FATIGUE BEHAVIOUR OF ADDITIVELY MANUFACTURED STRUCTURES

Fraunhofer
LBF

Rainer Wagener, **Matilde Scurria**, Heinz Kaufmann

Fraunhofer Institute for Structural Durability and System Reliability LBF, Darmstadt, Germany

offen

Motivation

ADDITIVE MANUFACTURING TECHNOLOGIES

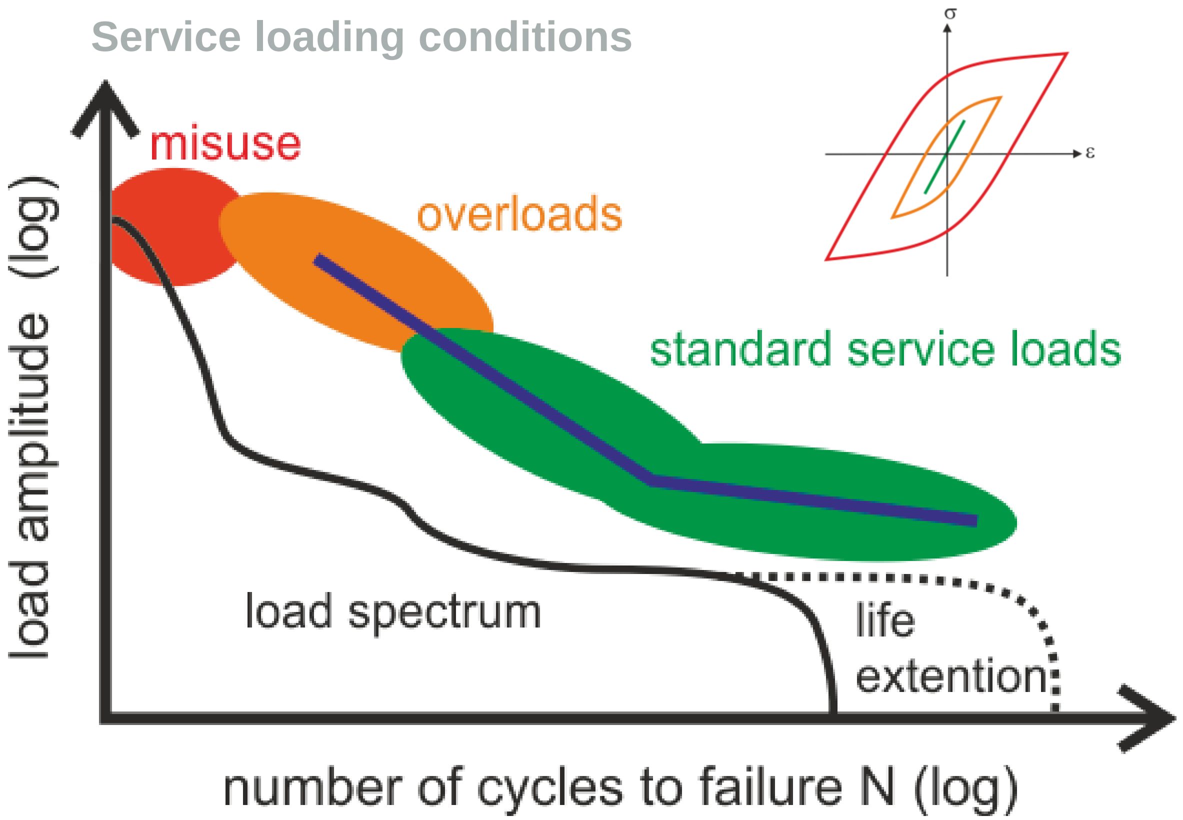
High design flexibility

Suitable for adaptive solutions

Sustainable production
(reduction of waste)

Fraunhofer LBF

Challanges



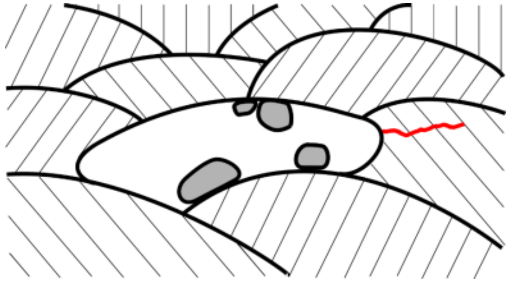
- material properties
- transferability
- considering the main influences
- reliable assessment of different loading conditions and components
- improved ratio of computational effort and simulation accuracy

⇒ Enable the light weight potential and get a benefit of design freedom of additive manufacturing.

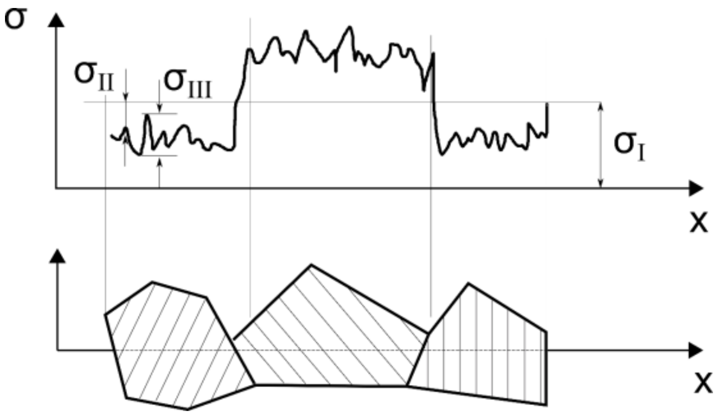
Influences on the structural durability

- **Surface:**
  - roughness,
  - notches,
  - open pores

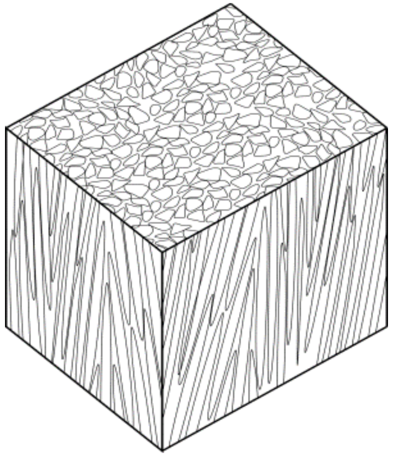
- **Internal irregularities:**
  - pores,
  - un-melted particles,
  - lacks of fusion



- **Residual stress**



- **Microstructure:**
  - grain orientation,
  - grain boundaries,
  - grain size,
  - inclusions



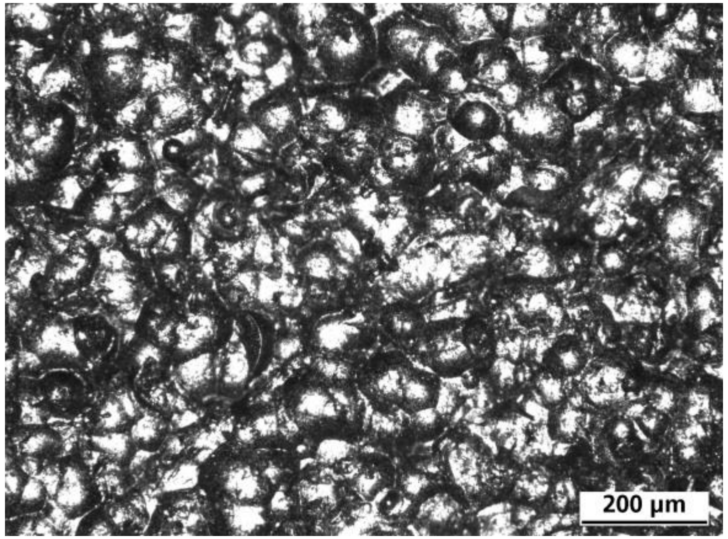
Fraunhofer LBF

Influences on the structural durability

- Support structures

- Surface:
  - roughness,
  - notches,
  - open pores

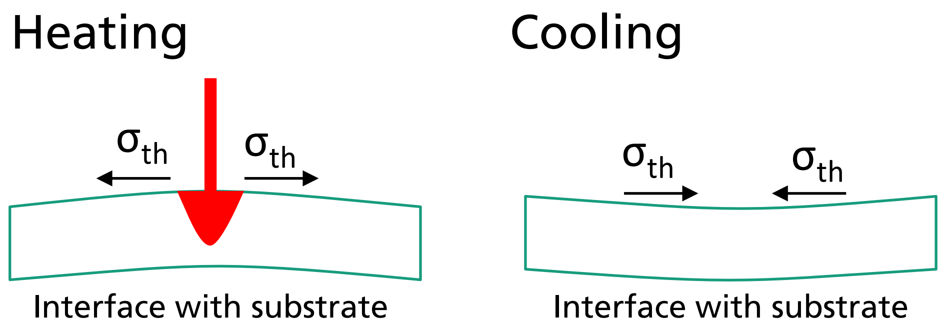
- Surface finish



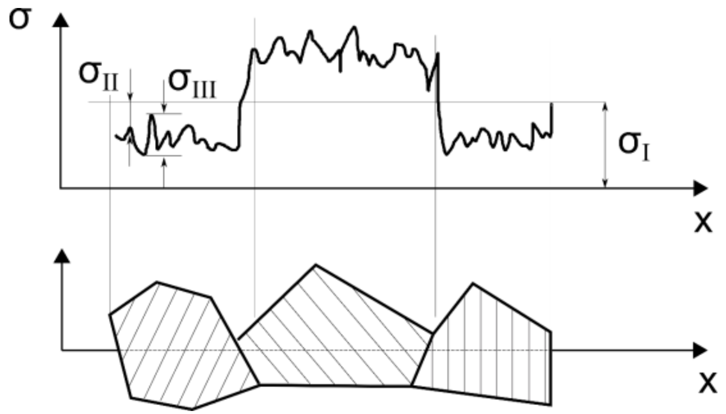
- Process parameters
  - Laser related
  - Scan related
  - Powder related
  - Temperature related

Influences on the structural durability

- **Process related**



- **Residual stress**

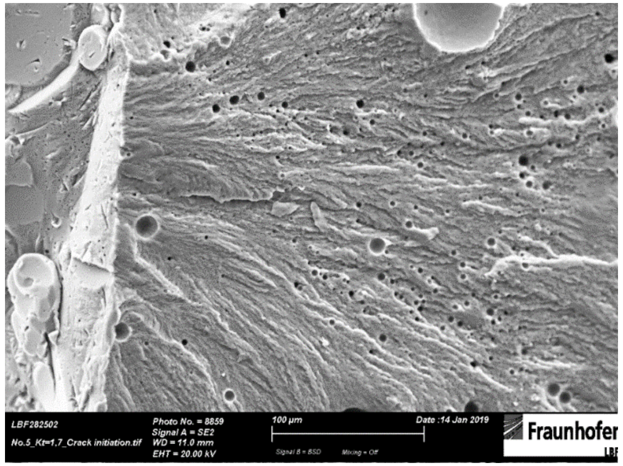


- **Support structures**

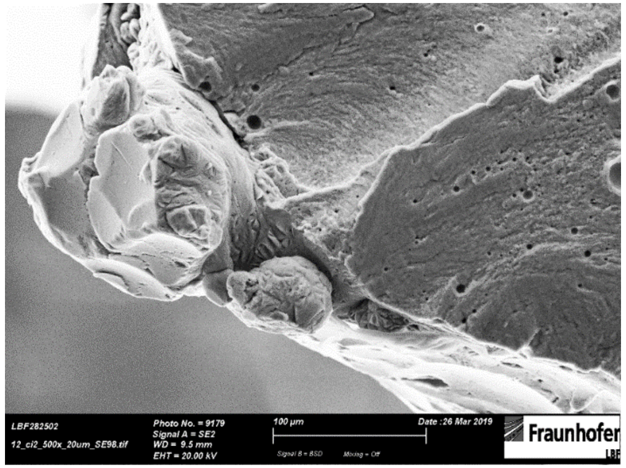
- **Temperature of the build platform**
- **Build orientation**

Influences on the structural durability

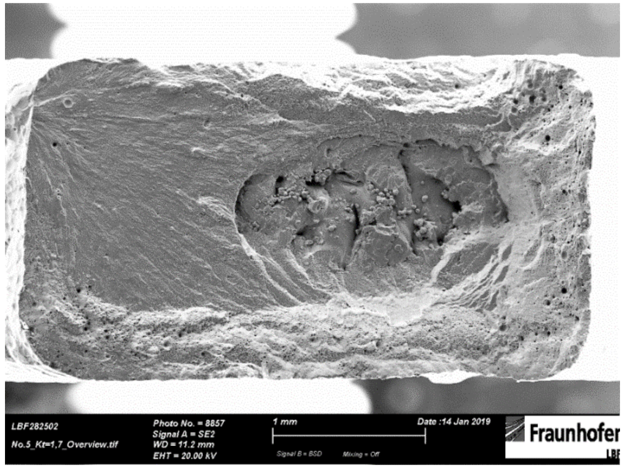
- Pores



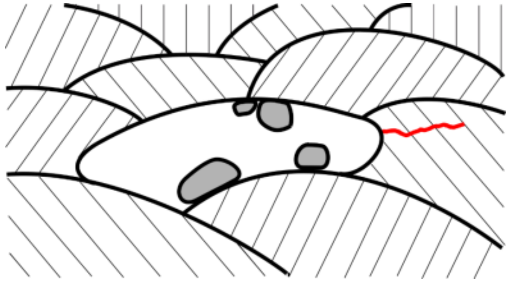
- Un-molten particles



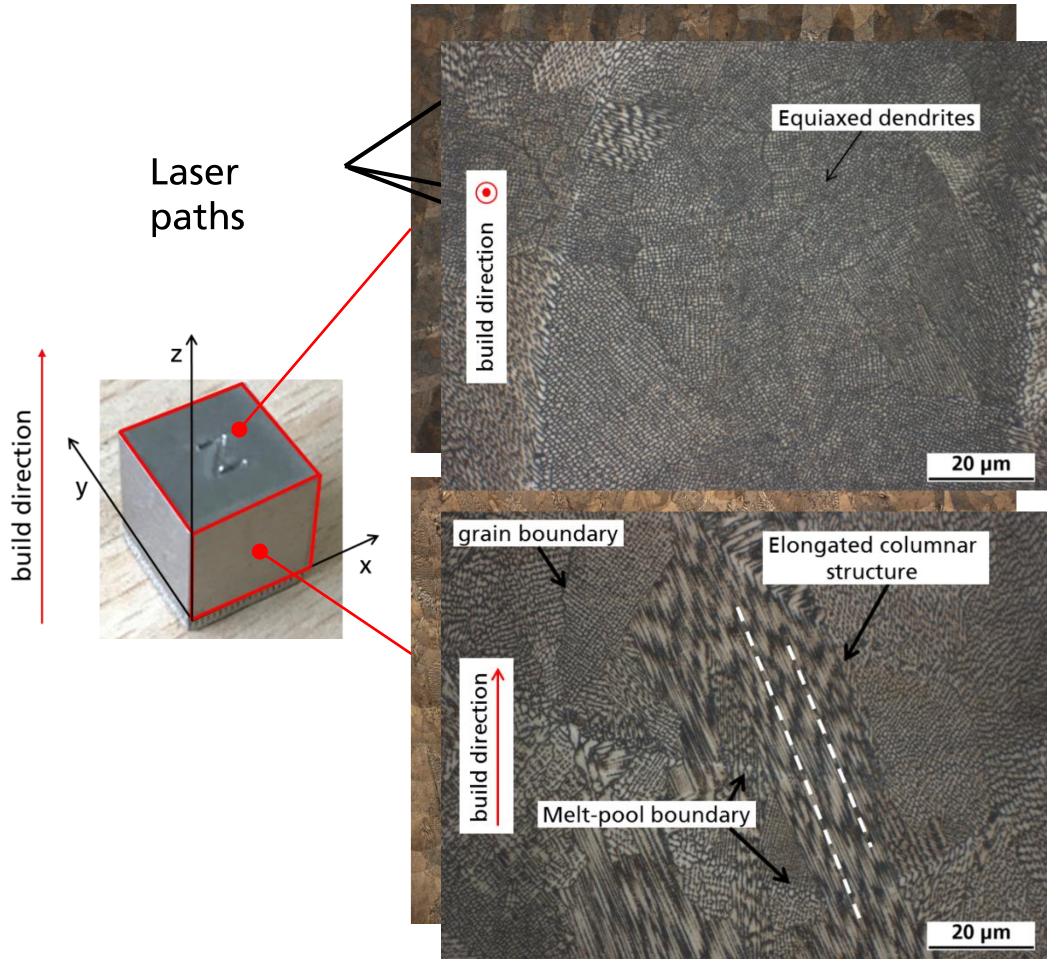
- Lacks of fusion



- Internal irregularities:
  - pores,
  - un-melted particles,
  - lacks of fusion

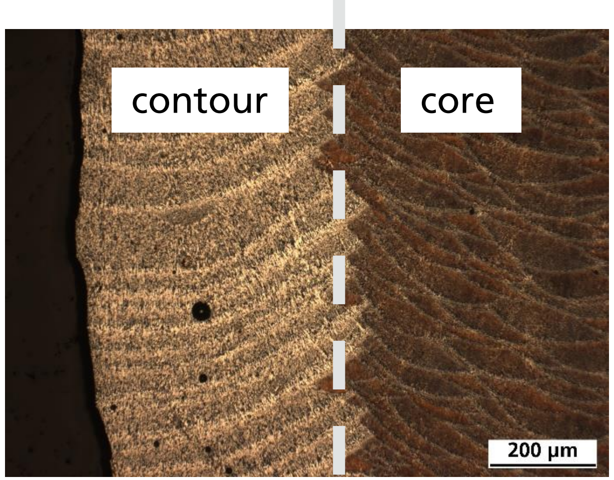


Influences on the structural durability



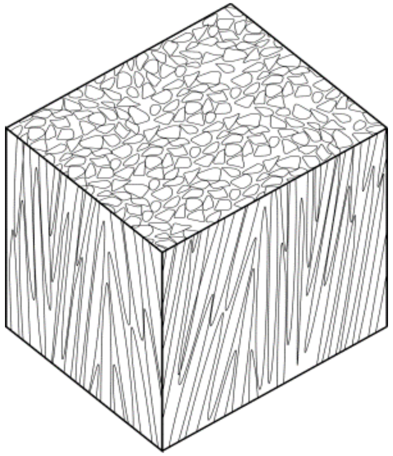
Inconel718

Different parameters → different microstructue



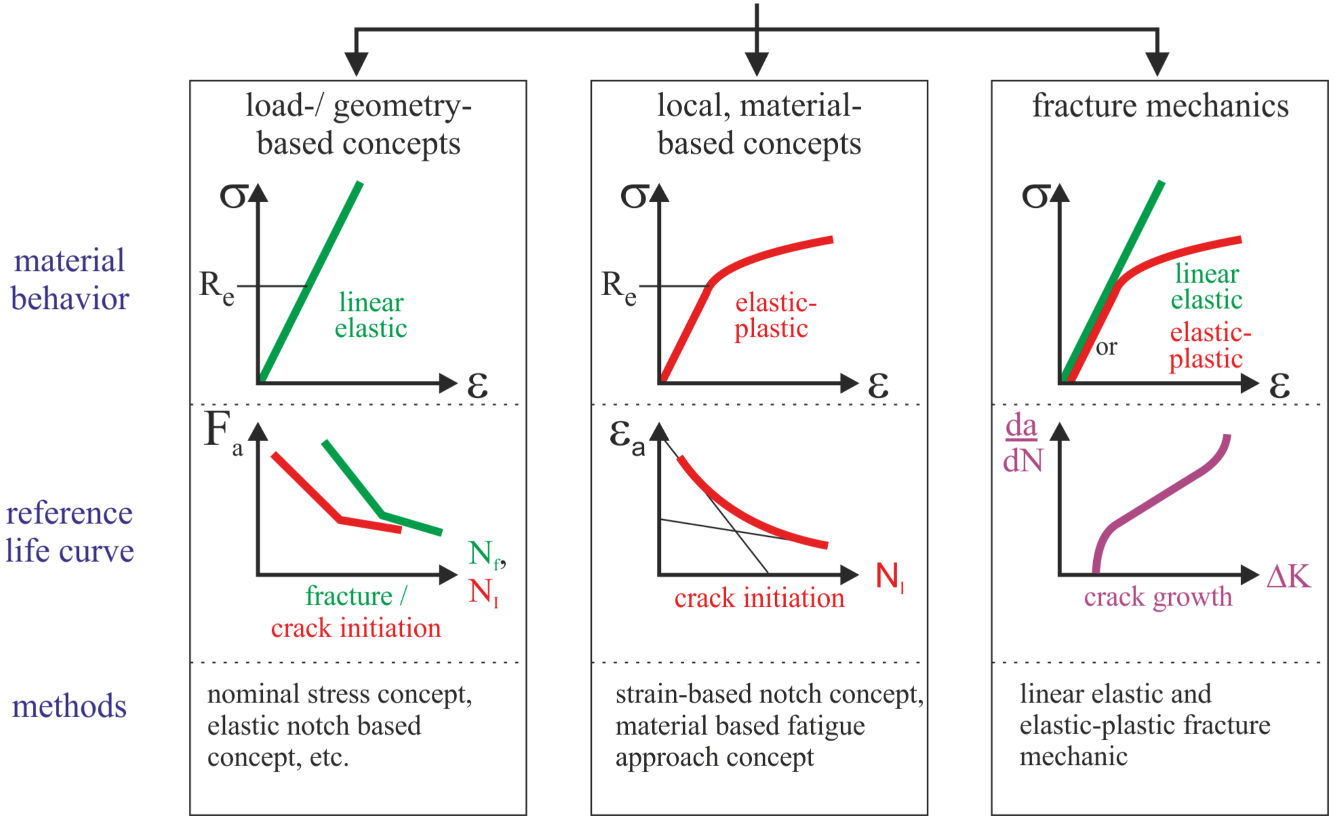
AlSi10Mg

- **Microstructure:**
  - grain orientation,
  - grain boundaries,
  - grain size,
  - inclusions



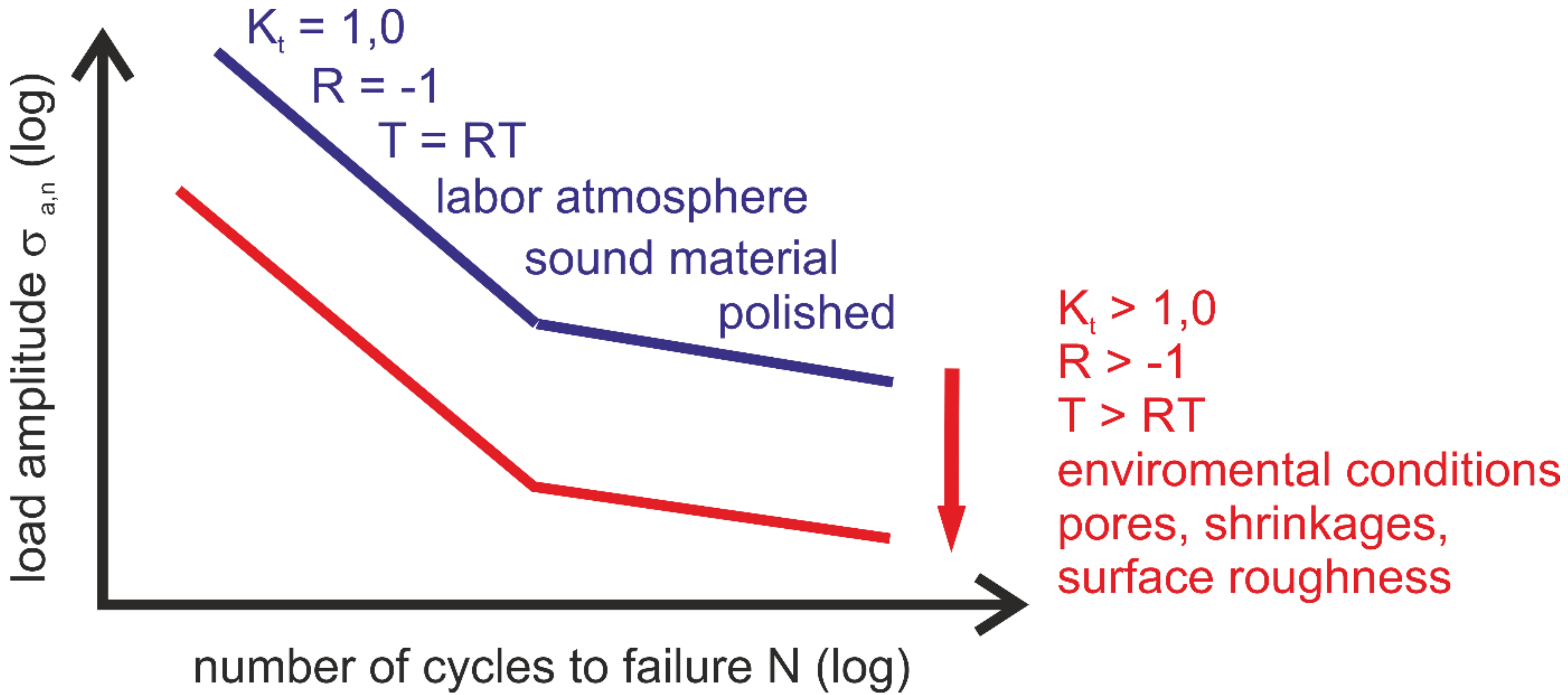
Fraunhofer
LBF

Fatigue Life Assessment Concepts



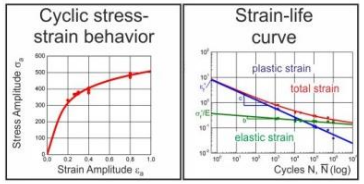
- Load-based concepts
  - linear elastic stress-strain behavior
  - homogeneous properties distribution
  - sensitivity factors to shift the SN-line
- Strain-based concepts
  - elastic-plastic stress-strain behavior
  - describing the local material behavior of an infinitesimal small volume
  - pore geometry and distribution have to be included to the FE-model

Nominal stress concept

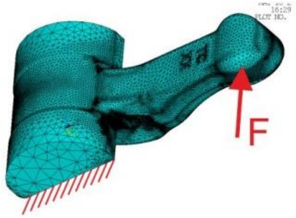


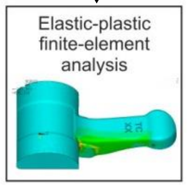
Local fatigue approach concept

Characterization of the cyclic material behavior with strain controlled tests on un-notched specimens

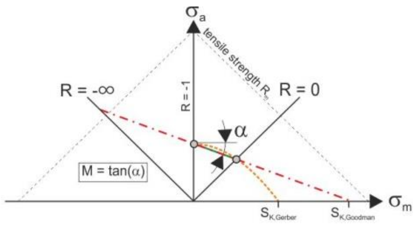


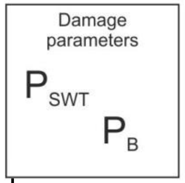
Elastic-plastic finite-element analysis using load assumption, boundary conditions, cyclic stress-strain behavior and component geometry



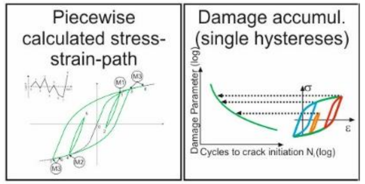


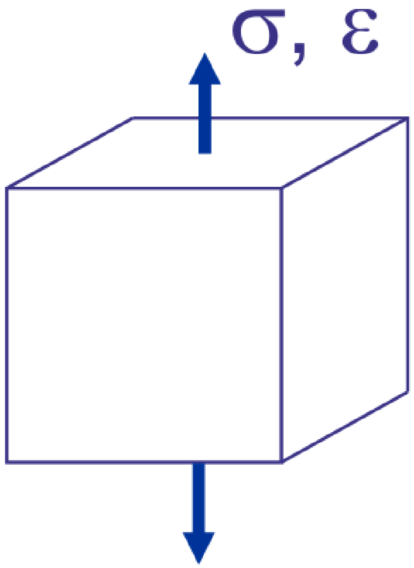
Accounting for mean stress effects using damage parameters, for example according to Smith-Watson-Topper





Fatigue life estimation for variable amplitude loading may entail a piecewise calculation of the stress-strain path if transient material behavior has to be considered





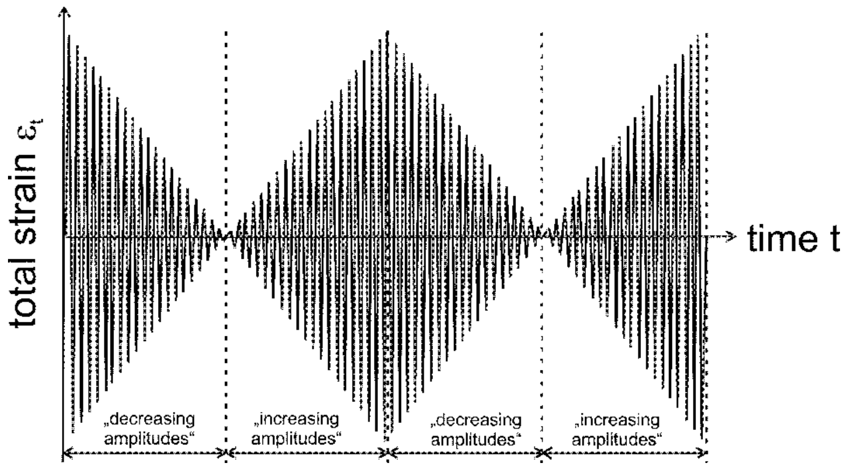
infinitesimal small volume,

homogeneous microstructure

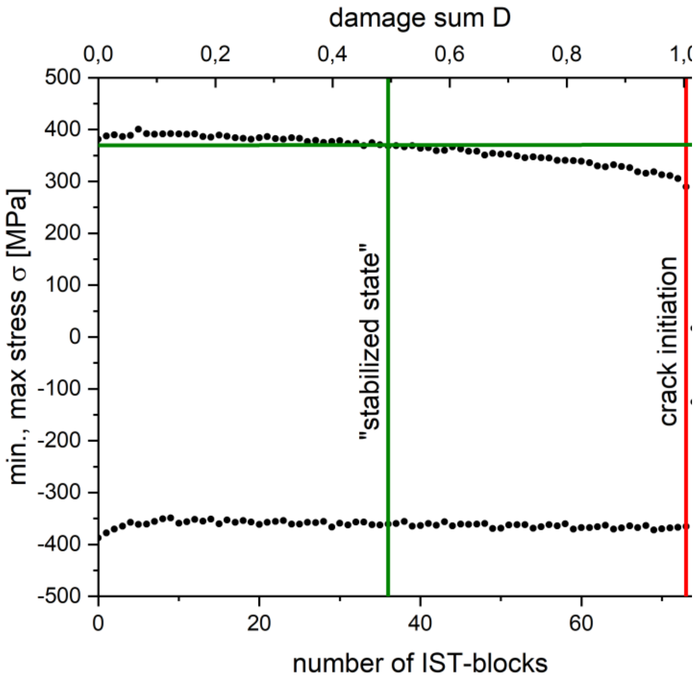
Fraunhofer LBF

Incremental Step Test

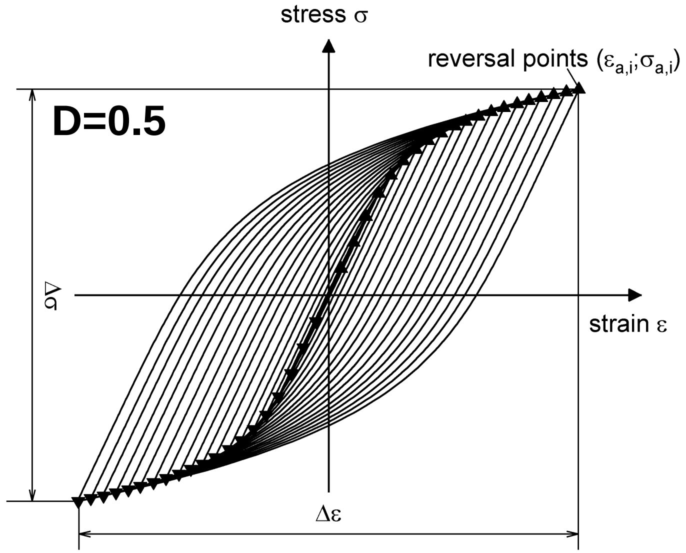
load time function



stress evaluation



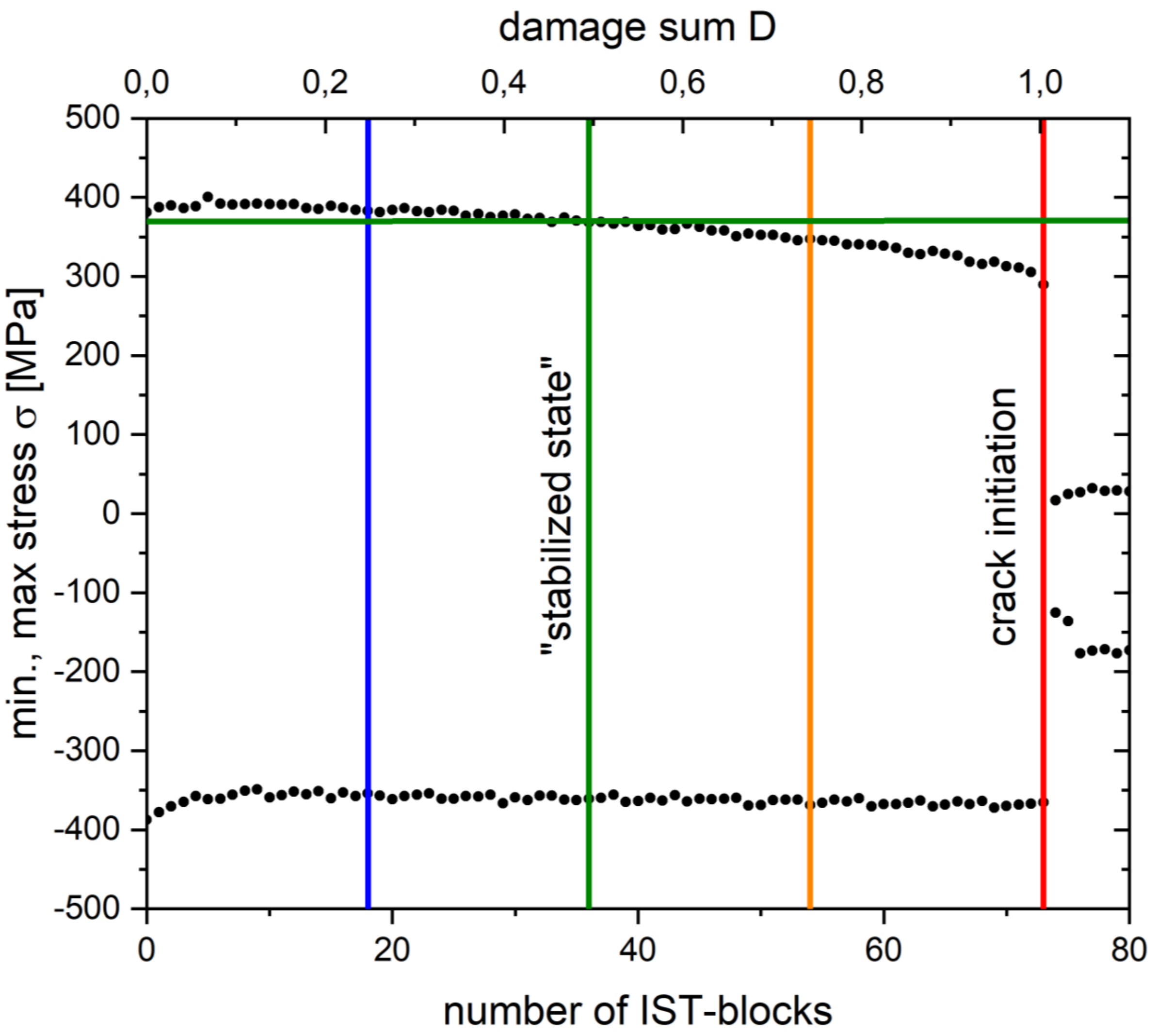
Stress-strain hysteresis loops of a single block

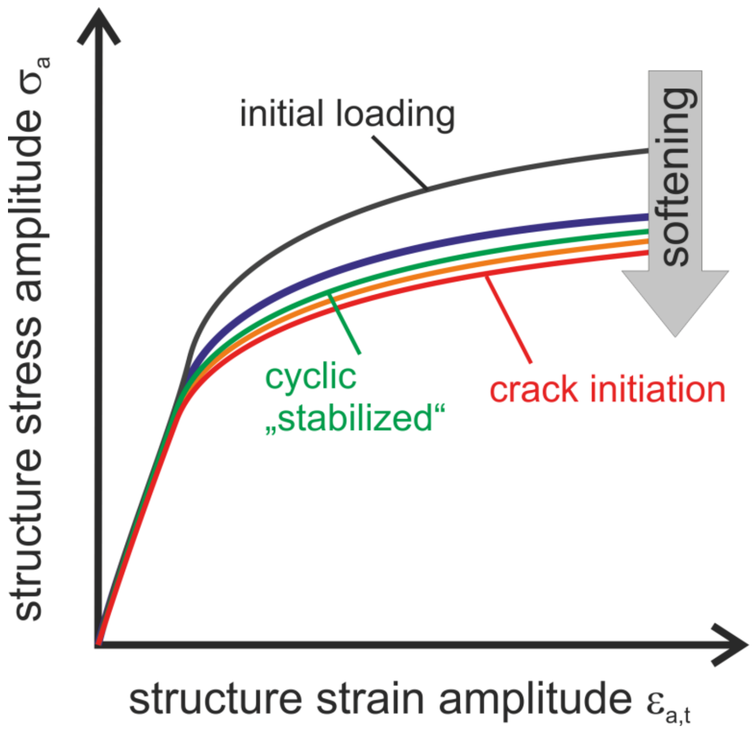


Reversal points describing the cyclic stress-strain curve

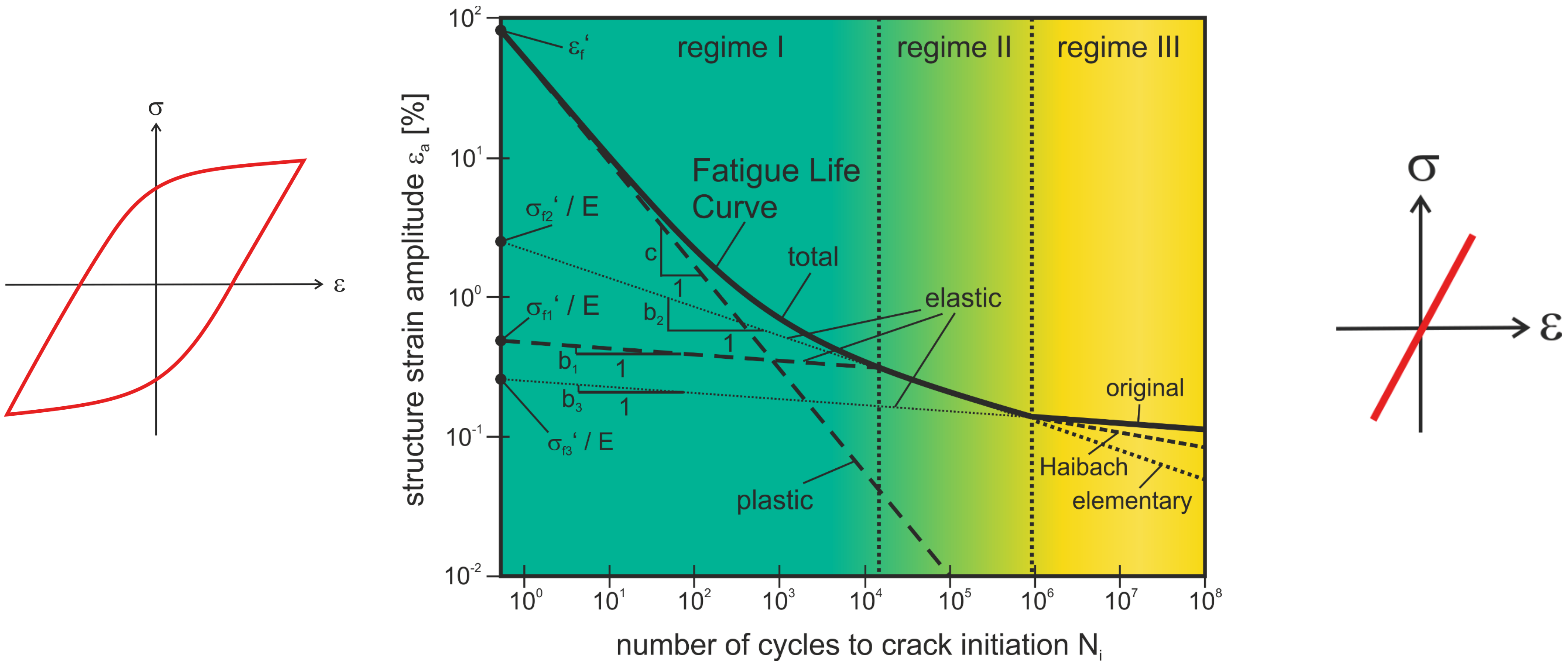
Fraunhofer LBF

Cyclic transient material behavior





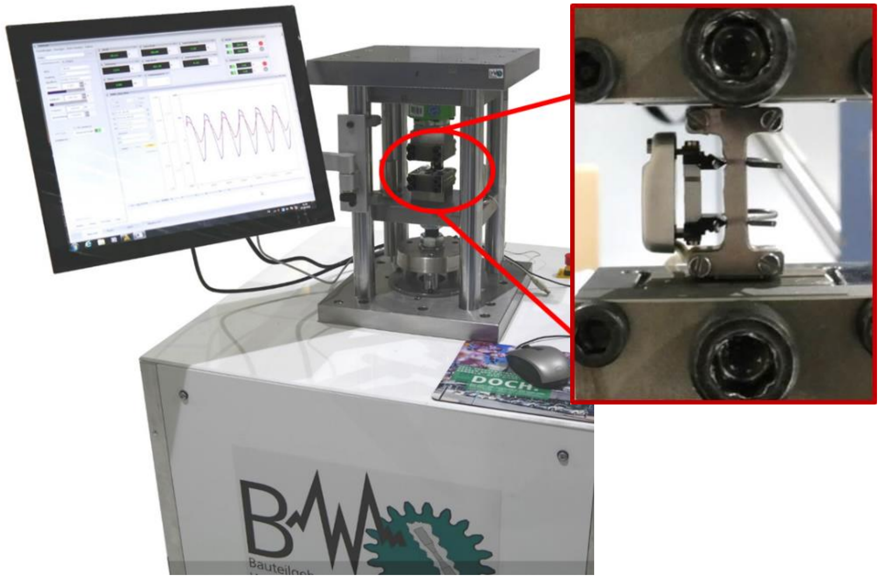
Fatigue Life Curve

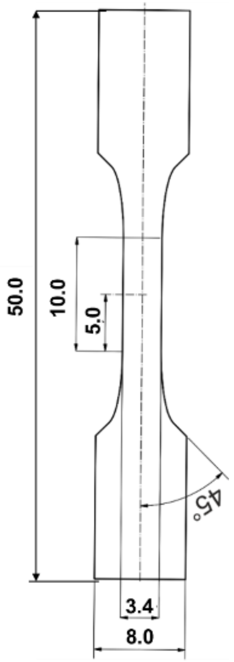


Fraunhofer LBF

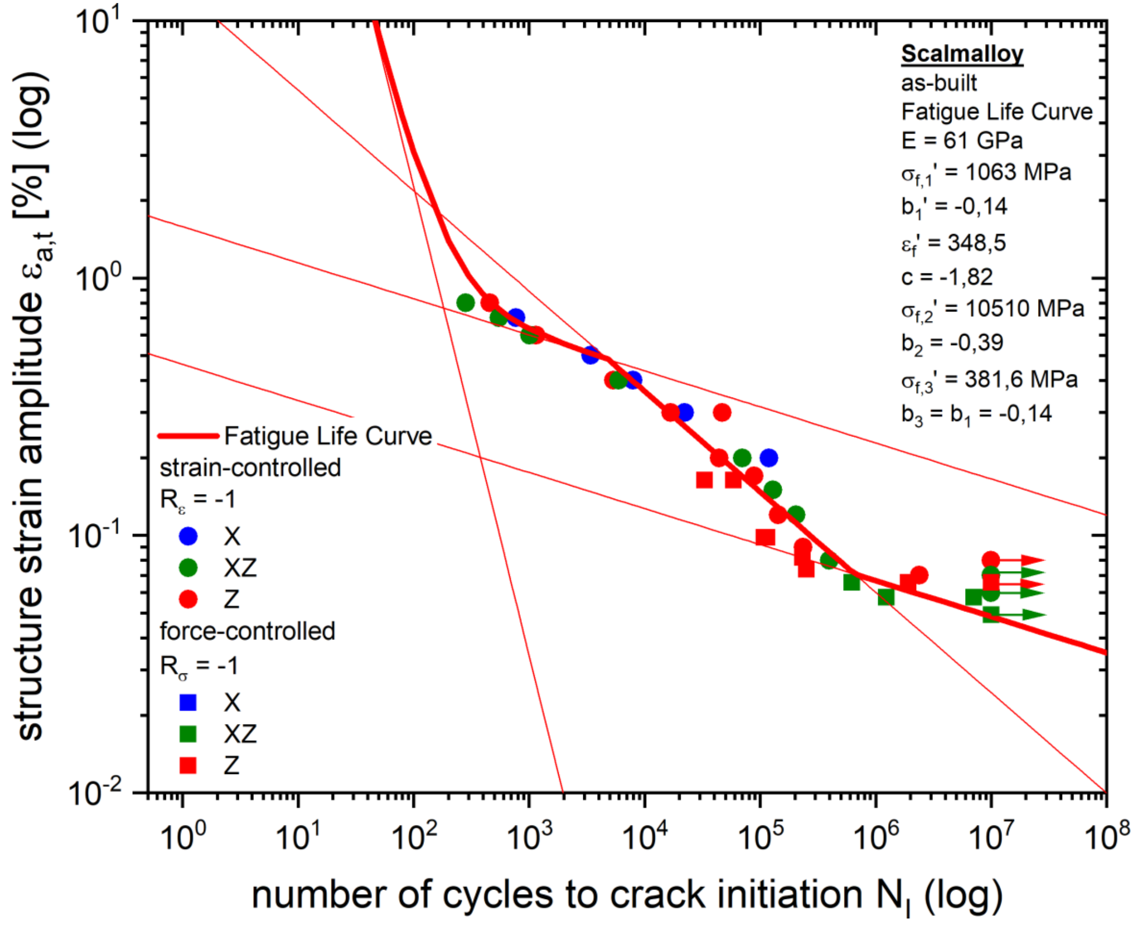
Test Equipment

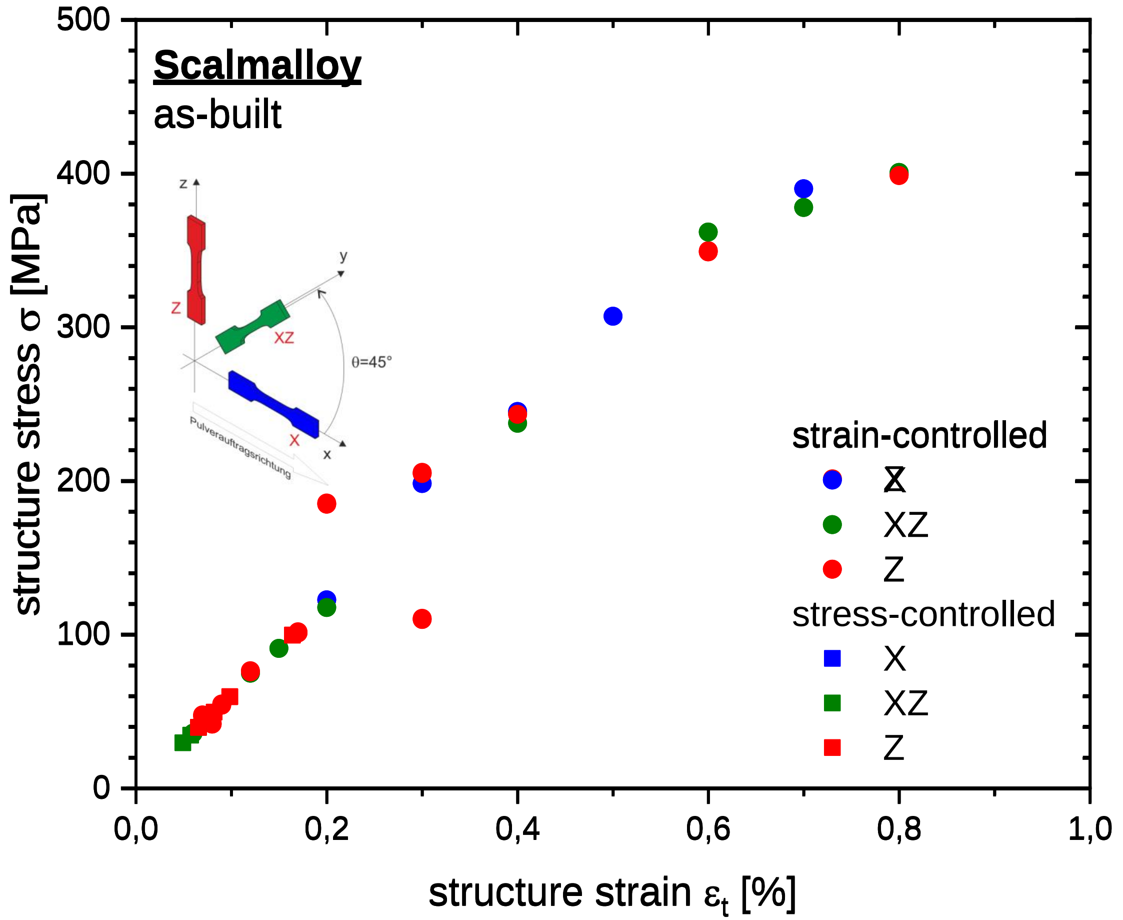
- **E-Cylinder test rig**
  - For low frequency, strain controlled tests
- **Piezo-based test rig**
  - For high frequency, stress- and strain controlled tests





Scalmalloy – as built





Fraunhofer LBF

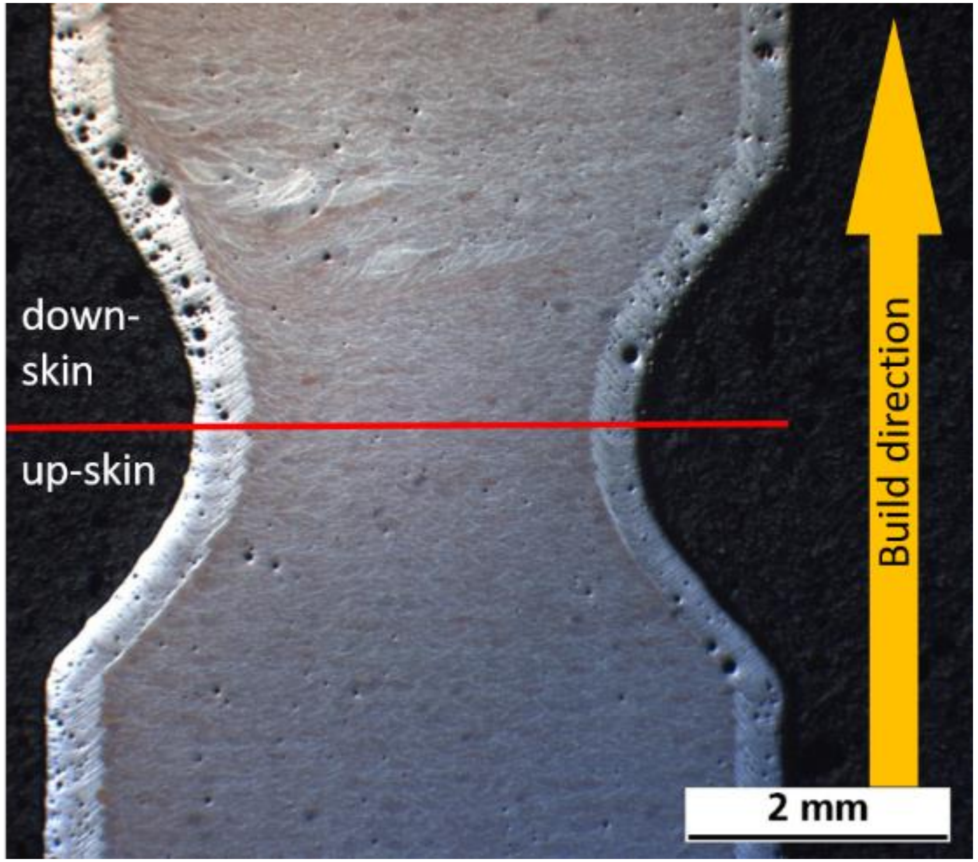
Magnification of the cross-sections

t ≈ 3mm

t ≈ 2mm

t ≈ 0.8mm

Structural analysis of a magnification



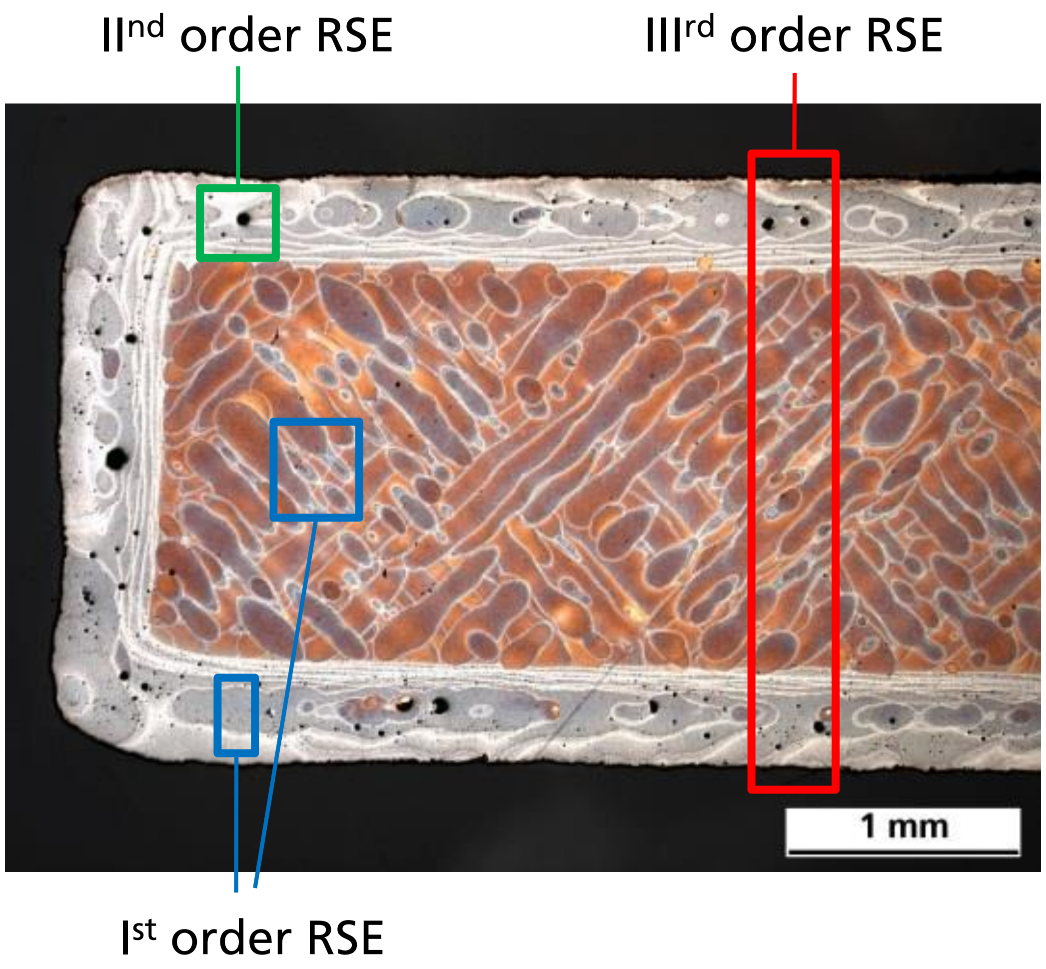
- Inhomogeneous microstructure, influenced by up-and down skin orientation
- Defects like pores and microcracks

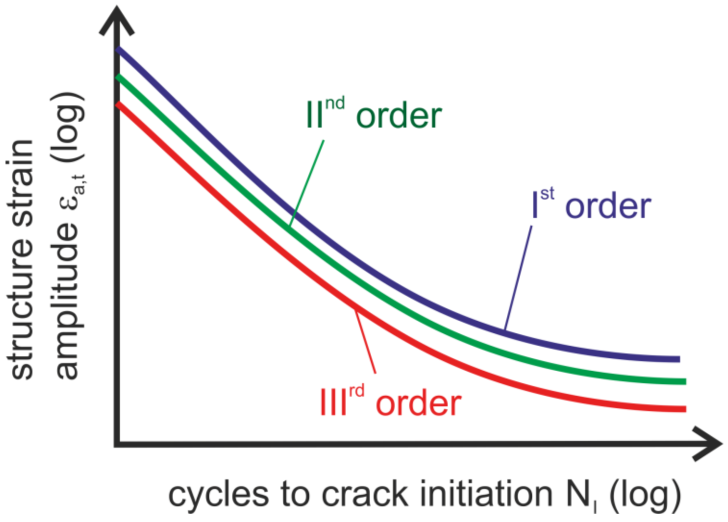
⇒ Local fatigue approach is required

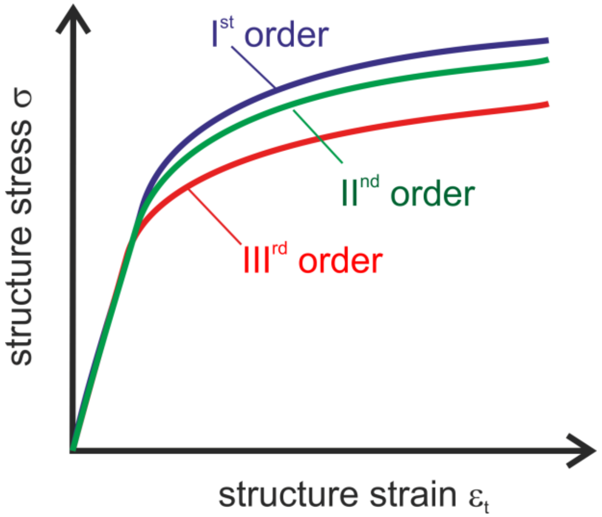
Disadvantage: increasing numerical effort

Fraunhofer LBF

Representative Structure Element RSE



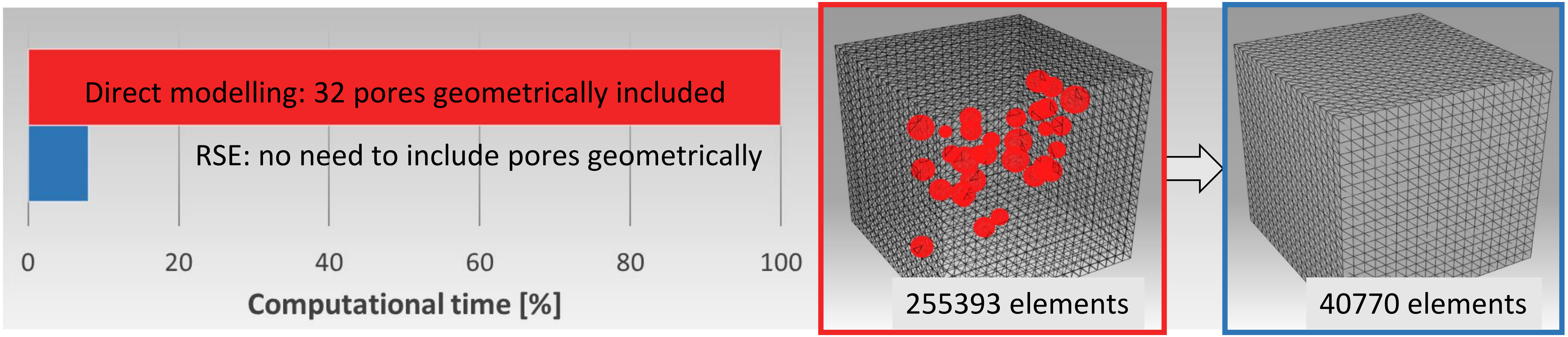




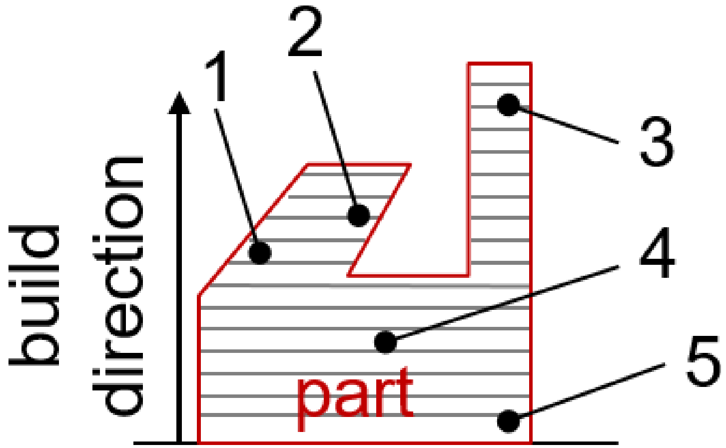
- Representative Structure Elements:
  - Ist order: sound material
  - IInd order: defects like pores, surface roughness
  - IIIrd order: different microstructures and defects

Fraunhofer LBF

Numerical simulation effort



Conclusions



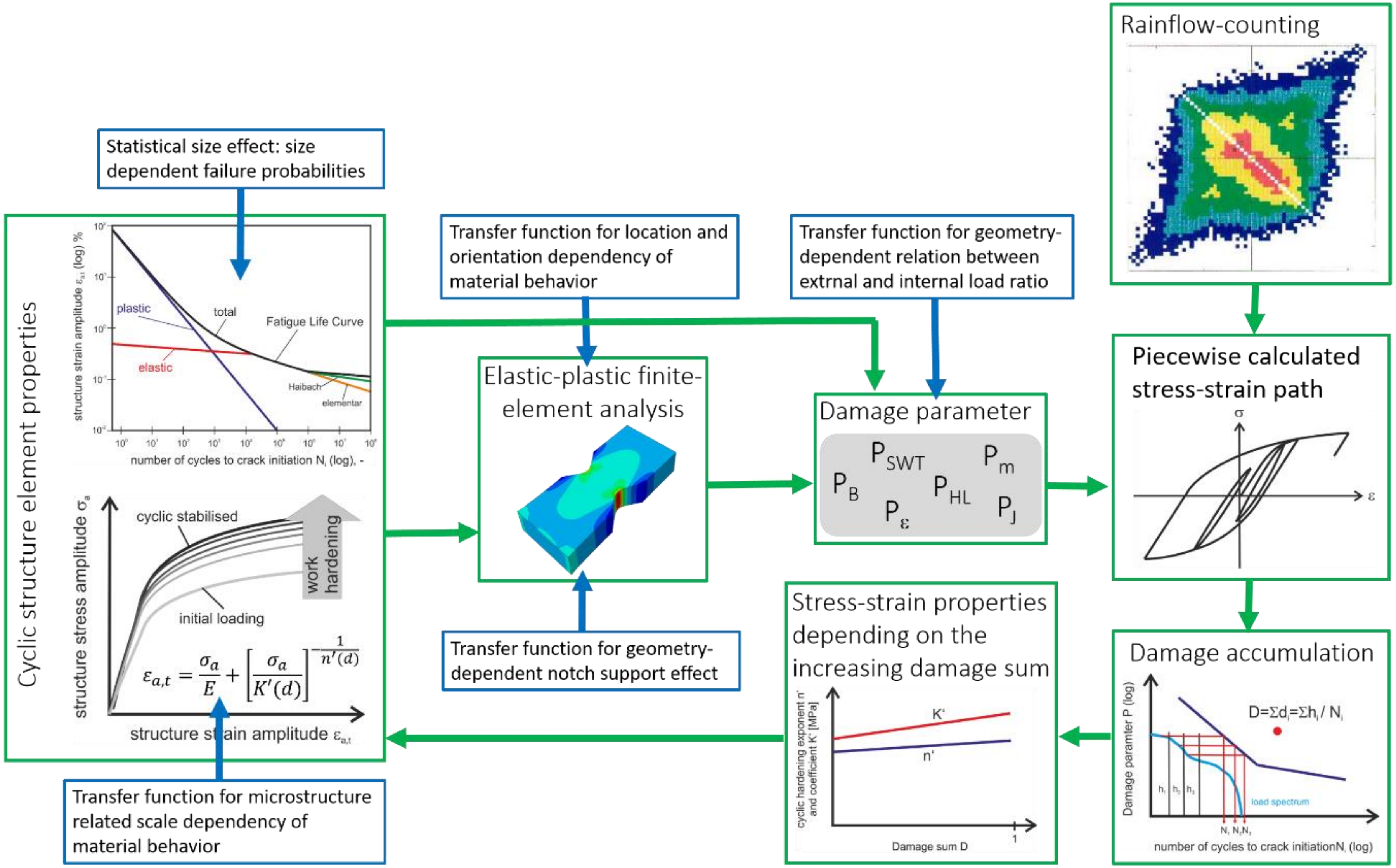
Applying Representative Structure Elementes

Depending on the component orientation, scan and support structure strategy different Representative Structure Elements can be used

- Stress-strain behavior derived by Incremental Step Tests with a max amplitude related to the expected max service loads
- Fatigue Life Curve to describe strain – fatigue life relation

Fraunhofer LBF

Outlook - RSE based fatigue approach concept



Acknowledgements

The research and development projects 'VariKa' and 'BadgeB' that form the basis for this publication are funded within the scope of the "PAiCE Digitale Technologien für die Wirtschaft" technology programme run by the **Federal Ministry for Economic Affairs and Energy** (VariKA) and within the scope of the "Additive Fertigung – Individualisierte Produkte, komplexe Massenprodukte, innovatiove Materialien" (Pro_Mat_3D) by the **Federal Ministry of Education and Research** (BadgeB). The project VariKA is managed by the DLR project management agency „Gesellschaft, Innovation, Technologie -Informationstechnologien/Elektromobilität"at the German Aerospace Center in Cologne and the project BadgeB by the KIT project management agency "Projektträger Karlsruhe – Produktion und Fertigungstechnologien", respectively.

GEFÖRDERT VOM

Bundesministerium
für Bildung
und Forschung

Gefördert durch:

Bundesministerium
für Wirtschaft
und Energie

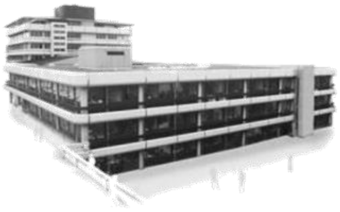
aufgrund eines Beschlusses
des Deutschen Bundestages

Fraunhofer
LBF

Thank you for your kind attention!

Fraunhofer LBF

Institute Director : Prof. Dr.-Ing. Tobias Melz

Structural Durability	Smart Structures	System Reliability	Plastics
	 		

matilde.scurria@lbf.fraunhofer.de

Fraunhofer LBF