# Technische Universität Darmstadt

Zentrum für Konstruktionswerkstoffe
State Materials Testing Institute Darmstadt (MPA)
Chair and Institute for Materials Technology (IfW)

**DP700**-Phase 1 — RFCS-2015
Grant Agreement number: 709954

Guidelines for Dealing with Plasticity Associated with Cyclic Operation (WP1/Task 1.3)

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**AUSC3-Workshop, Rome, 13th December 2017**

# Outline

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- Introduction & motivation
- Sources of cyclic plasticity
- Experimental reproduction, generation of design data
- Calculative approaches
- Summary and conclusion

# Operation of powerplants Formerly & Nowadays

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in recent times …

- Creep loadings were supposed to be predominant.
- Load changes, due to start-ups and shutdowns, were considered as rare events.

nowadays …

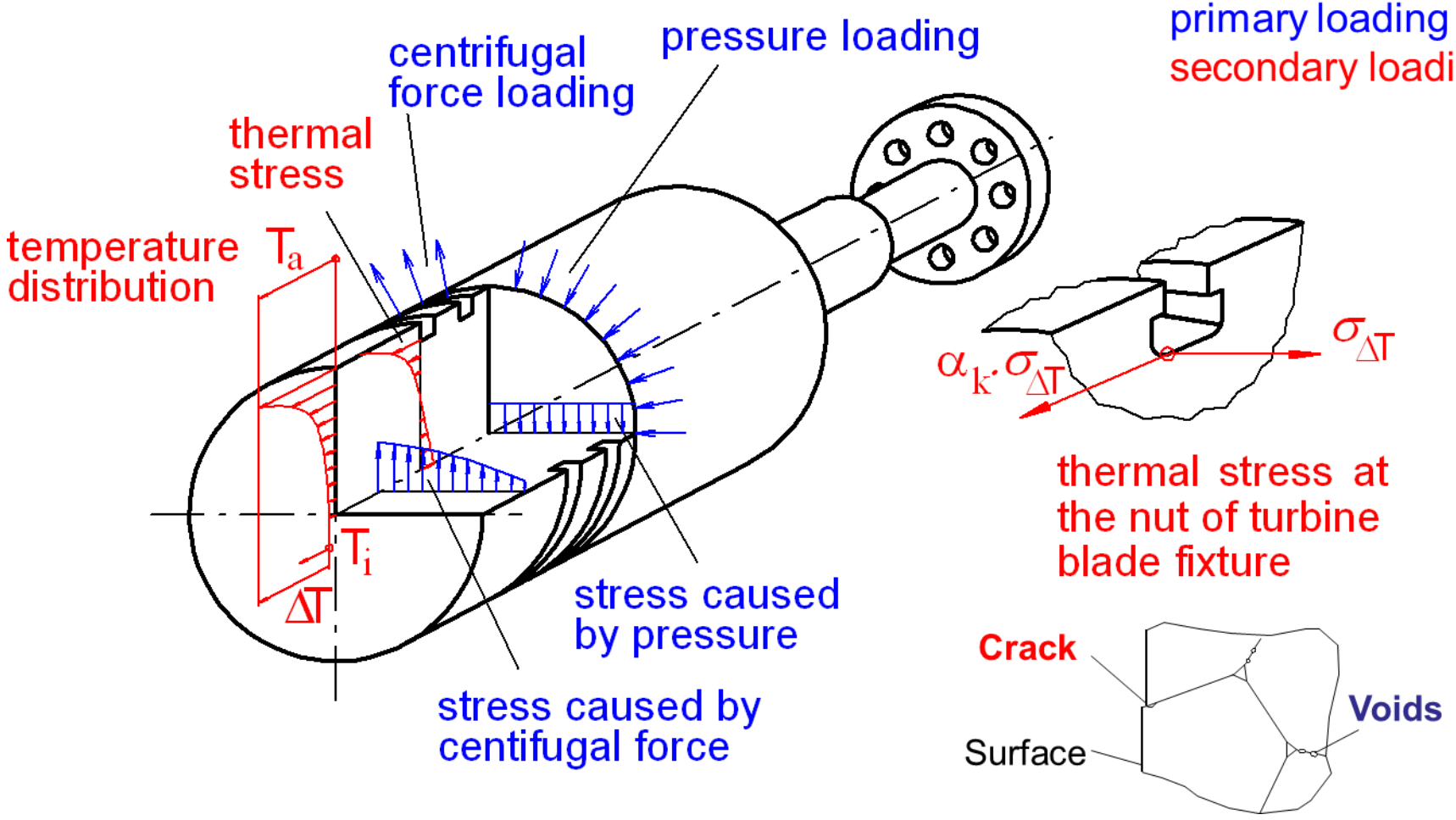
- Due to the increase in generation of volatile renewable energy, conventionally fired power plants need to keep up the grid stability.
  - Reduction of base load hours.
  - Increase of transient conditions.

    → Dominant fatigue damages due to strain constraints in pipe walls.

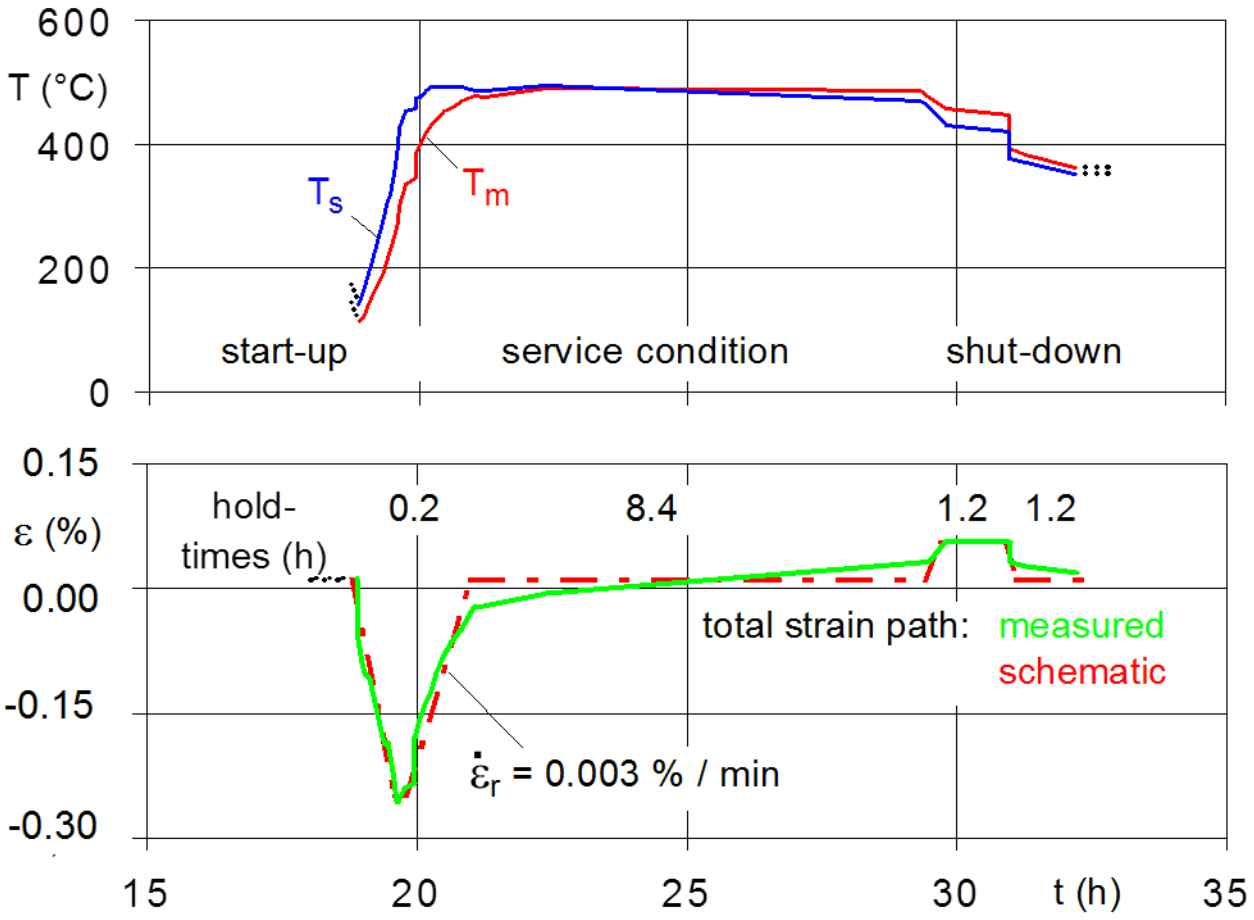
    → Shortened time interval between revisions required.

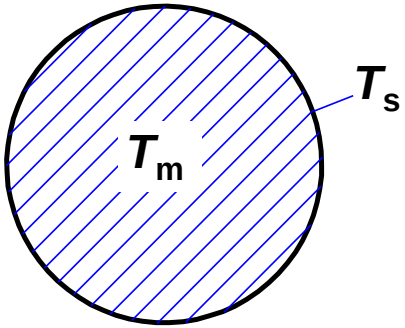
**Guidelines Required for Dealing with Plasticity**

# Loading Conditions at a Turbine Rotor



# Thermal Gradients
# Source of Strain controlled LCF



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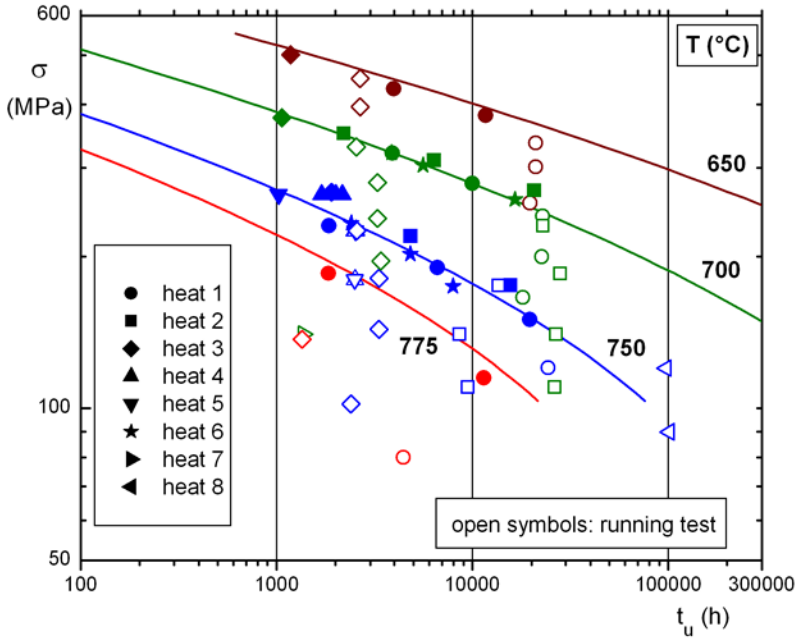
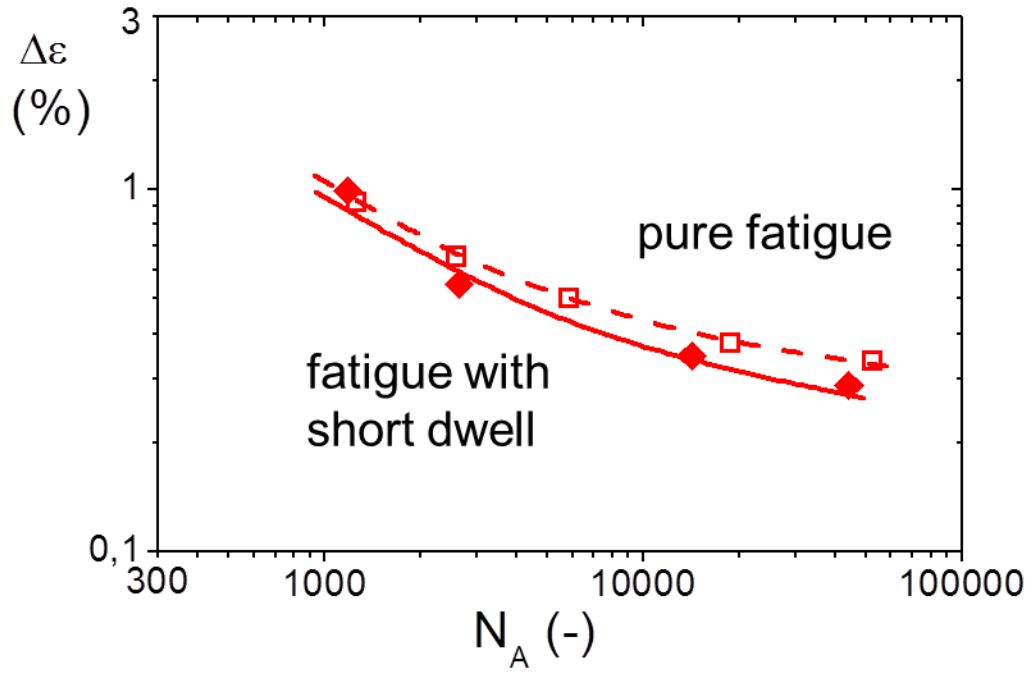
# Generation of design data
# Experimental Work

# Creep Experiments
# LCF-Experiments w/wo dwell time

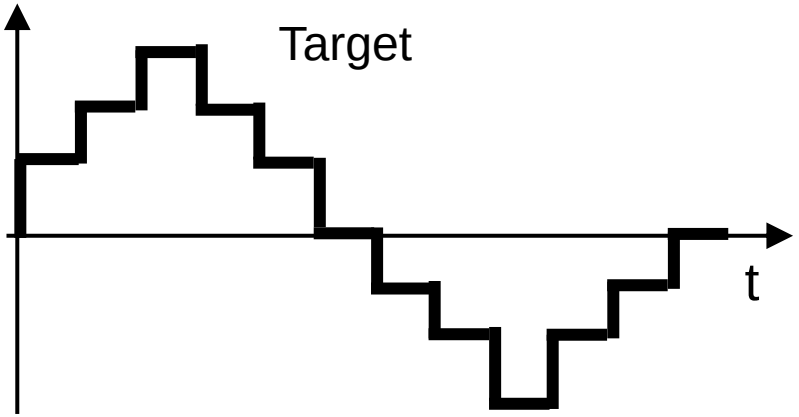


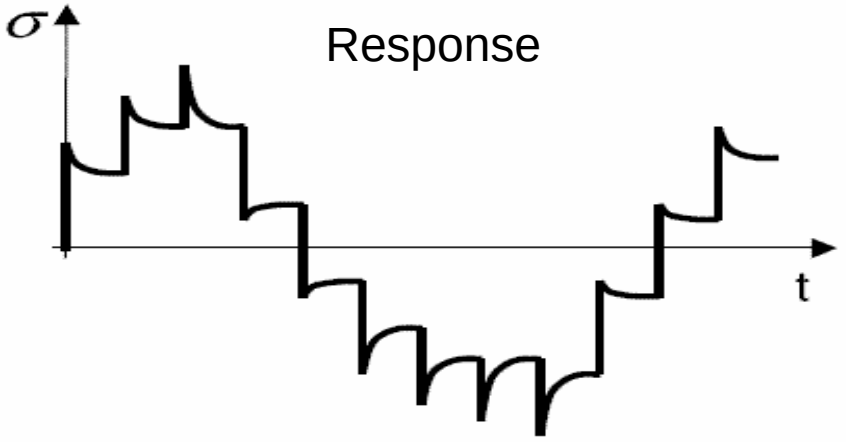



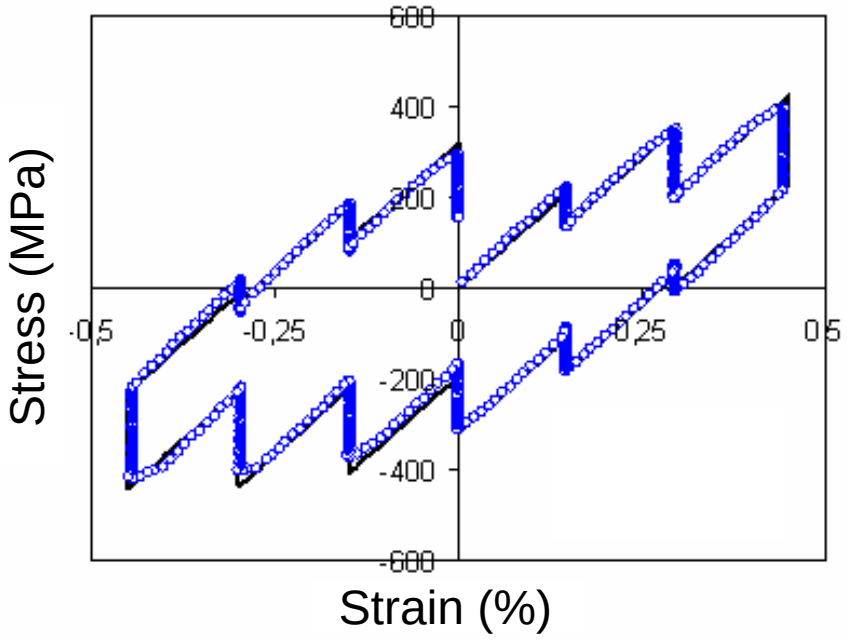

Reliable data essential for design and calculation
Data collation within DP700 → WP2, Task 2.1

**„Standard“ experiments: design data & identification of model parameters**

# Cyclic stress relaxation tests (Strain-controlled)

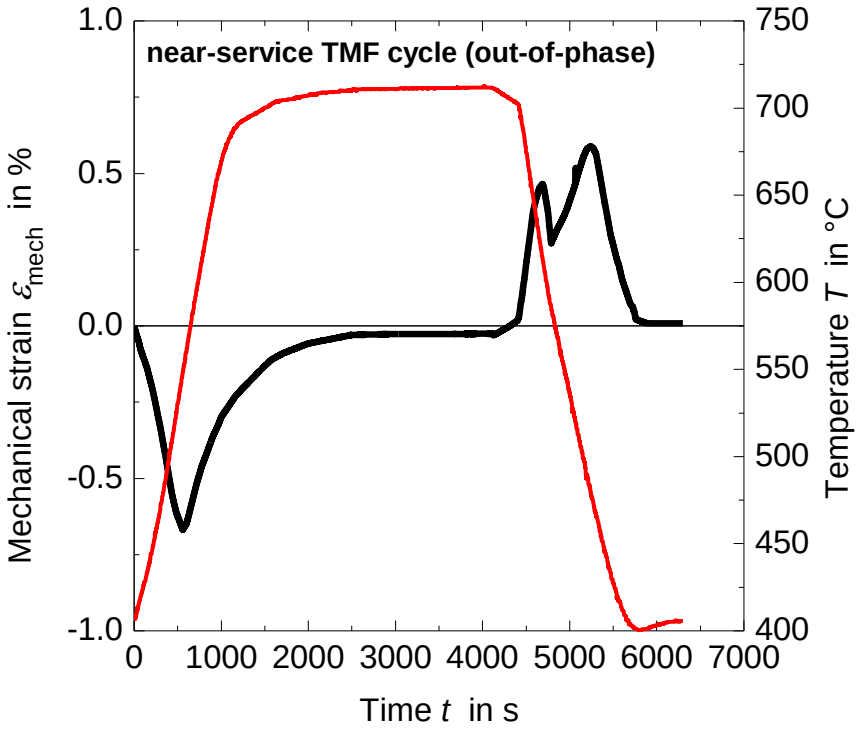


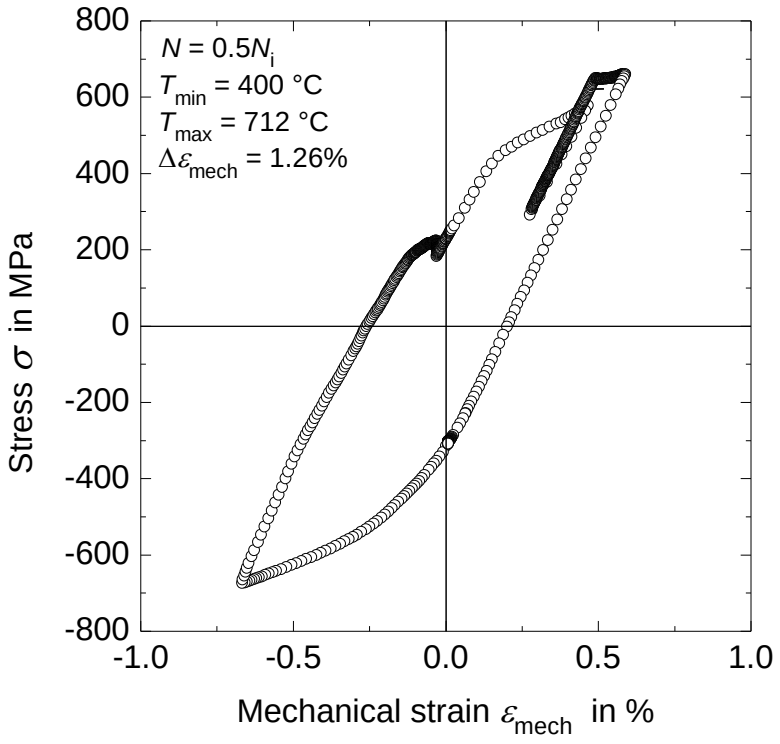




**Cyclic stress relaxation tests for modelling of the deformation behaviour**

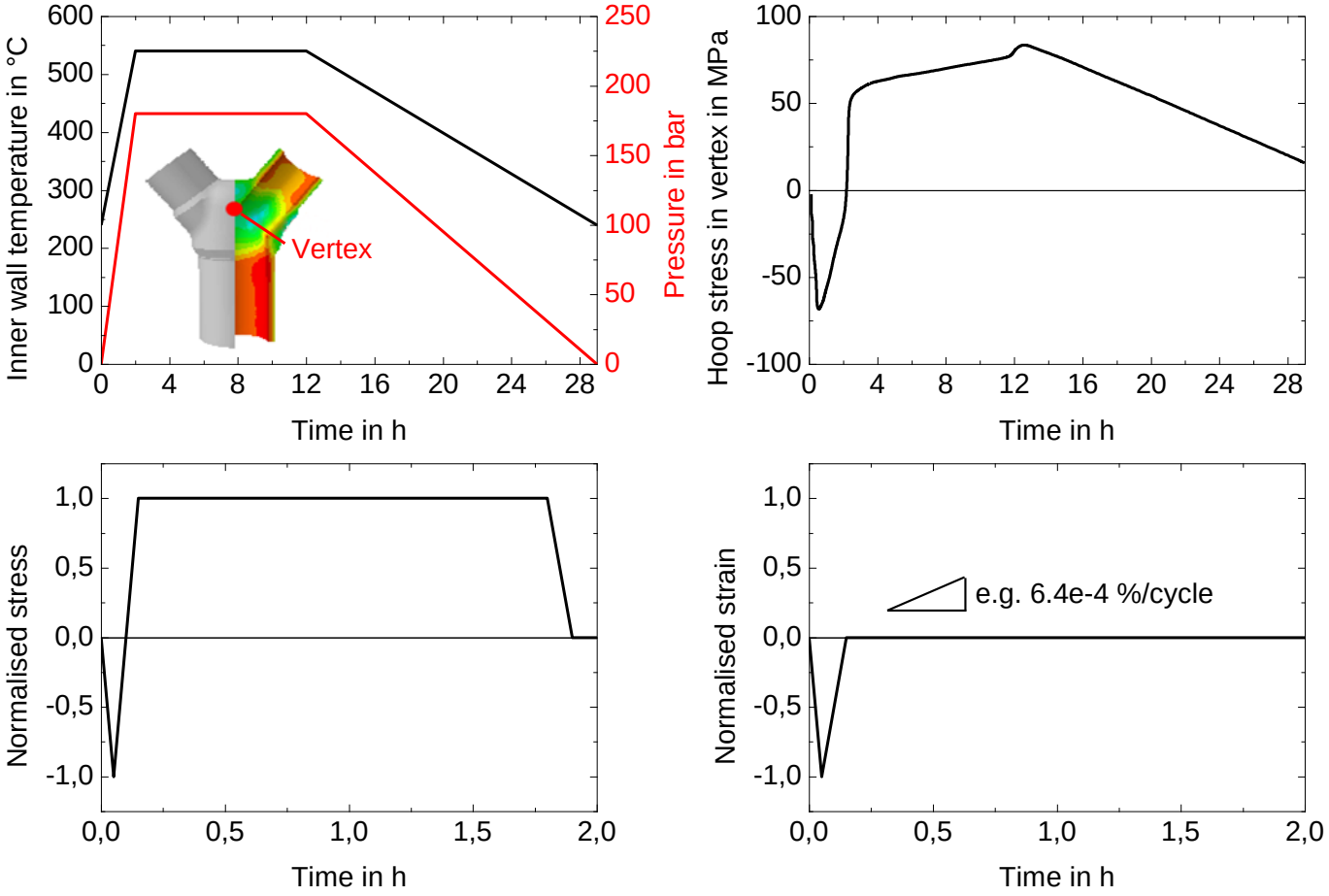
# Thermomechanical fatigue
# Example: Out-of-phase loading



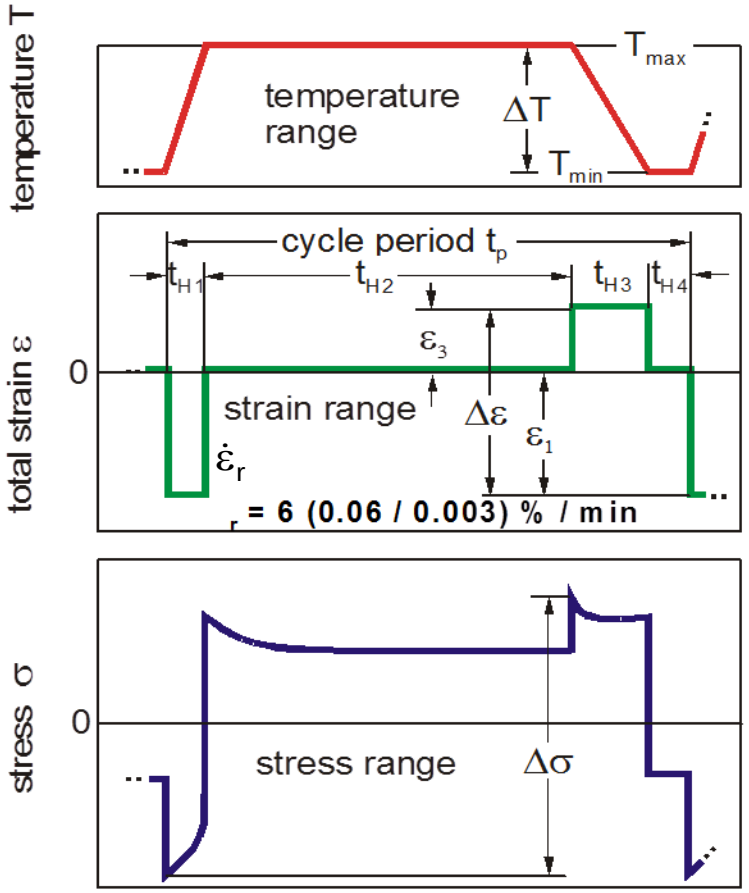

**OP-TMF cycle of a pipe with two-stage cooling**
**➔ Verification of parameter sets for deformation modelling**

# Experimental approach
# From operating data to laboratory testing




P. Schmitt et al.: Methods of Life Assessment at flexible service-like Loadings of Power Plants
A Comparison of Codes and Standards, 43rd MPA-Seminar, Stuttgart, 2017

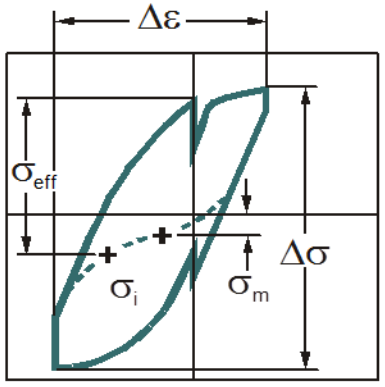
# Simulation of „service-type" strain cycling




$\varepsilon_3 = \Delta\varepsilon / 3$

$\varepsilon_1 = -2\Delta\varepsilon / 3$

| hold-phase j | hold-time $t_{Hj}$ |
|---|---|
| 1 | $0.075 \cdot \Sigma t_{Hj}$ |
| 2 | $0.700 \cdot \Sigma t_{Hj}$ |
| 3 | $0.150 \cdot \Sigma t_{Hj}$ |
| 4 | $0.075 \cdot \Sigma t_{Hj}$ |




**Standardization of complex experiments**
**➔ Intercomparison of materials and calculative approaches**

# Calculative approach
# Component integrity

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| | **short term** | **long term** |
|---|---|---|
| **static load** | Tensile or hot tensile strength<br>$\sigma < \sigma_{allow}(T)$ | Creep rupture strength<br>$\sigma < \sigma_{allow}(T, t)$<br>Creep strength<br>$\varepsilon_{pl} < \varepsilon_{pl,allow}$ |
| **cyclic load** | Fatigue strength<br>$n_{cycles} < N_{i,\,ref}$ | Fatigue strength<br>$n_{cycles} < N_{i,\,ref}$ |

Reliability:

*„Ability of a system to carry out a given function in given conditions during a given time period"*

# Two general options
# Accumulative & Constitutive approach

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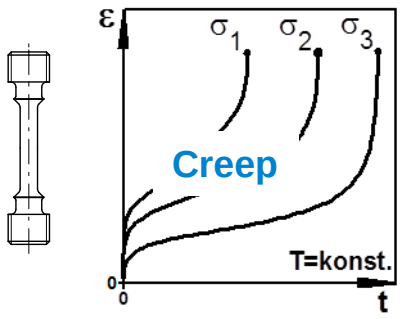
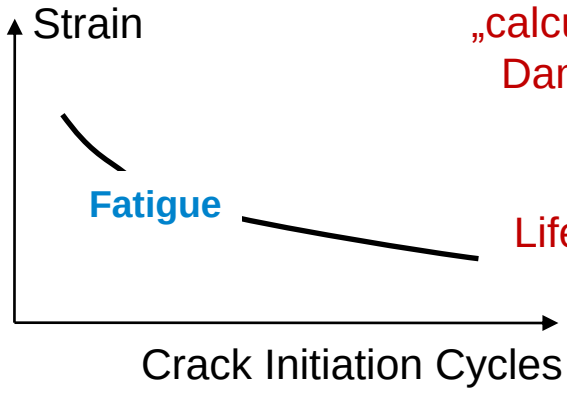
## Accumulative Models




Loading

+

„calculated" Damage



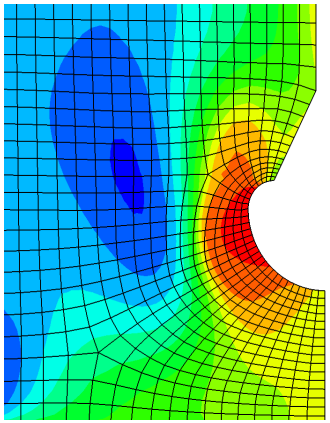

Lifetime

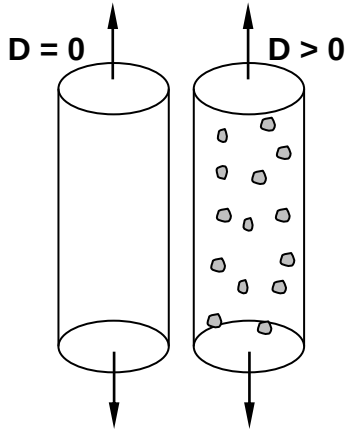
Stress
Strain
Temperature
Time

## Constitutive Models

Component Loading

**Materialparameter for Deformation and Damage**






Lifetime

# Accumulative approach

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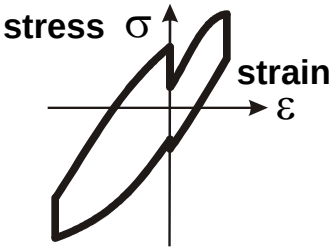
## Deformation Description

### Ramberg-Osgood

$$\varepsilon = \frac{\sigma_{eff}}{E} + \left(\frac{\sigma_{eff}}{K}\right)^{\frac{1}{n'}}$$

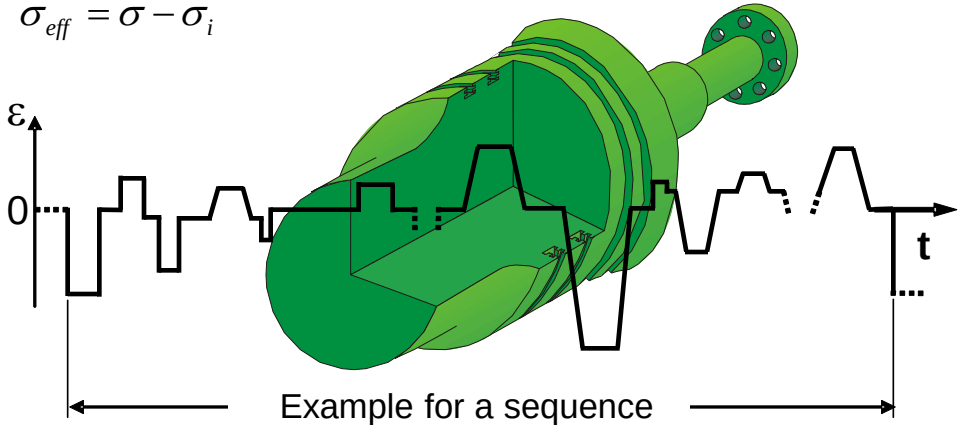



### Norton-Bailey

$$\varepsilon_f = K \cdot \sigma_{eff}{}^{n} \cdot t^{m}$$

10CrMoWVNbN, rotor 600°C
10CrMoWVNbN, cast , 600°C
1CrMoNiV, 500, 525 °C
12CrMoV, 550, 600 °C

$$\sigma_{eff} = \sigma - \sigma_i$$

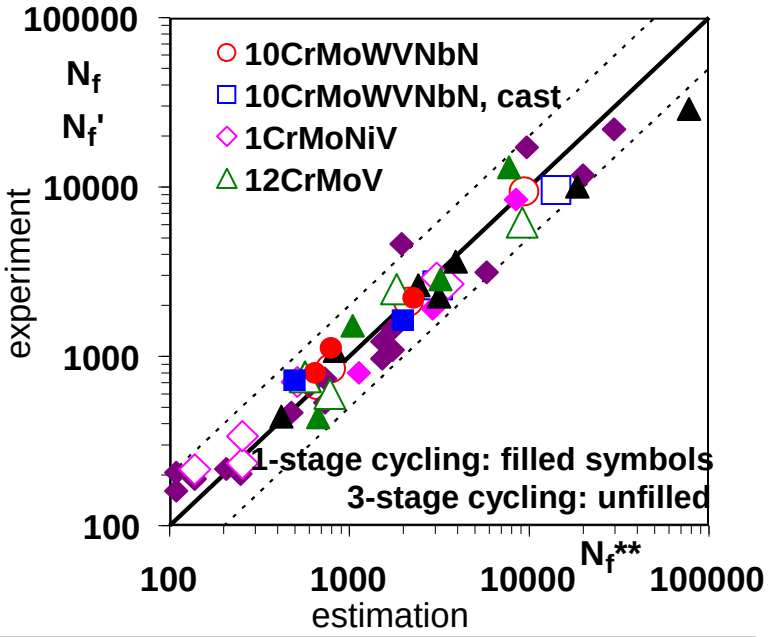



**Rangemean -, Rainflow - Cycle Counting**

## Damage Accumulation

### Creep Fatigue Interaction Concept

$$\sum \frac{N}{N_{fo}} + \sum \frac{\Delta t}{t_r} = D$$



# Damage accumulation

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## Damage Accumulation

Damage Summation Principle:

Fatigue Damage: $D_{Fatigue} = \sum_{i=1}^{n} \frac{n_i}{N_i}$ (Palmgren-Miner)

Creep Damage $D_{Creep} = \sum_{j=1}^{m} \frac{t_j}{T_{B,j}}$ (Robinson-Rule)

Linear Accumulation:

$$D_{tot.} = D_{Fatigue} + D_{Creep} \leq 1$$

Nonlinear accumulation:

$$D_{Creep} = 1 - \frac{1 - C}{C} D_{Fatigue} \quad \text{for } D_{Fatigue} \leq C \qquad D_{Creep} = \frac{C}{C - 1}(D_{Fatigue} - 1) \quad \text{for } D_{Fatigue} > C$$

# Creep-Fatigue Interaction
# Transition time concept (I)

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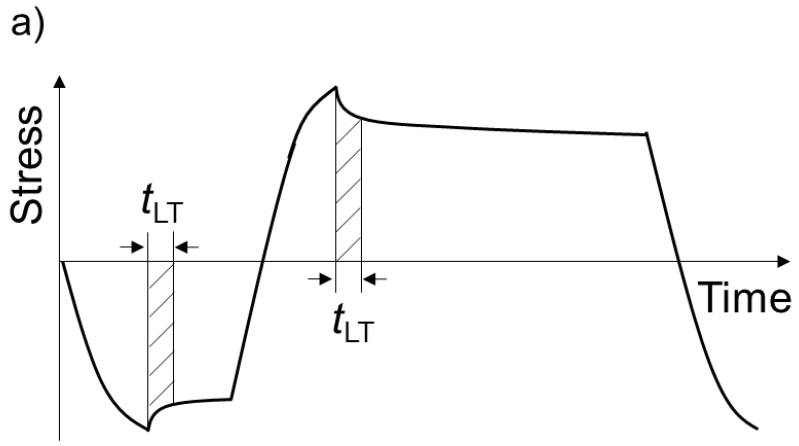
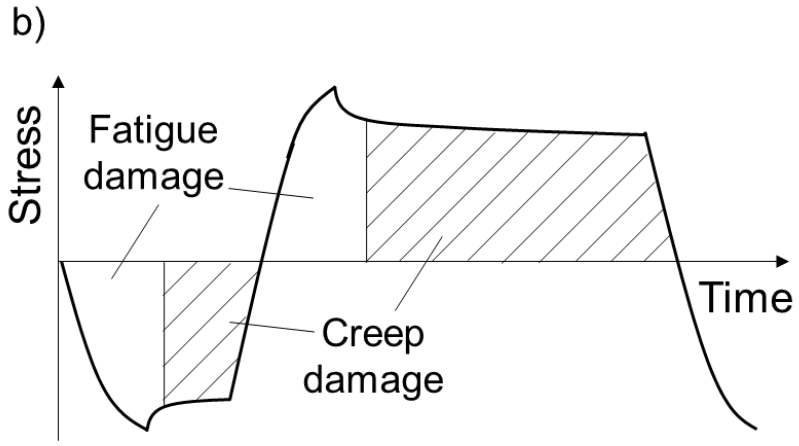
- A modified approach considers the creep-fatigue interaction by means of a limit-time or transition-time, the so called Transition-time-concept.
- Partition of the stress-time path into two segments for both, creep and fatigue.
- Assumption:
  - Fast stress relaxation in the first period of hold time $t_{LT}$, leads to a fatigue damage.
  - Due to a mechanism mismatch, conventional creep data is not suitable.



# Creep-Fatigue Interaction
# Transition time concept (II)

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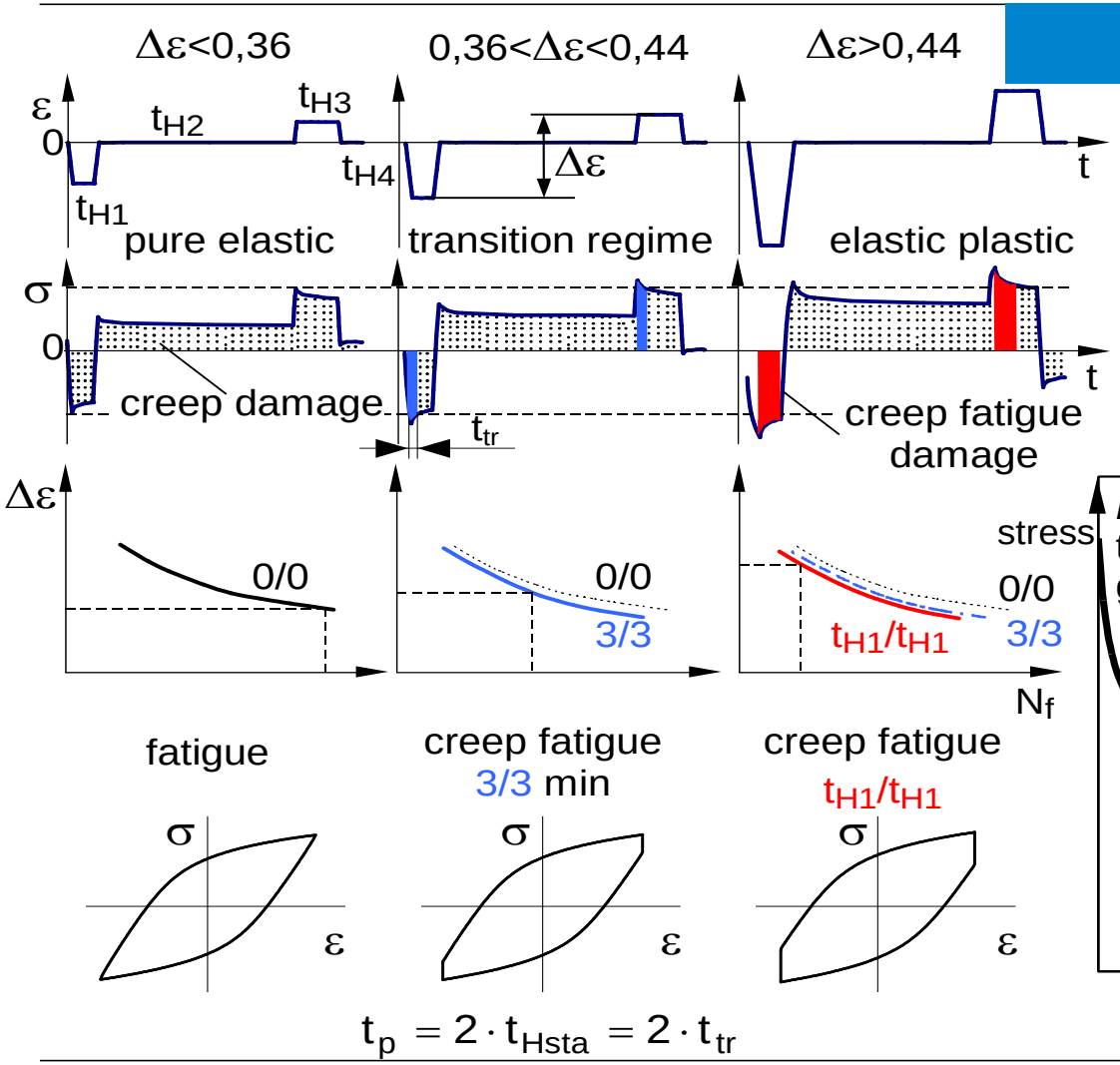
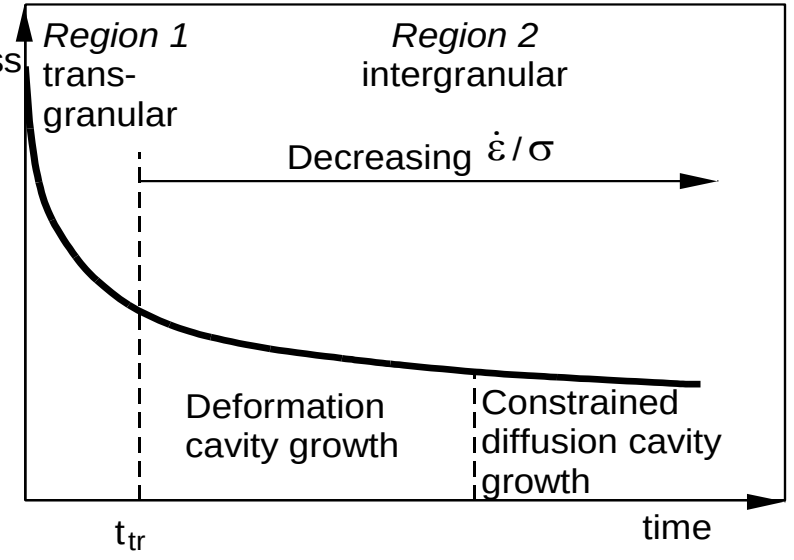
## Damage Accumulation




$$t_p = 2 \cdot t_{Hsta} = 2 \cdot t_{tr}$$

Transition-time concept as a mechanism-based Damage-Guide



# A brief overview of codes and standards
# Creep-Fatigue Interaction

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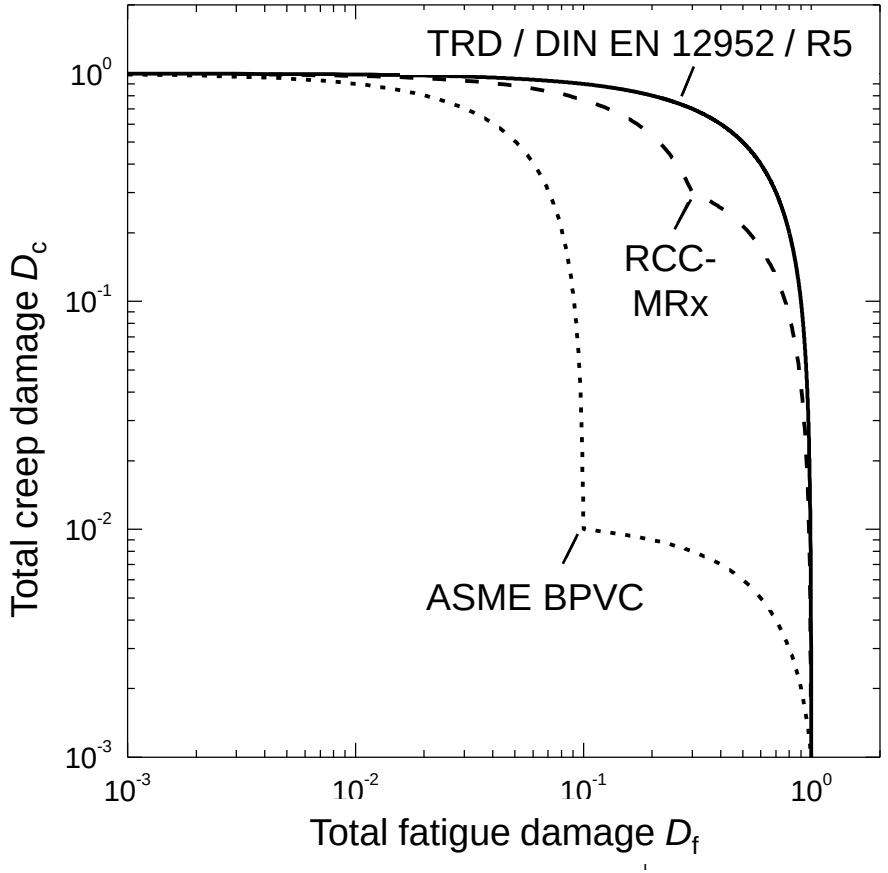
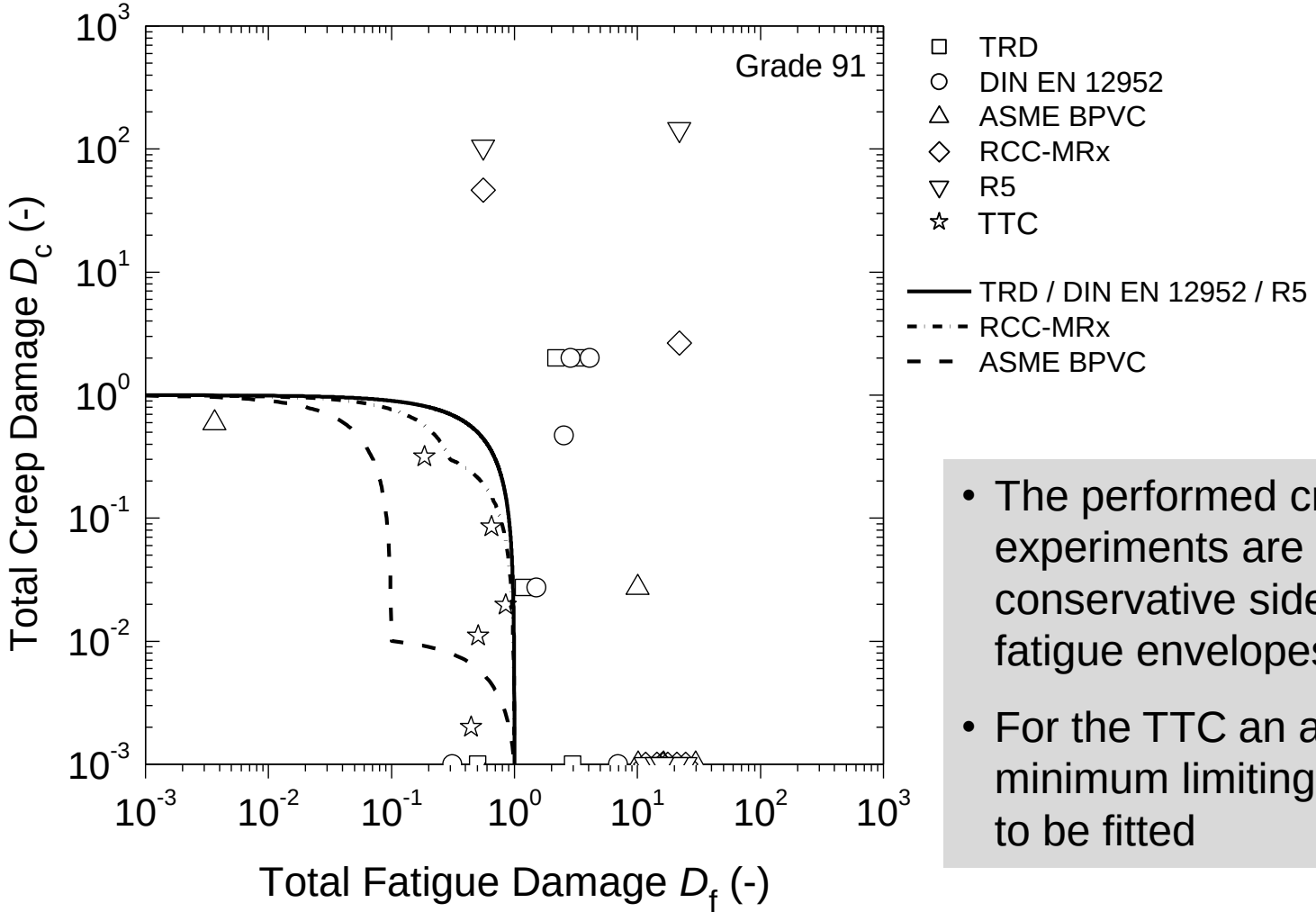
- Different codes use different envelopes.
- A component is considered to be safe, if the total damage value is within the envelope.
- Creep-fatigue interaction is the linear summation of creep damage and fatigue damage:

$$D = D_f + D_c$$



# Results of the damage assessment Creep-Fatigue Experiments – Grade 91




- The performed creep-fatigue experiments are on the conservative side of the creep-fatigue envelopes.
- For the TTC an average or minimum limiting curve needs to be fitted

# Accumulative approach: slightly better fit
# Constitutive approach: all purpose & flexible

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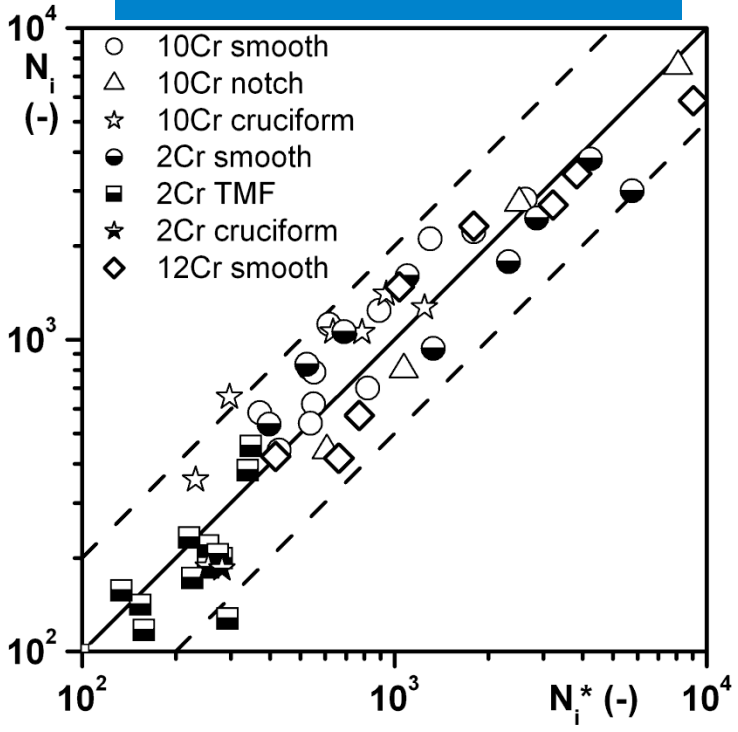
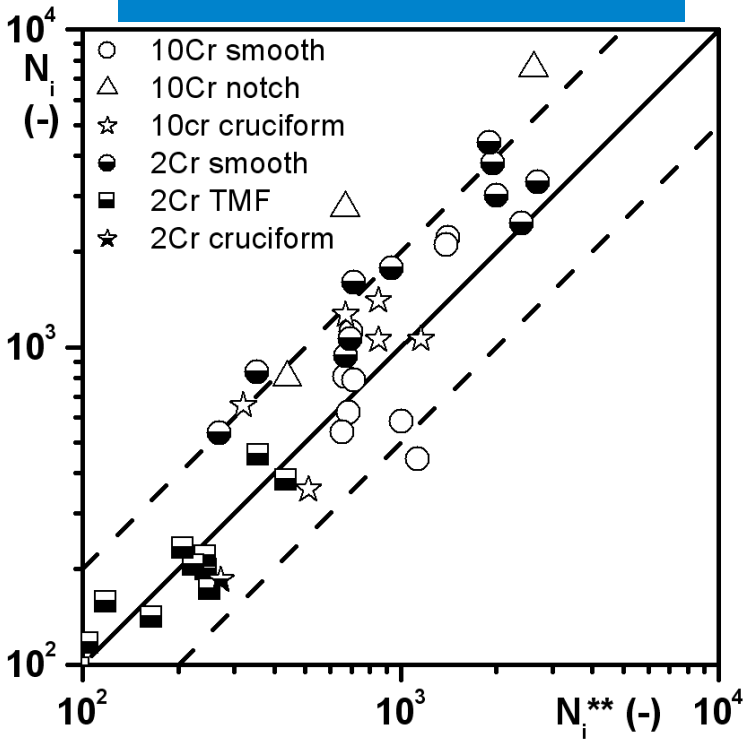
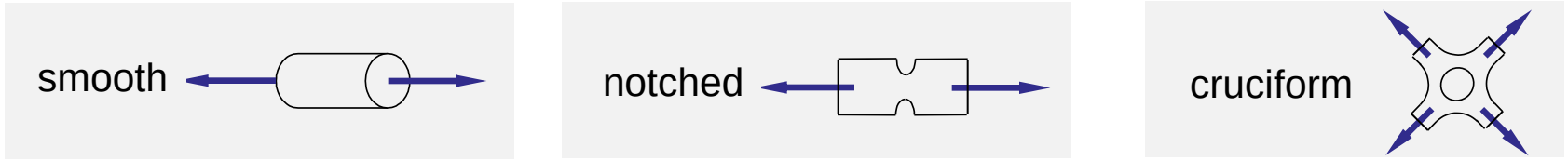
## Accumulative Approach



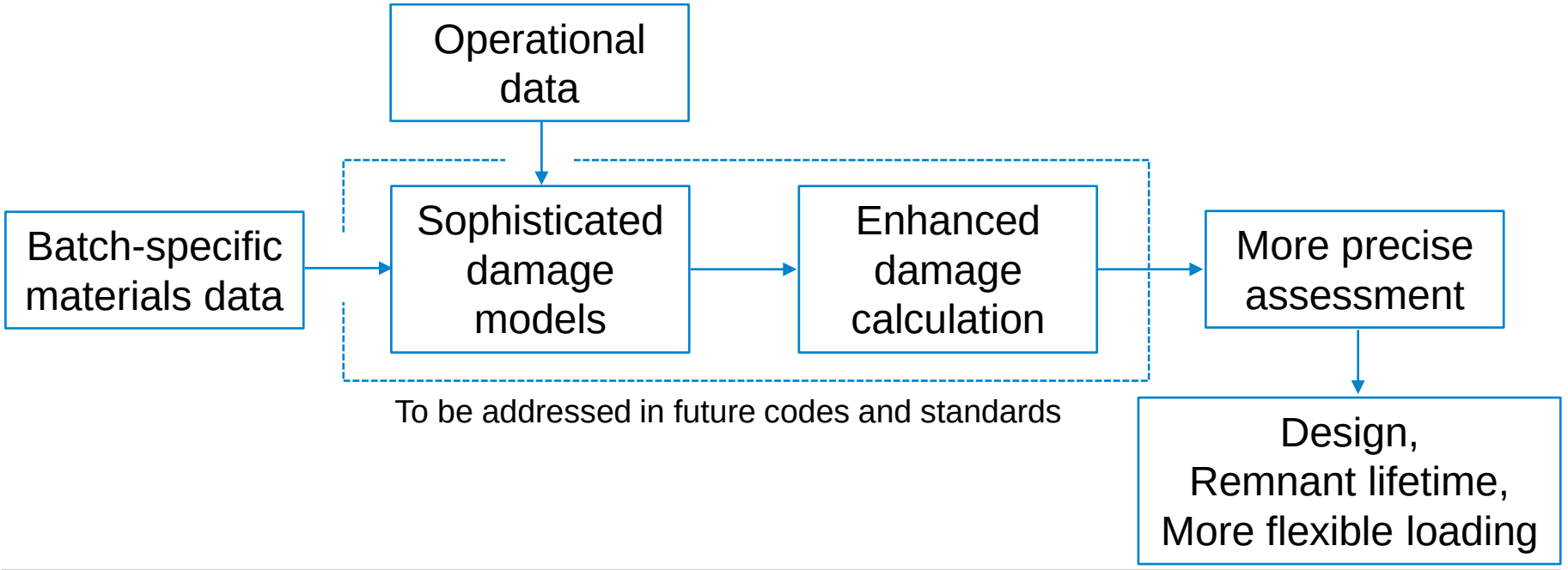

## Constitutive Approach



# Conclusion

- Methods for experimental data generation and calculative approaches for dealing with cyclic plasticity are available
- Various "competing" codes and standards exists
- Material property scatter, stochastic elements and improved data monitoring and improved damage models should be addressed in the future



# Thanks for your attention