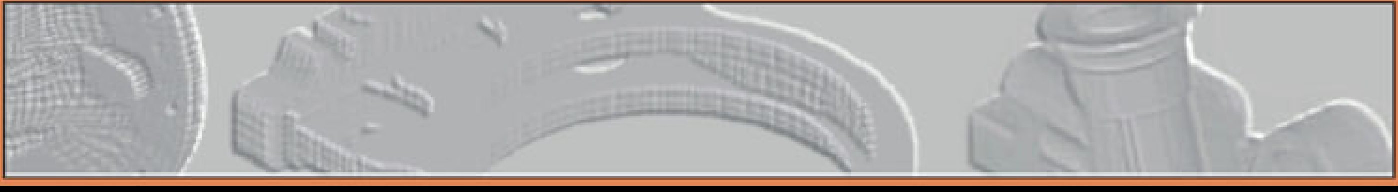
CCOPPS



Creep loading of pressurized components – phenomena and evaluation

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Education and Culture
Leonardo da Vinci
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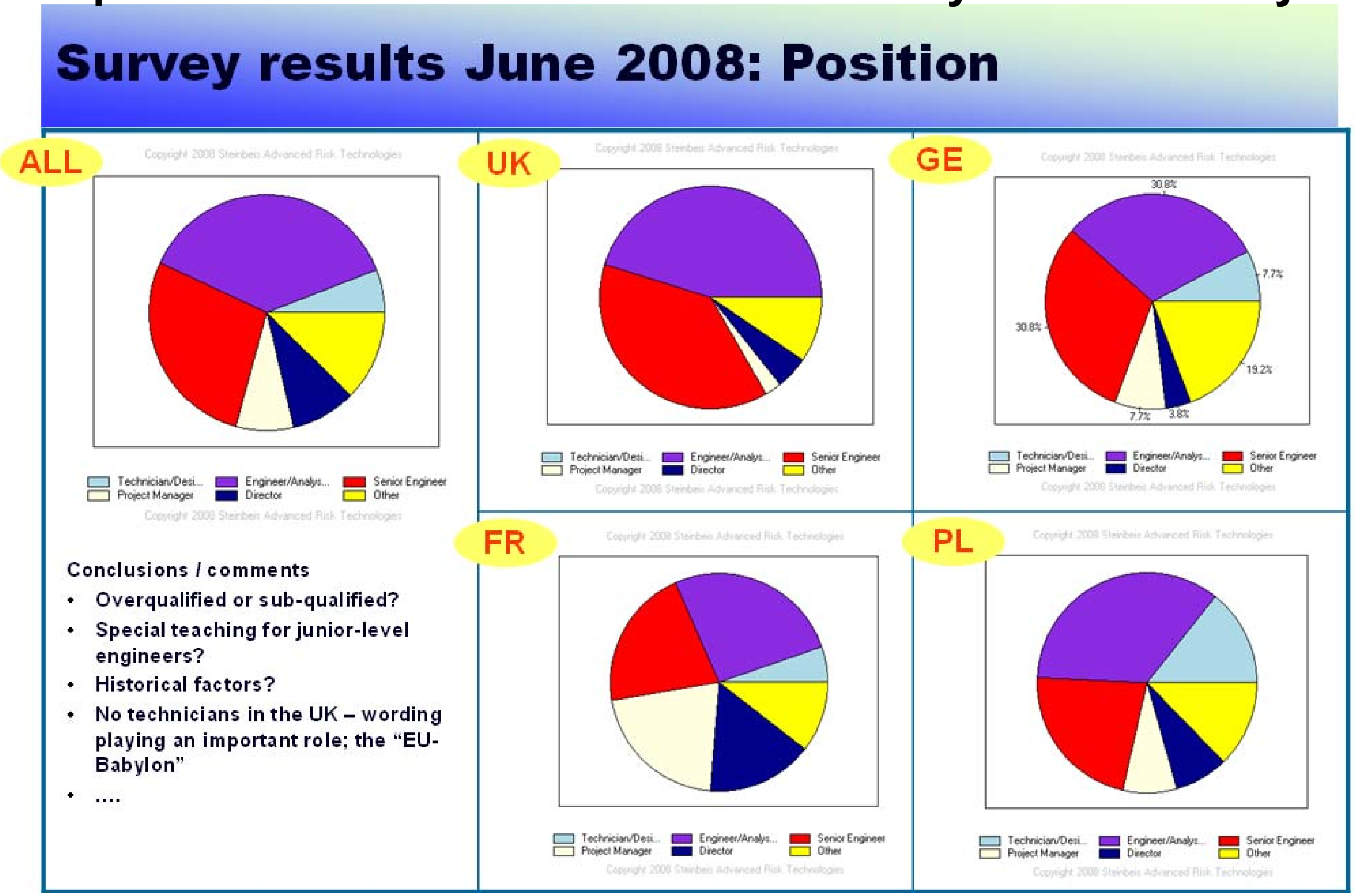
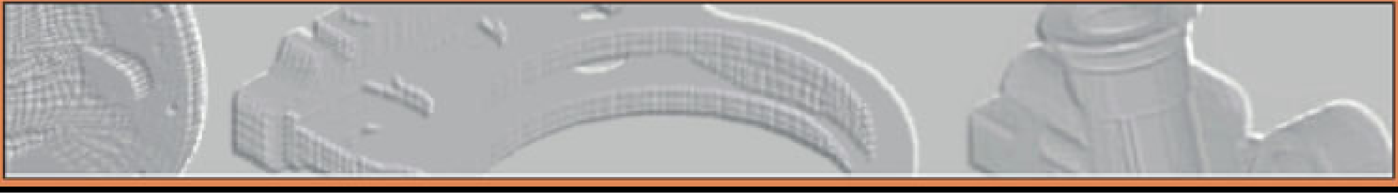


Survey results June 2008: Position

Conclusions / comments

- Overqualified or sub-qualified?
- Special teaching for junior-level engineers?
- Historical factors?
- No technicians in the UK – wording playing an important role; the "EU-Babylon"
- ....



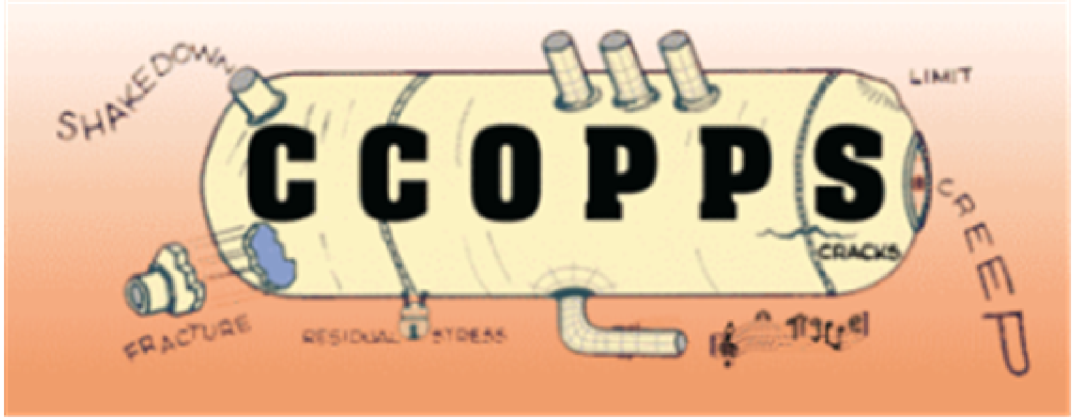
CCOPPS: Creep Loading of Pressurized Components - Phenomena and Evaluation

CCOPPS Project

Wednesday, July 23rd at 10am EDT / 3pm BST / 4pm CET

Register for this webinar

Event Type: Webinar
Location: Online, UK
Date: July 23, 2008



Webinar Presenter

Prof. Karl Maile

MPA University of Stuttgart
Germany

(intro)

Prof. Aleksandar Jovanovic

Steinbeis Advanced Risk Technologies
Stuttgart, Germany

Webinar Presenter

Prof. Karl Maile

MPA University of Stuttgart
Germany

Mechanical Engineer, PhD, … ca. 300 publication, several textbooks (including those for students) … chairperson of many conferences and expert groups … respected colleague and dear friend …

Head of department "Materials behaviour" and Deputy Director of the State Institute for testing of Materials (MPA)
University of Stuttgart, Stuttgart, Germany

Particular interests: Influence of deformation behaviour, oxidation and temperature on long term low cycle fatigue behaviour of creep resistant steels", Advanced methods for the description of the deformation and damage behaviour of components operating in the high temperature range, associate professor

Outline

1. **Motivation**
2. **Part I - Creep Phenomena**
3. **Part II - Component Behaviour**
4. **Part III - Numerical simulation**
5. **Summary and Conclusions**

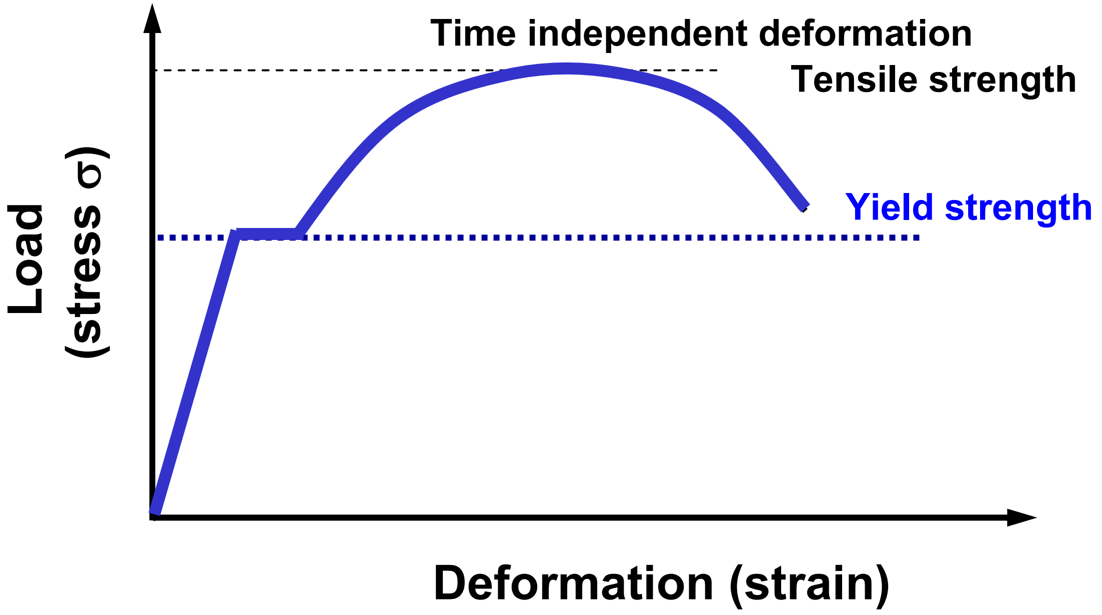
Motivation

Technical significance

In the pressure equipment sector high temperature is part of the specific loading situation

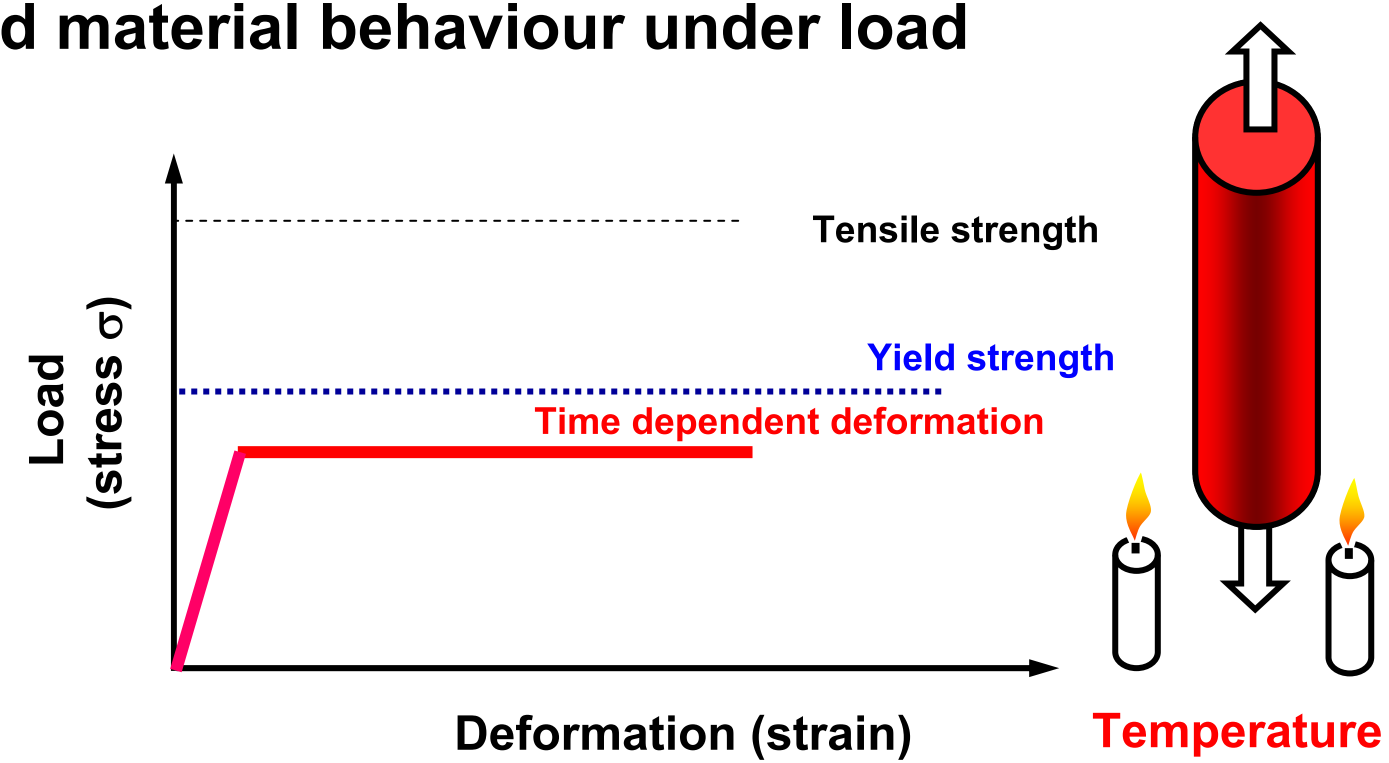
Understanding of creep mechanisms is the key to prevent failures and to optimize the design and life time assessment of pressurized components

Standard material behaviour under load at low temperatures



Plastic deformation: load exceeds the yield strength of the material - balance between load and deformation

Standard material behaviour under load



Creep deformation takes place even if the load is below the yield strength of the material

Part I – Creep phenomena

Creep tests

To characterize creep deformation and rupture behaviour specific creep tests are required

Measurement of

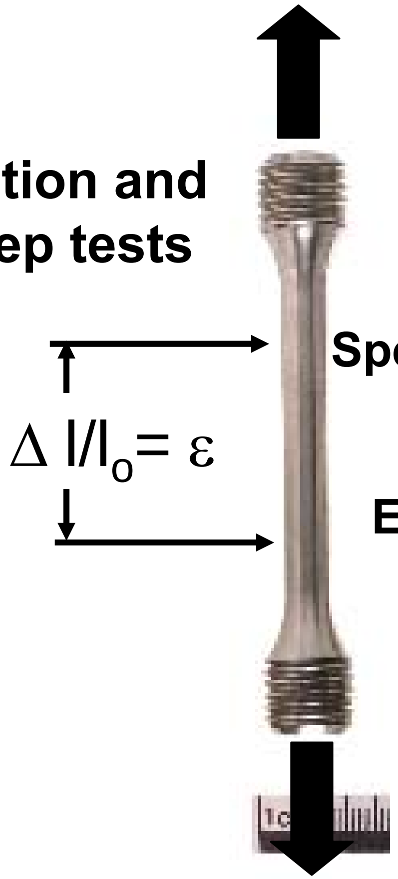
- **creep strain**
- **time to rupture**

Standard:

EN 10291

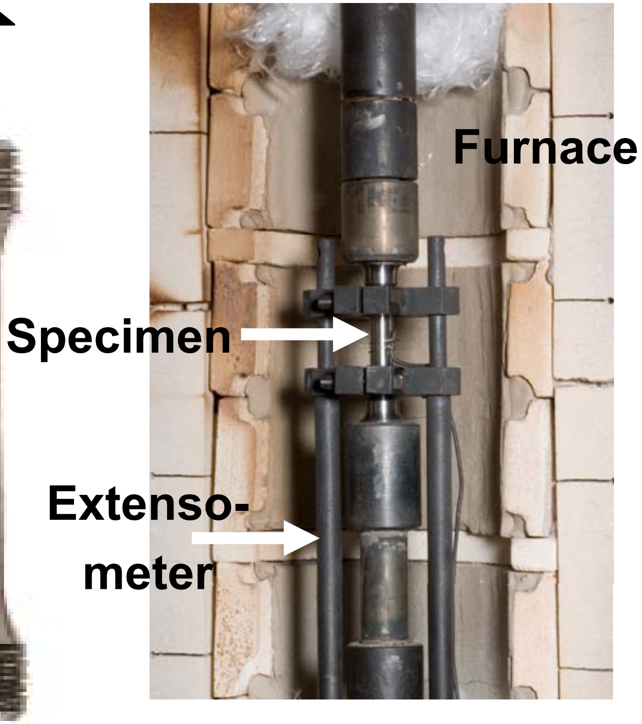
ECCC Recommendations

ASTM E139-06



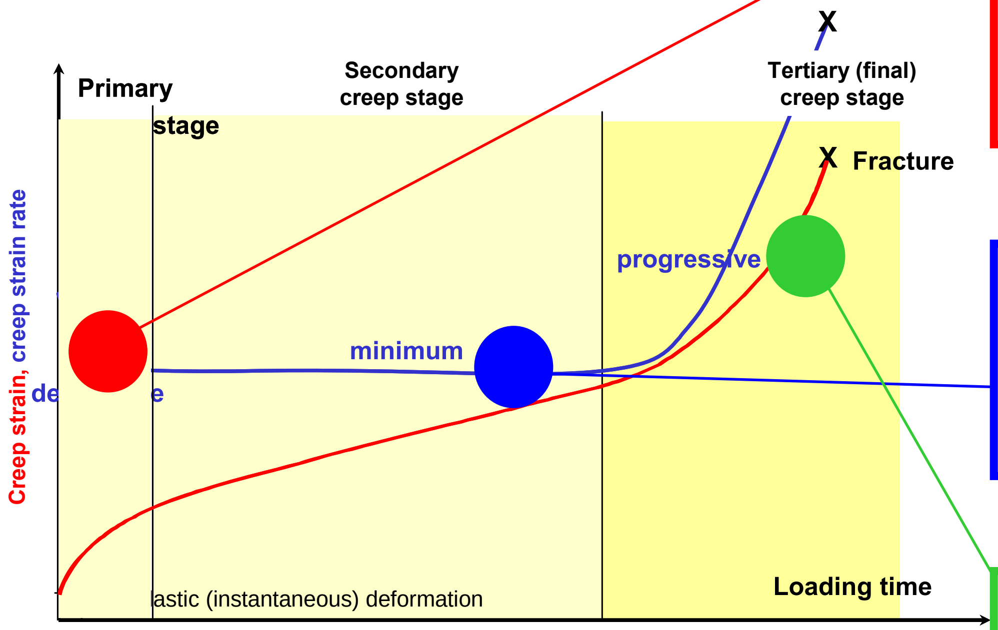
$\Delta l/l_o = \varepsilon$

Constant load tests at constant temperatures



Recording:
creep strain,
time to rupture

Evolution of creep strain



Dislocation movement (climb)

Comes from thermally activated atom mobility, giving dislocations additional slip planes in which to move

Constant strain rate – Increasing resistance to slip due to the buildup of dislocations and other microstructural barriers

Increasing strain rate – decreasing resistance to slip due to changes in microstructure, internal cracking

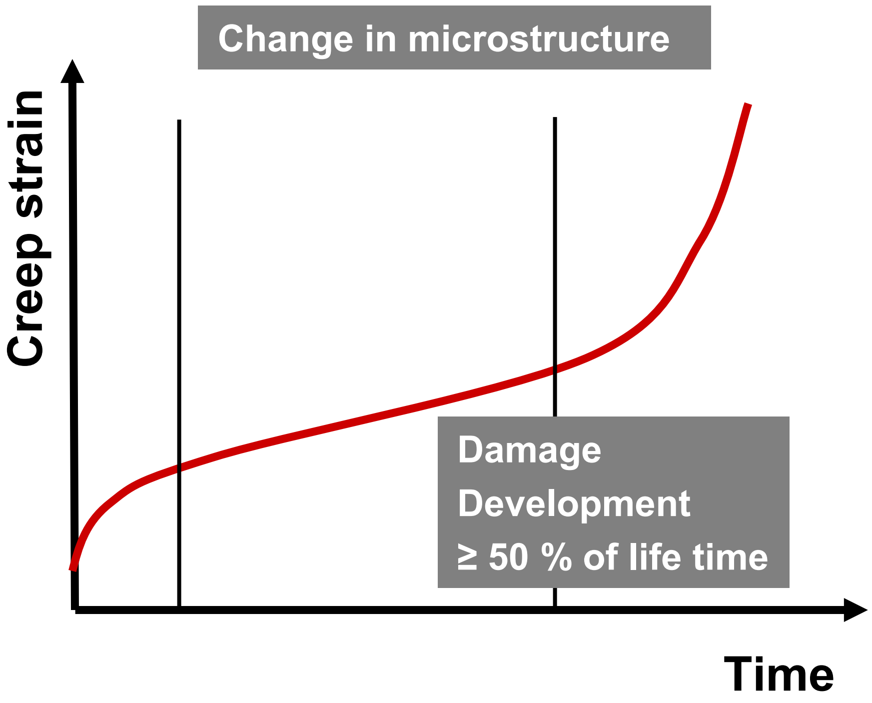
Part I – Creep phenomena

Evolution of creep damage

Time dependent process

Starting during regular operation time of the component

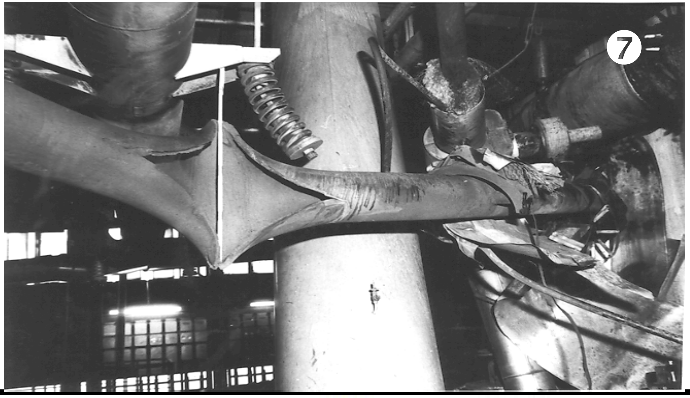
Damage appearance is linked to consumed life time, loading situation, temperature, material

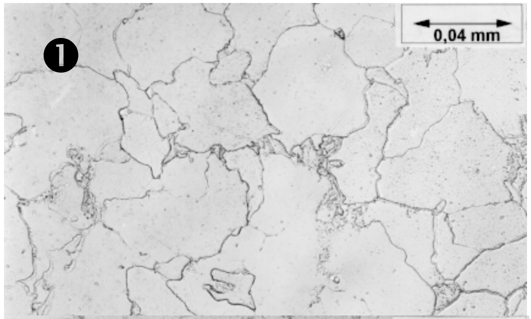


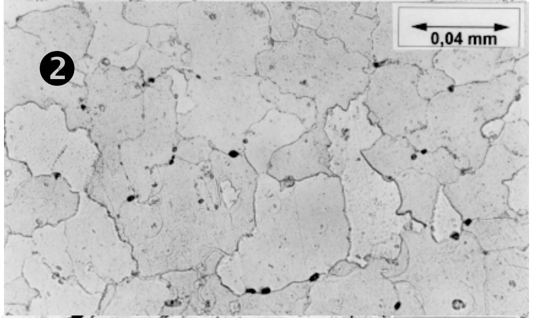
Part I – Creep phenomena

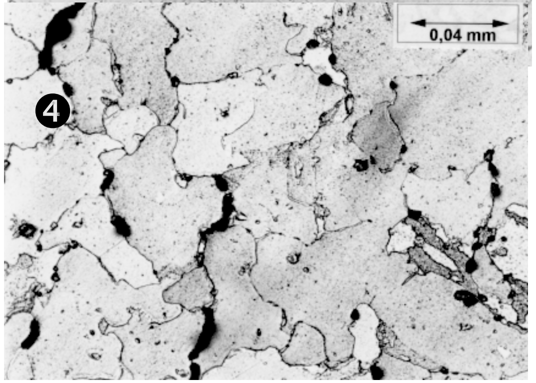
Creep damage development

1. Creep deformation
2. Cavity nucleation
3. Cavity formation, orientation to maximum principal stress
4. Formation of microcracks
5. *Creep crack growth*
6. *Unstable crack growth – failure*
7. *Ligament failure*

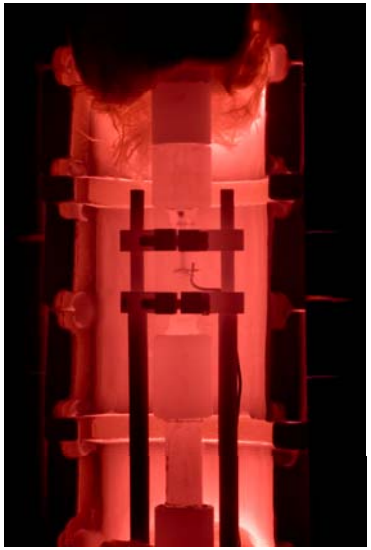


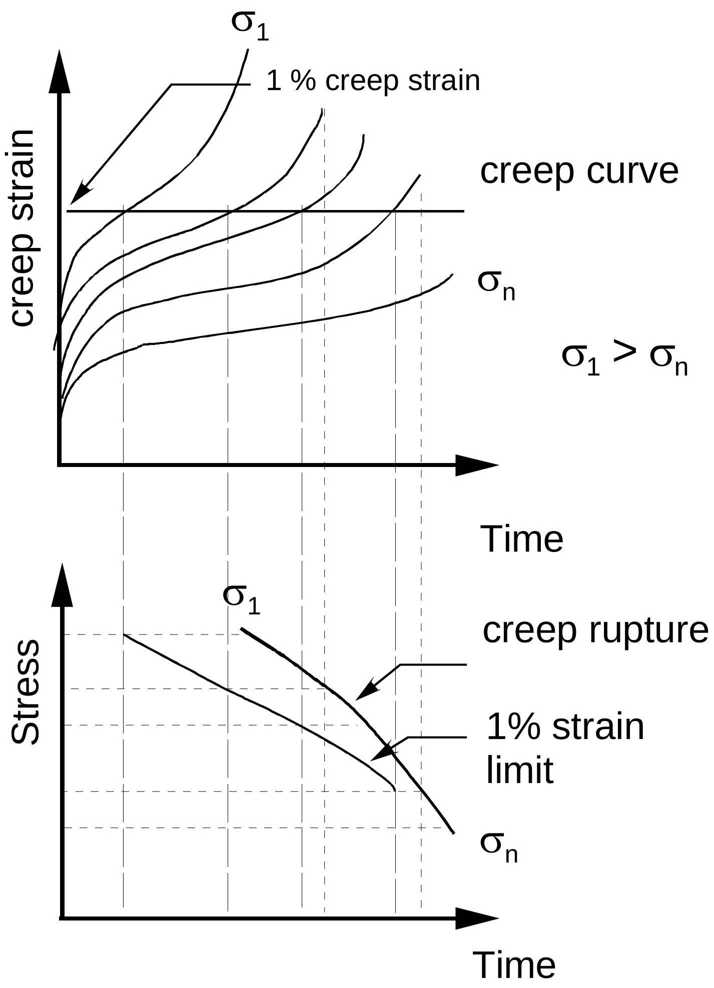






Characteristics for design



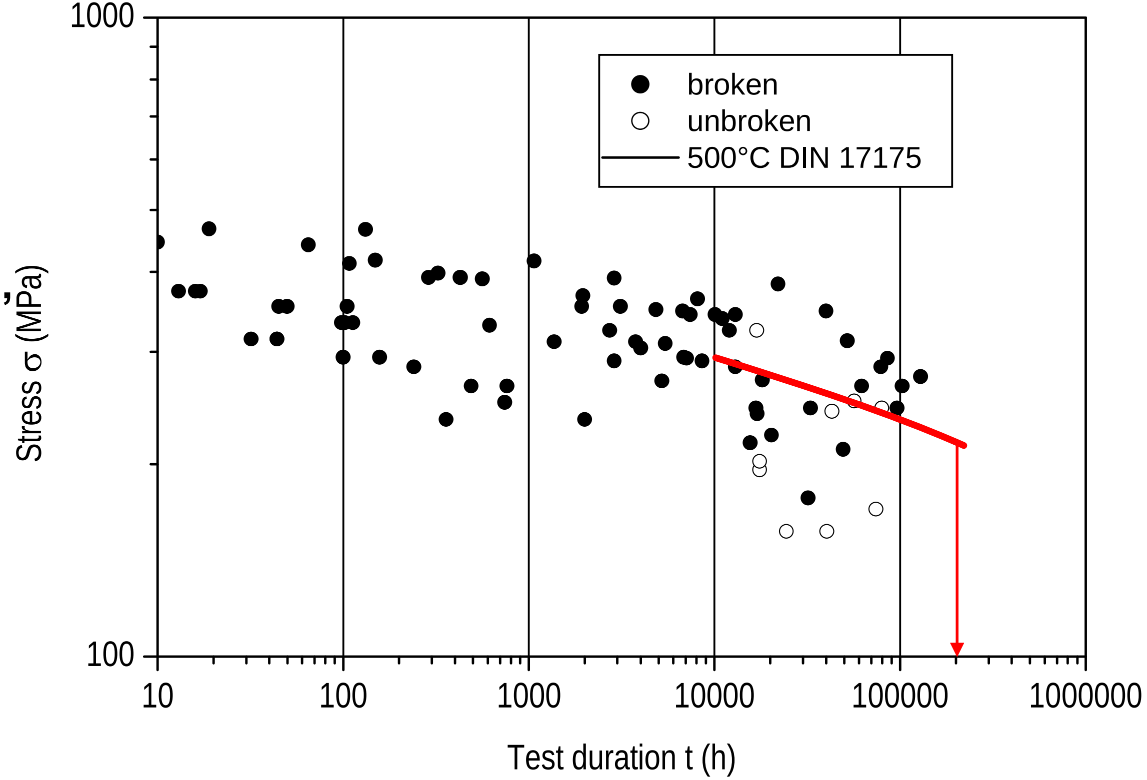


$R_{1/t/\vartheta}$	**Strength to achieve 1% creep strain at time t and temperature**
$R_{u/t/\vartheta}$	**Rupture Strength at time t and temperature**

Interpretation of creep data

Scattering of rupture data caused by:

- **differences in**
  - **chemical composition,**
  - **heat treatment,**
- **different manufacturing processes**
- **Influence of testing lab**

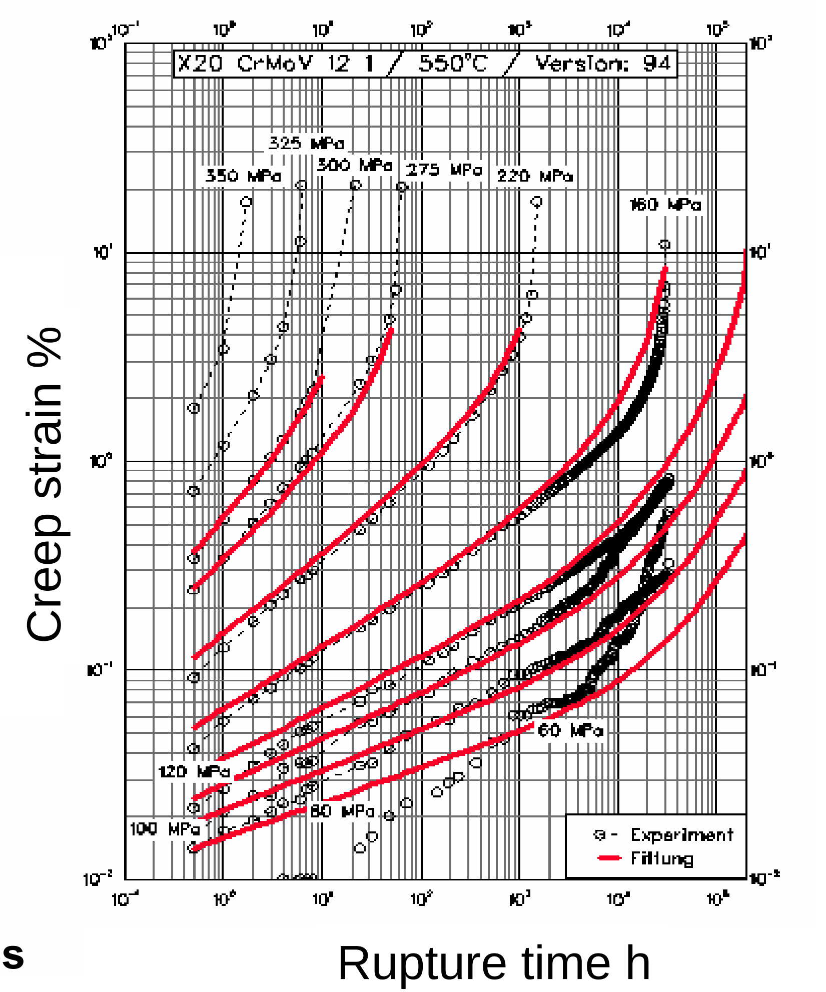


Creep rupture strength data of steel grade X20CrMoV12-1 at 500 °C (10 heats, bars and tubes) obtained by the German Creep Committee

Interpretation of creep data

Scattering of creep strain data

Crossover of creep curves at service like low stresses



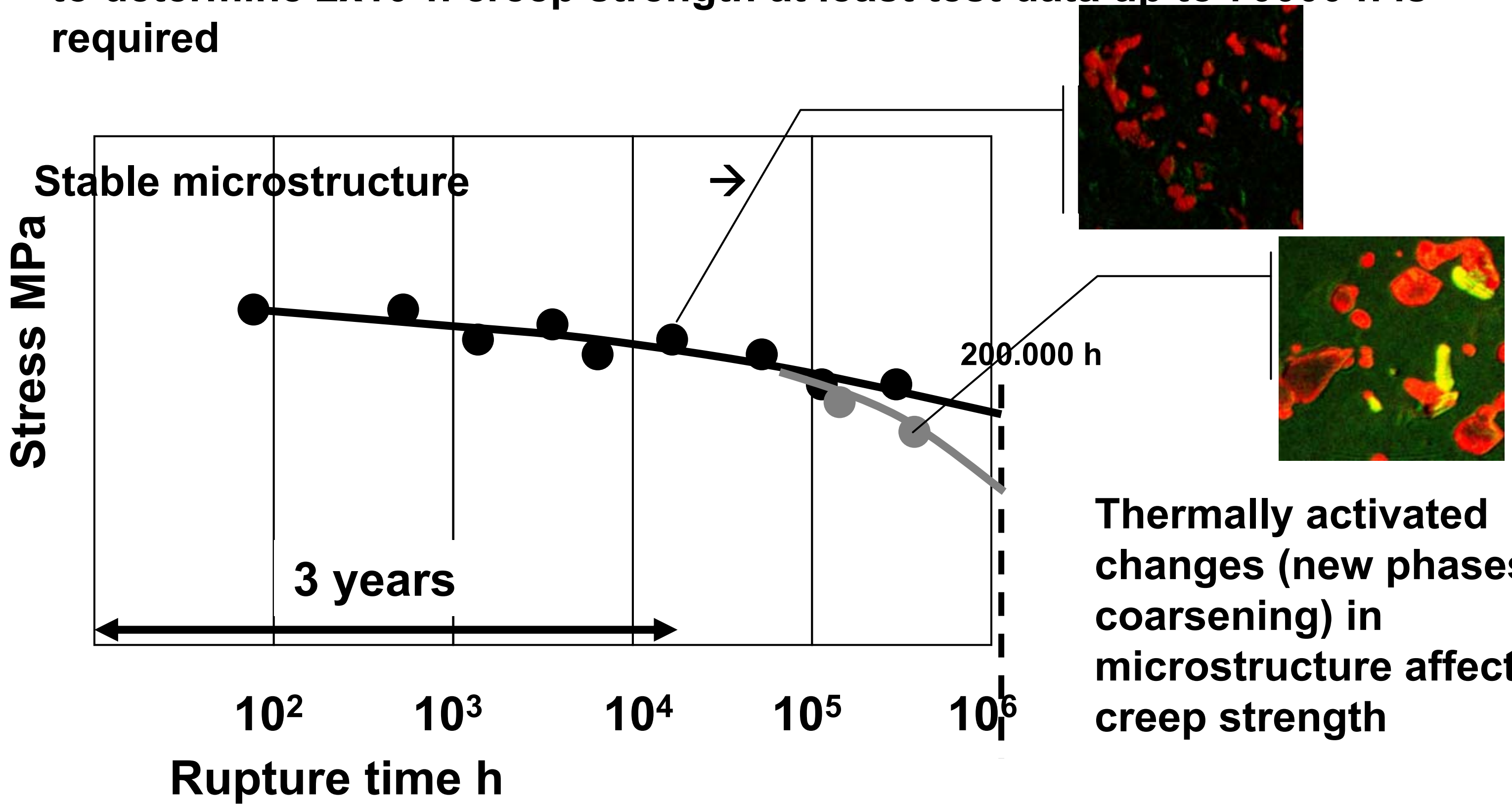
Steel grade X20CrMoV12-1 at 550 °C

Specimens of one melt but different places

Reliability of long term creep data

Extrapolation to long term behaviour: Do not exceed factor 3 in time

⇨to determine $2x10^5$h creep strength at least test data up to 70000 h is required

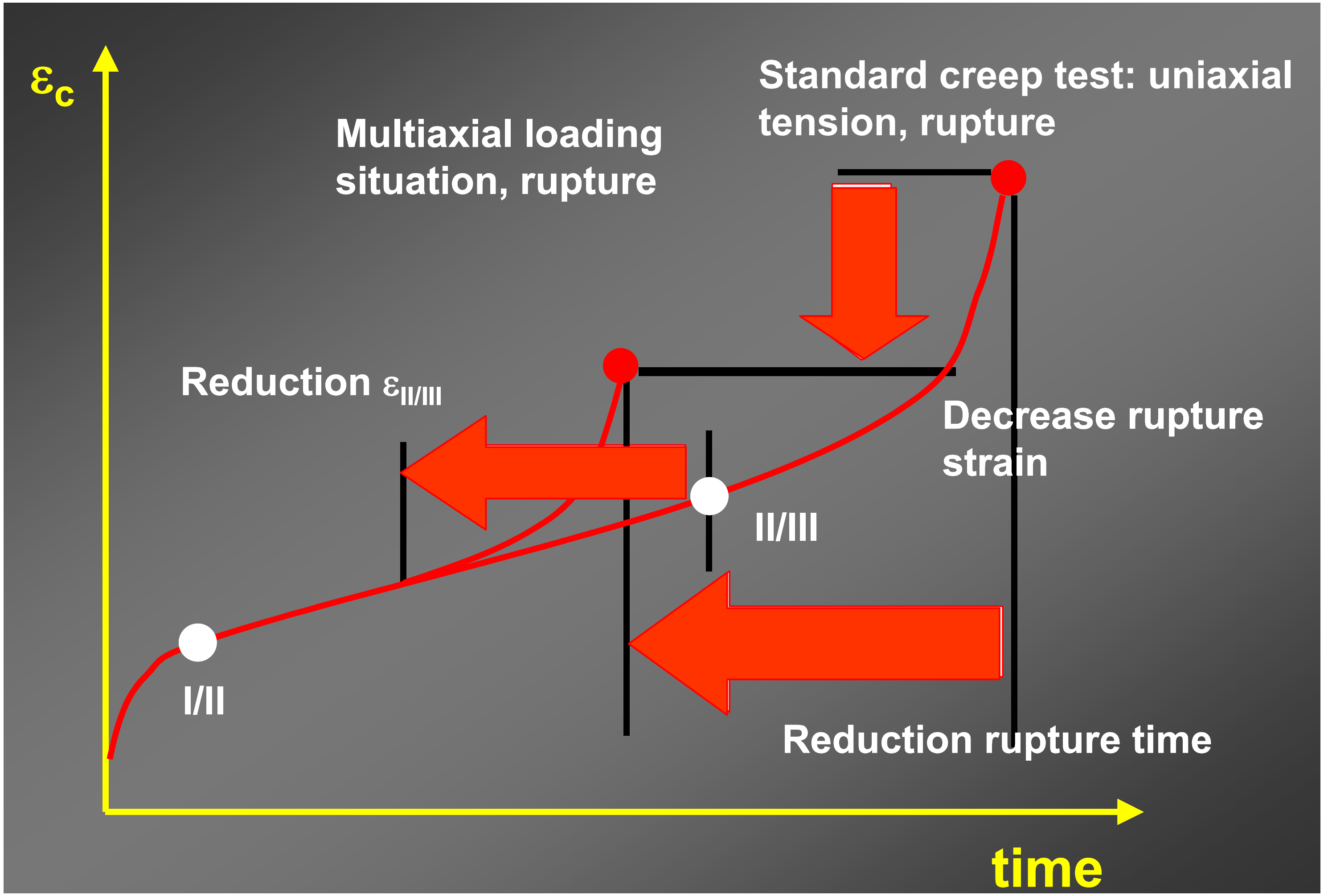


Thermally activated changes (new phases, coarsening) in microstructure affect creep strength

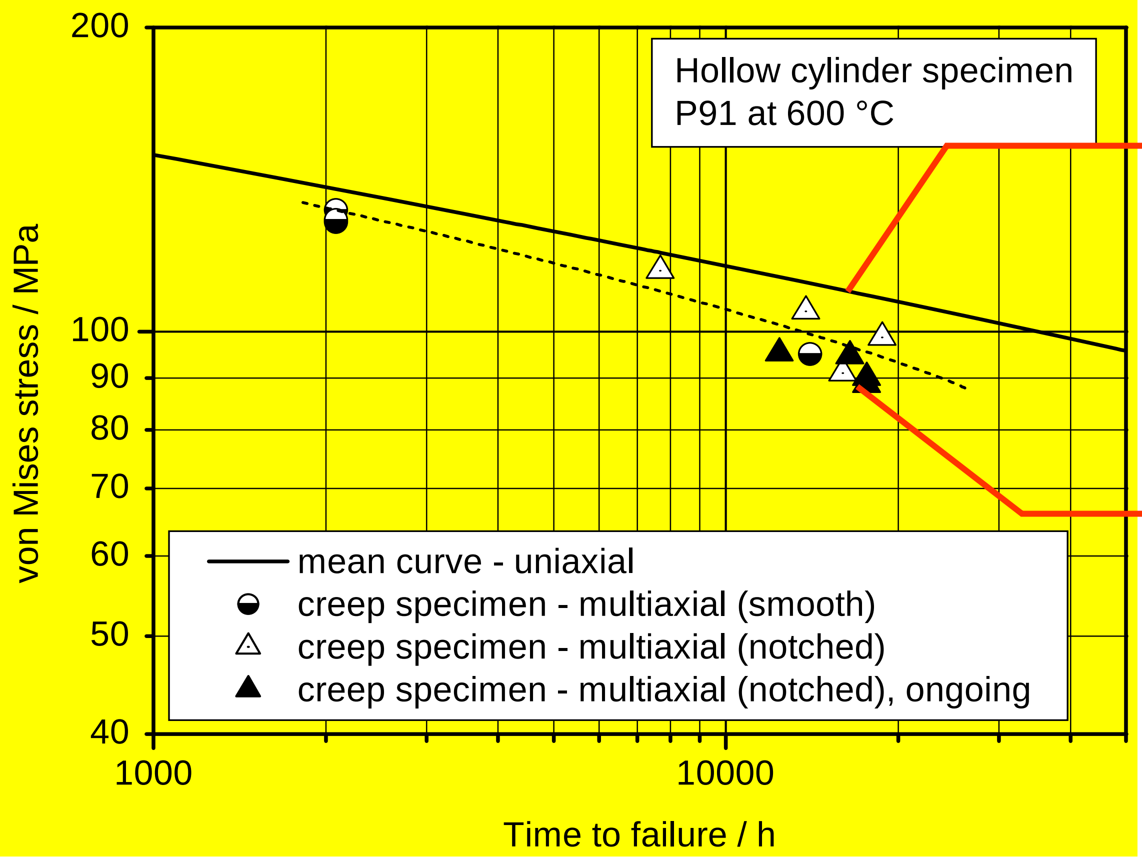
Part I – Creep phenomena

Multiaxiality

Influence on creep deformation and rupture behaviour



Part I – Creep phenomena

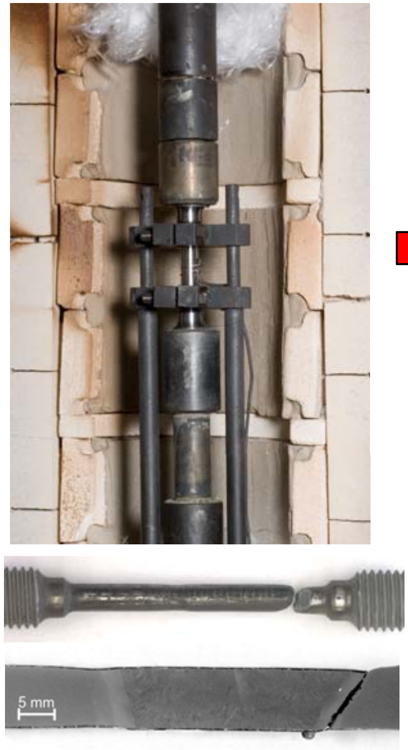


Smooth specimens

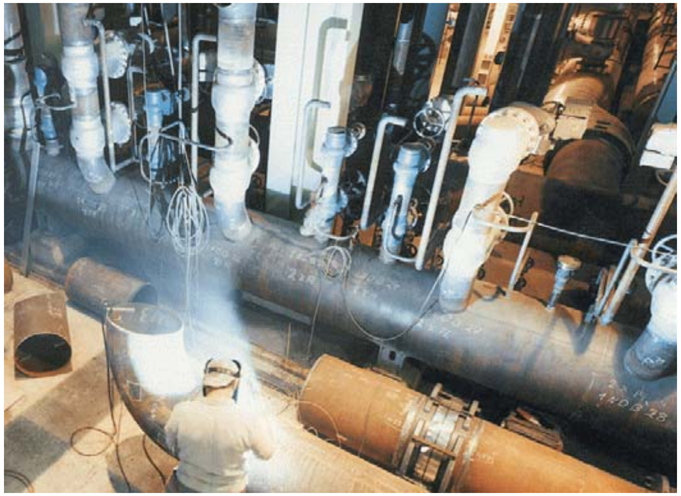
Hollow cylinders

Decrease in rupture time due to multiaxial loading

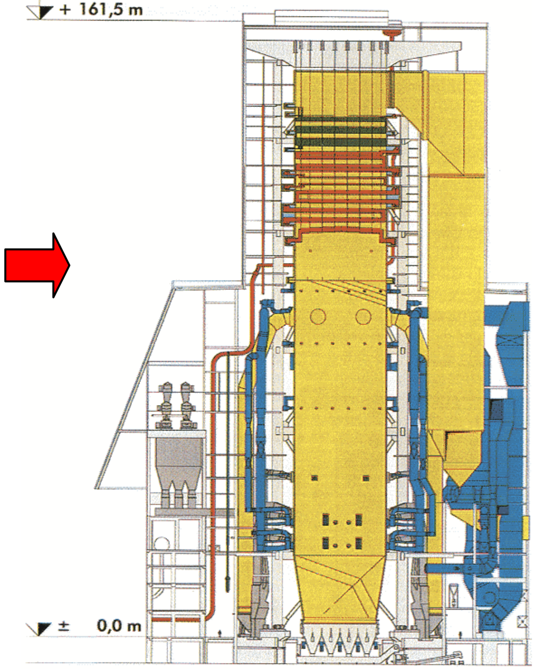
Transferability of creep test results to components



Small scale lab specimen



On site manufacturing



Large scale components

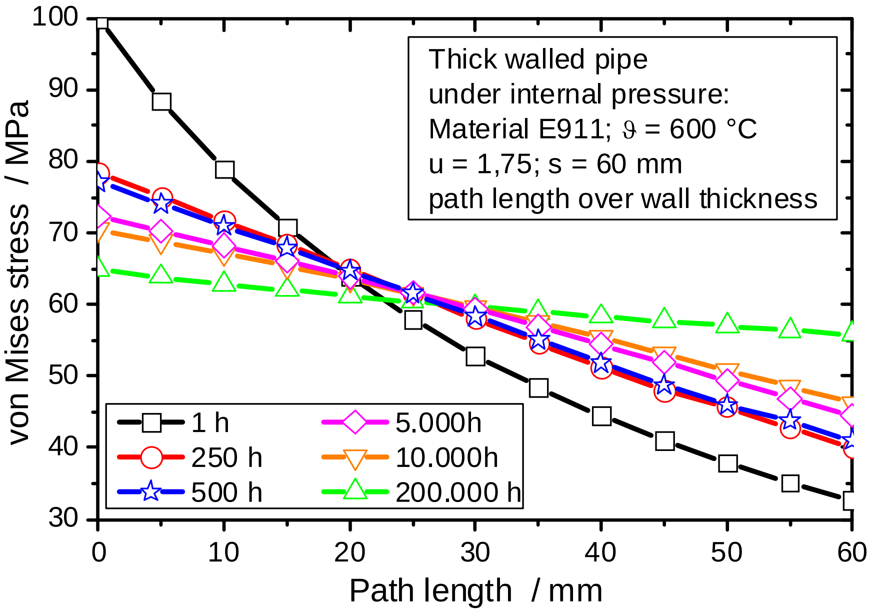
Basic requirements for transferability

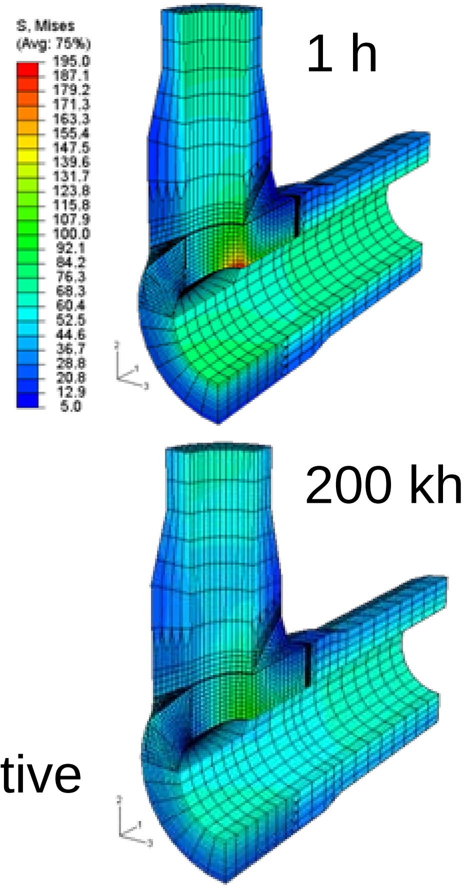
- Execution of the creep tests should be in accordance with an international code.
- Lab should accredited
- Microstructure/heat treatment of the lab specimen is representative for the component or several melts have to tested in order to determine the average creep behaviour.
- Testing time and rupture time of the lab specimens should be in accordance with dominating creep damage mechanism of the component.
- Stationary service conditions at the component have to be assumed, i.e. creep processes should not be influenced by cyclic loading.

Part II – Component Behaviour

Thick walled components under internal pressure:

Even after long loading times, no homogeneous stress distribution can be observed.





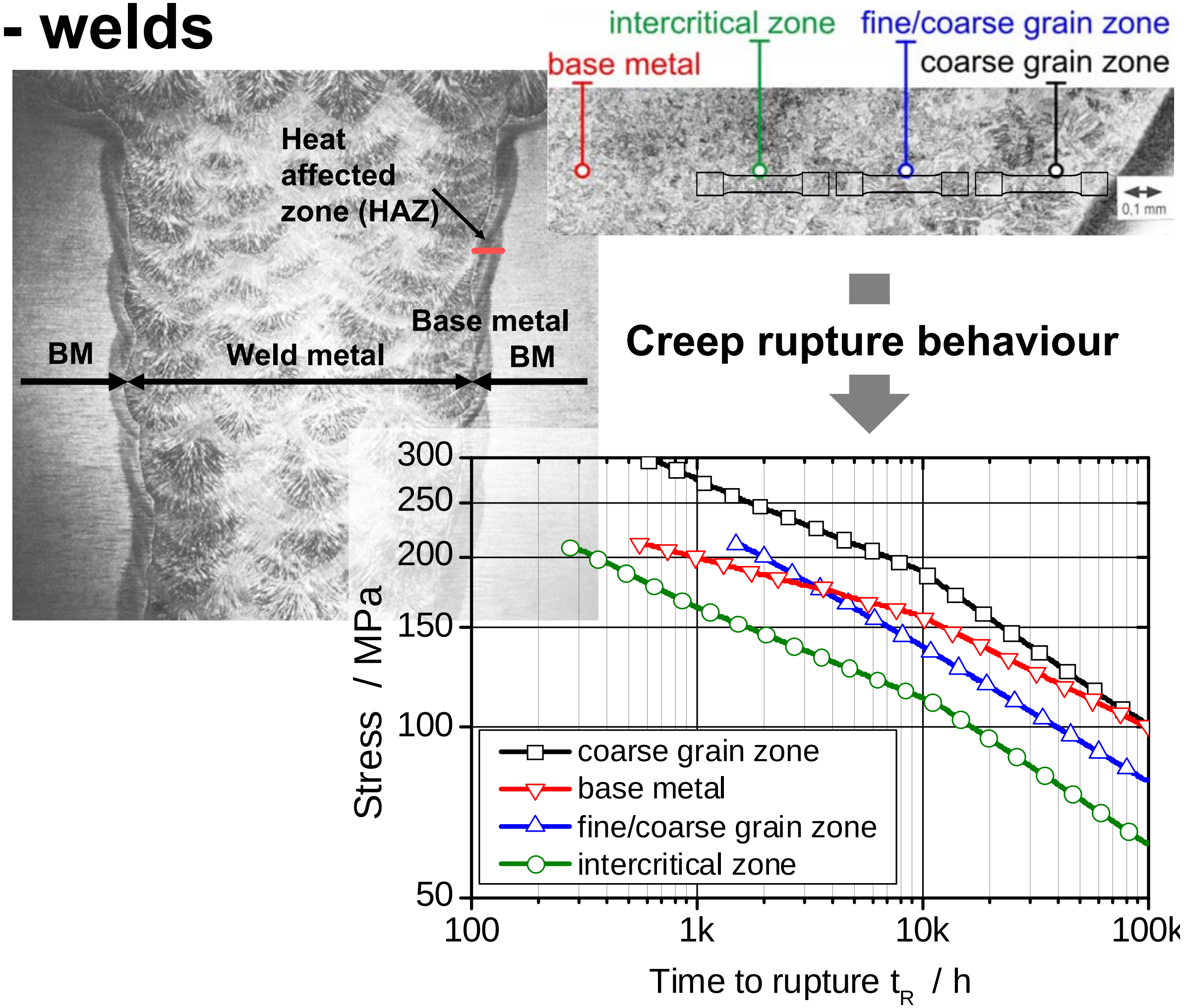
Material properties from creep test can be applied if analytical methods are used to determine a representative stress in the cross section – conservative results

Specific problems - welds

Unfavourable heat input during welding leads to:

- Changes of the micro-structure (phase transformation)
- Changes of grain size
- Change of precipitation characteristics

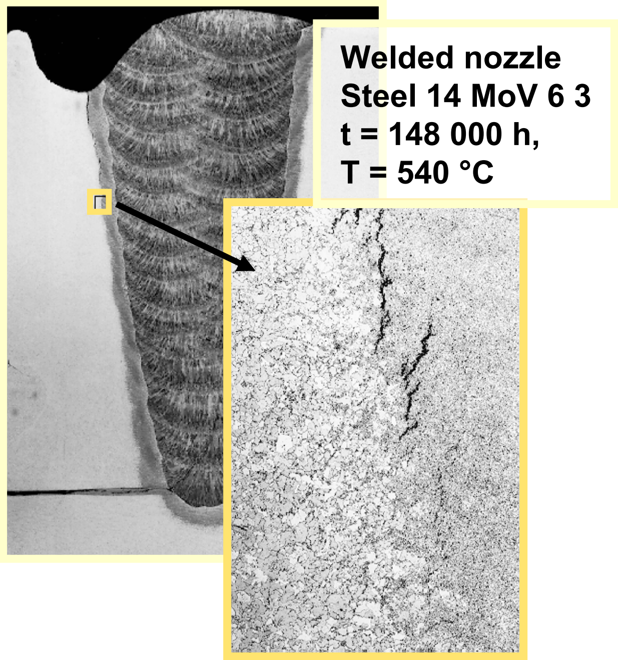
Combination of different materials with different creep behaviour



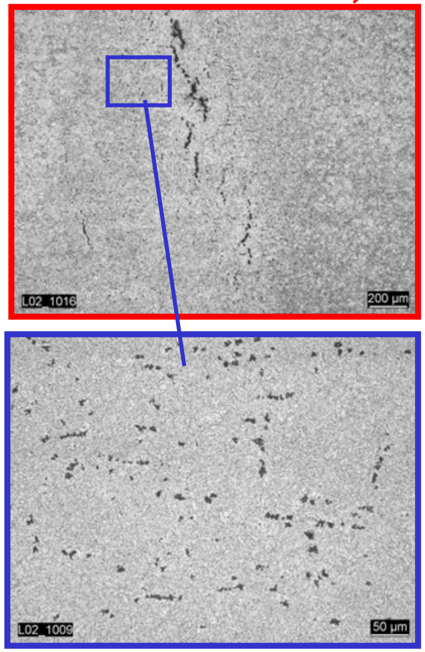
Creep rupture behaviour

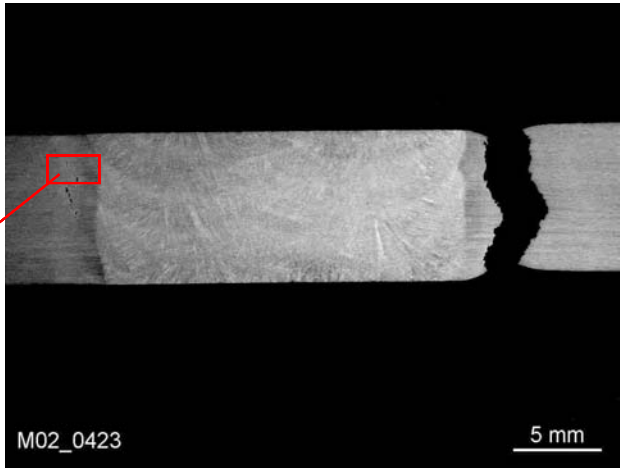
Formation of creep cavities in the outer area of HAZ (intercritical zone): Type 4 cracking

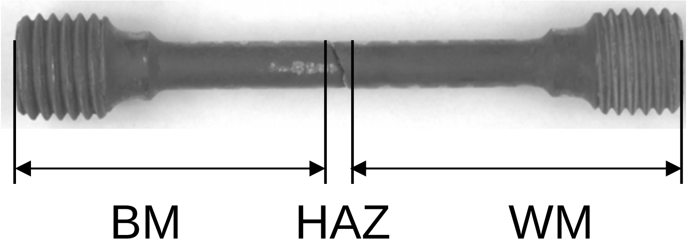
HAZ has to be considered as area with increased creep failure probability



Welded nozzle
Steel 14 MoV 6 3
t = 148 000 h,
T = 540 °C

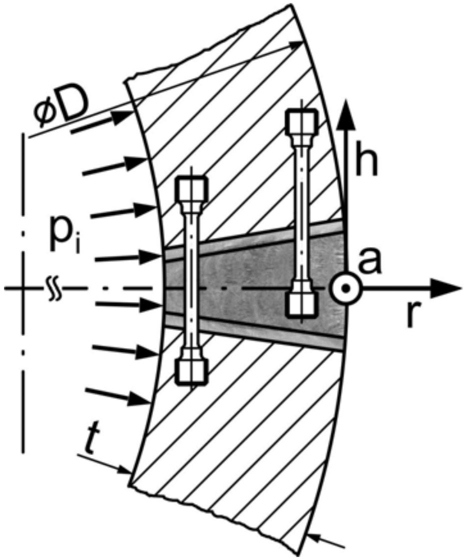






$$\mathrm{WSF} = \frac{R_{m/t/\delta}\,(\text{welded joint})}{R_{m/t/\delta}\,(\text{base metal})}$$

Thin walled pipes with long. seams under internal pressure:



$$\sigma_a = \frac{1}{2}\sigma_h$$

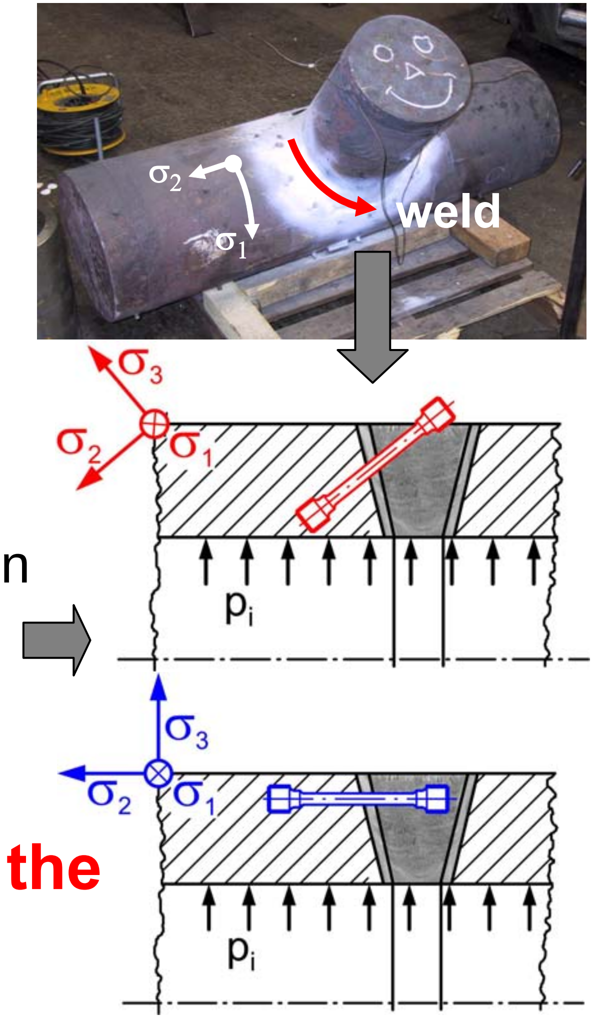
- Longitudinal welds are fully loaded in pipes under internal pressure

  $(\sigma_h = \sigma_1 = \sigma_{max})$.
- After stress redistribution almost homogeneous stress situation.
- Creep data from crossweld samples represents the component behaviour

Thick walled, welded components under internal pressure:

Inhomogeneous microstructure over the cross section (e. g. BM, HAZ, WM)

- Varying stress situation in the cross section containing welds due to different creep behaviour.
- Influence of the orientation of the cross section to the direction of maximum principle stress.
- Varying constraint
- Stress states of different multiaxiality

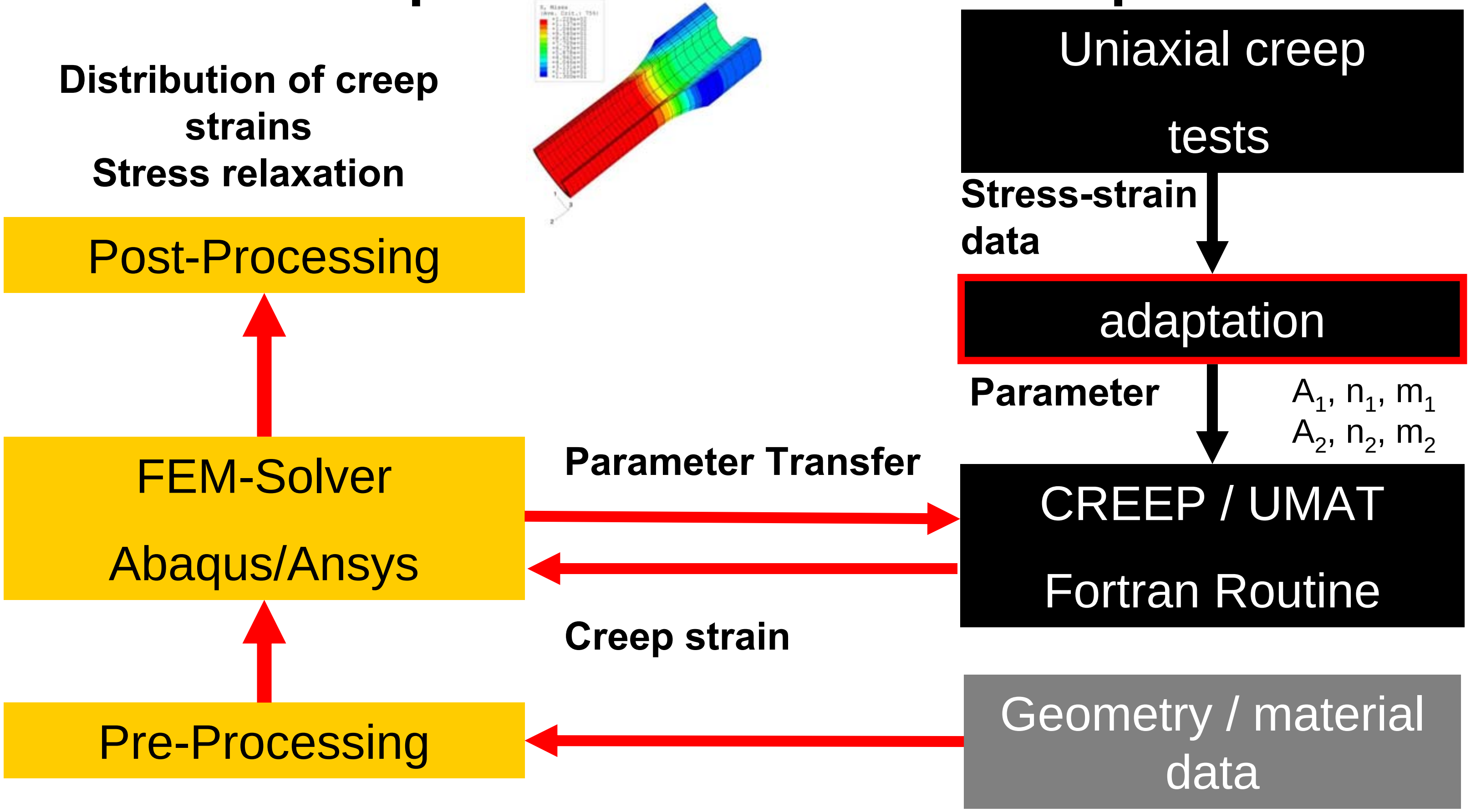


FE-analysis adequate tool to describe the local stress-strain situation

Specific problems with creep behaviour:

1. Use of creep data set in the formulation of creep laws
2. Description of effect of multiaxial stress state on creep deformation and creep damage
3. Stress-strain relaxation of welded structures – type IV cracking

Formulation of creep laws - scheme of a creep routine



Distribution of creep strains
Stress relaxation

Post-Processing

FEM-Solver

Abaqus/Ansys

Pre-Processing

Parameter Transfer

Creep strain

Uniaxial creep tests

Stress-strain data

adaptation

Parameter

A_1, n_1, m_1
A_2, n_2, m_2

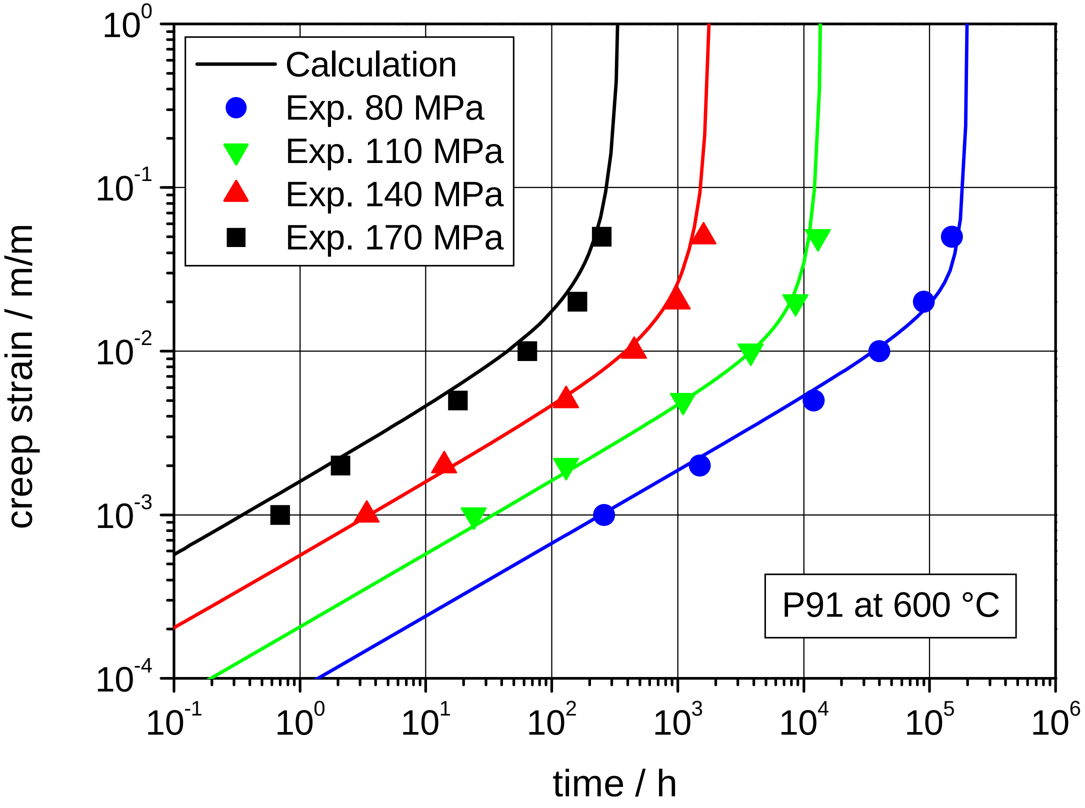
CREEP / UMAT

Fortran Routine

Geometry / material data

Formulation of creep laws

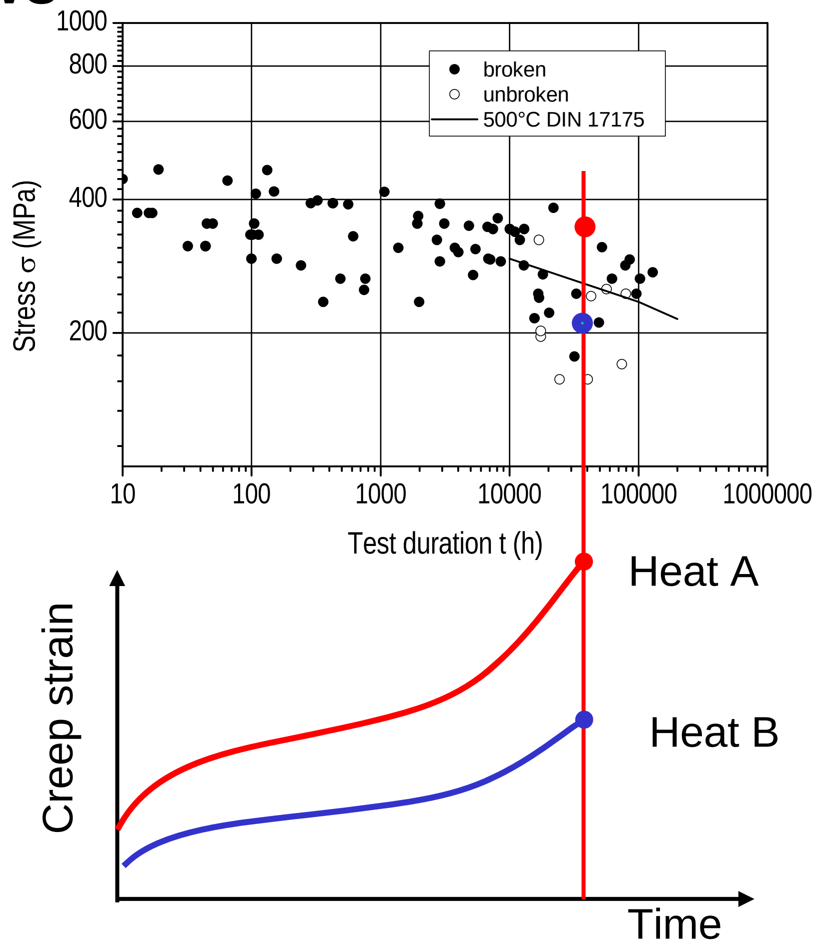
$$\dot{\varepsilon}_{cr} = A_1' \sigma^{n_1} \varepsilon_{cr}^{\ m_1} + A_2' \sigma^{n_2} \varepsilon_{cr}^{\ m_2} + A_3' \sigma^{n_3} \varepsilon_{cr}^{\ m_3}$$



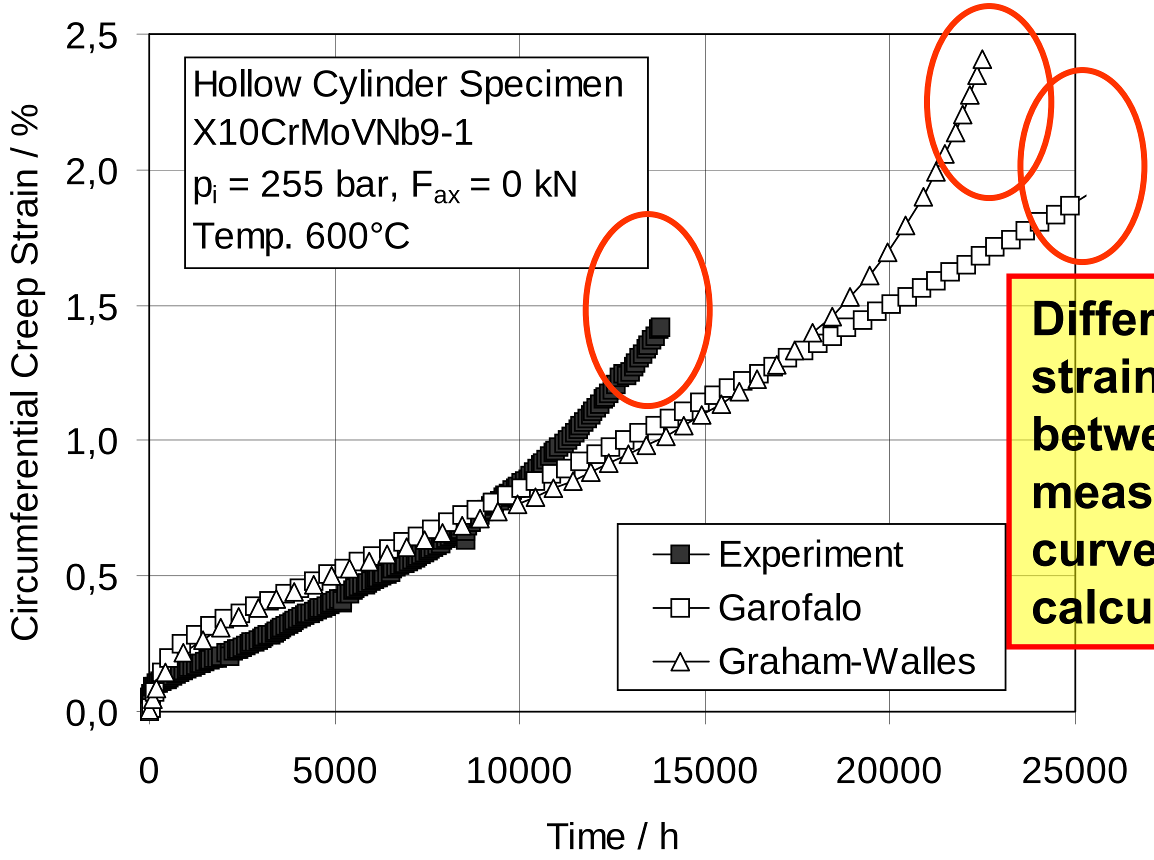
- **All stages of creep should be covered, e.g. by a Graham-Walles formulation**
- **Reliable data base should be used, describing the short time behaviour as well as the long term behaviour**
- **For component calculation at least creep data covering 1/3 of component life should be available**

Formulation of creep laws

- Scatterband caused by different melts
- Individual creep strain behaviour of each melt
- Different parameters in creep law
- Average behaviour of steel grade should be considered in the creep law, if no melt specific data is available



Part III - Numerical simulation

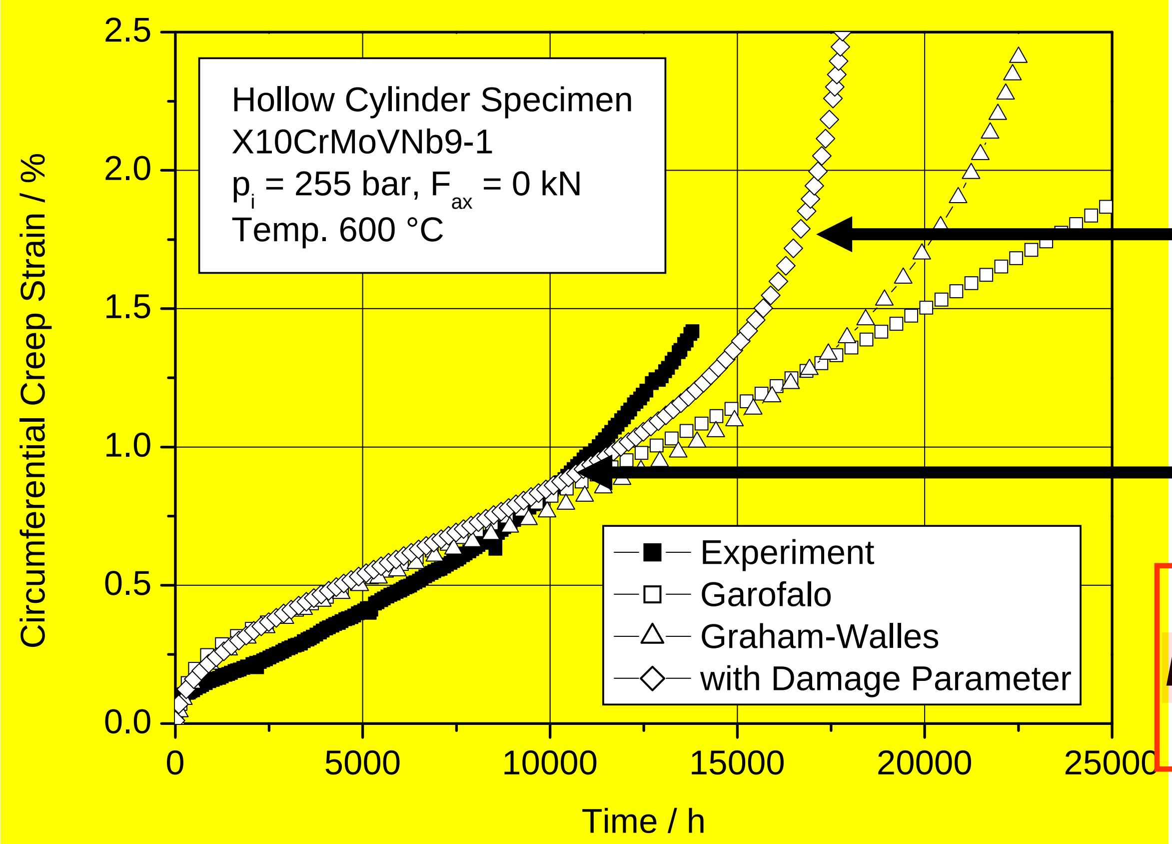


Difference in the strain rate between the measured creep curve and the calculation

Multiaxiality of stress state:

Higher strain rate at the end of experiment

Part III - Numerical simulation



Implementation of a multiaxiality damage factor D

Better accordance with experiment

Earlier start of secondary creep stage

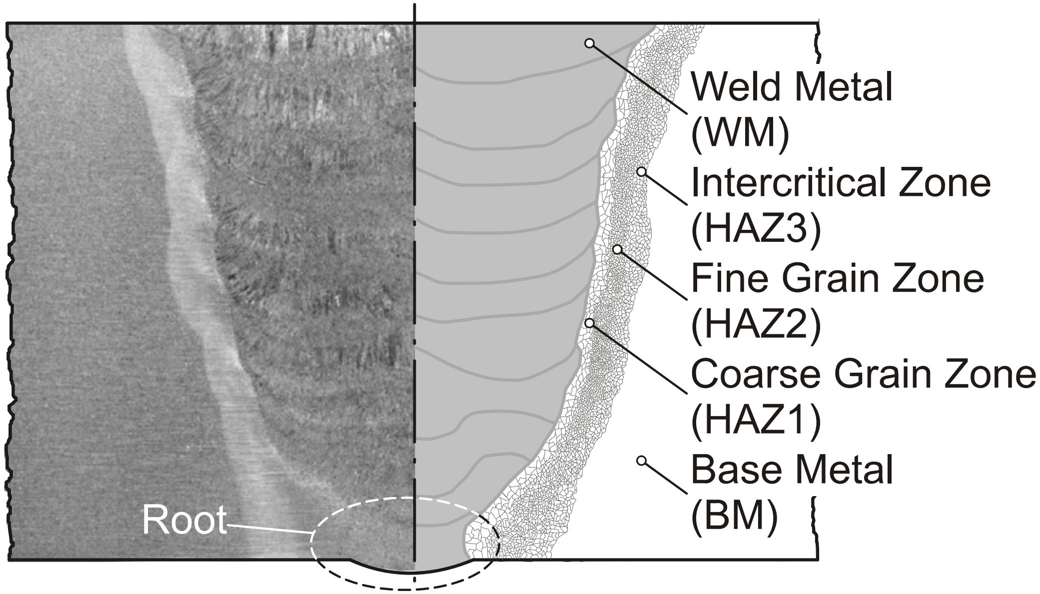
$$\dot{D} = A_D \cdot \left[\left(\frac{\sqrt{3}}{q} \right)^{\alpha} \cdot \sigma_v \right]^{n_D} \cdot \dot{\varepsilon}_{cr}^{\ m_D}$$

$$\dot{\varepsilon}_{cr} = A_1 \cdot \left(\frac{\sigma_v}{1-D} \right)^{n_1} \cdot \varepsilon_{cr}^{\ m_1} + A_2 \cdot \left(\frac{\sigma_v}{1-D} \right)^{n_2} \cdot \varepsilon_{cr}^{\ m_2}$$

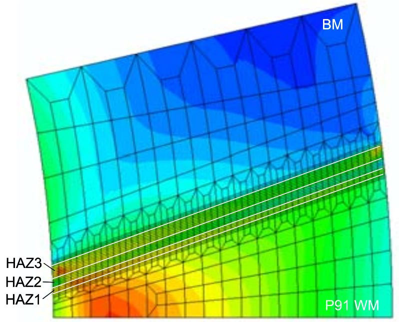
$$q = \frac{1}{\sqrt{3} \cdot h} = \frac{1}{\sqrt{3}} \cdot \frac{\sigma_{mises}}{\sigma_{hydro}}$$

Stress-strain relaxation of welded structures

For structural modeling of welds most accurate results can be expected using five material zones with different creep behaviour.



This is most important for the type IV failure mechanisms since the creep behavior of the component is influenced by the different creep behavior of this zones

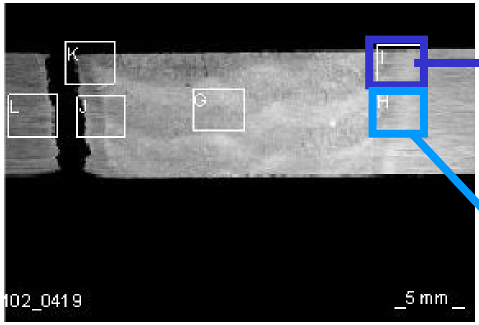


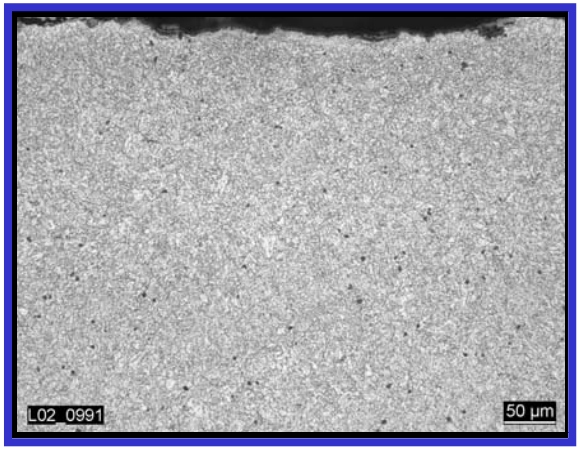
Part III - Numerical simulation

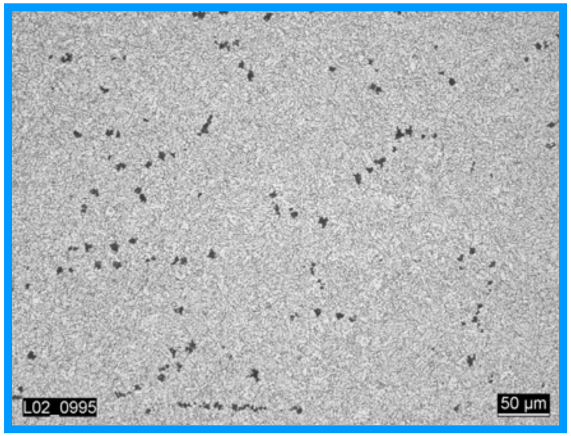
Deformation shown with a scale of 5:1

Stress-strain relaxation of welded structures

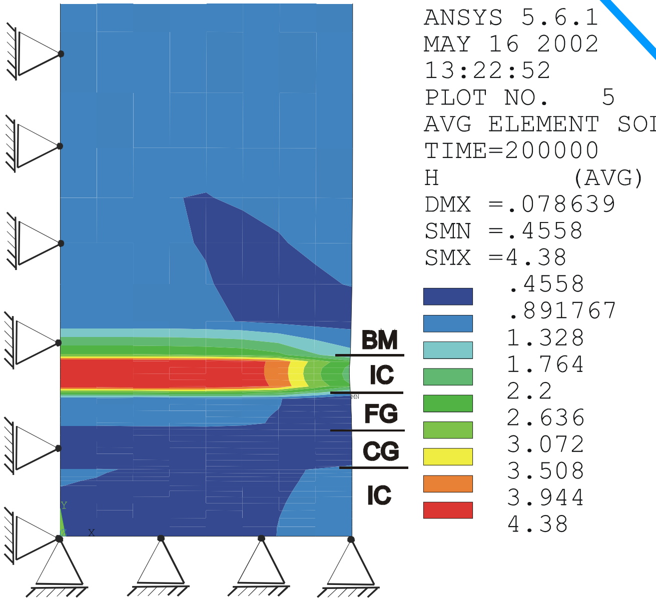
<ins>Numerical result:</ins>
Highest degree of multiaxiality in the center of the specimen







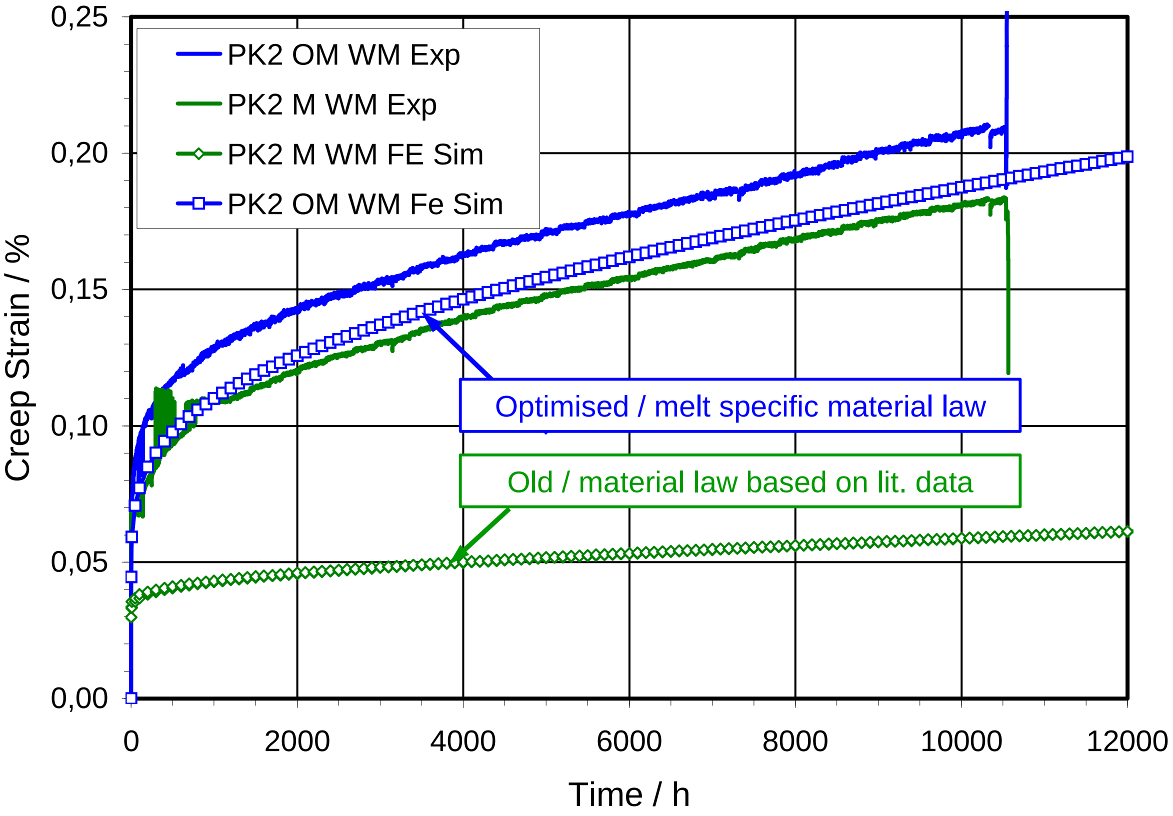
<ins>Metallographic result:</ins>
Highest cavity density in the centre of the specimen



```
ANSYS 5.6.1
MAY 16 2002
13:22:52
PLOT NO.   5
AVG ELEMENT SOI
TIME=200000
H          (AVG)
DMX =.078639
SMN =.4558
SMX =4.38
```

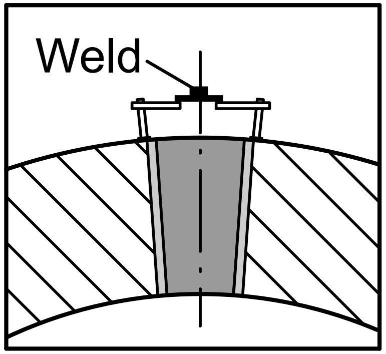
🟦	.4558
🟦	.891767
🟦	1.328
🟩	1.764
🟩	2.2
🟩	2.636
🟨	3.072
🟧	3.508
🟥	3.944
	4.38

Stress-strain relaxation of welded structures

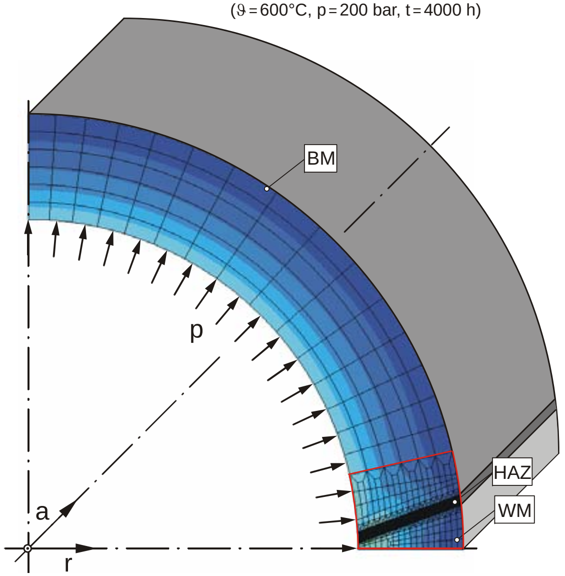


Optimised / melt specific material law

Old / material law based on lit. data



Pipe E911 Equivalent Creep Strain ε_{cr} / m/m
($\vartheta = 600°C$, $p = 200$ bar, $t = 4000$ h)



Summary and Conclusions

The standard tensile test alone cannot predict the behaviour of a structural material at elevated temperatures, where time dependent plastic deformation occur

Creep deformation and damage is strongly influenced by parameters like temperature, stress state, manufacturing process, heat treatment

Consequently a large scattering of data could be observed and has to be accepted and considered in the numerical modelling of creep processes

Summary and Conclusions

With regard to the transferability to components operating in the long term range (>100000h) an accurate assessment of the data used for the fitting of creep laws has to be done, in particular:

- Data should cover the same microstructural creep deformation mechanism
- For extrapolation the factor 3 in time should not be exceeded
- If no heat specific data is available, the data for fitting the parameters should meet the mean values of the creep scatterband of the respective steel grade

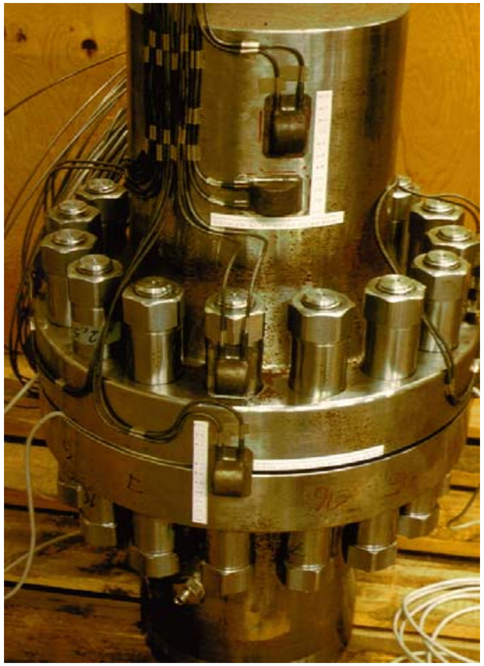
Summary and Conclusions

The creep laws used in creep routine/user UMAT in the FE-Code should include a creep damage factor, which describes the influence of stress state (multiaxial stress state) on creep deformation development in secondary and tertiary creep stage

For the numerical modelling of creep loaded structures a multi-material modell is essential, describing the time dependent behaviour of the different areas in HAZ as well as the base metal and weld metal

Thus the stress relaxation due to the combination of different materials should be described

Summary and Conclusions



Thank you for your attention