BAM
Bundesanstalt für Materialforschung und -prüfung

Sicherheit in Technik und Chemie

WMRIF 5th International Workshop for Young Scientists, November 8-10, 2016, Tsukuba

FRACTURE MECHANICS-BASED DETERMINATION OF THE FATIGUE STRENGTH OF WELDMENTS

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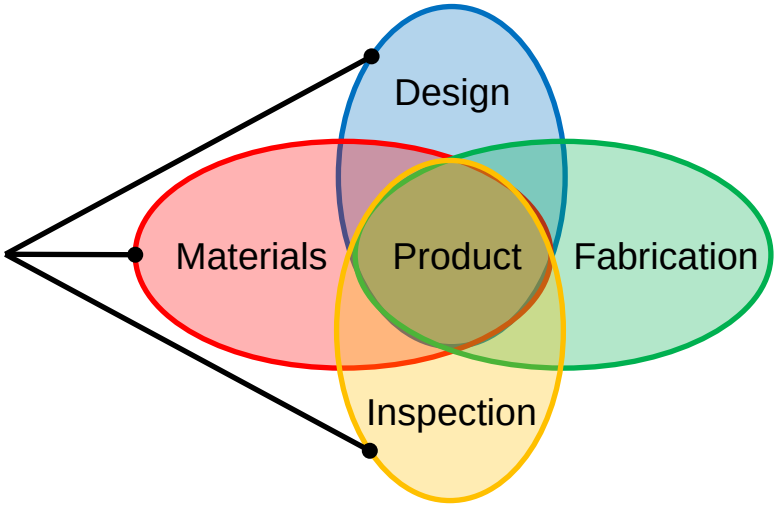
Outline

- ✓ Motivation
- ✓ Experimental evidence
- ✓ Description of the analytical procedure
- ✓ Validation case studies
- ✓ Conclusions and outlook

Motivation (1)

- ✓ Worldwide enormous economic losses due to fatigue failure of weldments
- ✓ Need for welded structures optimized with respect to fatigue strength and service life
- ✓ Interactive Model for Product Development is the optimum approach for failure avoidance/reduction
- ✓ Great potential for improvement by using fracture mechanics



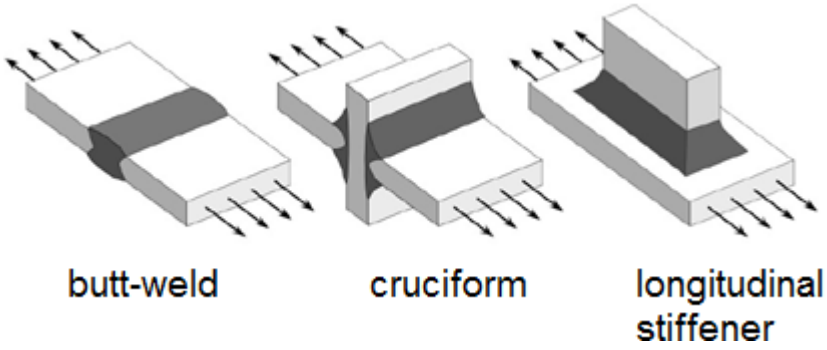
- ✓ Problem: existing approaches are usually oversimplified and therefore limited

Motivation (2)

Goal of the present work: Development of a more sophisticated and physically sound method for the reliable determination of the fatigue strength of weldments

Methodology adopted in the project IBESS:

- ✓ 3 different welded joints (fabrication from hot-rolled steel plates and assessment of stress-life curves)
- ✓ Determination of material properties (S355NL, S960QL)
- ✓ Analytical modelling of the crack propagation
- ✓ Verification and validation



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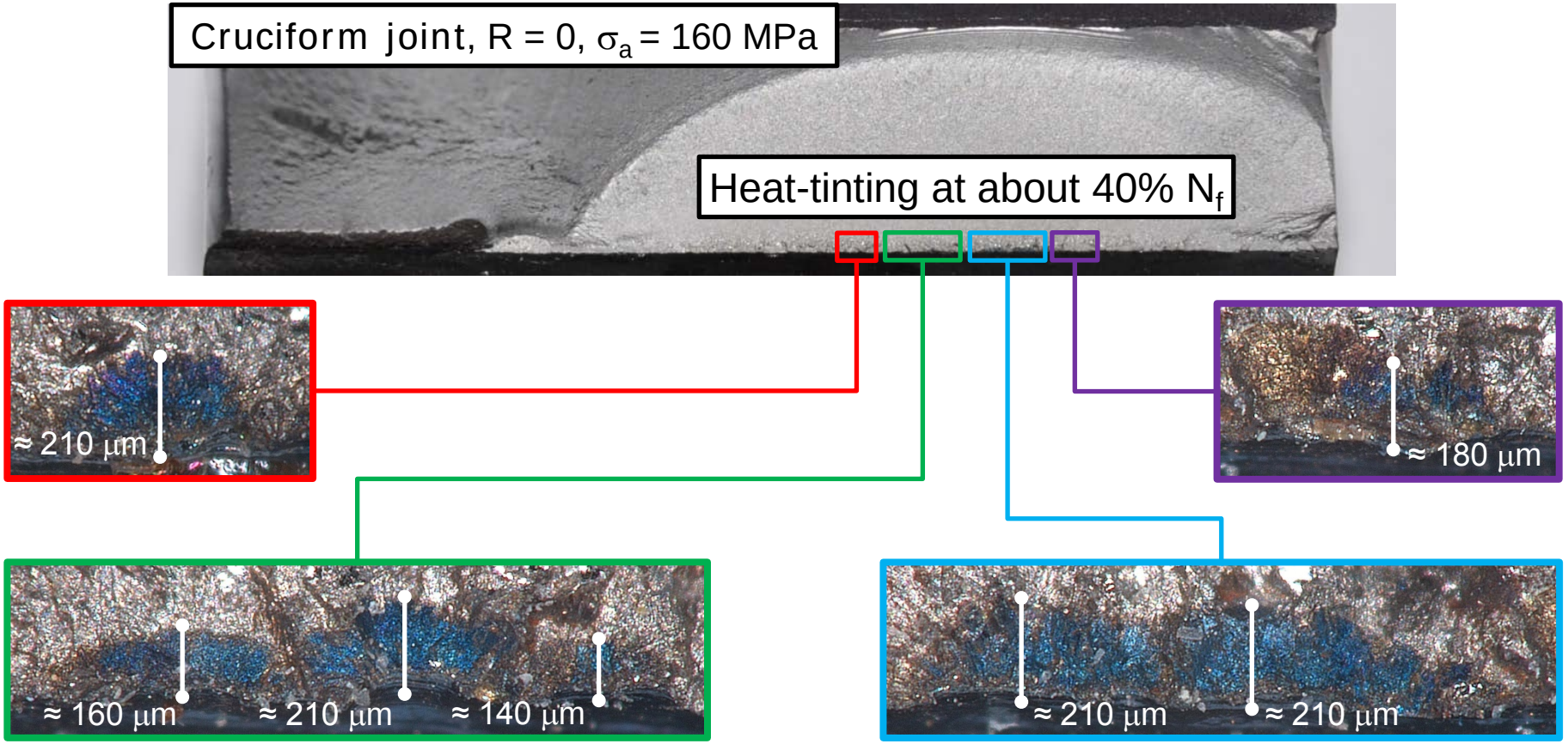
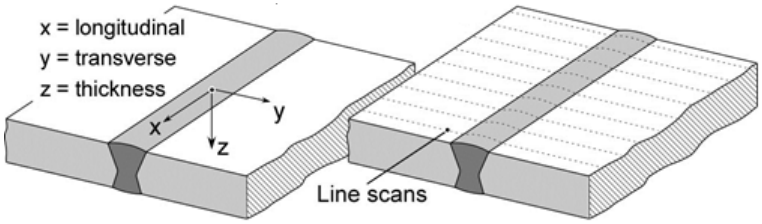
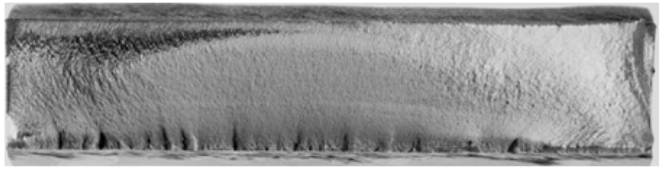
Crack propagation

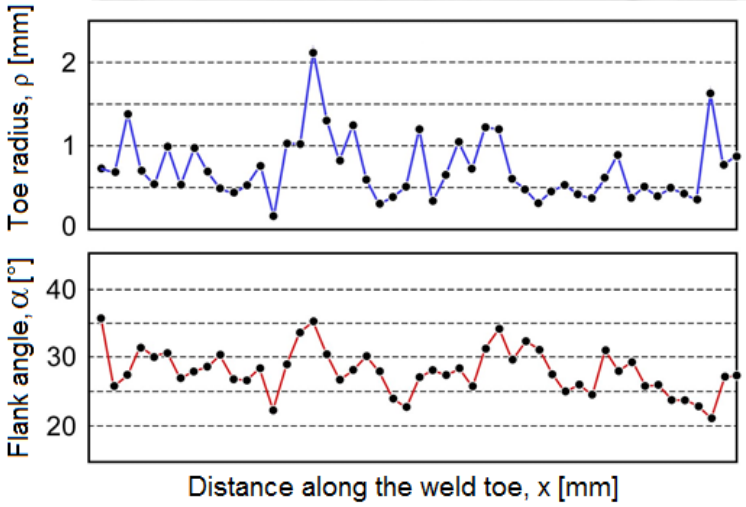


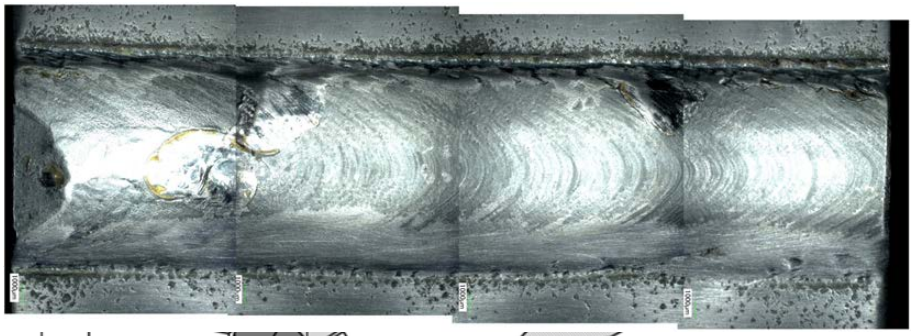
The fatigue life is controlled by the initiation and propagation of short cracks

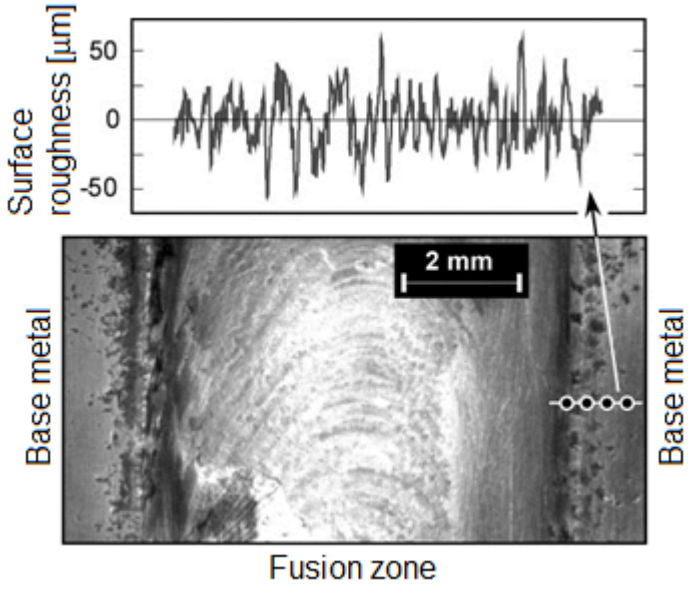
Geometry and imperfections



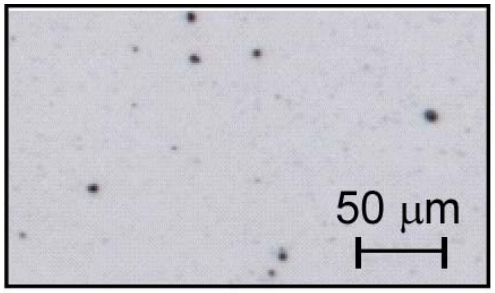


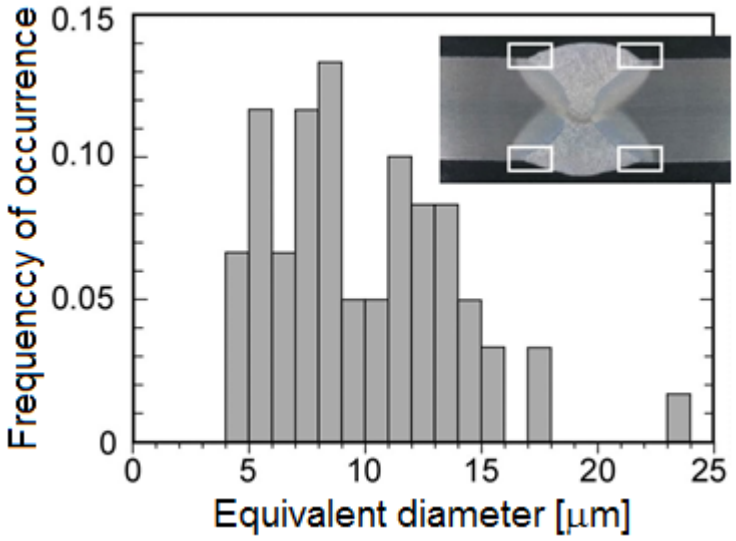


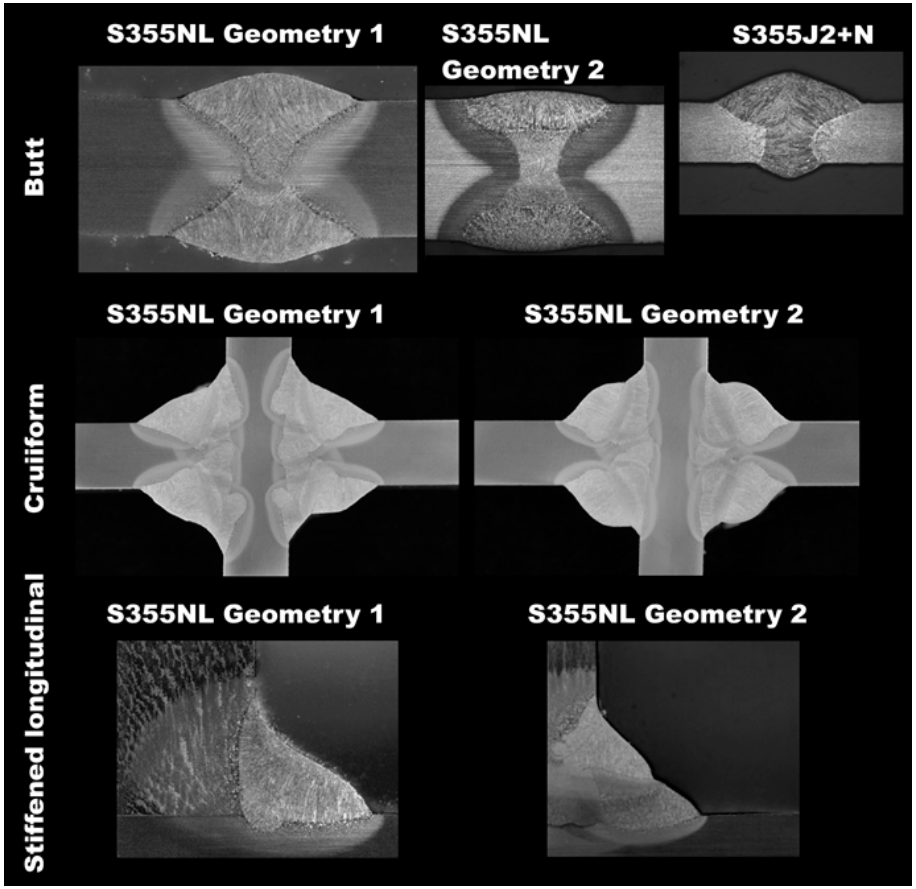




Metallographic examinations

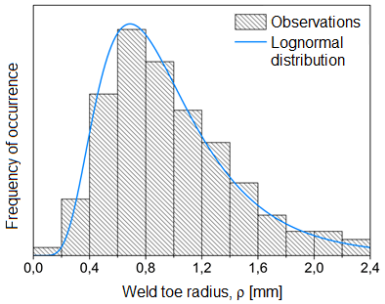


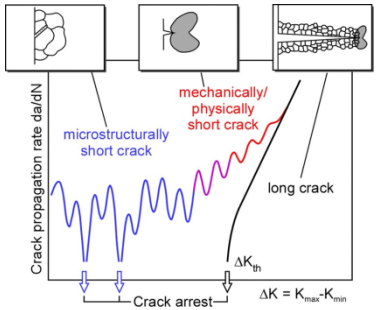


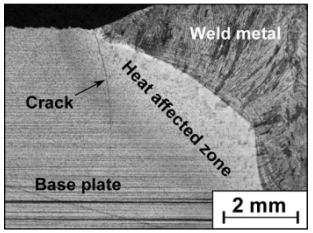


Summary: what is new?

- ✓ Statistical treatment of the local geometrical variables (weld toe radius, flank angle, surface imperfections)
- ✓ Main failure mechanism due to multiple-crack initiation and growth
- ✓ Growth of physically/mechanically short cracks
- ✓ The properties of the base metal and heat affected zone must be taken into account







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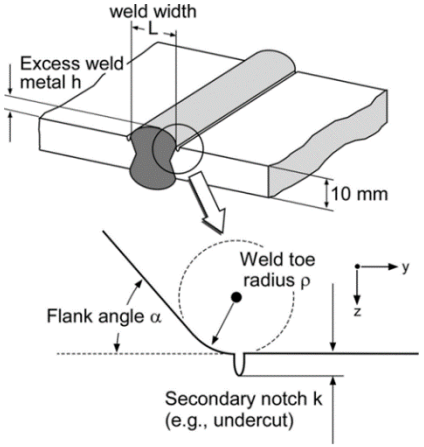
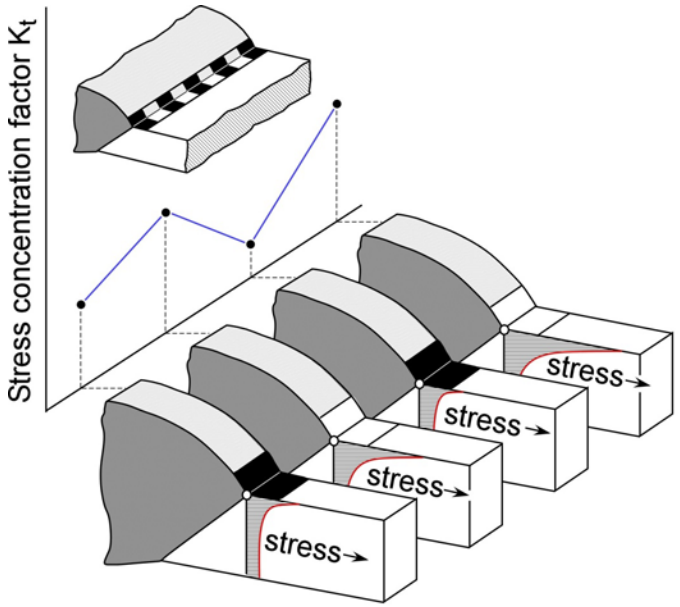
Probabilistic assessment of weld-toe geometry and imperfections

Random variables:

- ✓ Weld-toe radius ρ
- ✓ Flank angle α
- ✓ Excess weld metal h
- ✓ Secondary notch depth k

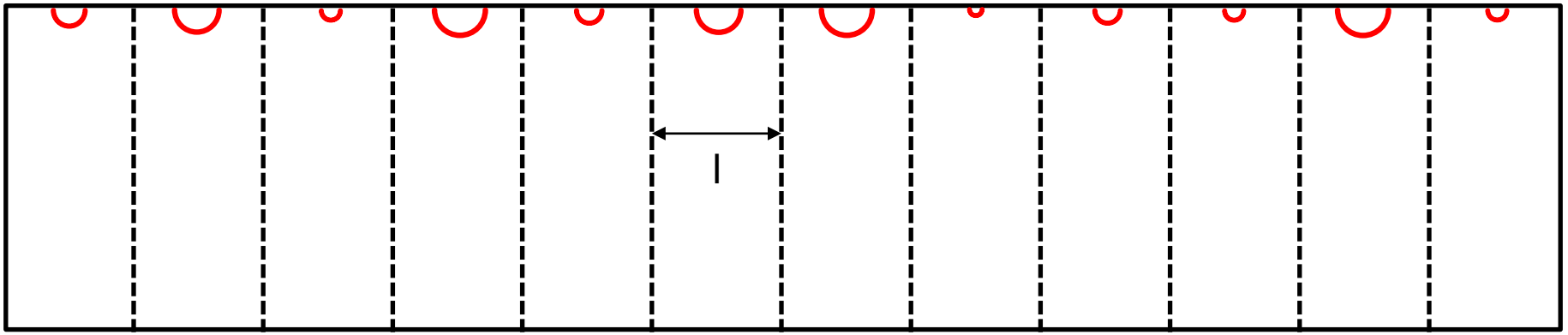


Result: probabilistic description of the through-thickness stress profile

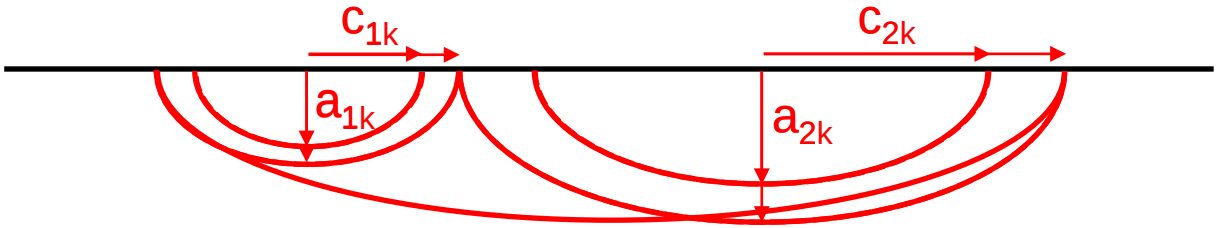


Multiple crack initiation

✓ Random distribution of cracks along the weld-toe ($a_i/c_i = 1$)

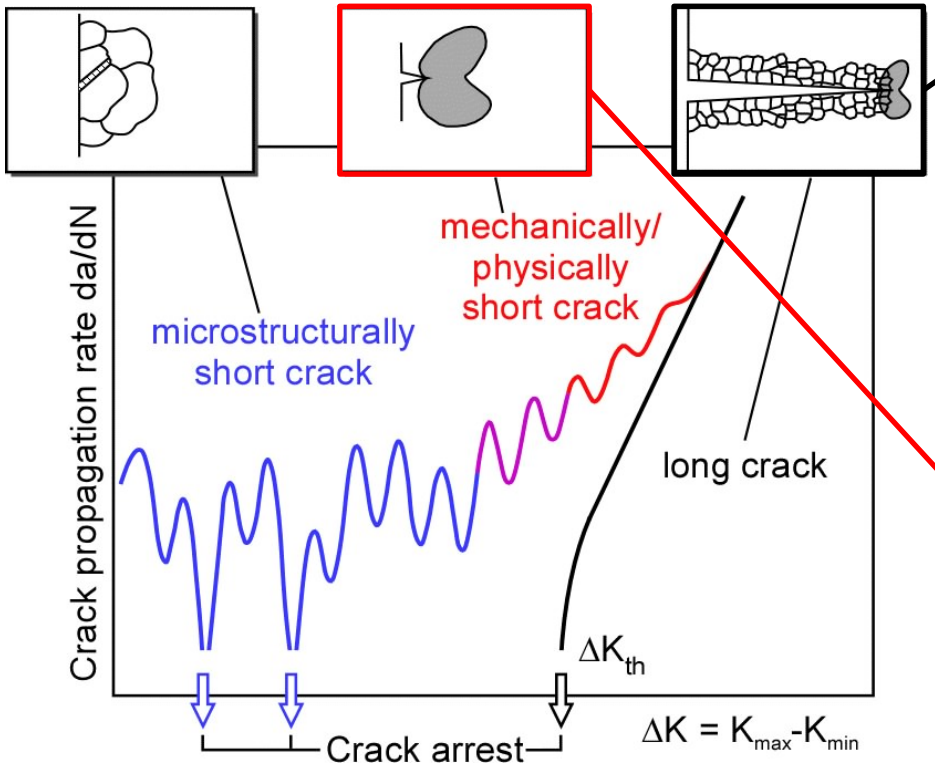


✓ Modelling of cracks coalescence mechanism



$a = \max(a_{1k}\,;\, a_{2k})$ $\quad c = c_{1k} + c_{2k}$

Modelling of short crack propagation: Plasticity correction



Long crack: small scale yielding holds!

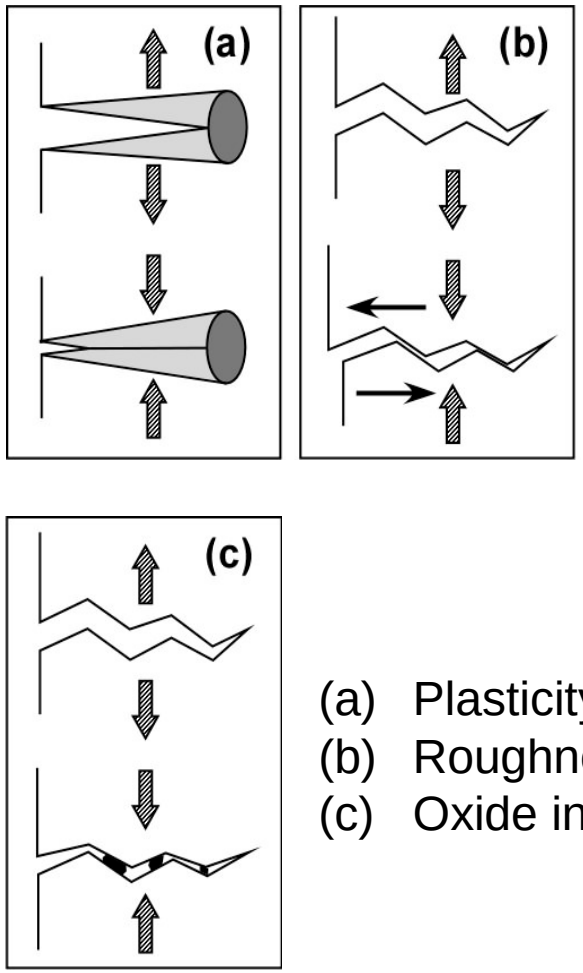
ΔK can be used to calculate the crack driving force

Mechanically/physically short crack: plastic zone in the order of crack size!

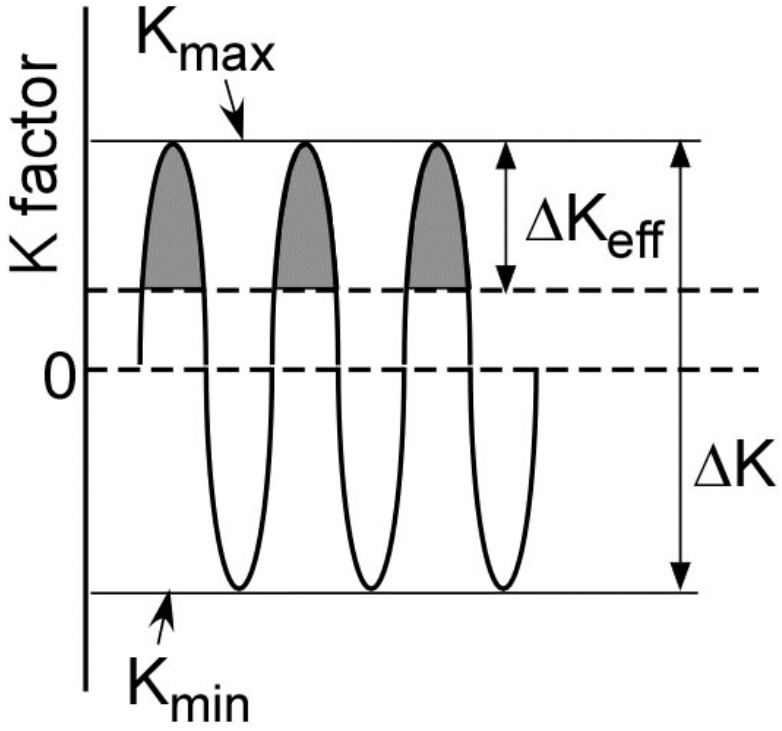
ΔK CANNOT be used to calculate the crack driving force

Solution: plasticity-corrected $\Delta K \longrightarrow \Delta K_{pl} = \sqrt{\Delta J \cdot E'}$

Modelling of short crack propagation: Crack closure effect (1)



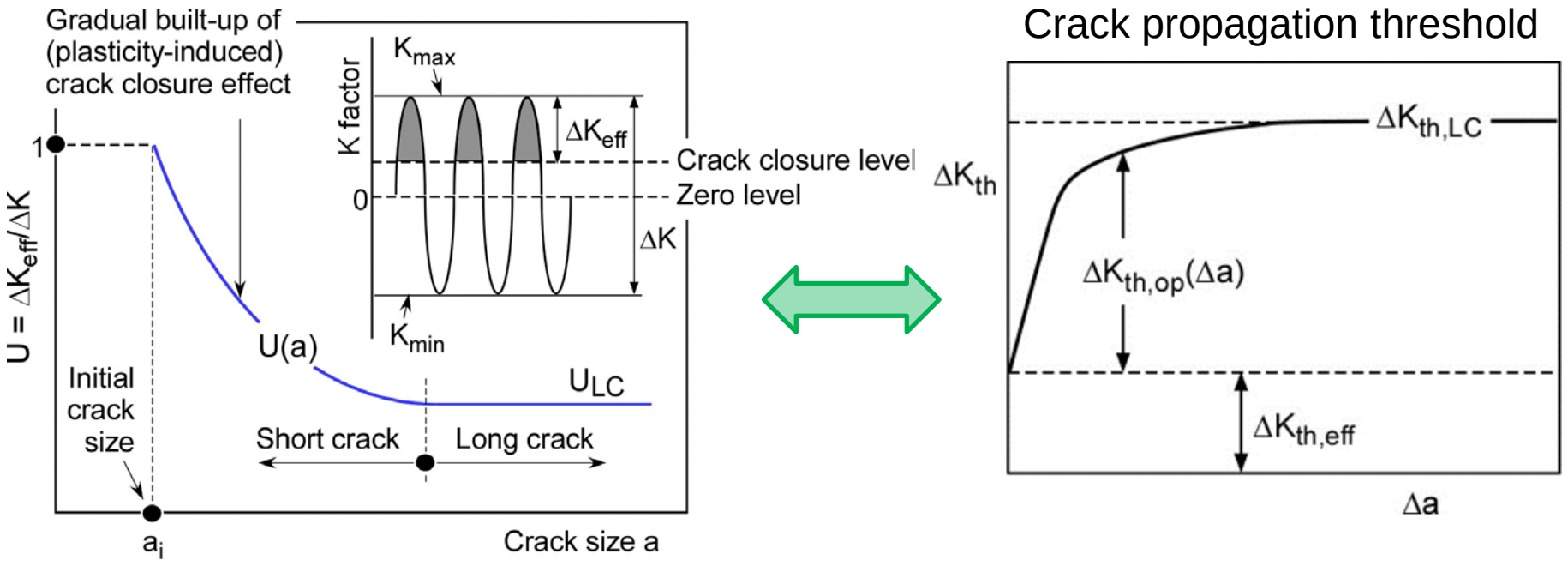
(a) Plasticity induced
(b) Roughness induced
(c) Oxide induced



Crack closure factor

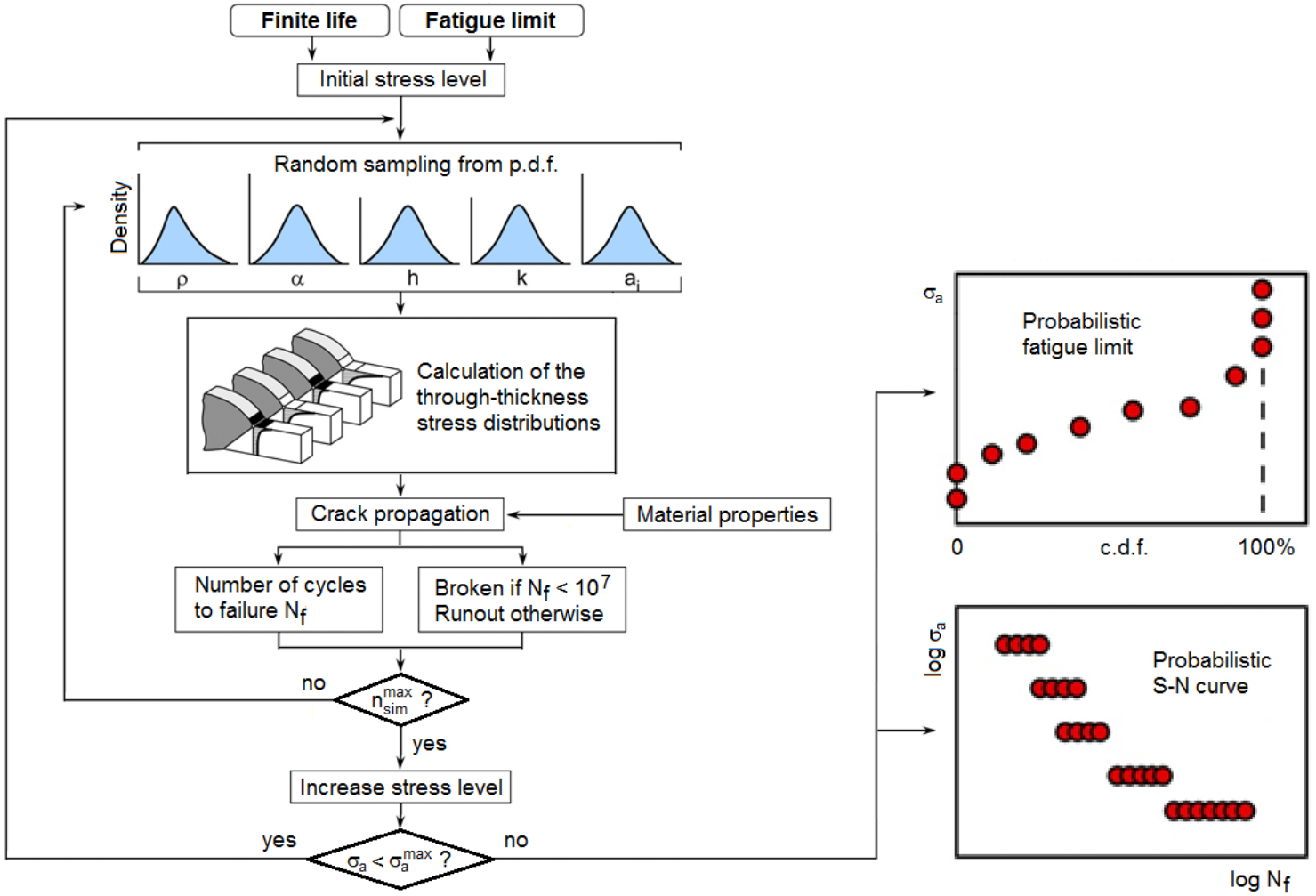
$$U = \Delta K_{eff} / \Delta K$$

Modelling of short crack propagation: Crack closure effect (2)



$$\frac{U(a)-1}{U_{LC}-1}=\frac{\Delta K_{th}(a)-\Delta K_{th,eff}}{\Delta K_{th,LC}-\Delta K_{th,eff}}$$

Program flowchart



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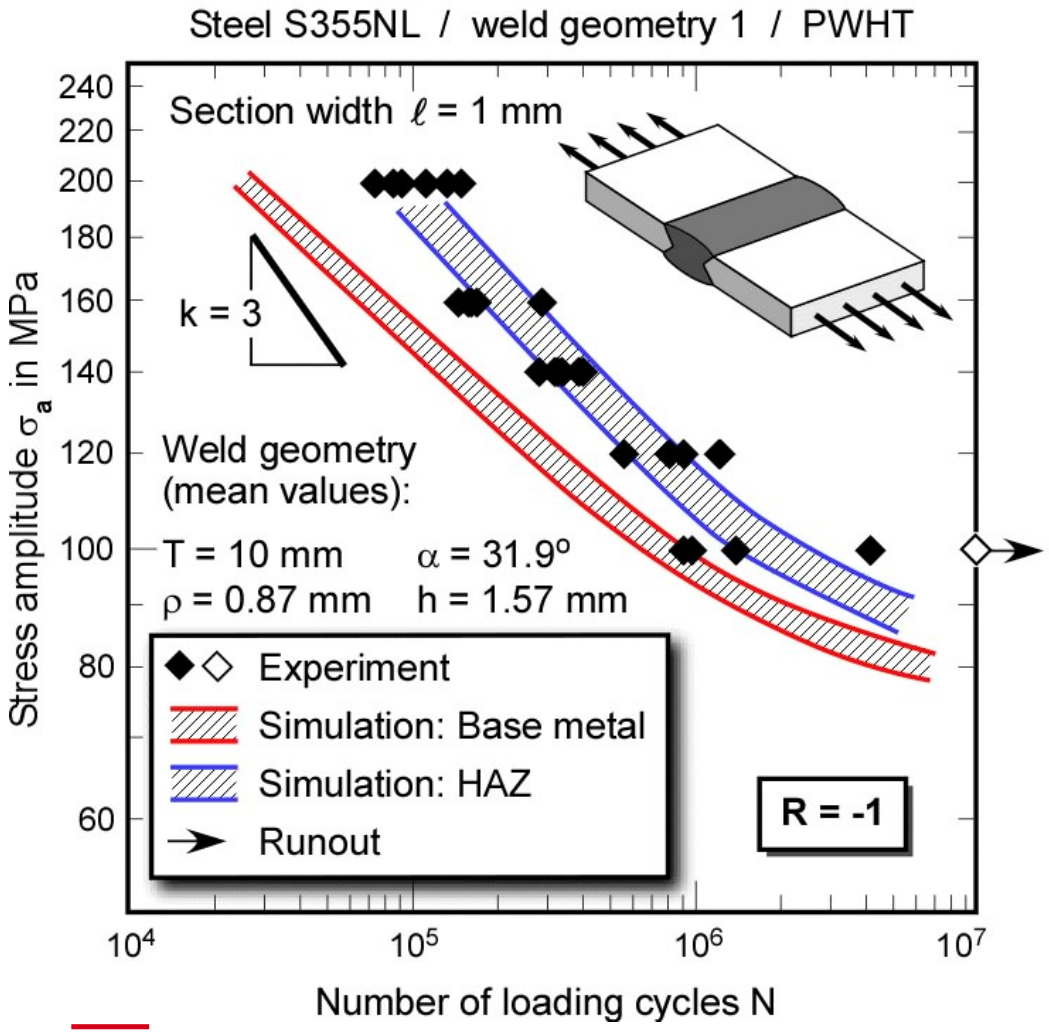
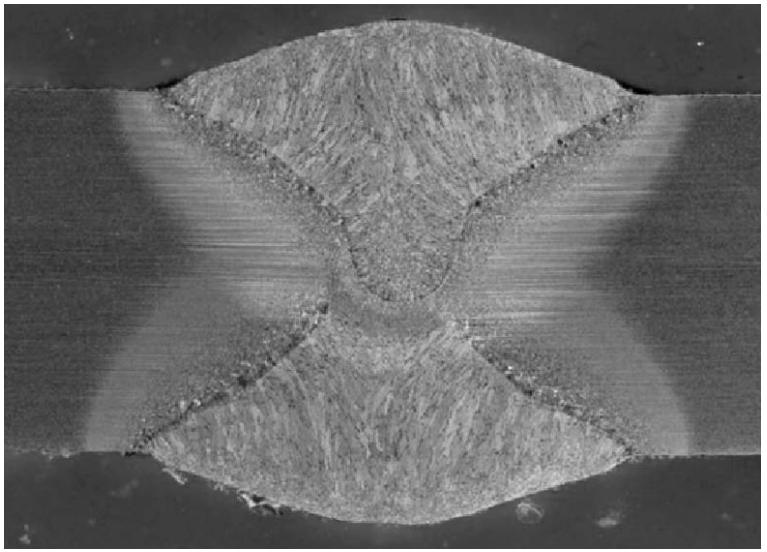
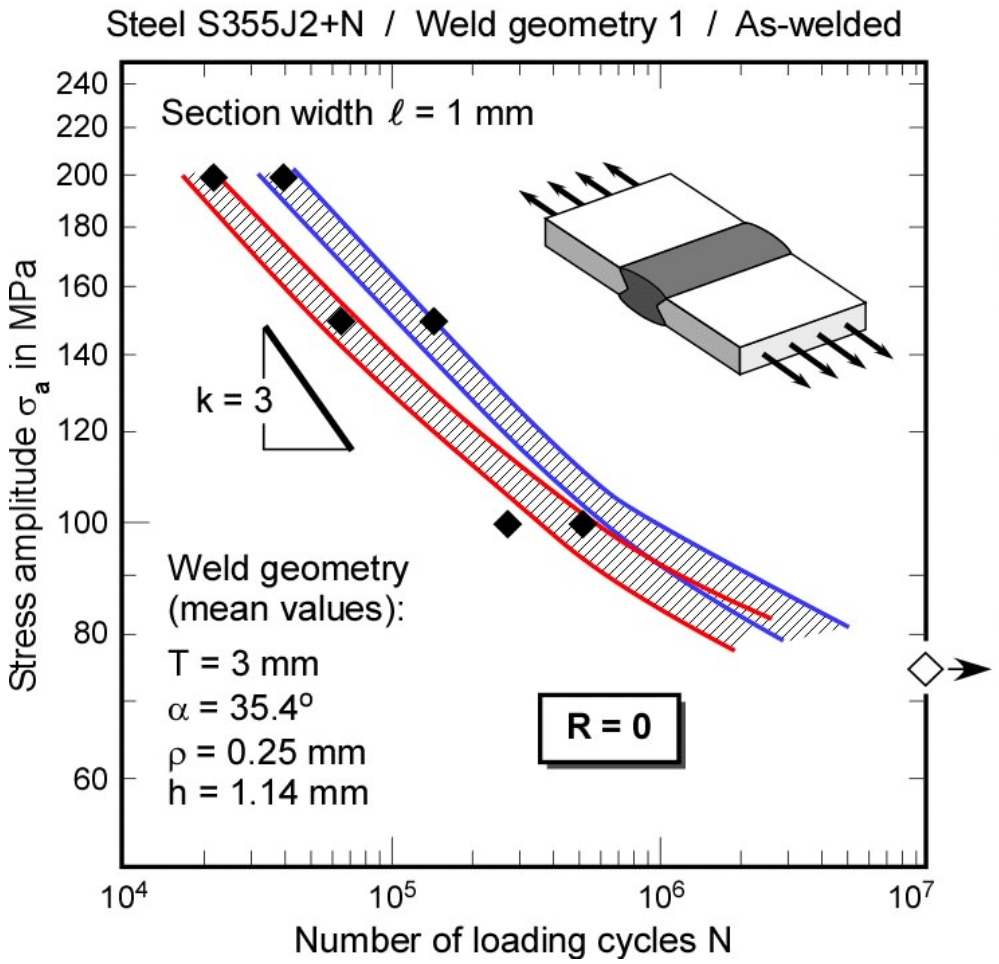
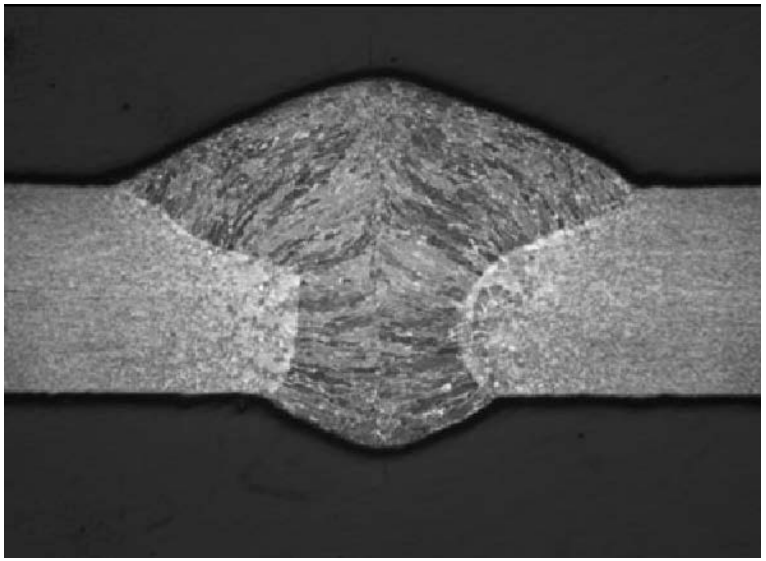
Case studies (1)





Case studies (2)





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Conclusions

An analytical procedure for the probabilistic assessment of the stress-life diagram for welded joints has been presented

Key-points of the modelling:

✓ Random input variables

✓ Calculation of the propagation of mechanically-short cracks
- Elastic-plastic assessment of the cracks driving force
- Description of the gradual build-up of crack closure (cyclic R-curve)

✓ Multiple crack initiation and propagation

Satisfactory / slight conservative approximation of the finite life and fatigue limit

Sensitivity analysis for evaluating the relevance of the model parameters

Outlook

Open questions and further development of the procedure:

- ✓ Systematic calculation of FAT-Classes
- ✓ Investigation of the residual stress relief
- ✓ Investigation of the effect of post-weld treatments
- ✓ Extension of the procedure to variable amplitude loading
- ✓ Experimental work to optimize the description of the cyclic R-curve
- ✓ Application of the procedure to further components and materials

IGF-Research Project 17518 N/1

Thank you for your kind attention!

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