TU Clausthal

Application of the FKM Guideline non-linear to welds

CEN/TC 54/WG 53/SG DESIGN CRITERIA

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What is the FKM Guideline non-linear?

<u>Notch strain approach</u>

- continuous description of the calculation procedure
- standardised
- secured by a safety concept

→ FKM: Research Association for Mechanical Engineering
→ published 02/2019 (VDMA)

FKM Guideline non-linear

FKM Guideline „Nichtlinearer Festigkeitsnachweis“ in German

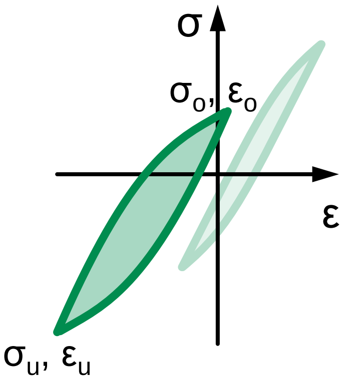
- elastic-plastic deformation behaviour
- fatigue strength assessment based on the notch strain approach
- calculated assessment possible up to crack initiation
- calculated assessment possible for all service life ranges ($N > 10$)

→ in contrast to FKM Guideline „ Analytical Strength Assessment of Components“: ($N \geq 10^4$)

Assessment of the fatigue strength with damage parameters

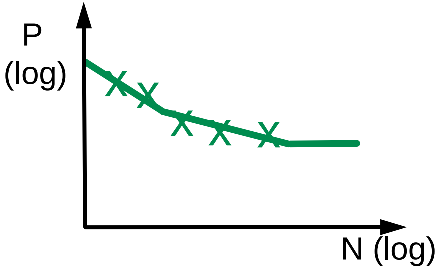
damage parameter P

- size to describe the damage relevant load state
- is calculated for each closed hysteresis
- can be presented as a spectrum



damage parameter-(P-)Wöhler curve

- determined via strain-controlled tests
- or: estimated from material properties



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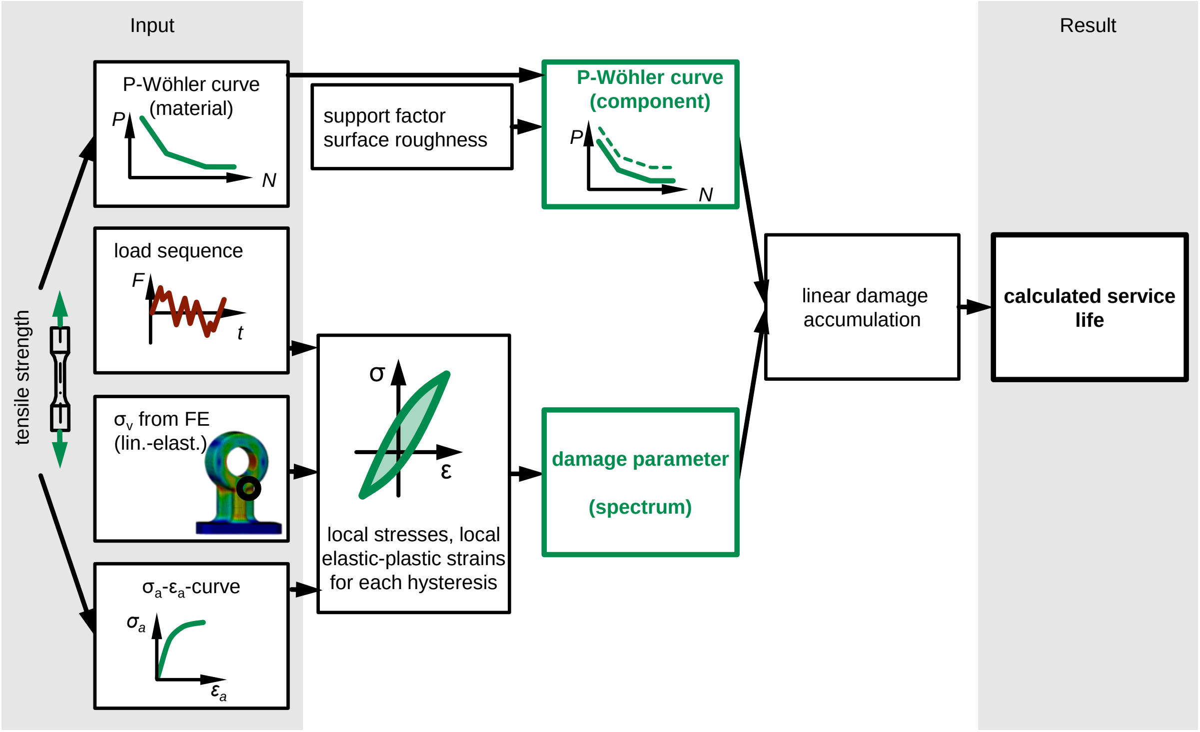
Scheme: Assessment of the fatigue strength



Advantages of the FKM Guideline non-linear

- standardised procedure for the application of the notch strain approach
- required inputs
  - all strength parameters can be estimated from the tensile strength
  - finite element calculation with linear-elastic material model
- safety concept
- all service life ranges included (N>10)

Application of the FKM Guideline non-linear to welds

research project „ Modellierung von Schweißnähten zum Nachweis der Ermüdungsfestigkeit mit dem Örtlichen Konzept“

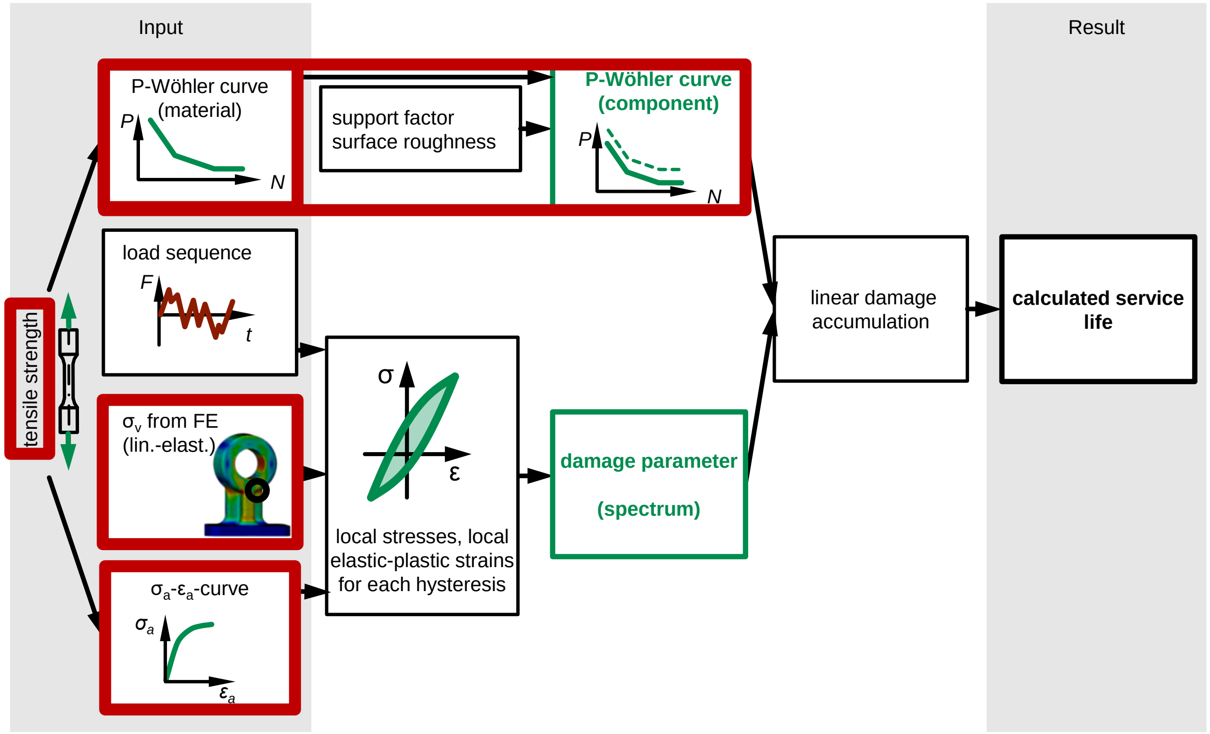
- Institute for Plant Engineering and Fatigue Analysis (IMAB), TU Clausthal
- Fraunhofer Institute for Mechanics of Materials (IWM), Freiburg
- 01.03.2018 – 31.10.2020

Aim and approach

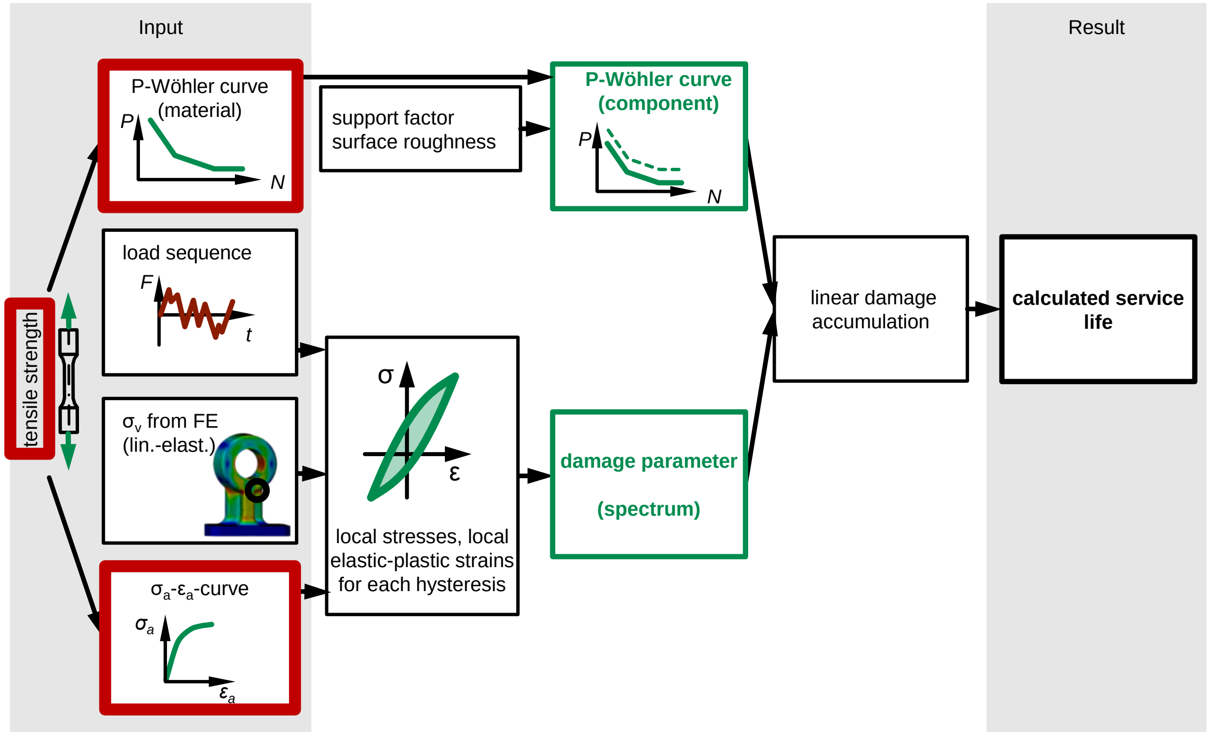
- assessment of applicability of FKM Guideline non-linear to welds out of steel
- adaptation of the calculation concept:
  - estimation method for cyclic material properties and damage parameter Wöhler-curves
  - modelling of welds and determination of local stresses
  - consider statistical size effect, stress gradient and surface roughness
- achieving a good accuracy

→ in this project, as a first approach, for constant amplitudes for now

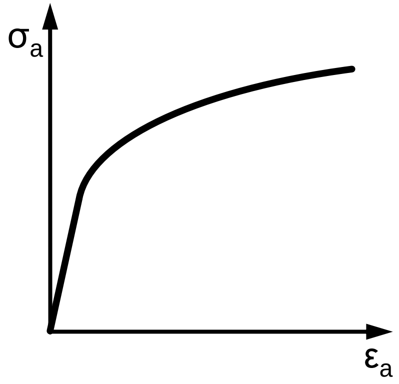
Scheme: Assessment of the fatigue strength



Scheme: Assessment of the fatigue strength



Cyclic stress-strain curve



- Ramberg and Osgood approach: $$\varepsilon_a = \frac{\sigma_a}{E} + \left(\frac{\sigma_a}{K'}\right)^{\frac{1}{n'}}$$

  with: K' cyclic strain hardening coefficient
  n' cyclic strain hardening exponent
  E Young‘s modulus

- E depending on material group
- n′ depending on material group
- K′ function of Vickers hardness

$$K' = \frac{41.4\ \text{MPa} \cdot HV^{0.63}}{\left(\min\left(\begin{matrix}0.338 \\ 189787 \cdot HV^{-2.23}\end{matrix}\right)\right)^{0.187}}$$

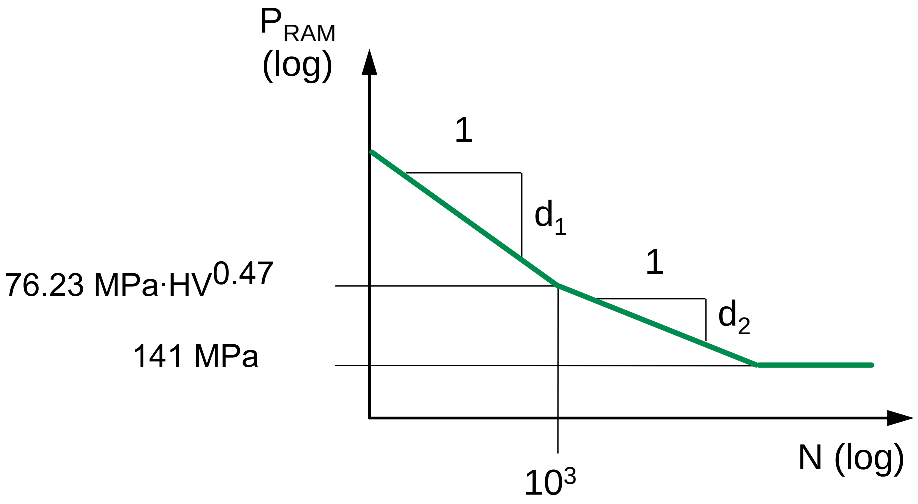
Damage parameter P_{RAM}

- value of P_{RAM} for each closed hysteresis

$$P_{RAM} = \begin{cases} \sqrt{(\sigma_a + k \cdot \sigma_m) \cdot \varepsilon_a \cdot E} & \text{für } (\sigma_a + k \cdot \sigma_m) \geq 0 \\ 0 & \text{für } (\sigma_a + k \cdot \sigma_m) < 0 \end{cases}$$

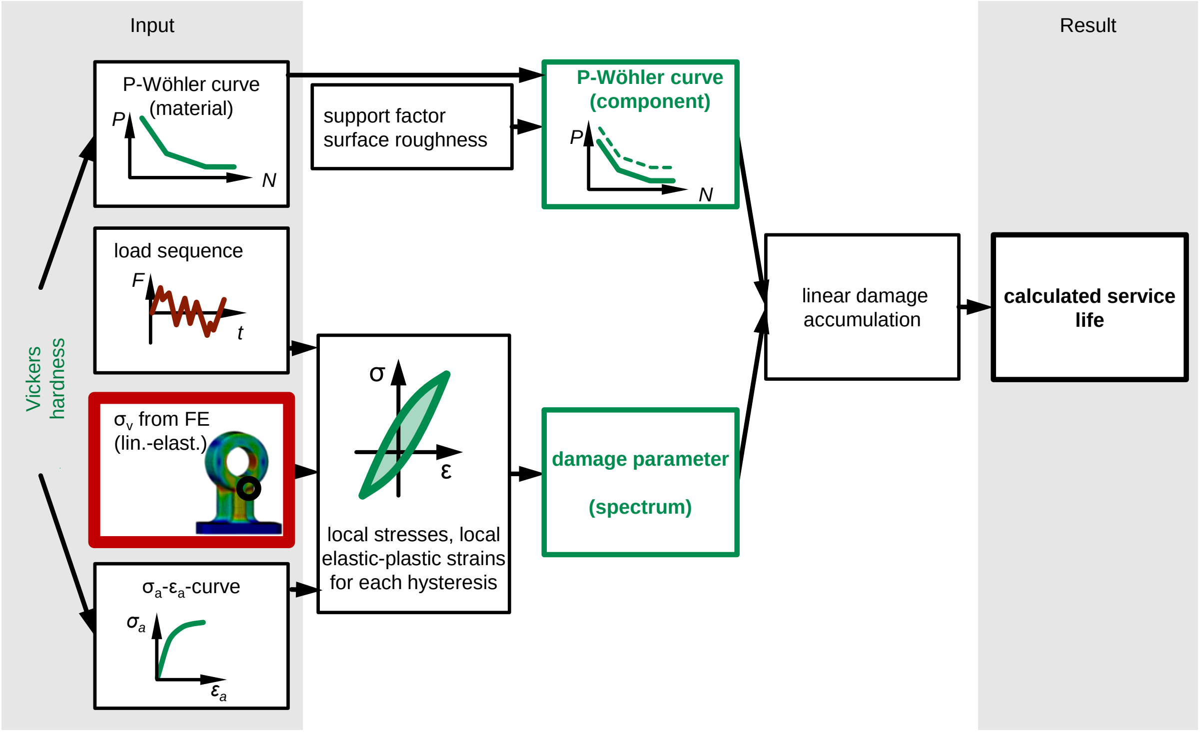
- RAM: Research Association for Mechanical Engineering
- based on damage parameter of Smith, Watson and Topper P_{SWT}
- k: consideres mean stress sensitivity

Damage parameter-(P-)Wöhler-curve for P_{RAM}



- slopes d_1 and d_2: depending on material group
- suspension point: function of Vickers hardness
- adaption of the fatigue limit to the effective notch stress approach

Scheme: Assessment of the fatigue strength

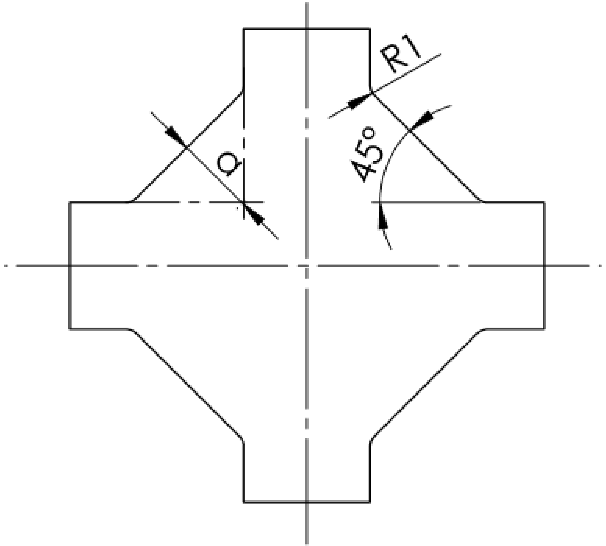


Modelling of welds

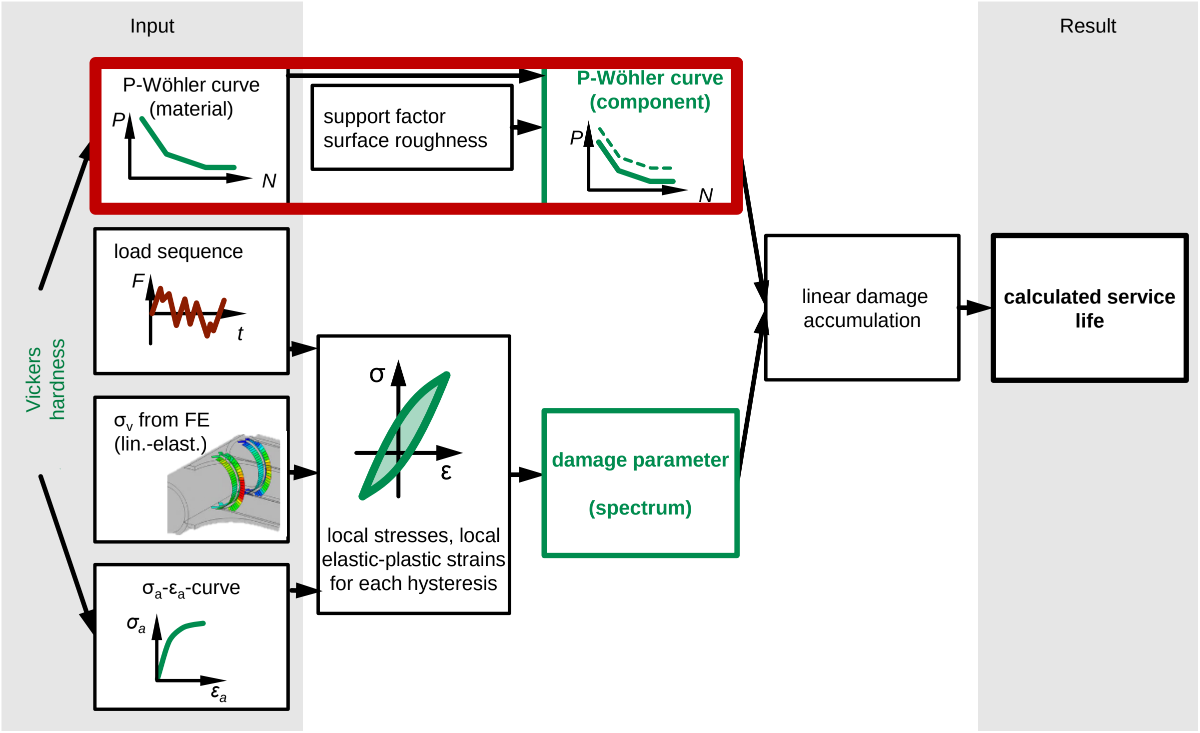
- Simplification
- according to IIW recommendation for effective notch stress approach

→ linear elastic finite element calculation

→ subsequent notch root approximation



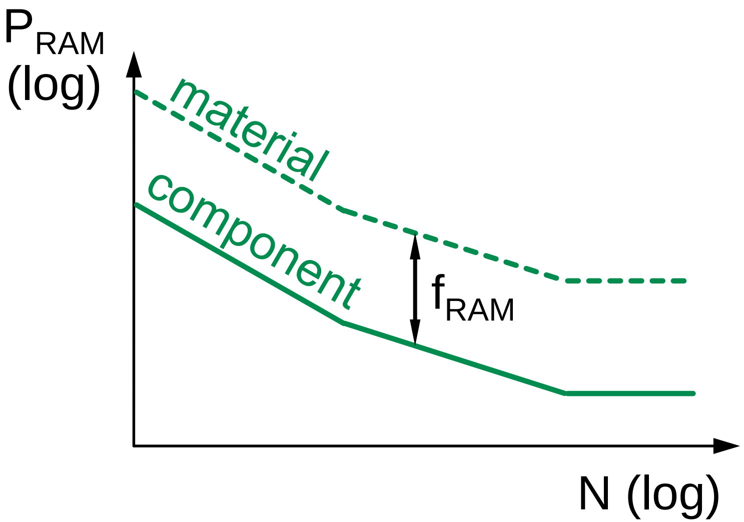
Scheme: Assessment of the fatigue strength



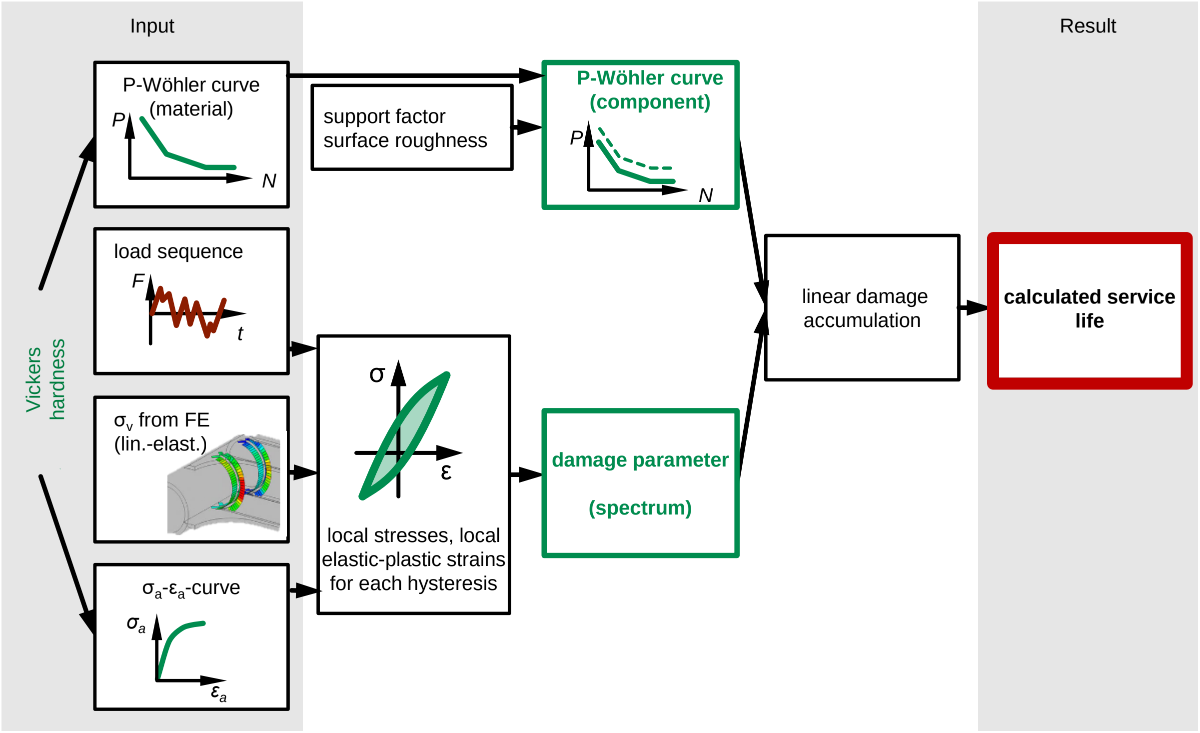
Support factor and surface roughness

factor f_{RAM}

- support factor
  - statistical size effect
  - stress gradient
- surface roughness

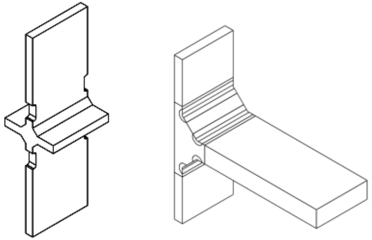


Scheme: Assessment of the fatigue strength

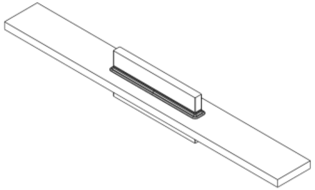


Database for the review of the adjustments for welds

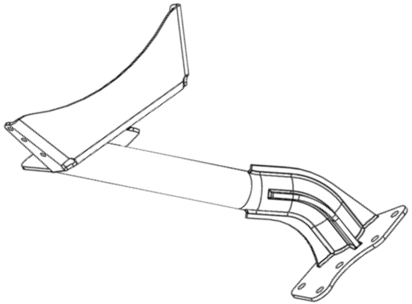
cruciform welded joints



longitudinal welded gussets



component

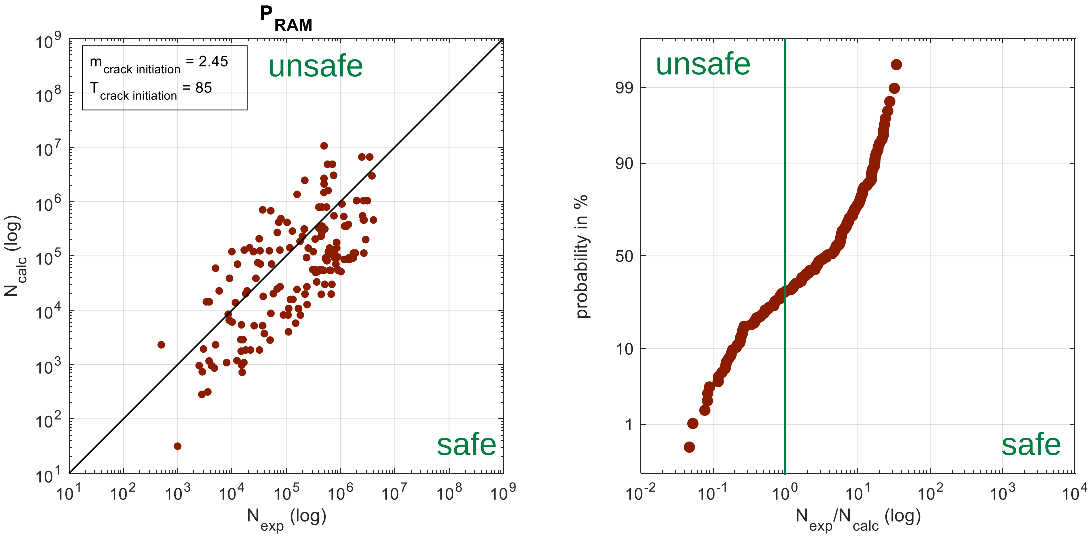


sources:

- this project
- Deinböck, A.; Hesse A.-C.; Wächter, M.; Hensel, J.; Esderts, A.; Dilger, K.: Berücksichtigung der höchstbeanspruchten Schweißnahtlänge im Kerbspannungskonzept. Schlussbericht, IGF-Vorhaben Nr. 19.033N, 2019
- Baumgartner, J.: *Schwingfestigkeit von Schweißverbindungen unter Berücksichtigung von Schweißeigenspannungen und Größeneinflüssen.* Dissertation TU Darmstadt, 2013

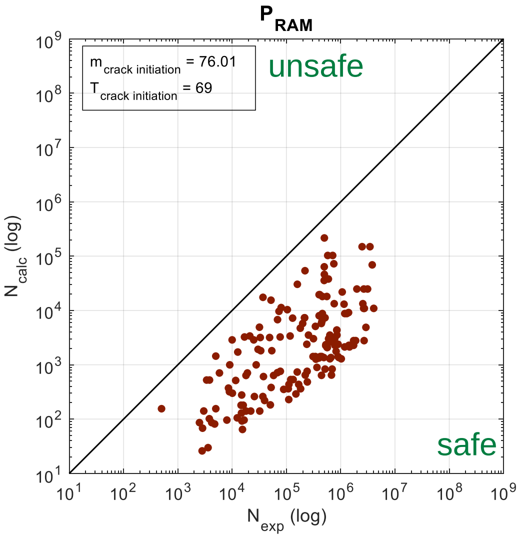
Analytical fatigue life prediction P_{RAM}

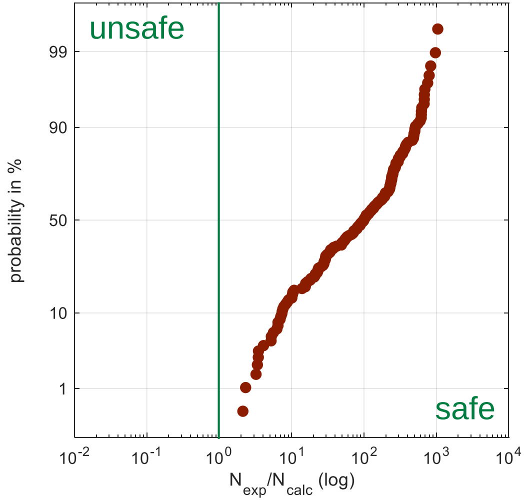
Input: Vickers hardness (heat-affected zone), safety factors = 1



Analytical fatigue life prediction P_{RAM}

Input: Vickers hardness (heat-affected zone), safety factors included





Conclusion

→ adapted algorithms of FKM Guideline non-linear are suitable for the design of welds, for

- steel
- Vickers hardness from 150HV – 330HV
- constant amplitude loading
- low or medium residual stresses

→ open issues

- variable amplitudes
- high residual stresses
- thin-walled steel sheets (sheet thickness < 5mm)
- aluminium

Acknowledgement

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iGF Industrielle Gemeinschaftsforschung

AiF ALLIANZ INDUSTRIE FORSCHUNG

DVS

FKM Forschung im VDMA