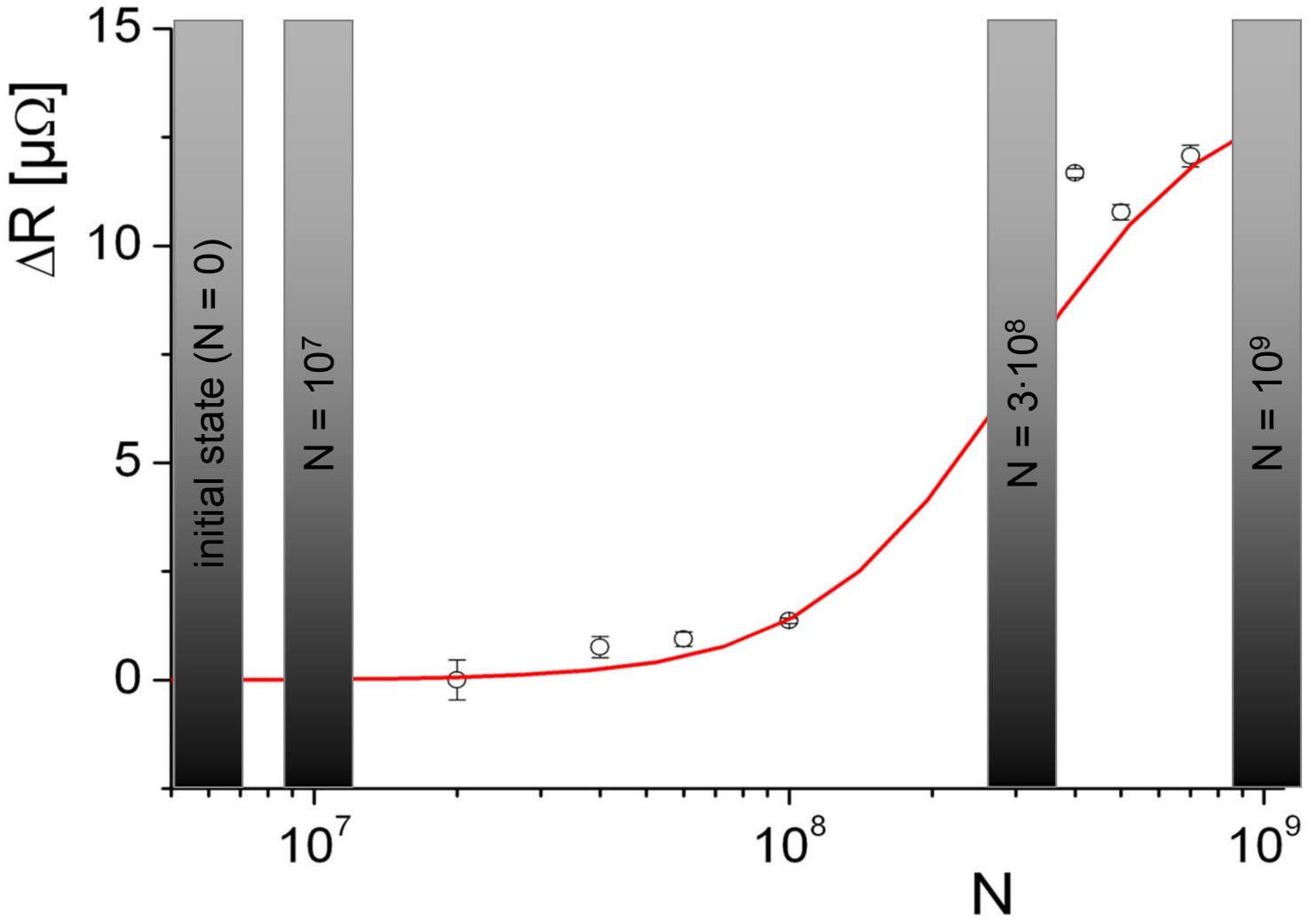


Electrical resistivity course



Frequency analysis for a specimen with 11% ferrite from section A2 (a) and 7% ferrite from section A1 (b) at σ_a = 410 MPa



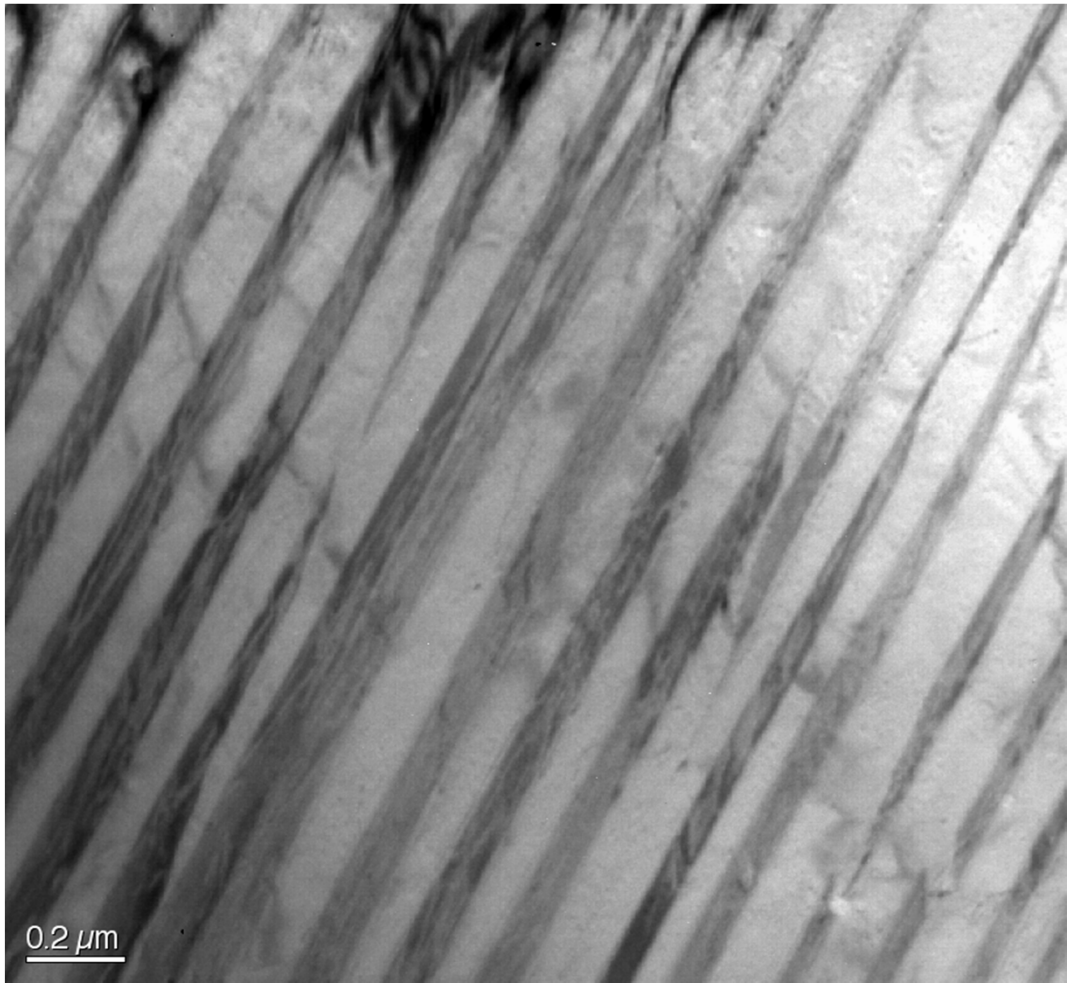


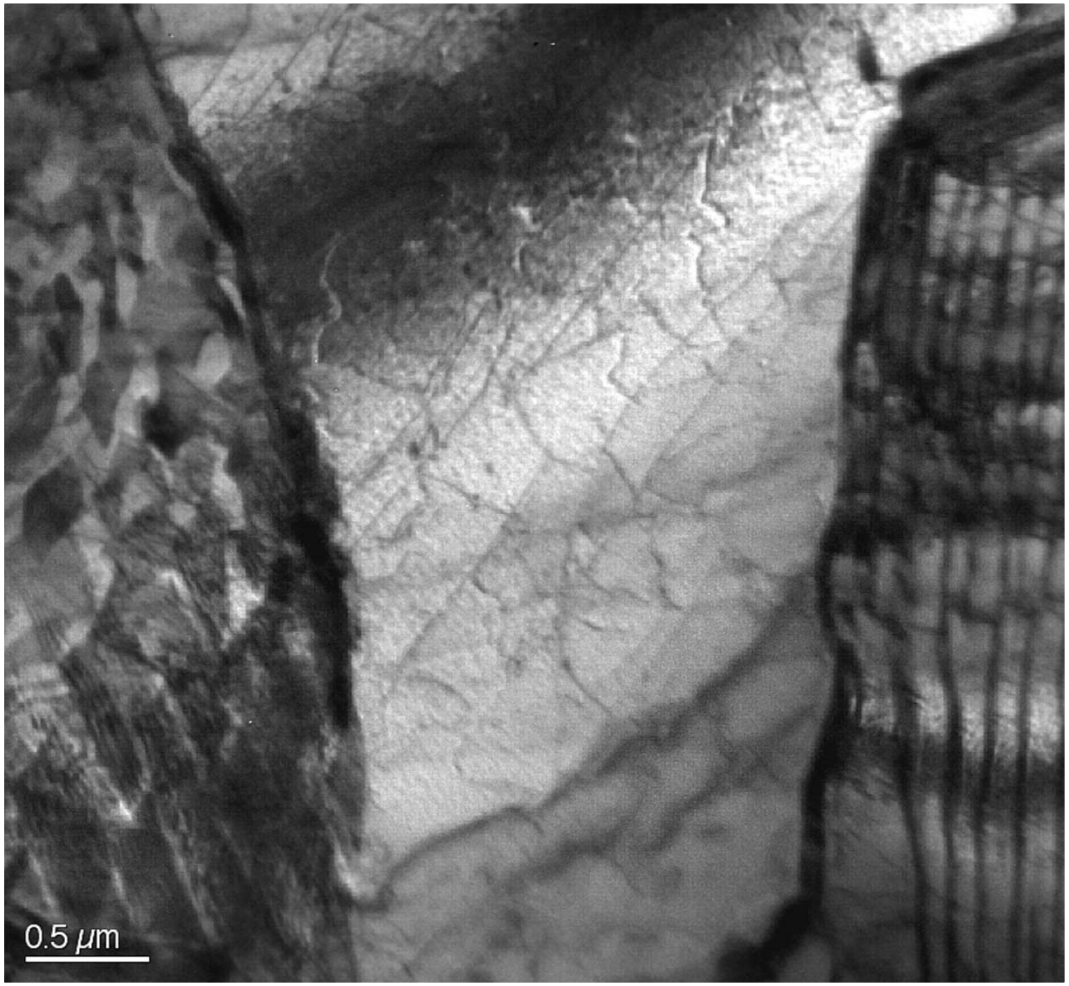
SAE 1050 (R7)

σ_a = 385 MPa

R = -1

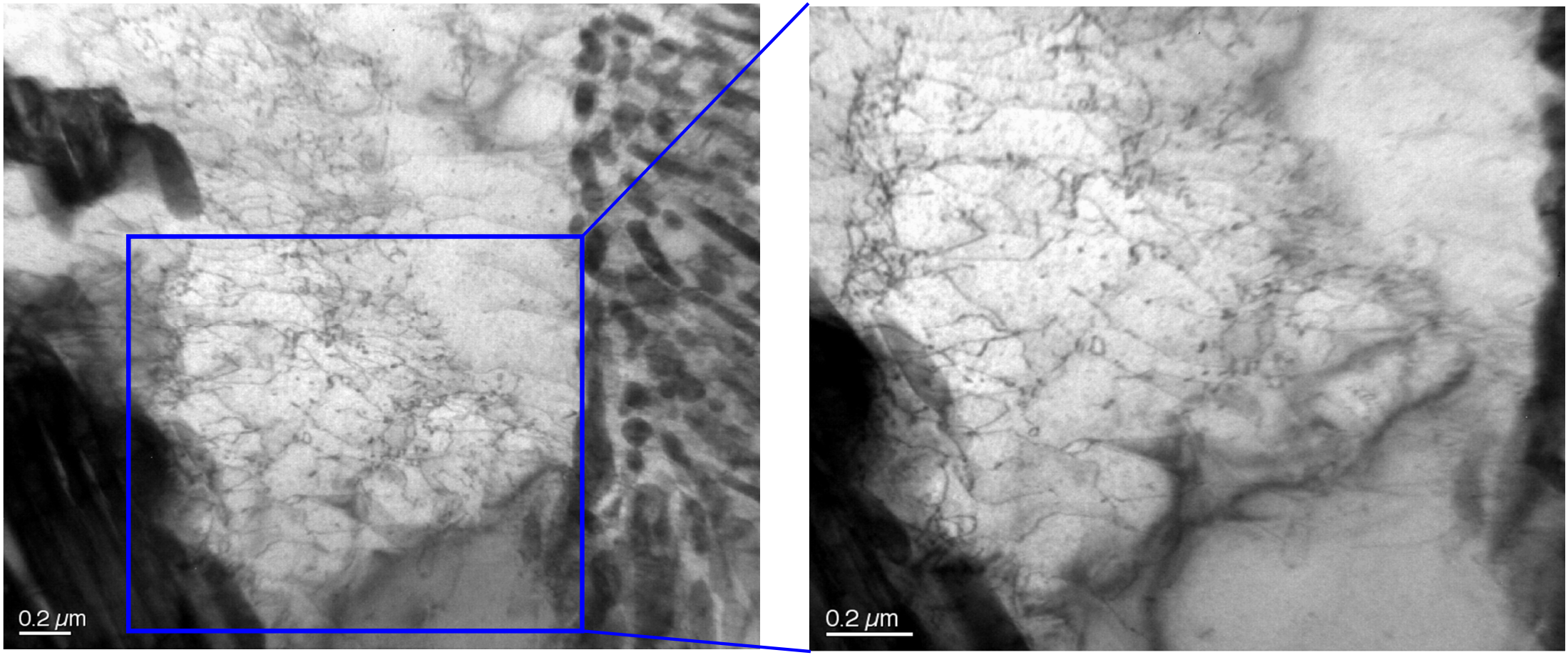
TEM-investigations at defined fatigue states



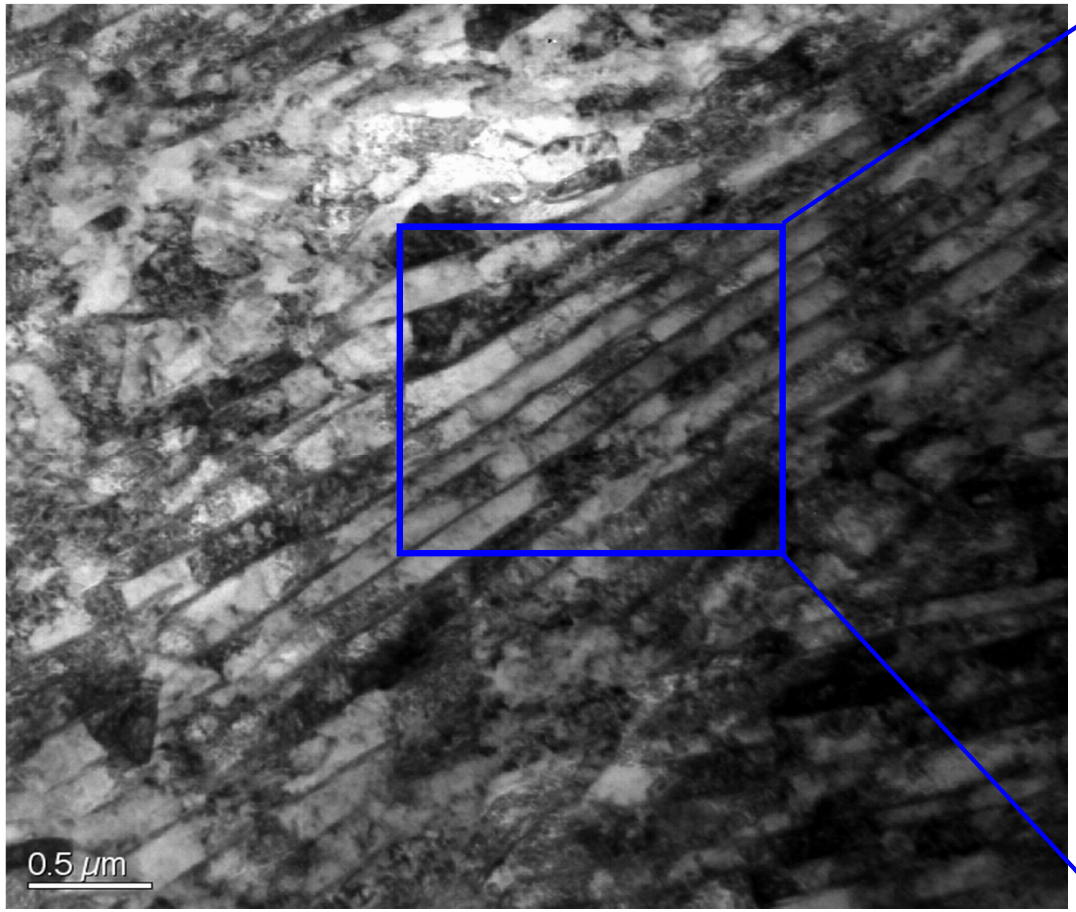


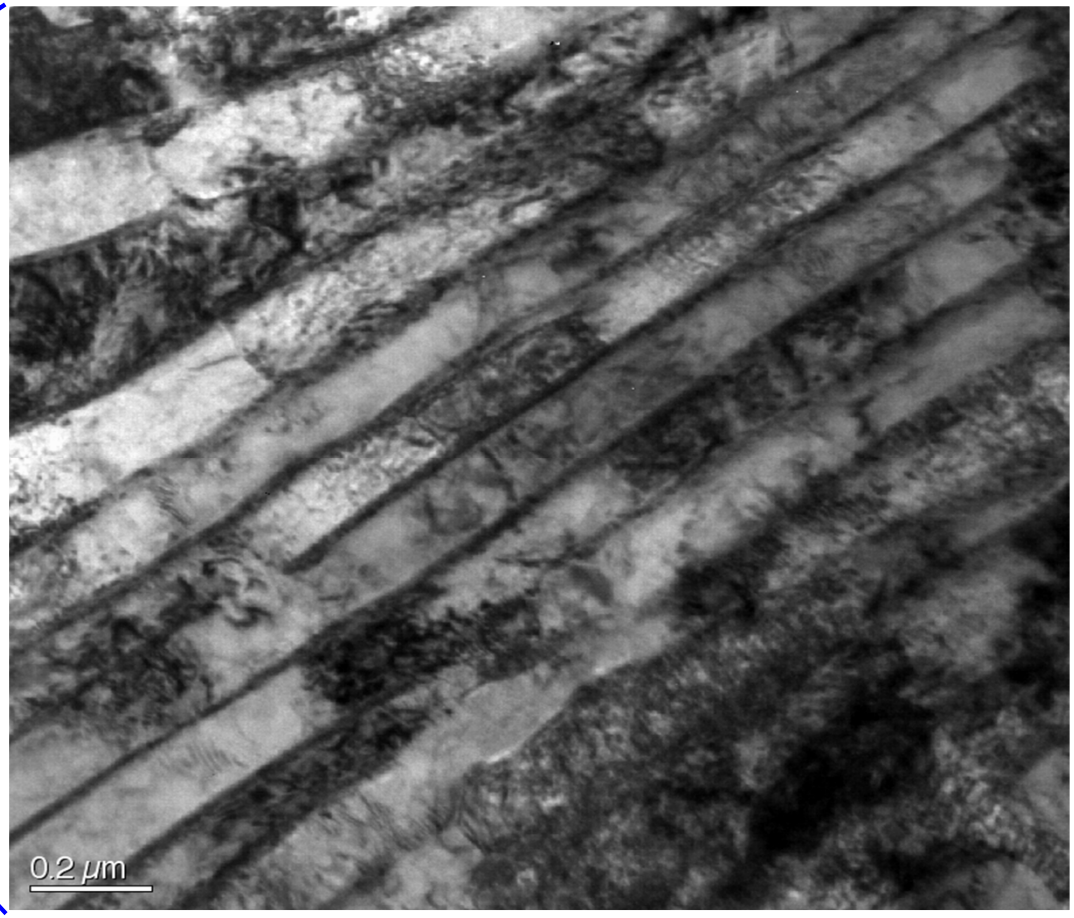
Cementite lamellae distance: 0,168 µm

TEM-micrographs: initial state, N = 0



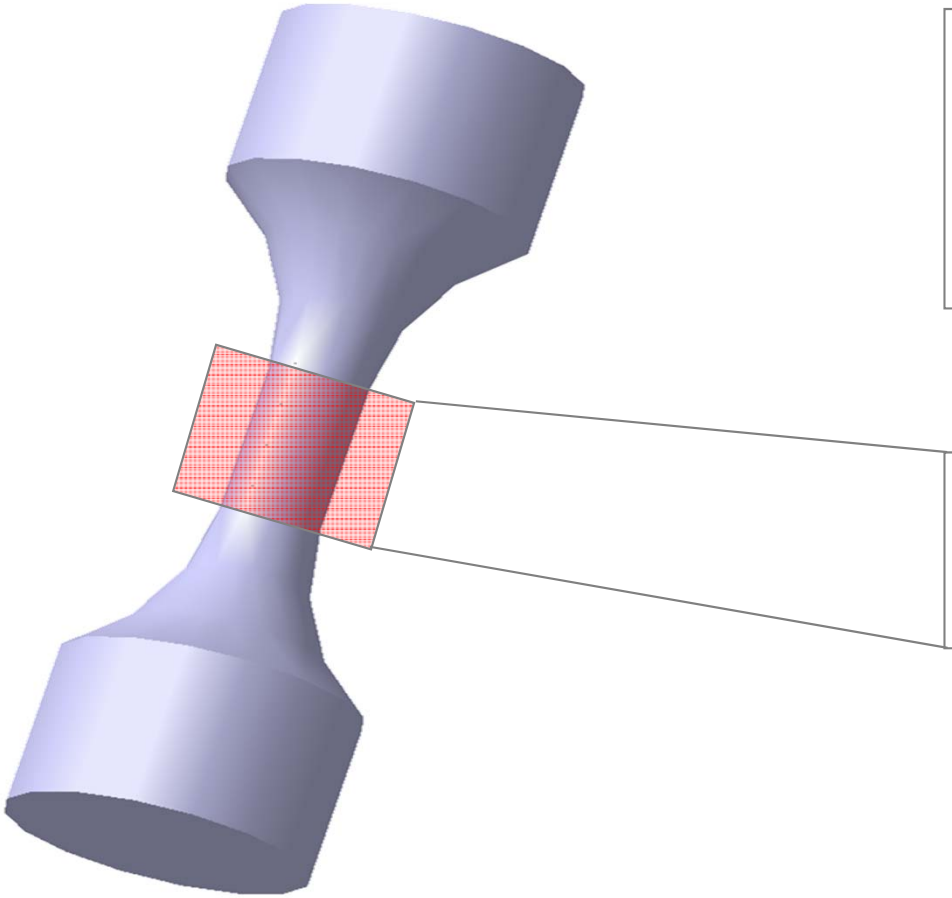
TEM-micrographs: N = 10^7, s_a = 385 MPa





Cementite lamellae distance: 0,175 µm

TEM-micrographs: N = 10^9, s_a = 385 MPa



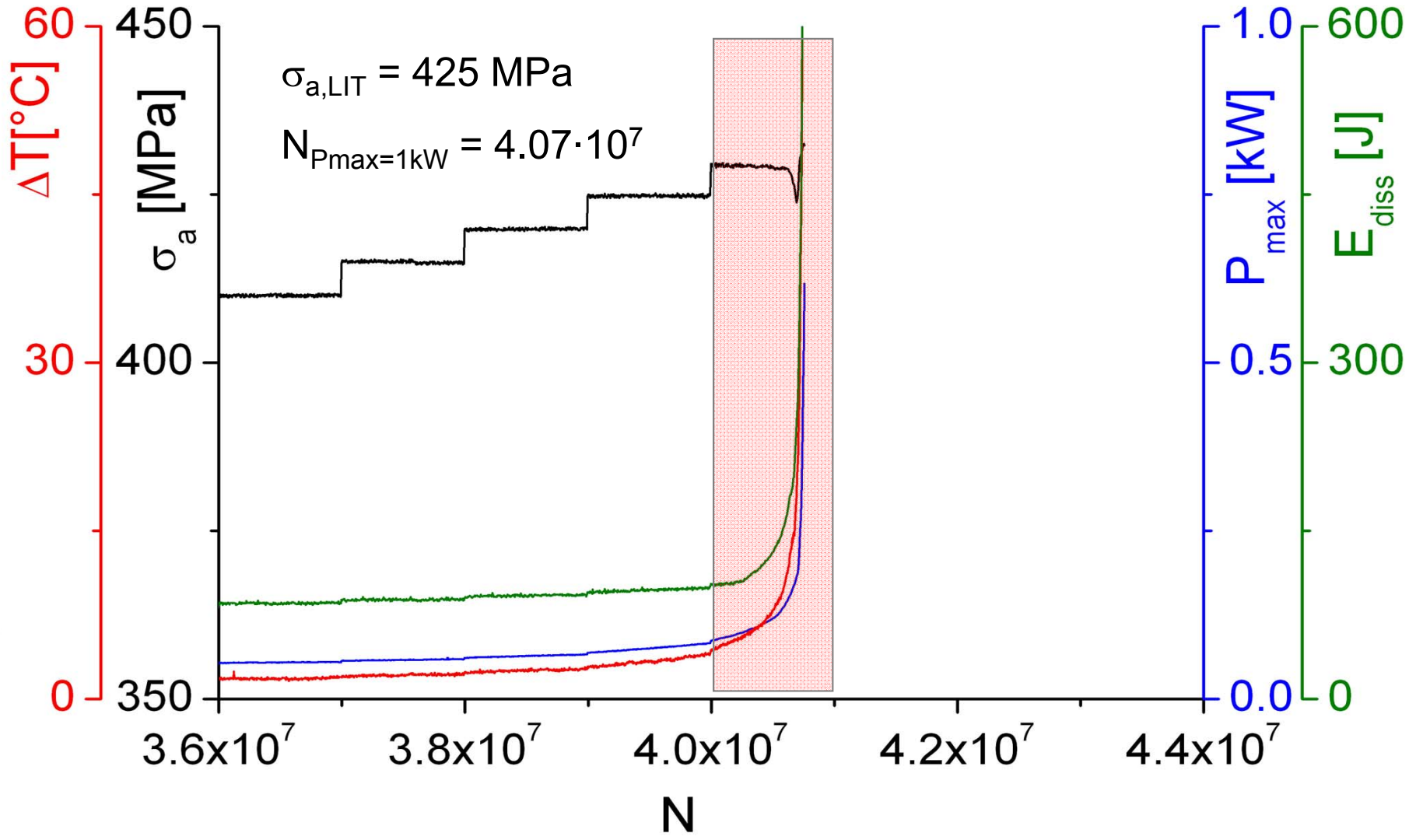
LIT:

- power increase
- test interruption at P = 1000 W

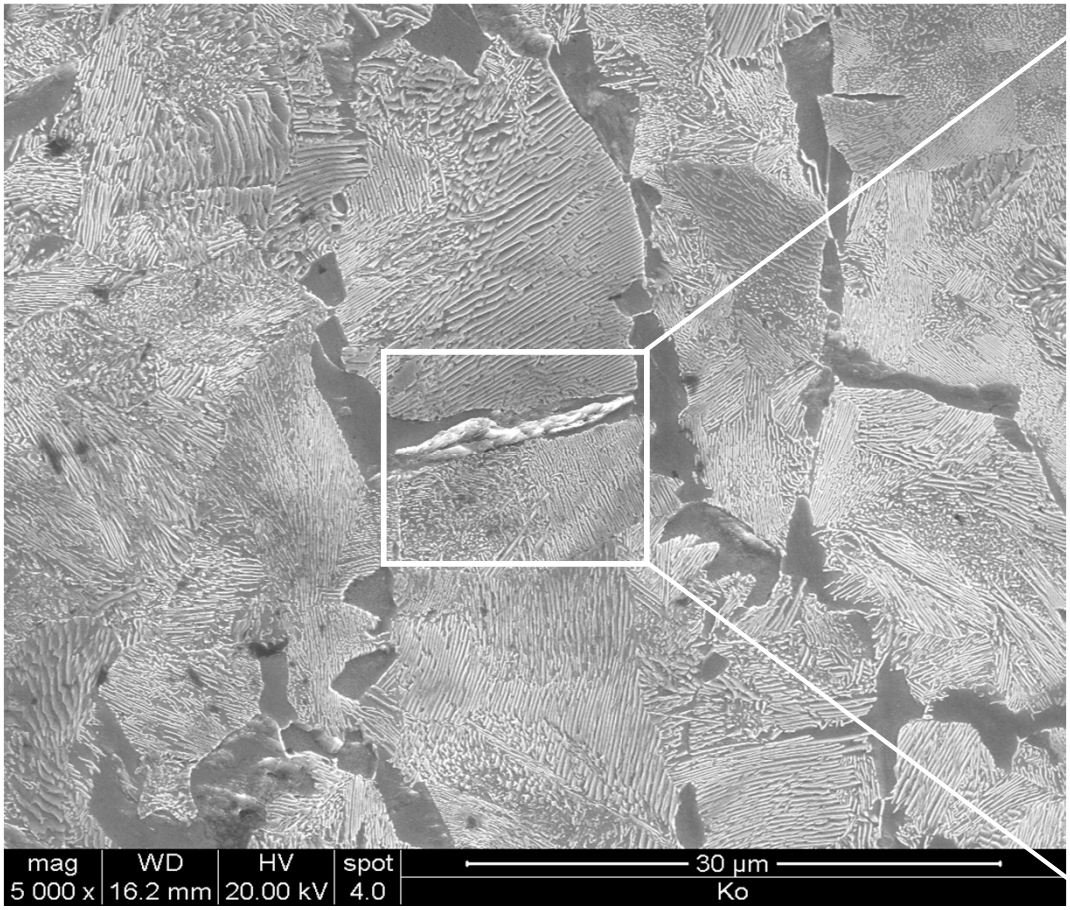
SEM – investigations:

- detection of slip lines

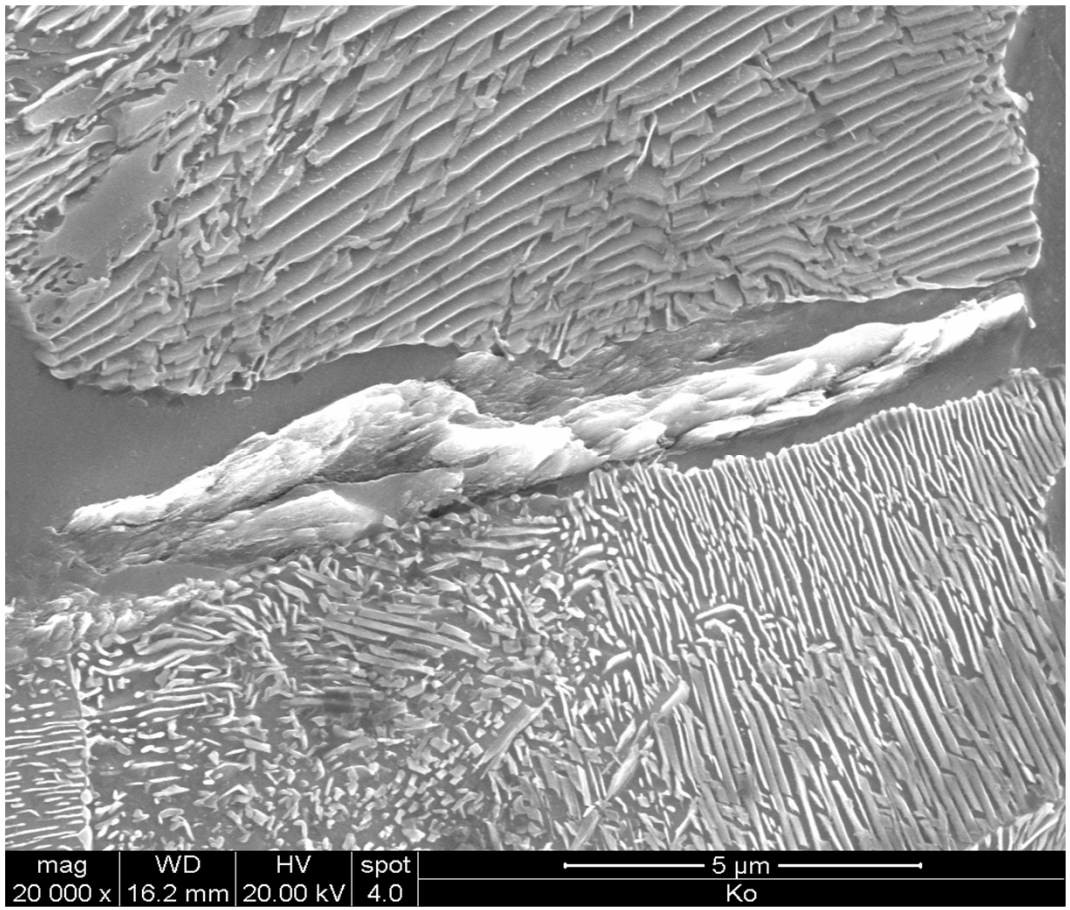
LIT: SEM-investigations



LIT, interruption of the test at P_{max} = 1000 W

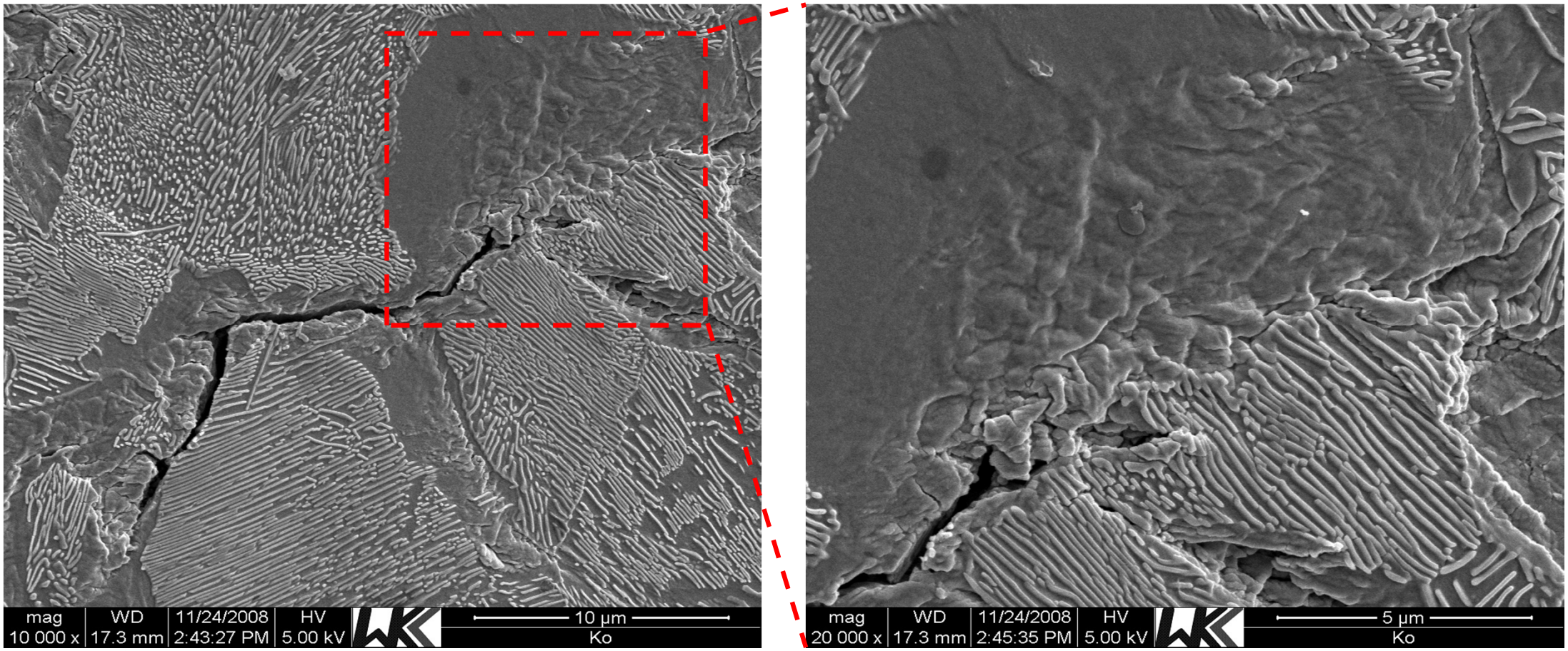


In- / Extrusion



In- / Extrusion

LIT: SEM micrographs, N= $4.07 \cdot 10^7$



LIT: SEM micrographs, N= $4.07 \cdot 10^7$

- Load increase and constant amplitude tests at the railway wheel steel SAE 1050 (R7) were carried out with the ultrasonic testing facility of the type UltraFAST-Kaiserslautern
- The physical quantities
  - generator power
  - specimen temperature and
  - electrical resistance

  can be used to characterize the cyclic deformation behavior in the VHCF regime
- SEM investigations prove that there exists a direct relation between the measured physical quantities and the observed microstructural changes
- On-line monitoring of power and temperature changes can be used as indicators of an increasing defect density in the bulk of the material during VHCF
- Especially the generator power can be used as a non-destructive testing method to characterize the actual fatigue status in the very high cycle regime

Conclusions

Thank you very much for your attention

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