Structural Durability of MTH Steel

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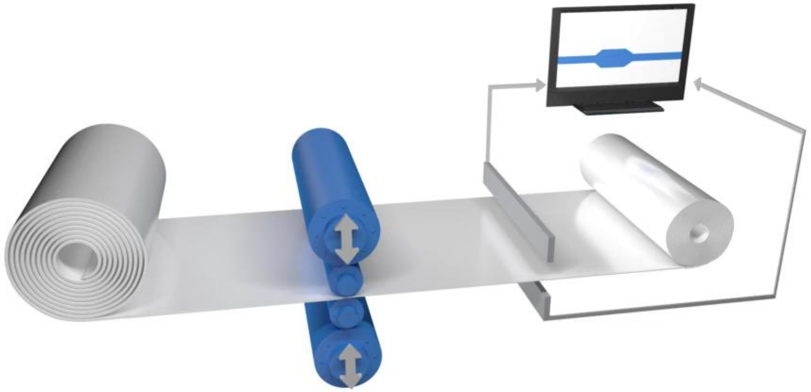
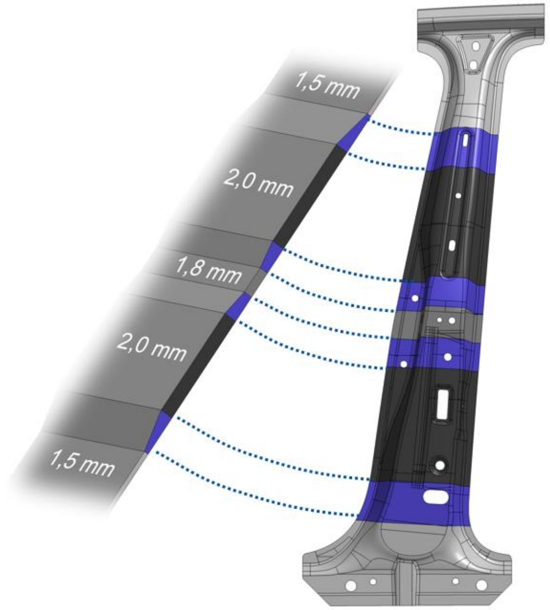
GREAT DESIGNS IN STEEL™

TRB – Tailor Rolled Blank (Flex Cold-Rolling)





Concept

- Cost efficient lightweight parts with load and function-optimized material usage

Implementation

- Flexible Cold-Rolling Process
- Flat material with repeated, varying thickness runs and harmonious transition zones
- Thickness run optimization drives the cost efficiency

Targets / Benefits

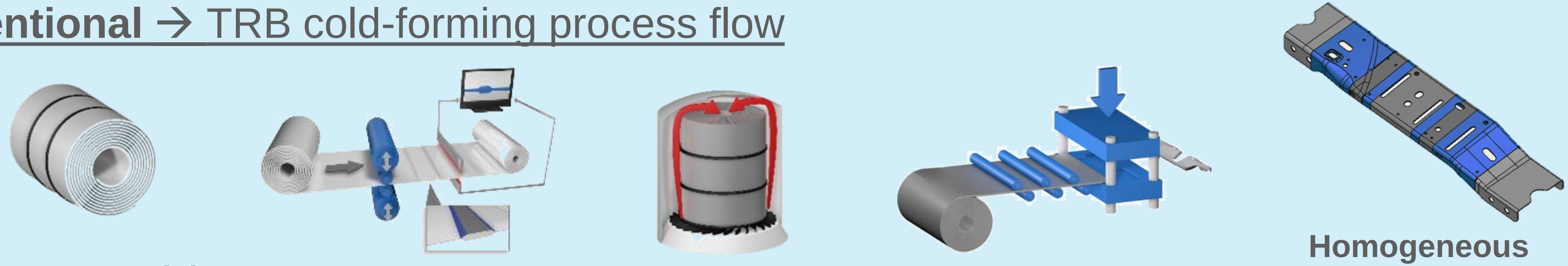
- Functional Improvement (Performance, Manufacturing, Quality)
- Part Integration / Design Simplification
- Weight Reduction / Cost Reduction

Established technology with over 20 years in mass production partnered with several renowned Global OEM's!

Mat. Innovation – Mubea TailorHardened (MTH)

GDIS

Conventional → TRB cold-forming process flow



Raw Material (HR500LA) | Flex Rolling | Batch Annealing | Part Production | Homogeneous mechanical properties “HC380 LA TRB“

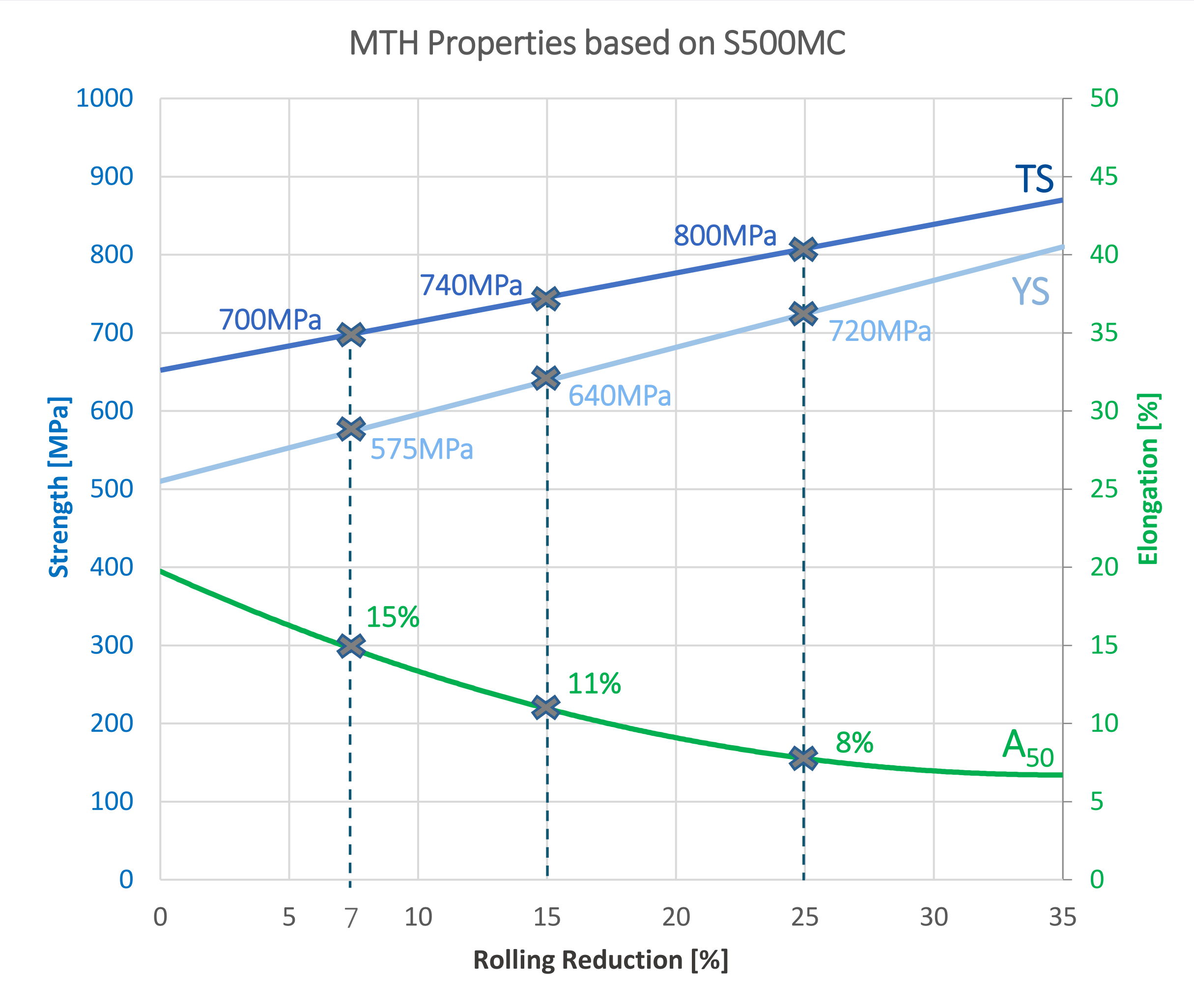
MTH → cost effective process flow

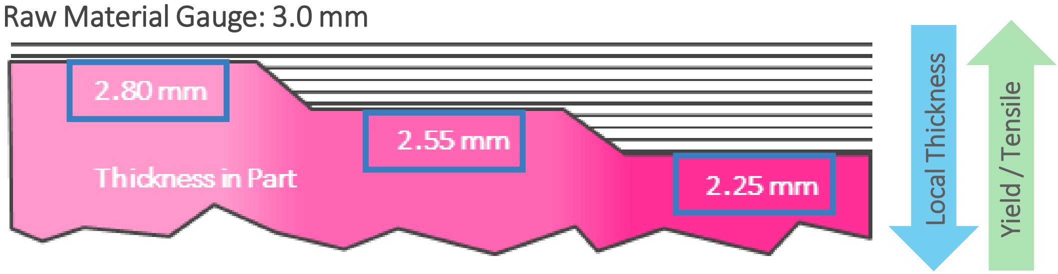
Raw Material (DD13) | Flex Rolling | Batch Annealing | Part Production | TailorHardened mechanical properties “MTH 260Y/530Y TRB“

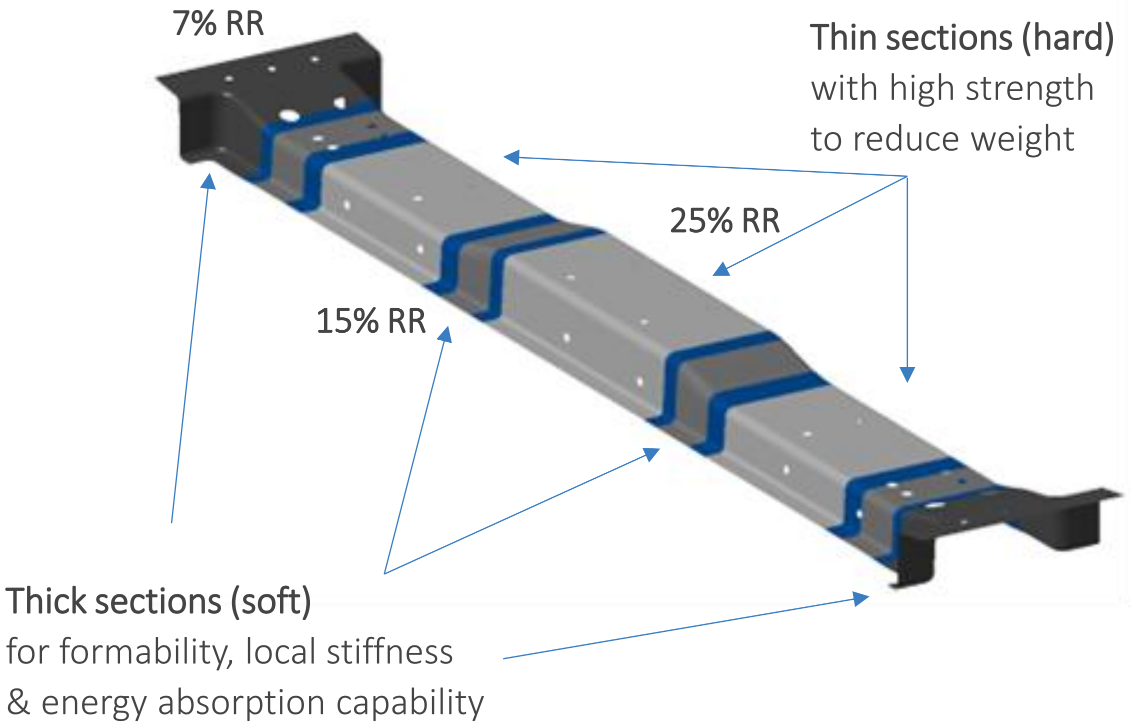
Manufacturing cost reduction through shorter process flow and less expensive raw material!

MTH – Mechanical Properties Behavior

Example: MTH575Y/720Y from HR500LA

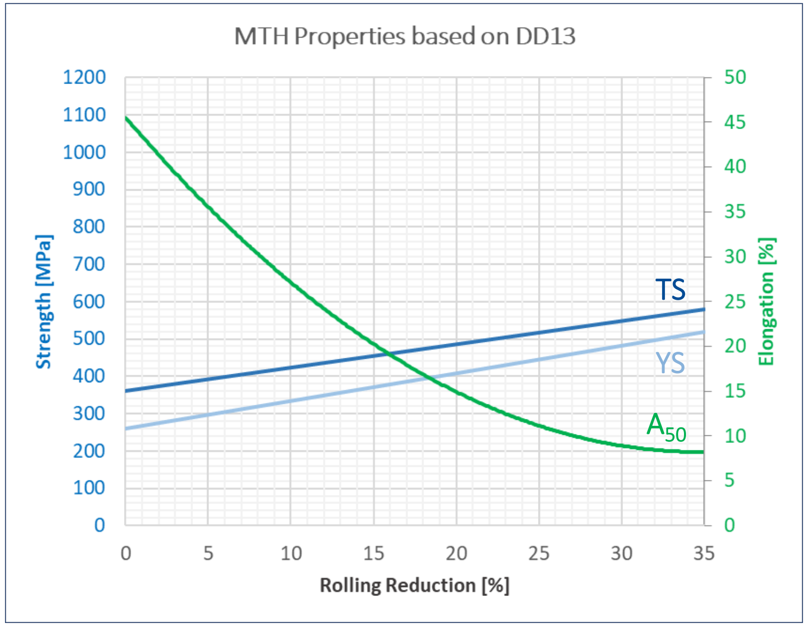


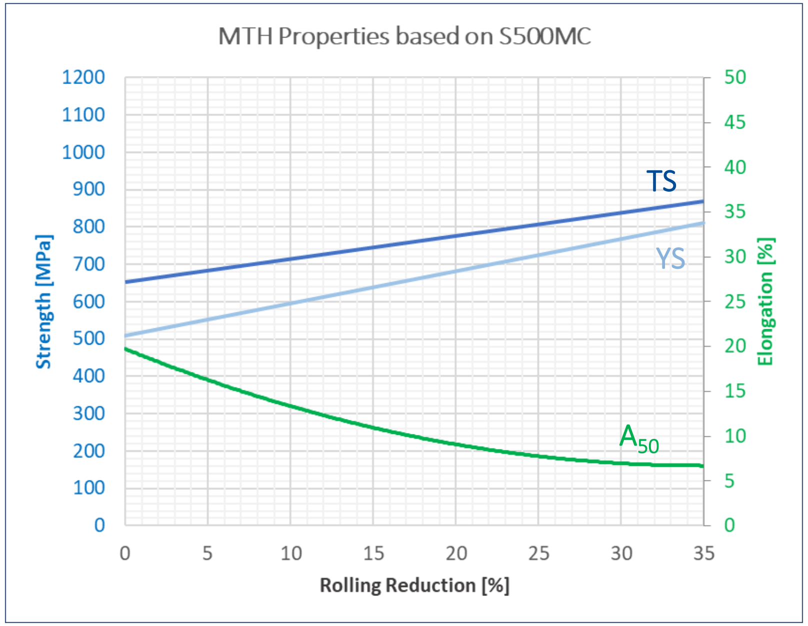


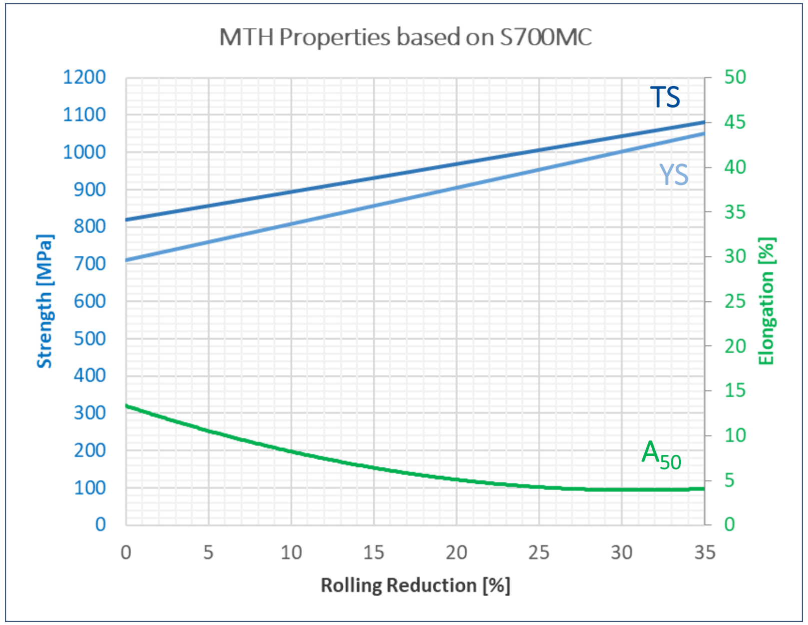


Cost Efficient Component Design & Manufacturing with Local Tailored Properties!

MTH – Mat. Characterization Status & Next Steps







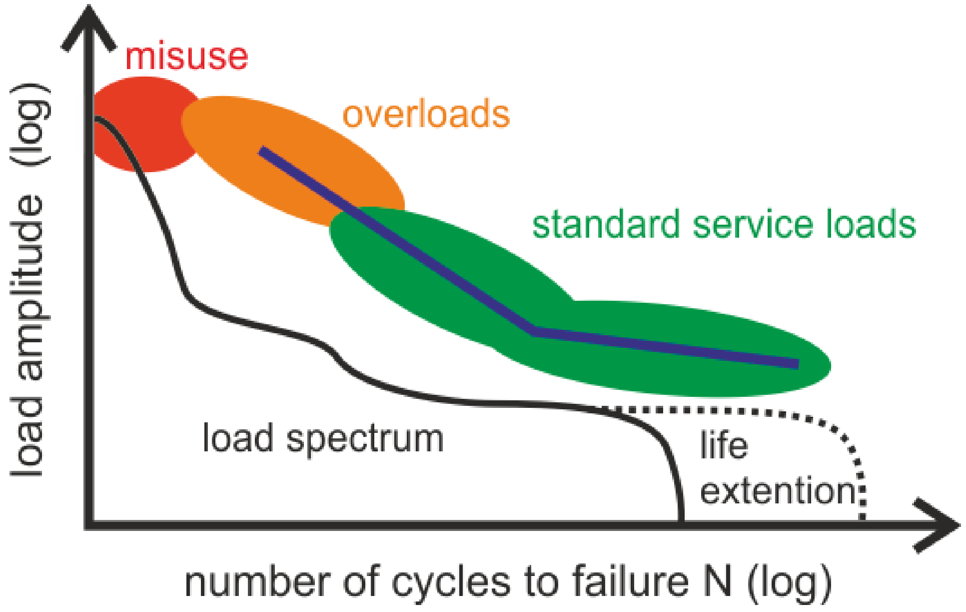
- MTH → Flex Cold-Rolled Steel based on HSLA grades → increasing Yield and Tensile Strength through Dislocation Hardening
- **High gauge →** mechanical properties slightly elevated due to minor Rolling Reduction with **Higher Elongation Capability**
- **Low gauge →** enhanced mechanical properties due to major Rolling Reduction with **Higher Yield & Tensile Strength Levels**

- **How about Fatigue → Do MTH steels show comparable increased Fatigue Strength? How to predict it reliably?**

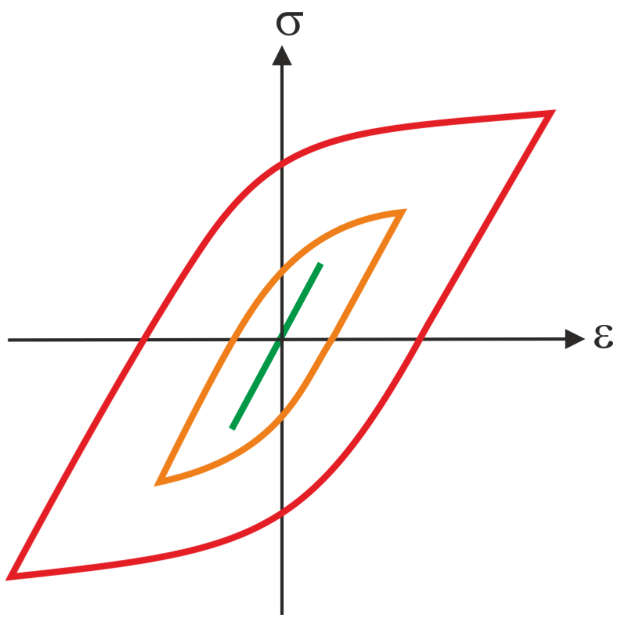
Next Steps = Fatigue Assessment Plan → Specimen Tests + Math Approach + Part Validation

Motivation – Fatigue Approach

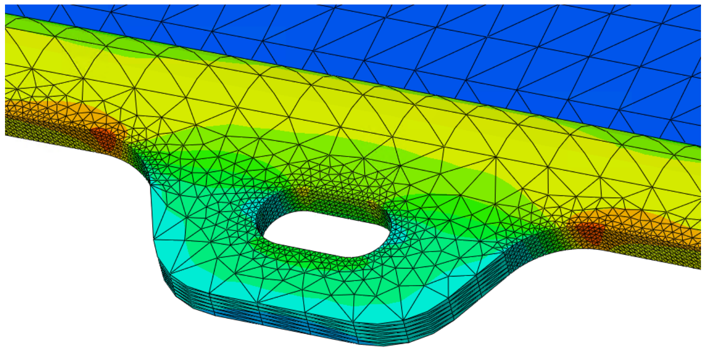
Service loading conditions



Stress-strain behavior

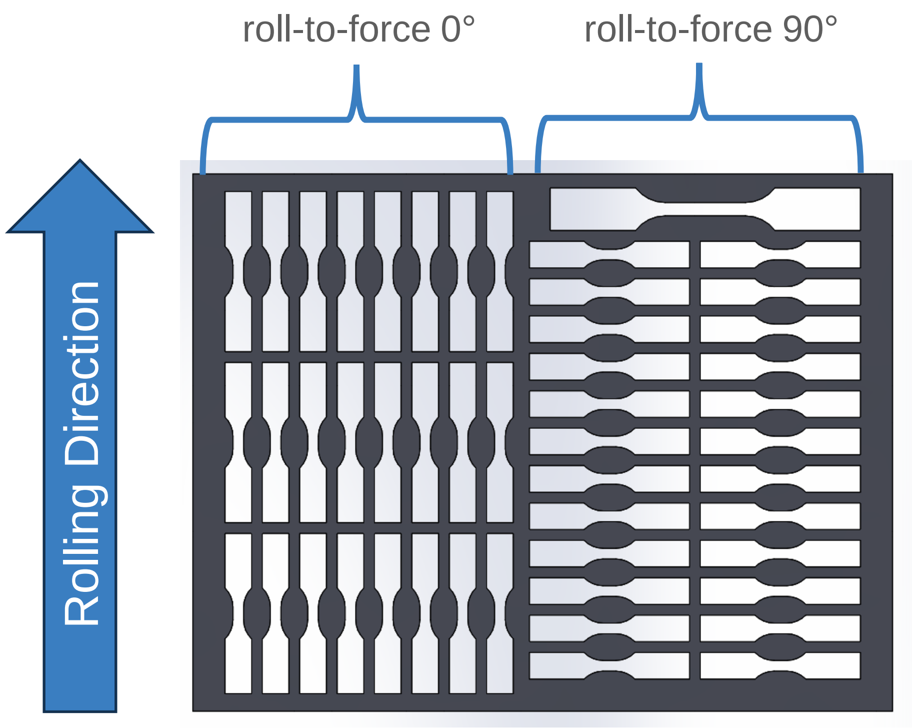


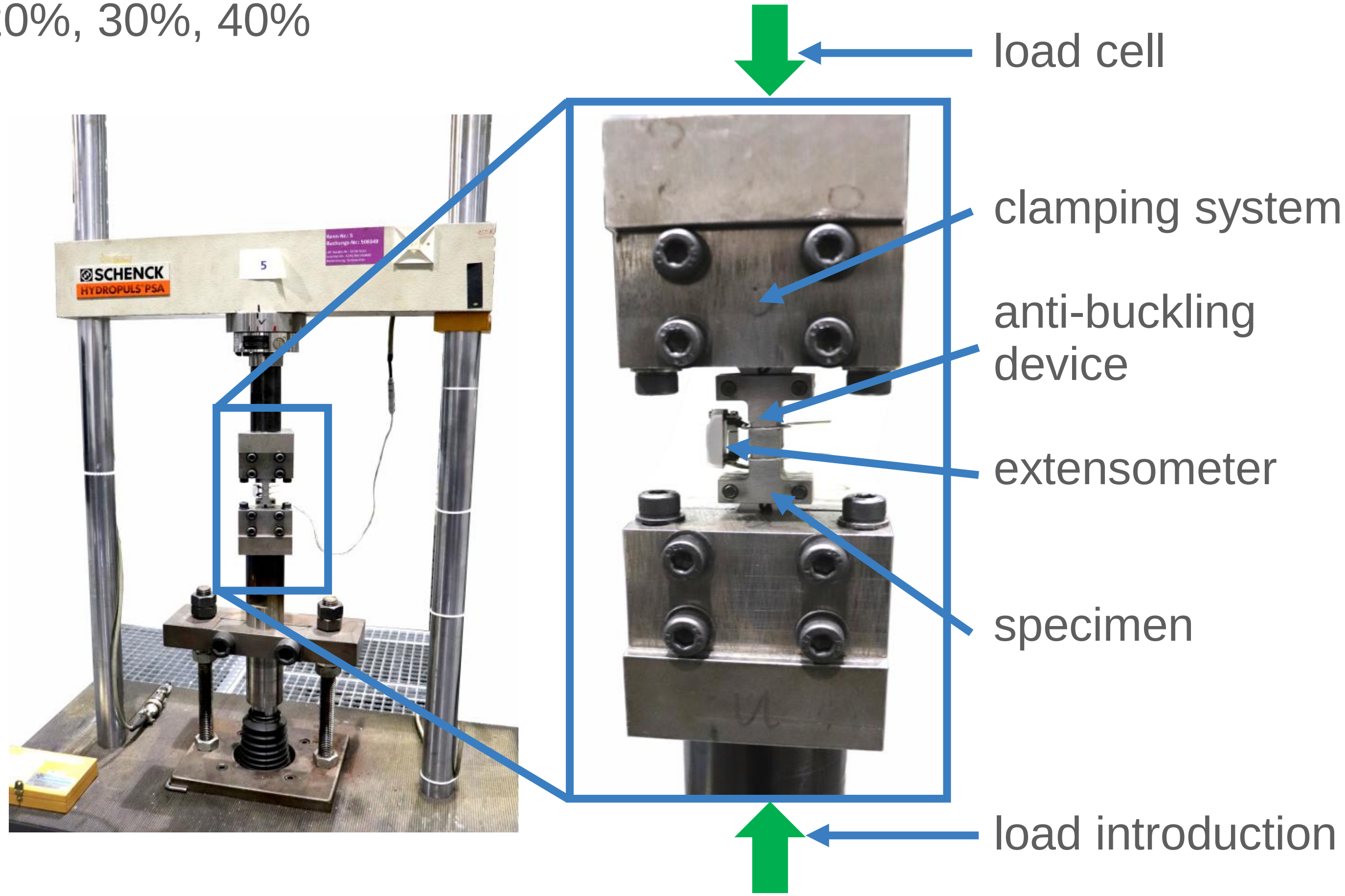
Deriving of material properties for CAE application



Test Campaign

- Strain-controlled fatigue tests [R=-1] according to ISO 12106, SEP1240, ASTM E606
- Force-controlled fatigue tests [R=-1] according to ISO 12107, DIN 50100
- 5 different rolling reductions (RR): 0%, 10%, 20%, 30%, 40%
- 2 roll-to-force orientations: 0°, 90°

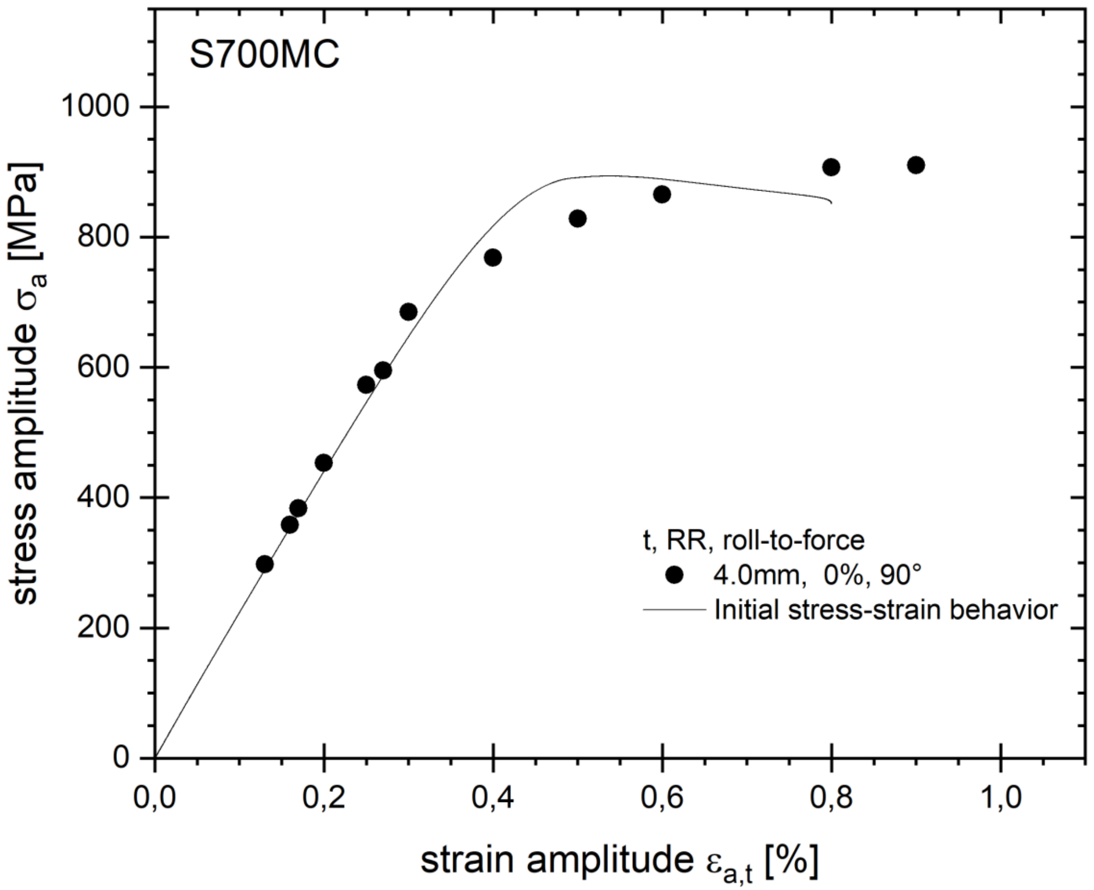




Specimen Test

Stress-Strain Curves

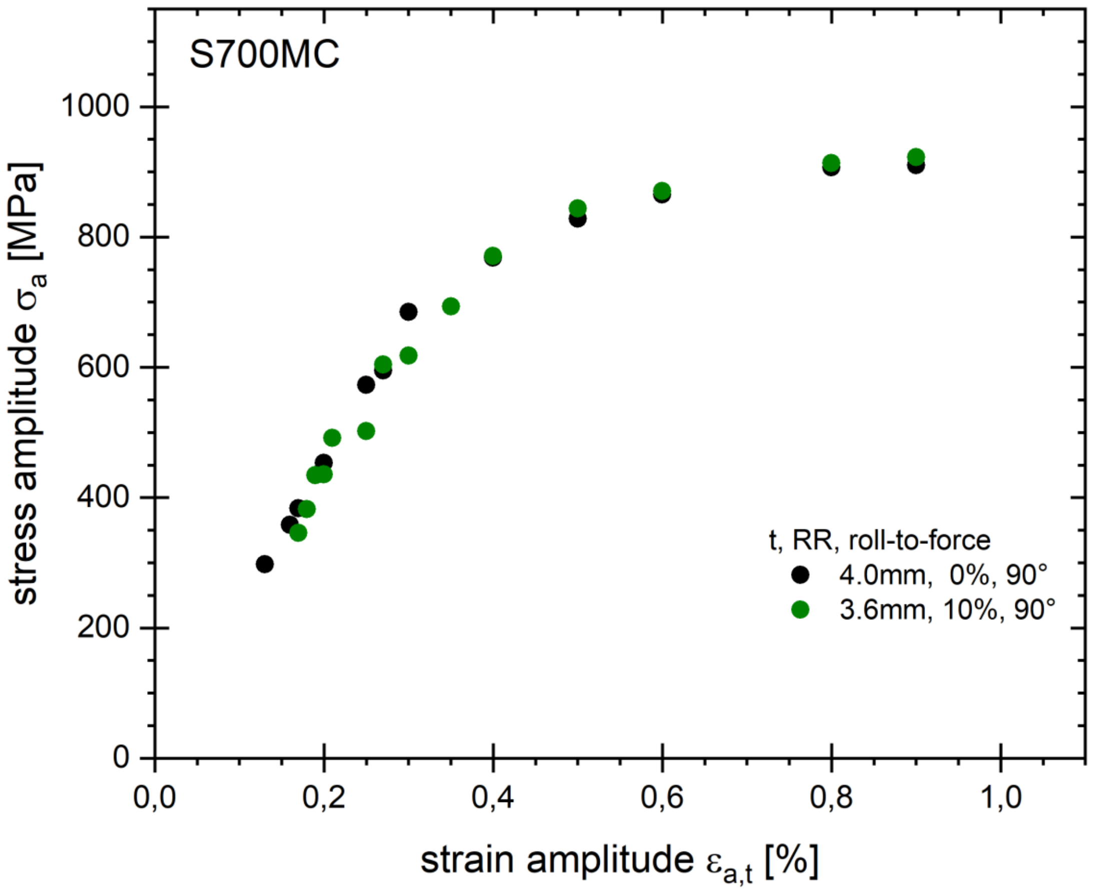
Influence of rolling reduction on the cyclic stress-strain behavior



- Raw material, RR=0%
- Solid line: Initial stress-strain behavior (comparable to quasi-static)
- Black dots: Cyclic stress-strain behavior (focus of investigations in this study)
  - Each datapoint is the result of one individual fatigue test

Stress-Strain Curves

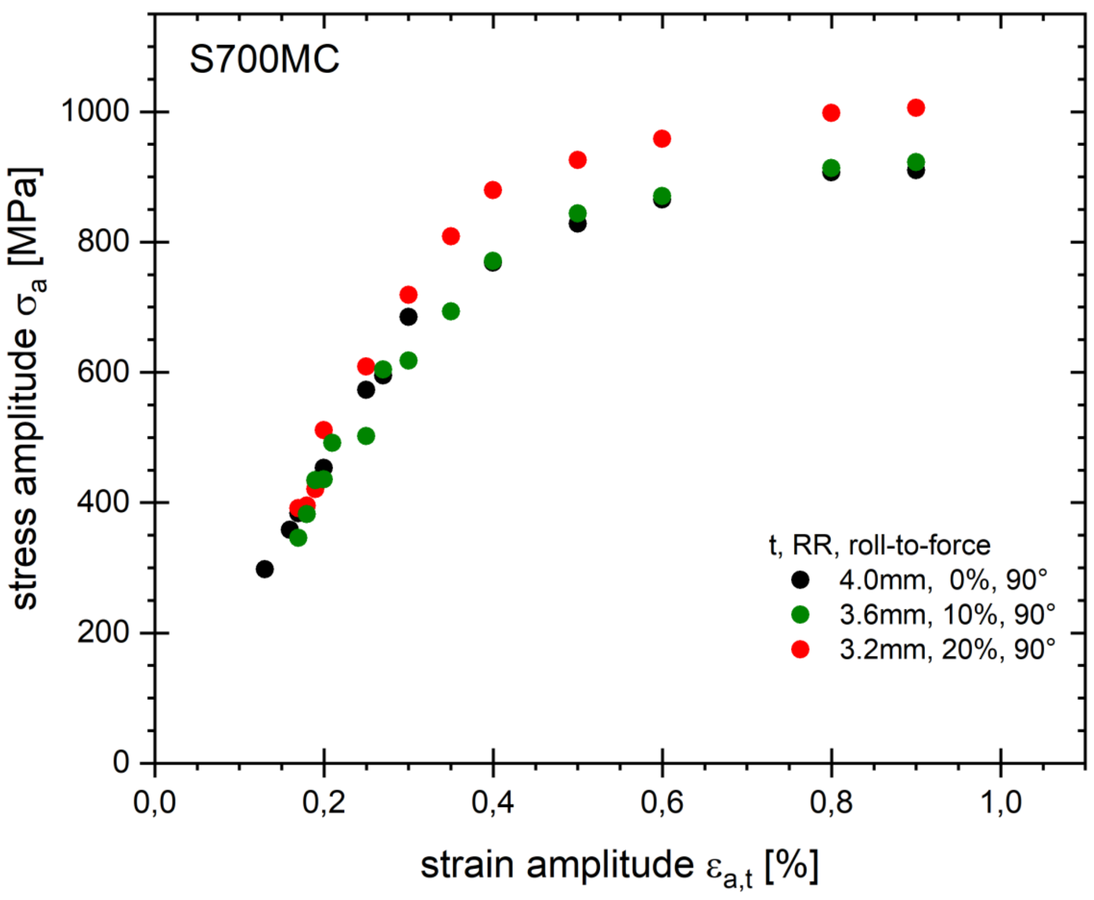
Influence of rolling reduction on the cyclic stress-strain behavior



- RR=10%
- A slight increase in strength with increasing rolling reduction can be observed, yet not very distinctive

Stress-Strain Curves

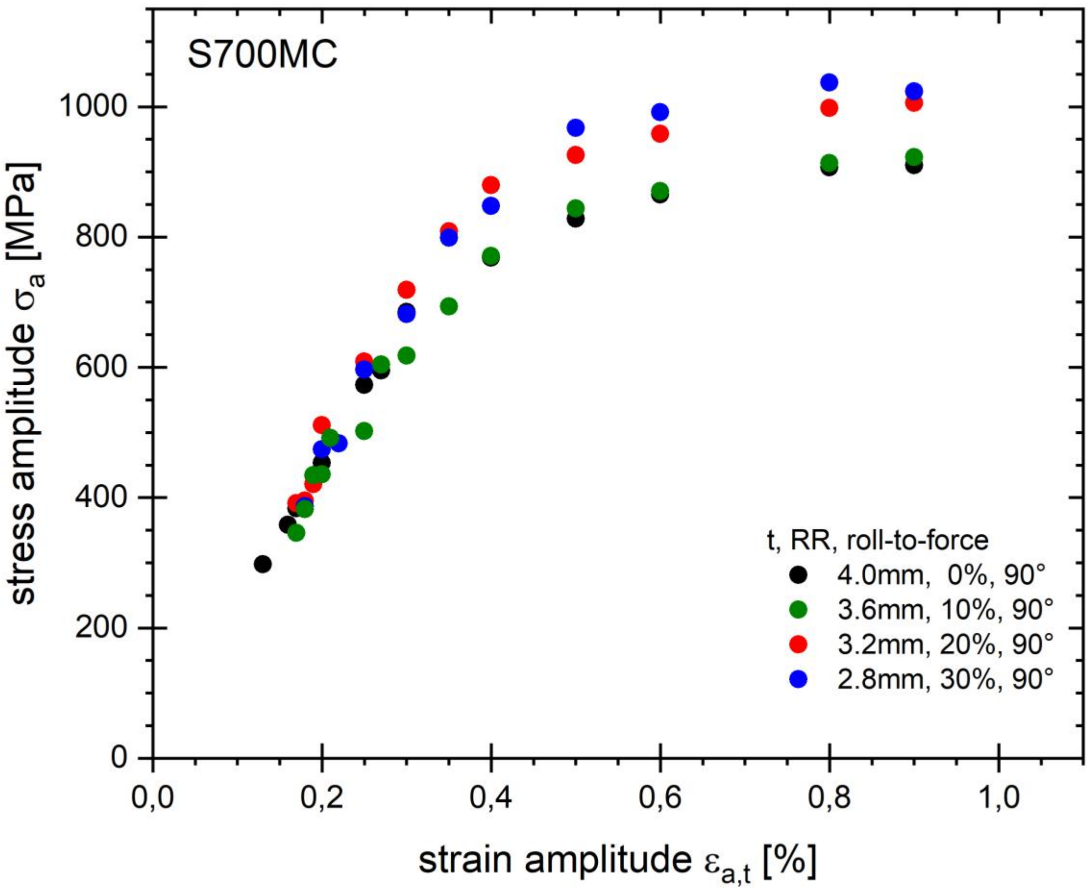
Influence of rolling reduction on the cyclic stress-strain behavior



- RR=20%
- From 20% of rolling reduction onwards the increase in strength becomes apparent
- **Increase of around 16%** of the stress amplitude at 0.8% of strain compared to initial condition

Stress-Strain Curves

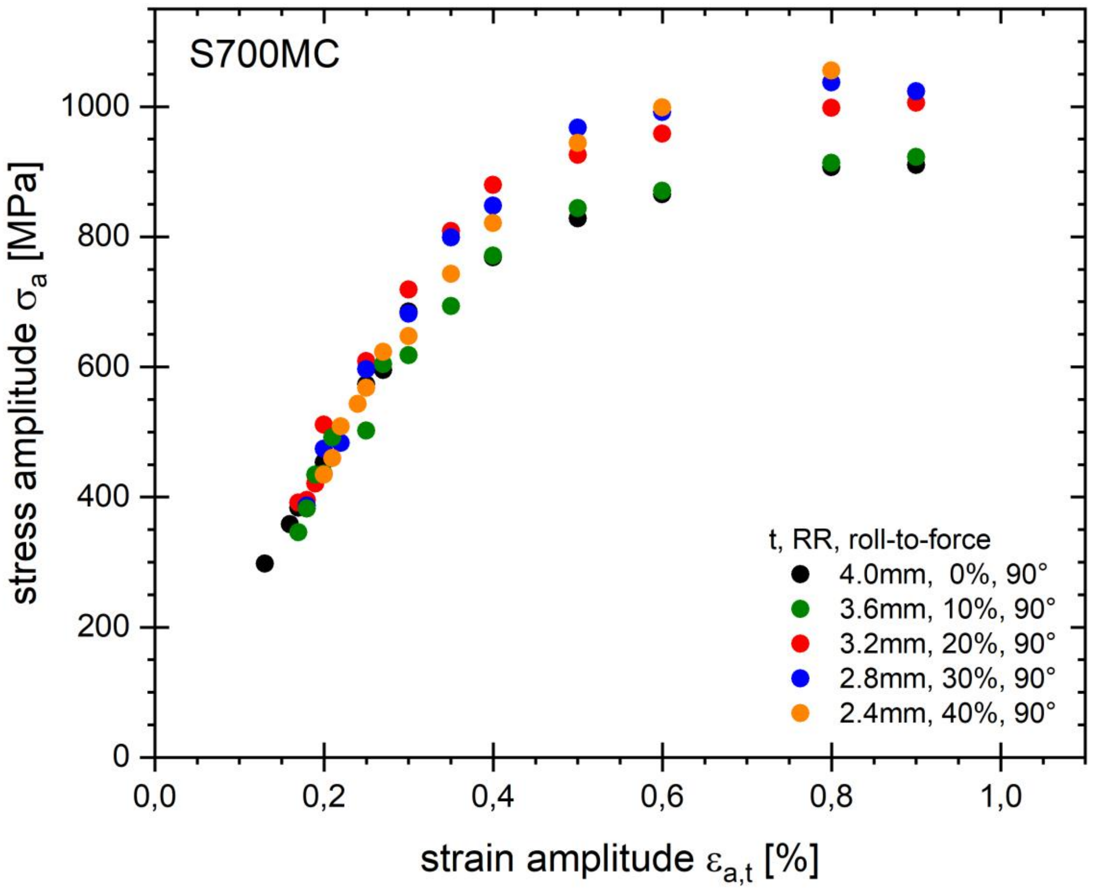
Influence of rolling reduction on the cyclic stress-strain behavior



- RR=30%
- Further increase of strength, but significantly less gain than between 10% and 20%

Stress-Strain Curves

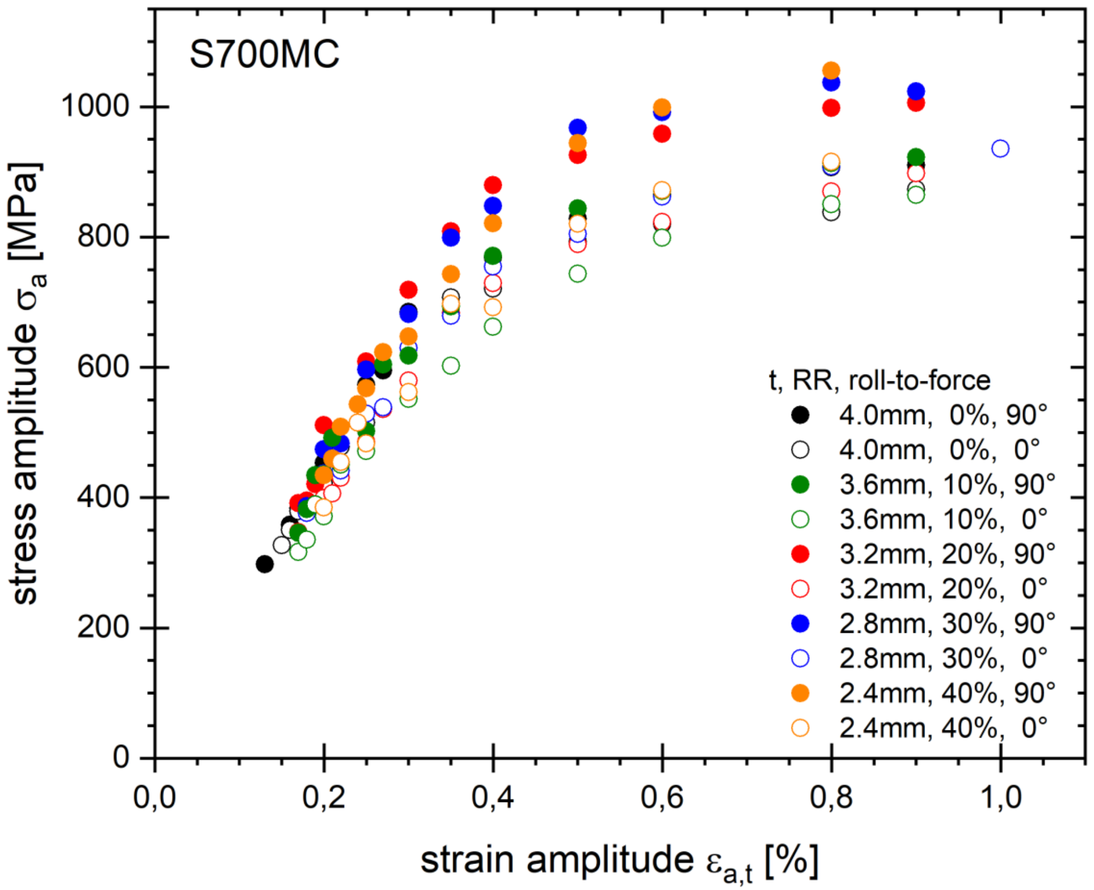
Influence of rolling reduction on the cyclic stress-strain behavior



- RR=40%
- Slight increase of strength

Stress-Strain Curves

Influence of rolling reduction on the cyclic stress-strain behavior



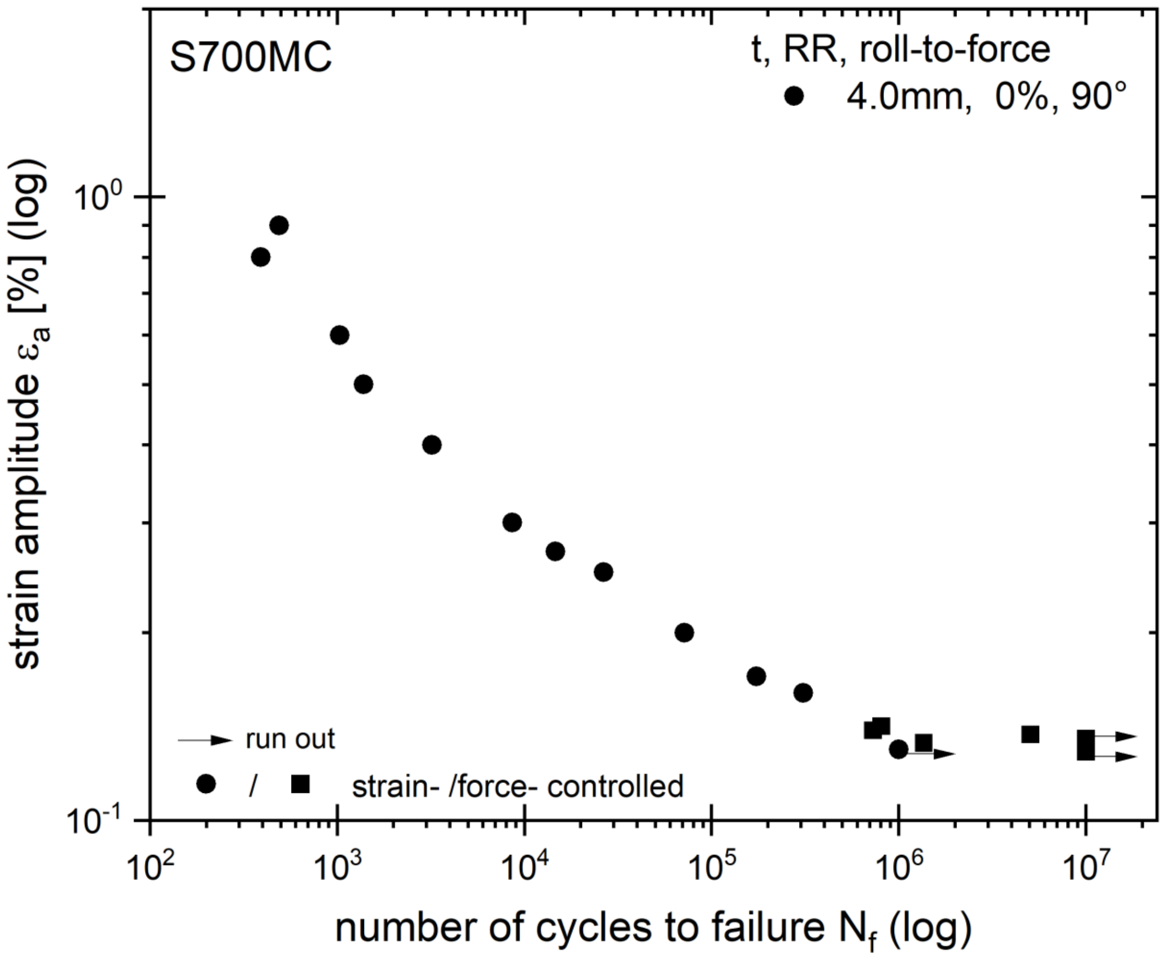
Anisotropic behavior observed due to rolling

MTH benefit: strength increase can be observed in both directions of roll-to-force

Difference between 0° and 90° for RR=40%

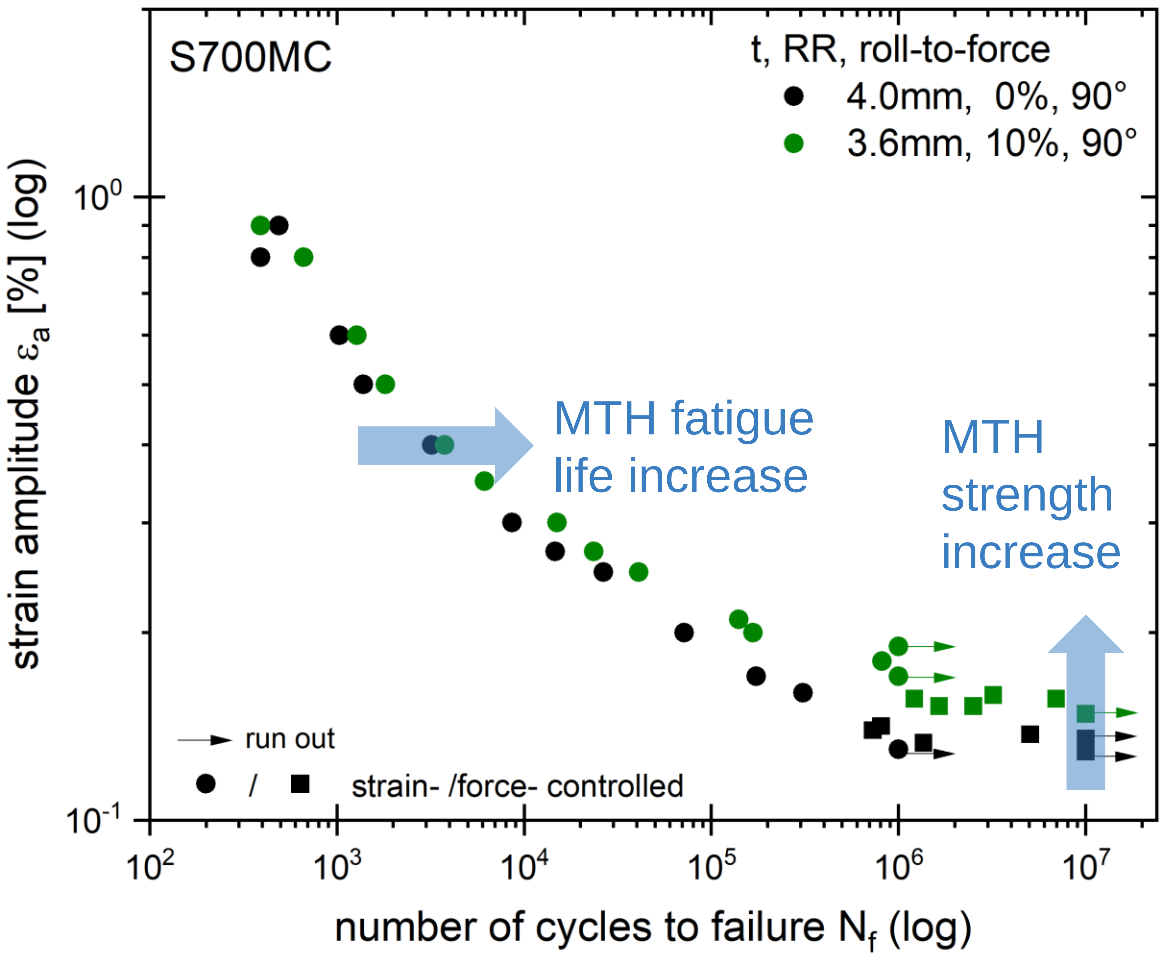
- at 0.2% of strain the stress amplitude for the 90° specimen was about **12% higher** than the 0° specimen
- at 0.8% of strain the stress amplitude for the 90° specimen was about **15% higher** than the 0° specimen

Fatigue Test Results



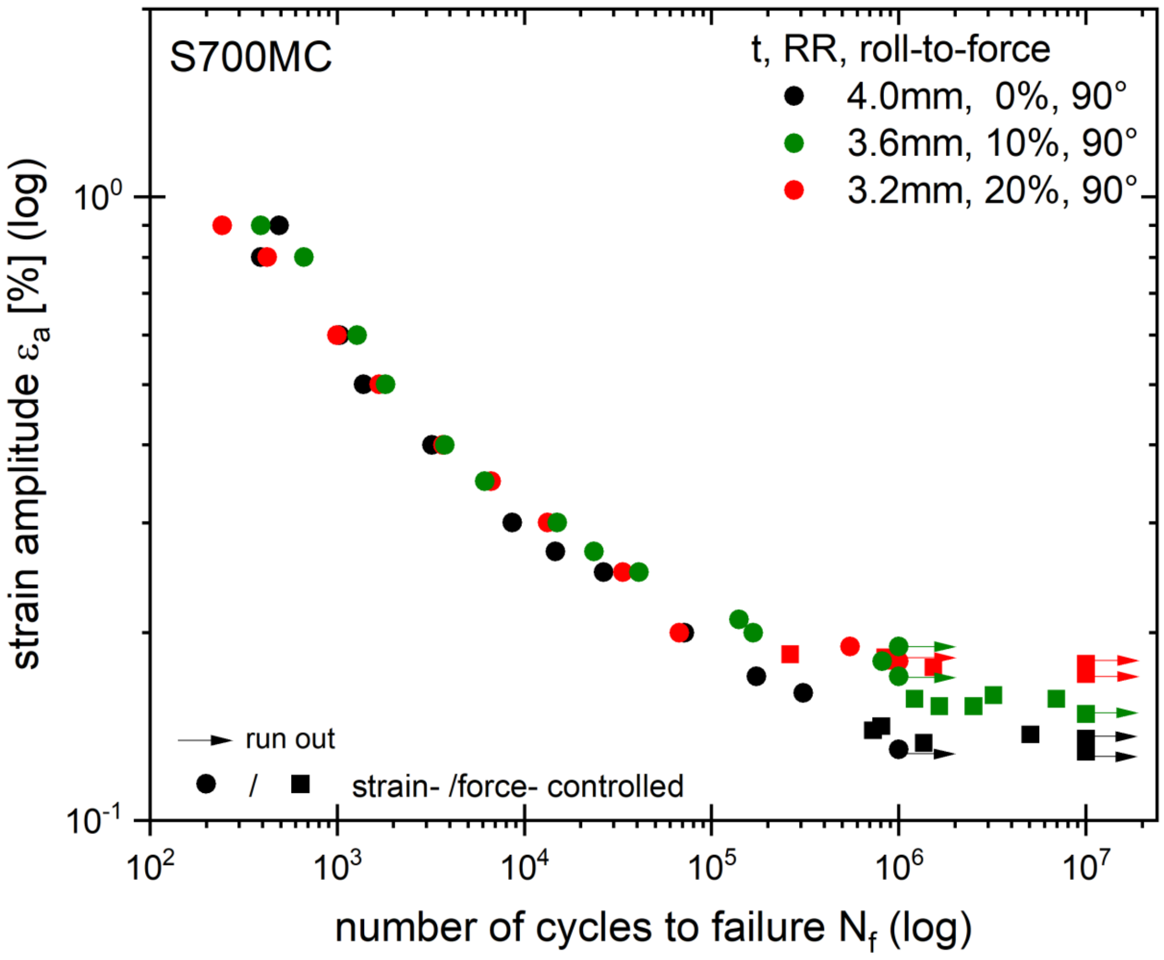
- Raw material, RR=0%
- Strain-controlled up to 10^6 cycles
- Force-controlled up to 10^7 cycles

Fatigue Test Results



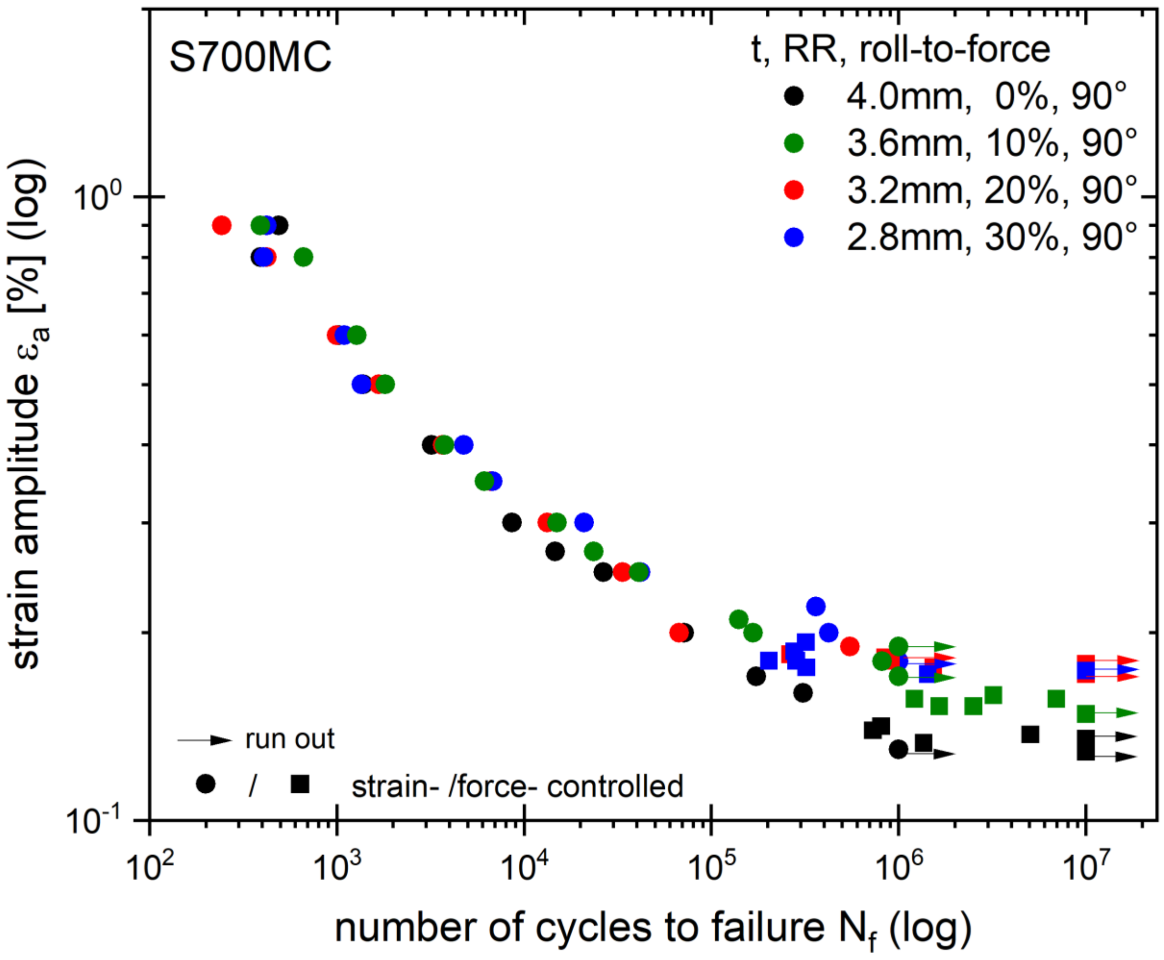
- RR=10%
- While the influence of 10% rolling reduction was not very distinctive in the stress-strain curve, increase is apparent within the strain-life curve!

Fatigue Test Results



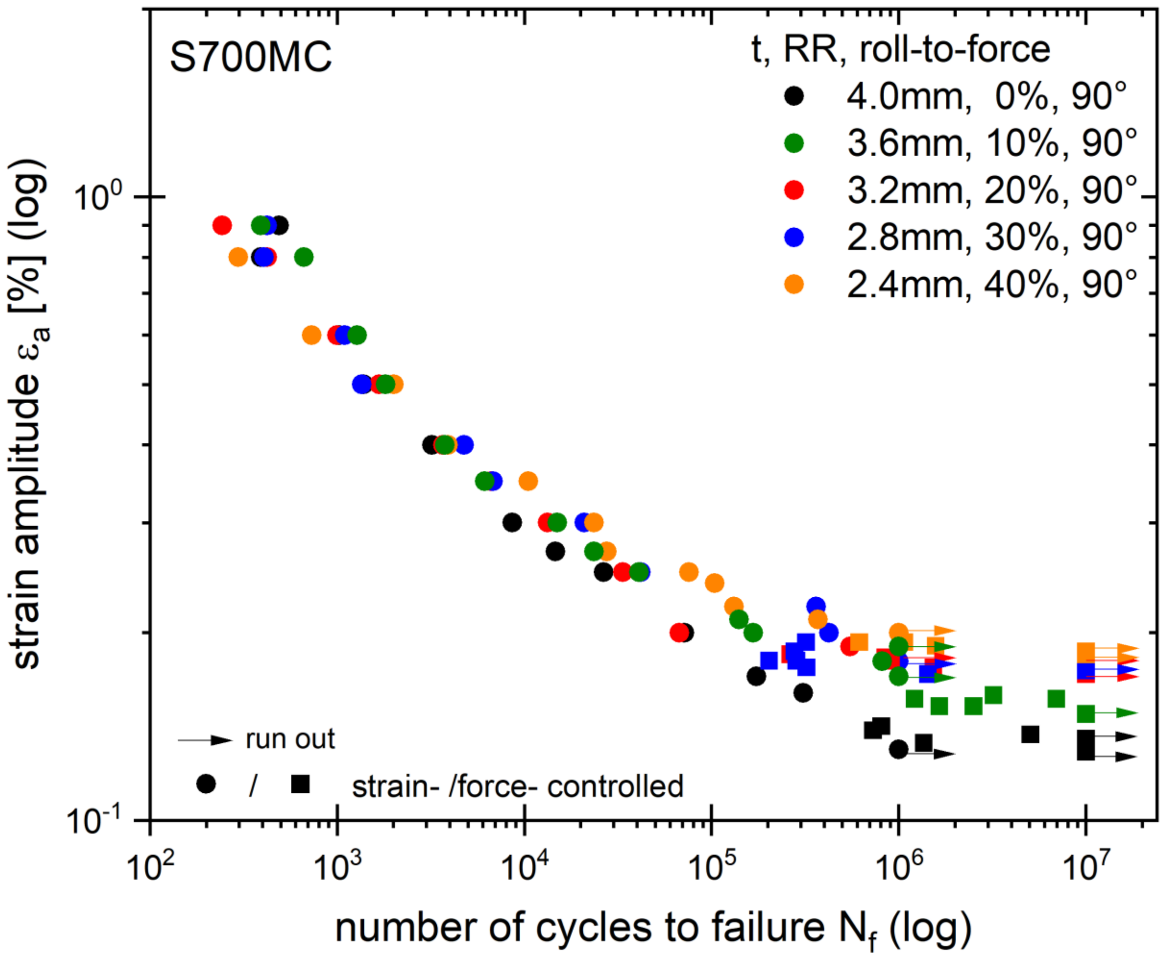
- RR=20%
- Further increase in fatigue strength can be seen

Fatigue Test Results



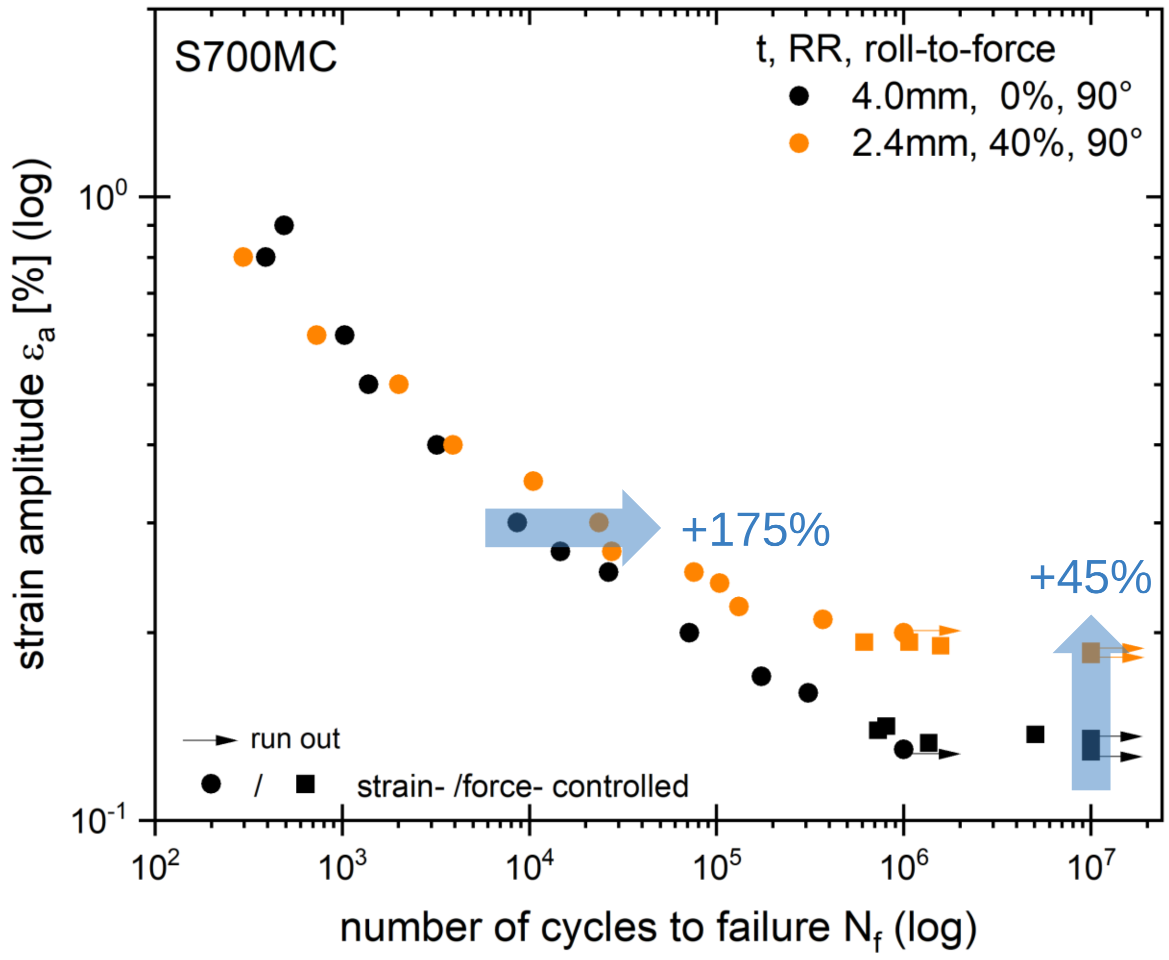
- RR=30%
- Both fatigue life and fatigue strength show significant gains

Fatigue Test Results



- RR=40%
- Further gains
- Fatigue life >10^6 for automotive applications:
  - further gains in fatigue strength that can be exploited

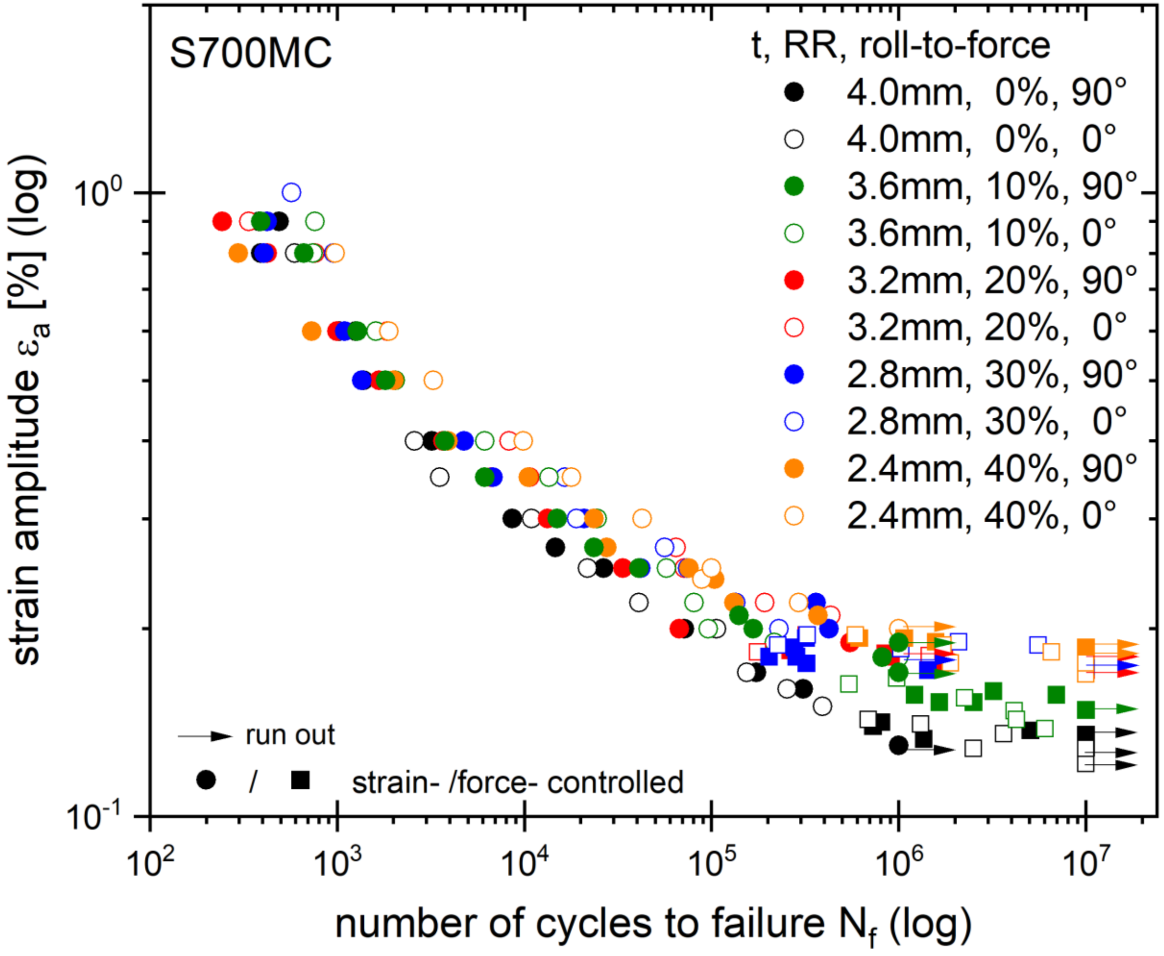
Fatigue Test Results



- RR=40%
- Further gains
- Fatigue life >10^6 for automotive applications:
  - further gains in fatigue strength that can be exploited
  - RR=0 % (Raw material) vs. RR=40%:
    - Fatigue life: ~+175% (at $\varepsilon_{a,t}$=0.3 %)
    - Fatigue strength: ~+45% (at N=10^7)

Fatigue Test Results

Anisotropic behavior



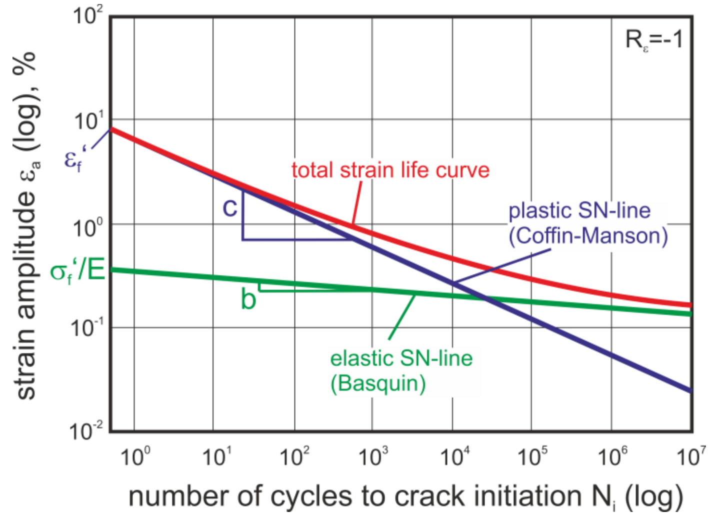
- Comparable behavior for the specimens extracted at 0° roll-to-force

Fatigue Behavior – Math. Approach (CAE-Application)

Cyclic Material Behavior

Strain-life and cyclic stress-strain curves

Basquin-Coffin-Manson-Morrow



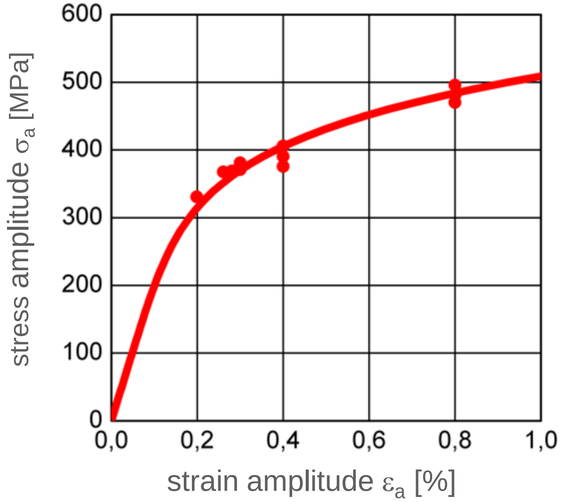
$$\varepsilon_{a,t} = \varepsilon_{a,e} + \varepsilon_{a,p} = \frac{\sigma_f'}{E} \cdot (2N)^b + \varepsilon_f' \cdot (2N)^c$$

σ_f'	fatigue strength coefficient
b	fatigue strength exponent
ε_f'	fatigue ductility coefficient
c	fatigue ductility exponent

$$n' = \frac{b}{c}$$

$$K' = \frac{\sigma_f'}{\varepsilon_f'^{\frac{b}{c}}}$$

Ramberg-Osgood

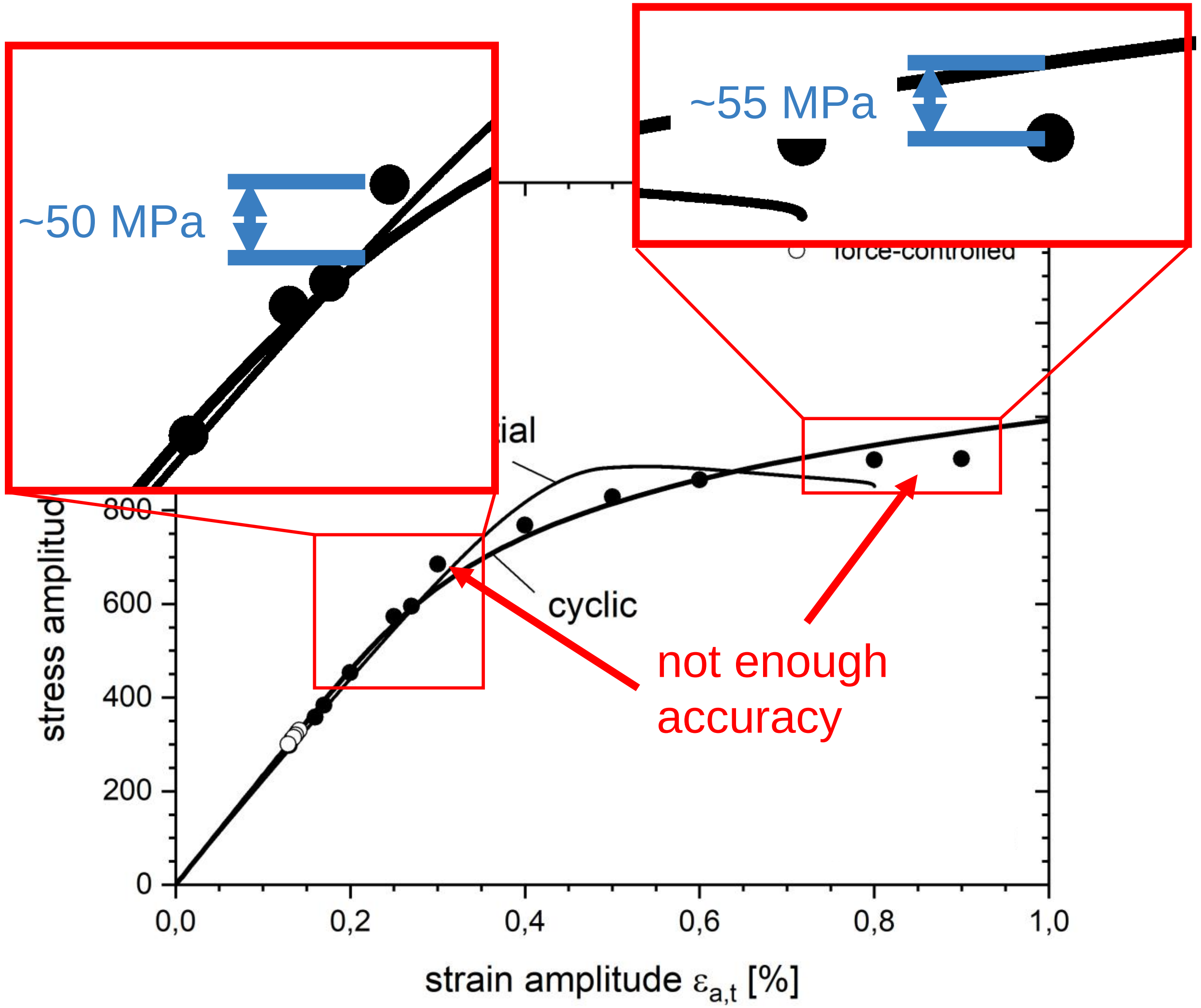


$$\varepsilon_{a,t} = \varepsilon_{a,e} + \varepsilon_{a,p} = \left(\frac{\sigma_a}{E}\right) + \left(\frac{\sigma_a}{K'}\right)^{\frac{1}{n'}}$$

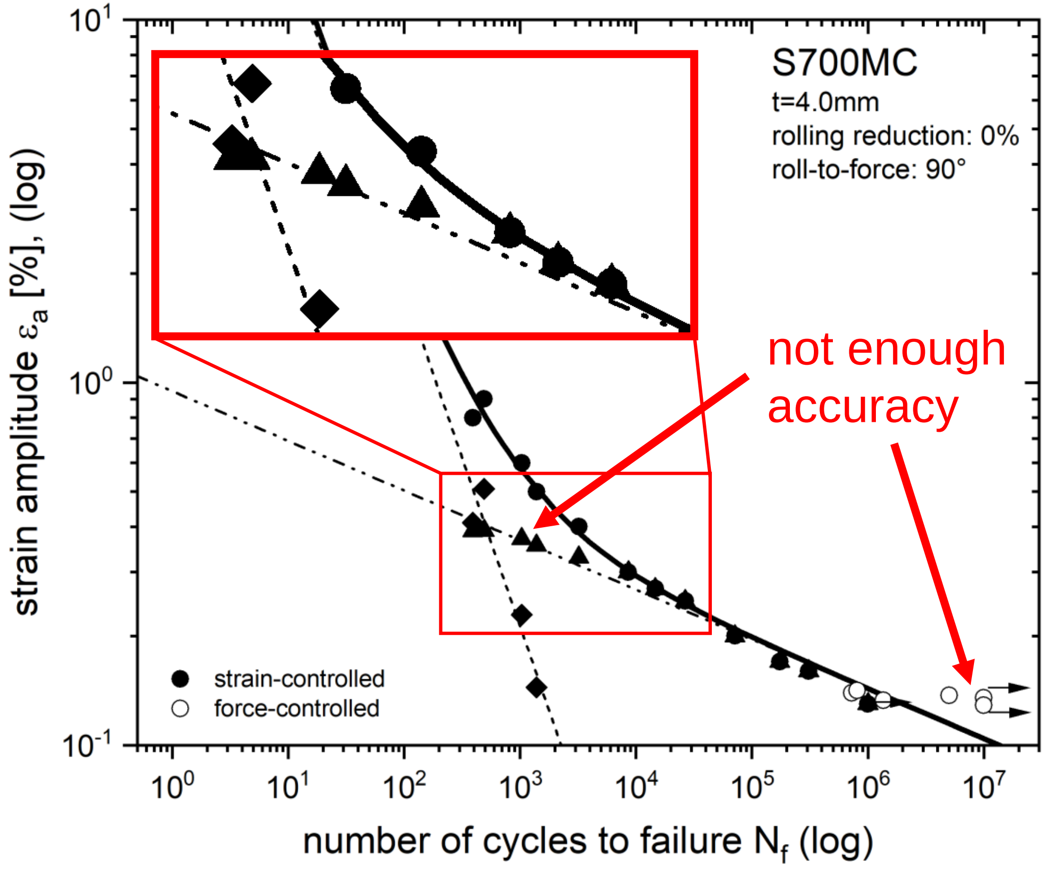
K'	cyclic hardening coefficient
n'	cyclic hardening exponent

Fatigue Behavior – Math. Approach (CAE-Application)

Cyclic stress-strain and strain-life curve / Conventional models



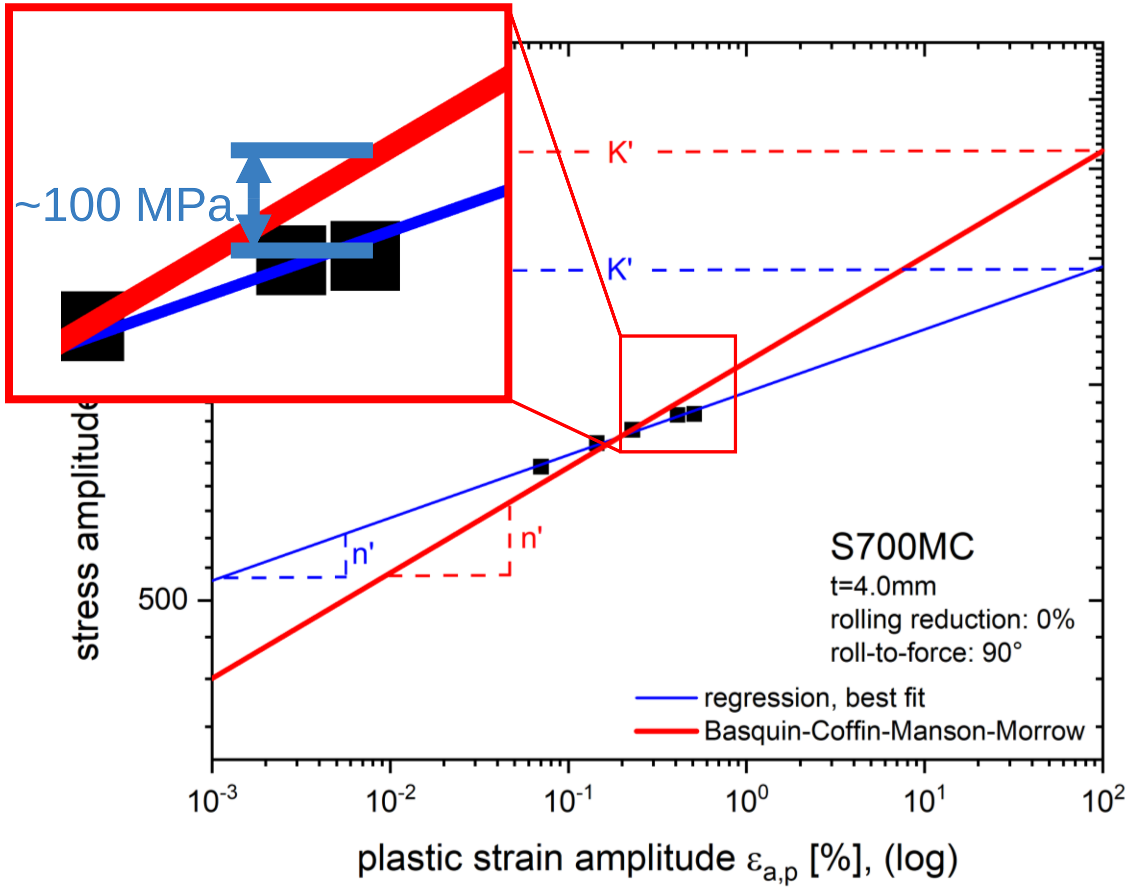
Ramberg-Osgood



Basquin-Coffin-Manson-Morrow

Check of the material model

Cyclic flow curve – log(σ_a) vs. log ($\varepsilon_{a,p}$)-curve – compatibility condition



R^2_{BCMM} = 0.521

$R^2_{REGRESSION}$ = 0.985

Red line:

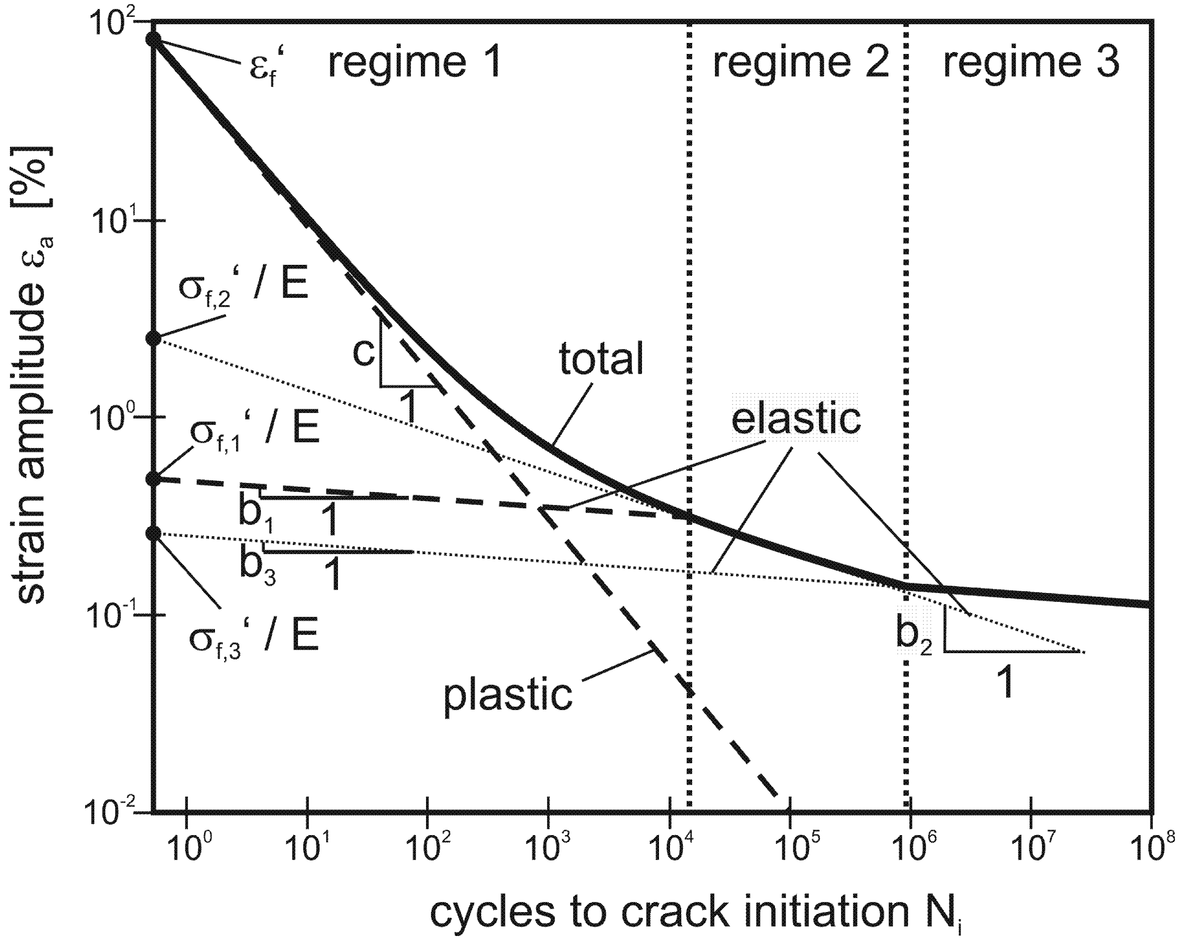
- Determined using the compatibility condition
- Basquin-Coffin-Manson-Morrow does not have enough accuracy

Blue line:

- Fits the datapoints according to regression
- Significantly different values K‘ and n‘ for the cyclic stress-strain curve according to Ramberg-Osgood

Fatigue Life Curve – New Math. Approach

Characteristic values

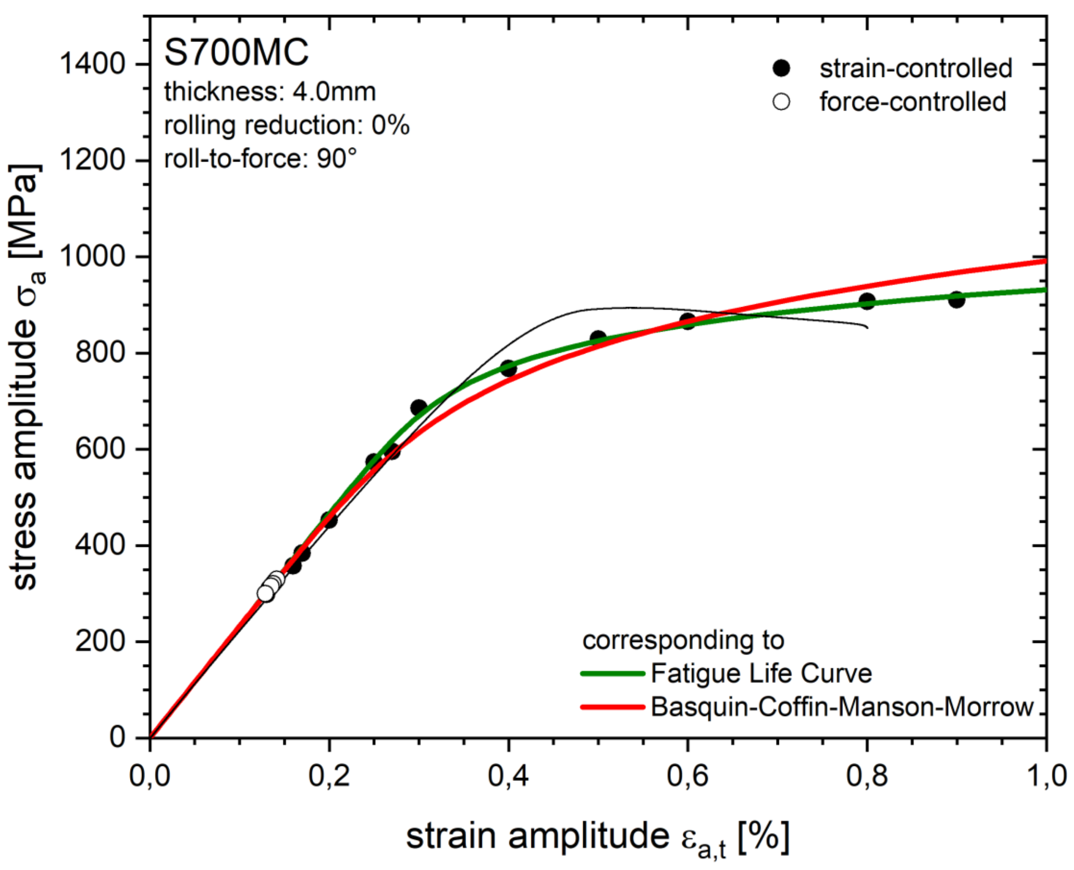


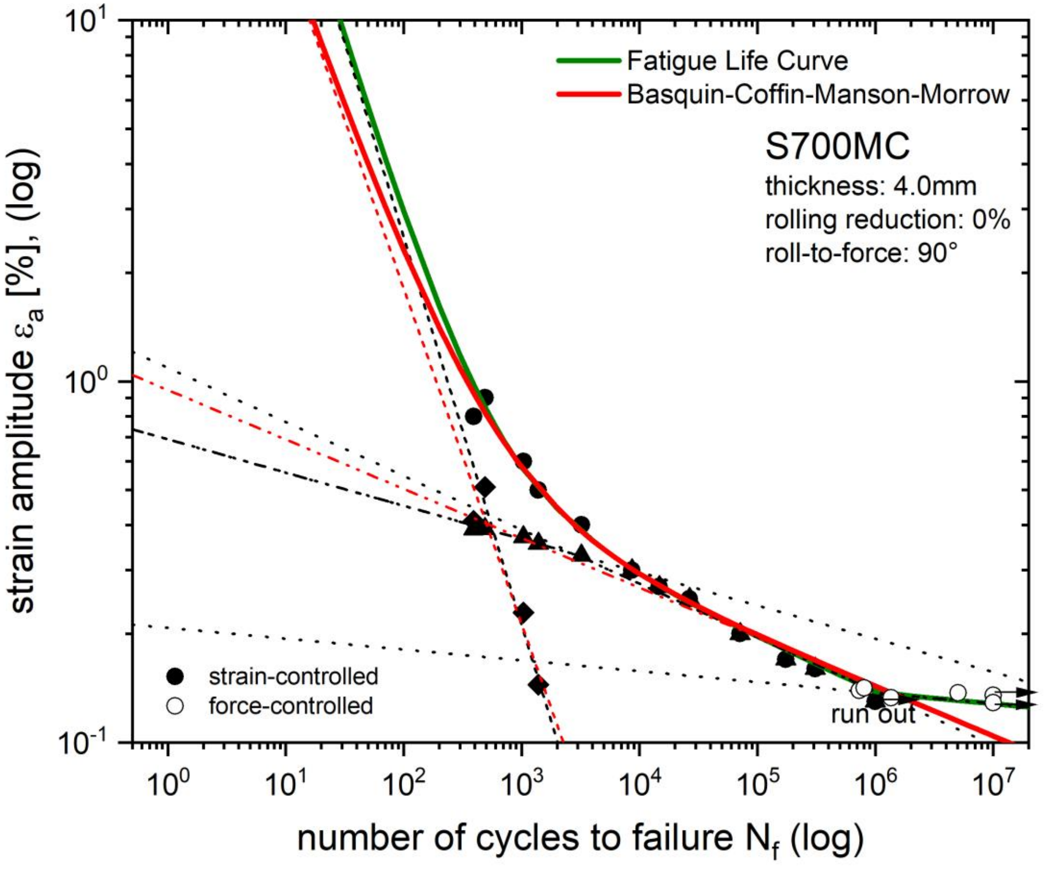
- Fatigue Life Curve as an improved approach with higher accuracy to describe cyclic material behavior compared to conventional models
- Partition of the strain-life curve into three regimes depending on the cyclic stress-strain behavior
  - Regime 1: elastic-plastic
  - Regime 2: transition zone
  - Regime 3: macroscopic elastic
- Combination of strain- and force-controlled test results possible with Fatigue Life Curve
- Recommended by German Association of the Automotive Industry (VDA) 239:300

(Source: R. Wagener und T. Melz, "Deriving a continuous fatigue life curve from LCF to VHCF", *SAE Technical Paper*, 2017-01-0330, 2017.)

S700MC, t=4.0 mm, RR=0%, roll-to-force: 90°

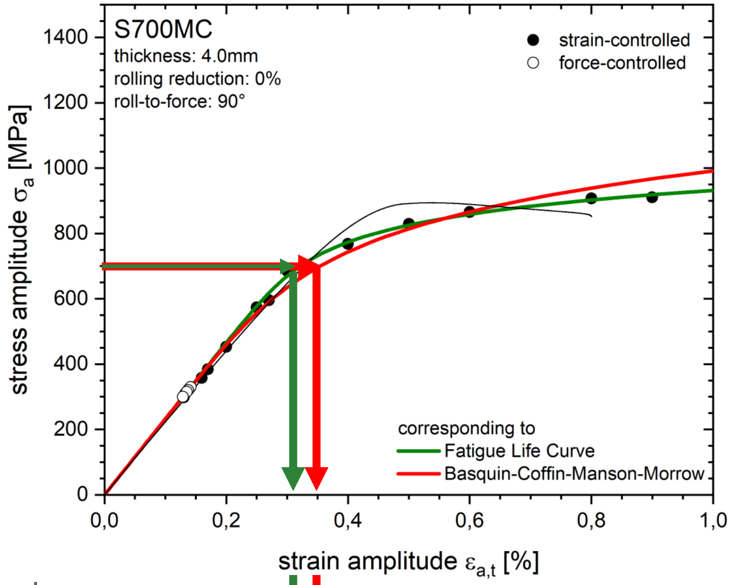
Fatigue Life Curve



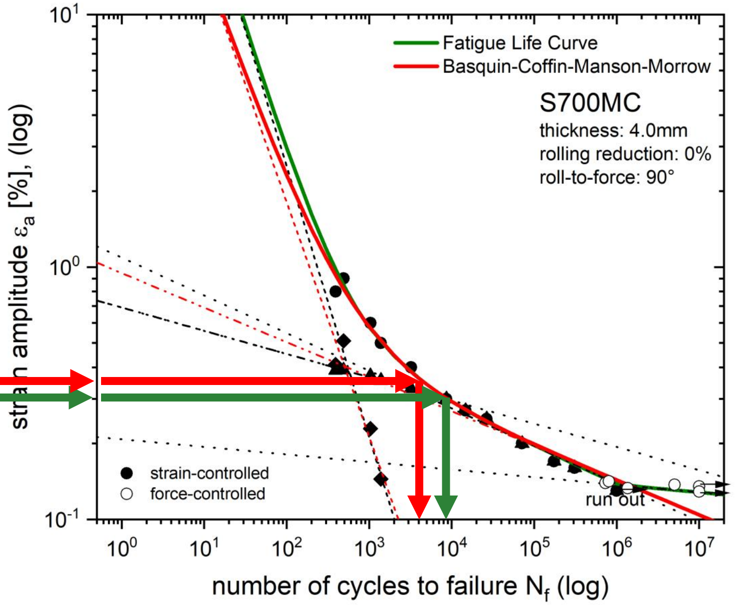


Deriving of Calculated Fatigue Life

1^{st} Step: stress calculation of applied force

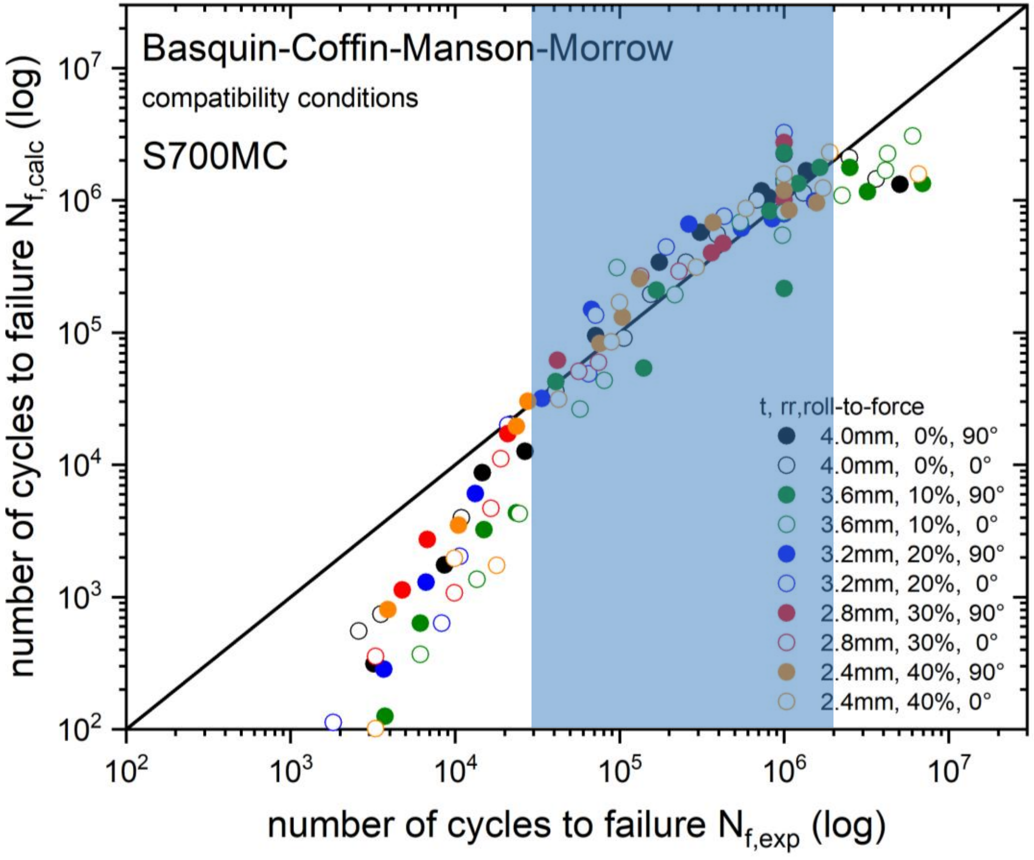


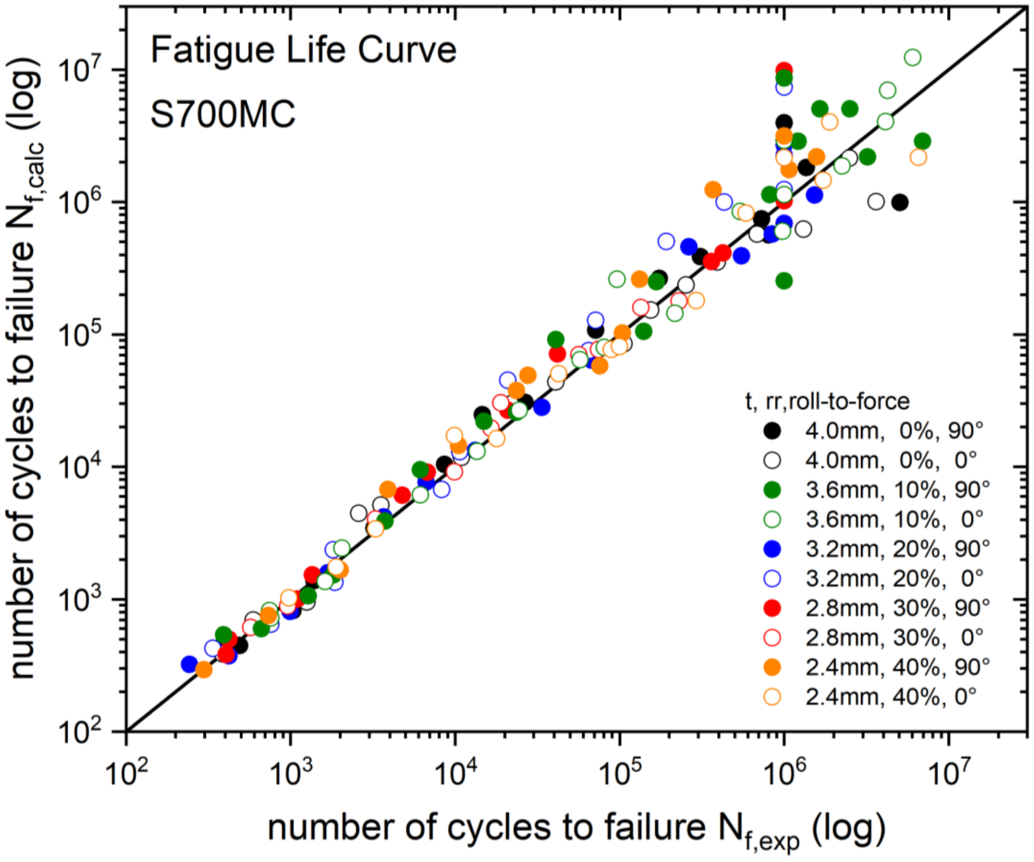
2^{nd} Step: determination of strain value



3^{rd} Step: calculation of fatigue life

Comparison of Calculated and Experimental Fatigue Life





$R^2_{BCMM(overall)}$ = 0.754

$R^2_{BCMM(30,000 > x > 2,000,000)}$ = 0.801

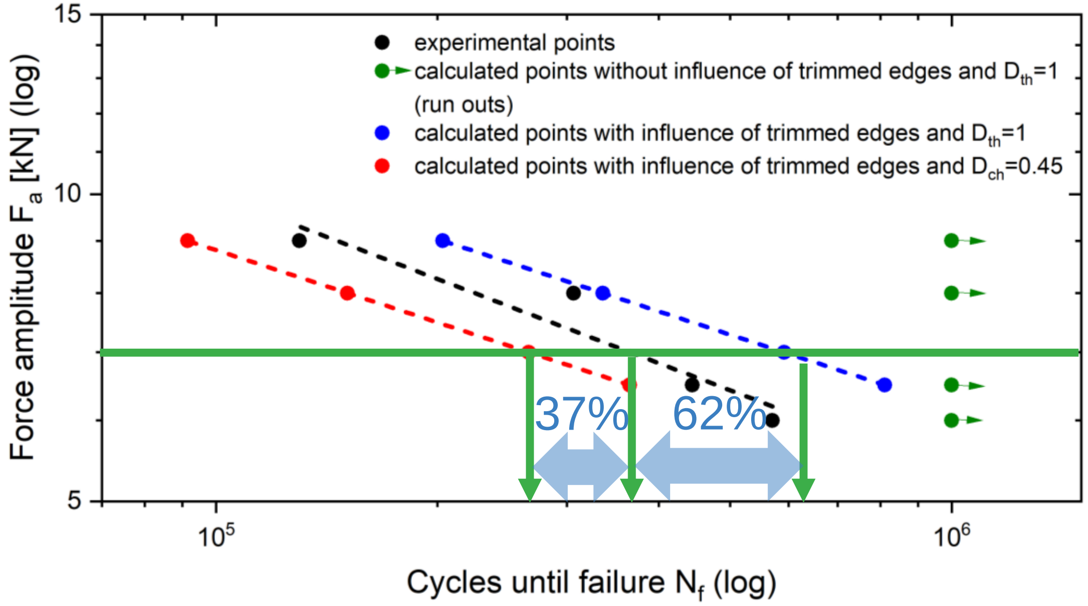
R^2_{FLC} = 0.932

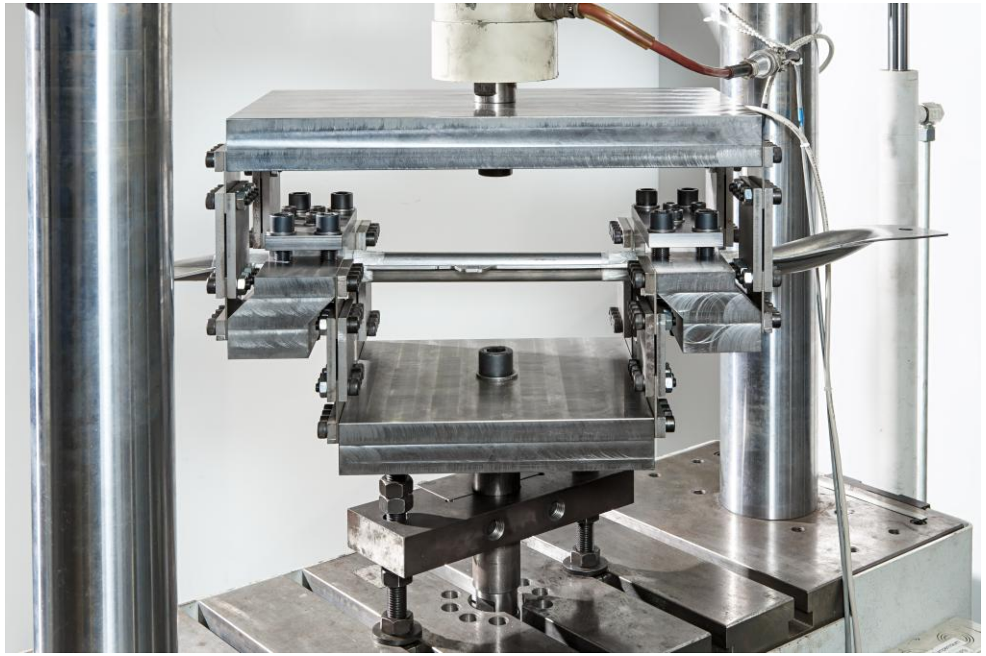
Part Validation

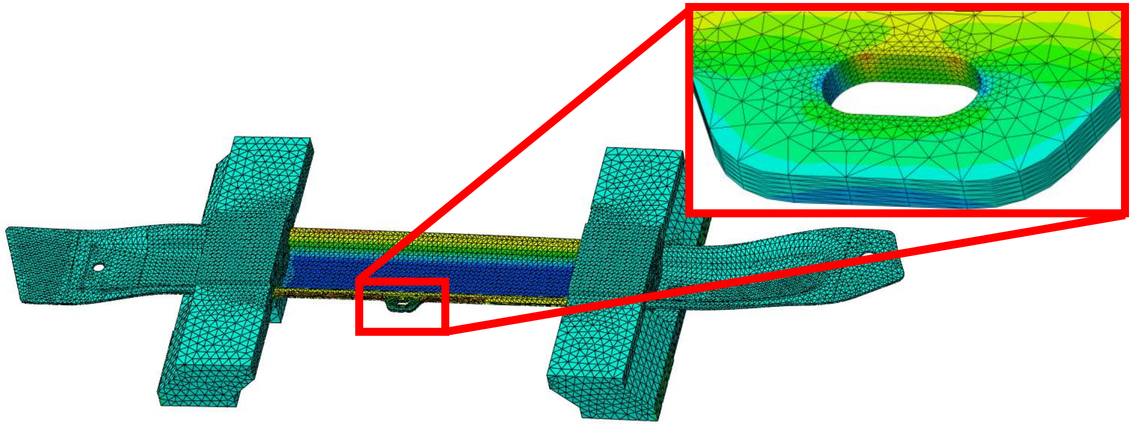
Part Validation

GDIS

1. Strains calculated from FE
2. Taking into account influence of edges by shifting the Fatigue Life Curve downwards through multiplication of strain value at N=1000 (×0.6) and N=100000 (×0.73) [1]
3. Fatigue Life from Fatigue Life Curve using FE-strains
4. Using $D_{characteristic}$ instead of $D_{theoretical}$ takes into account force-controlled bending loading [2]
5. Comparison calculated fatigue life vs. experimental data







[1] Häfele, P.; Volk, W.; Dittmann, F.; Pätzold, I.: Einfluss der Kantenbearbeitung auf die Festigkeitseigenschaften von Stahl-Feinblechen unter quasistatischer und schwingender Beanspruchung. FAT Schriftenreihe 306, VDA, FAT (2018).
[2] Karsten Nikkel: Lebensdauerabschätzung für Bauteile aus umgeformten Feinblechen in Abhängigkeit vom Simulationsaufwand, Diss. TU Clausthal, 2013.

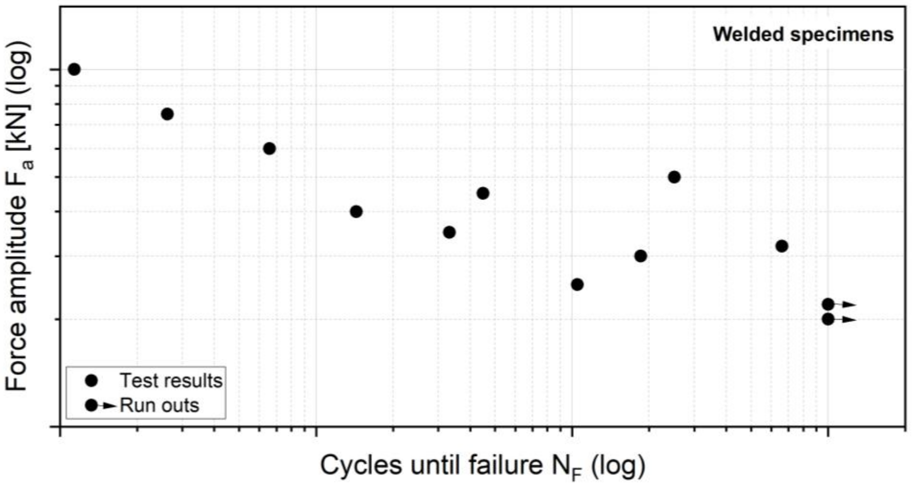
Summary & Outlook

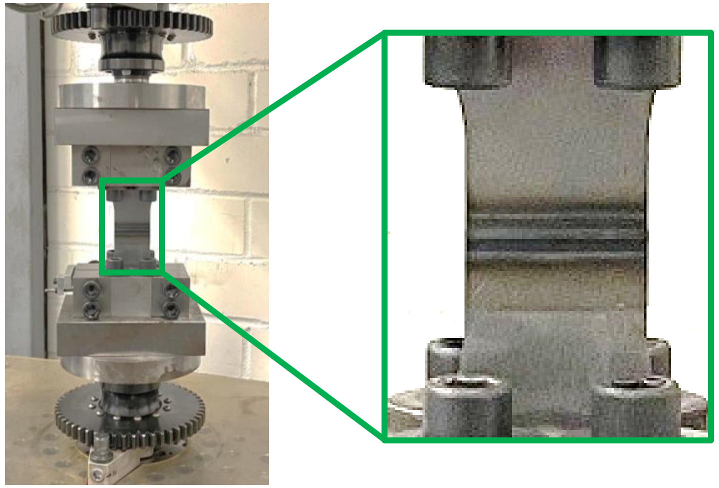
- MTH has a positive influence on the structural durability by increasing rolling reduction leading to:
  - Increase in fatigue life (reduced strain amplitude at same stress level)
  - Increase in fatigue strength (higher stress level for same strain amplitude)

- The Fatigue-Life Curve provides much more accuracy compared to the traditional approaches (Basquin-Coffin-Manson-Morrow and Ramberg-Osgood)

- Validation (Fatigue-Life Curve vs. experimental results) using automotive part shows satisfactory correlation

- Next step: Weld seams





Thank you for your attention!

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