Concepts for complementary materials testing simulating the service conditions of high efficiency power plants

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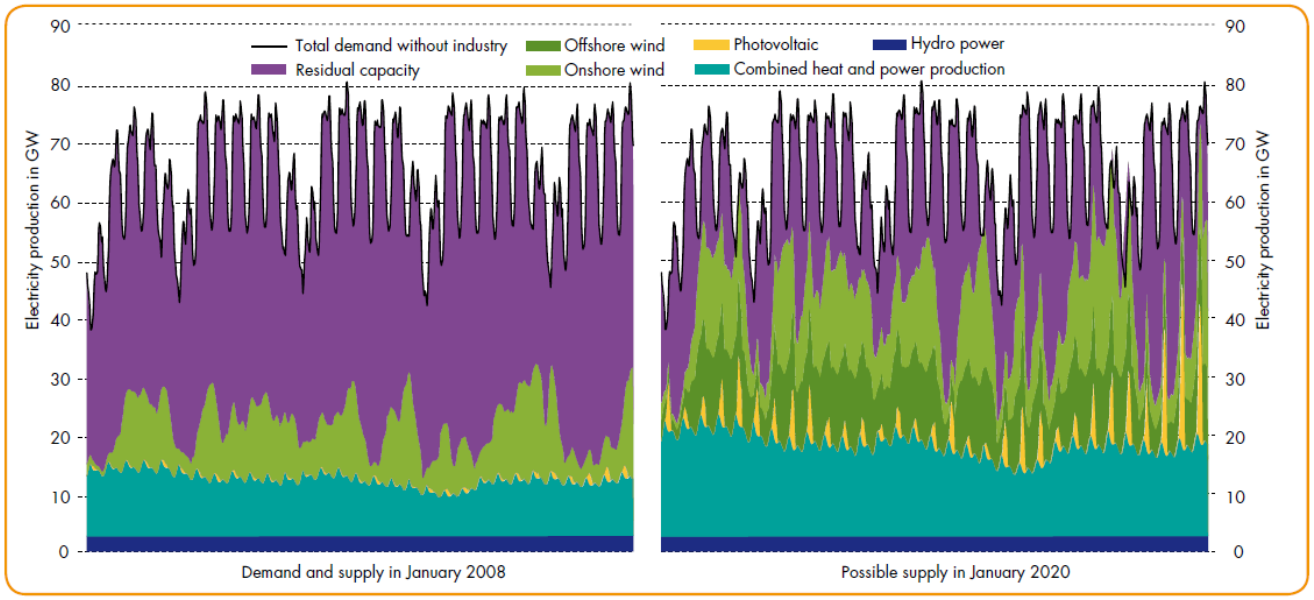
Flexible plant operation due to renewables (I)

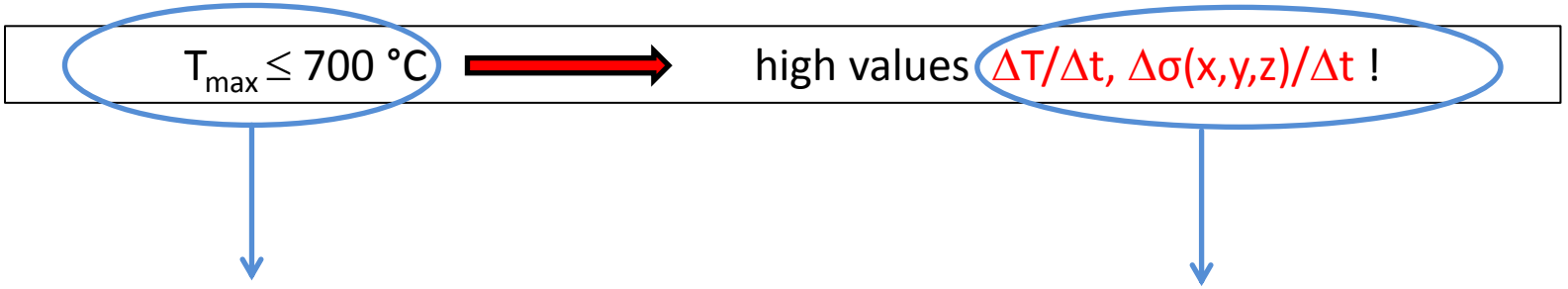


Increasing importance of renewable energy sources in power generation:

- fast load changes of conventional plants are required (goal: ~15-100 % of max. output)
- high steam temperature rates $\Delta T/\Delta t$ are desired

Flexible plant operation due to renewables (II)

In the case of high efficiency units:



static operation (T = const):

- HT corrosion
- creep

dynamic operation (T ≠ const):

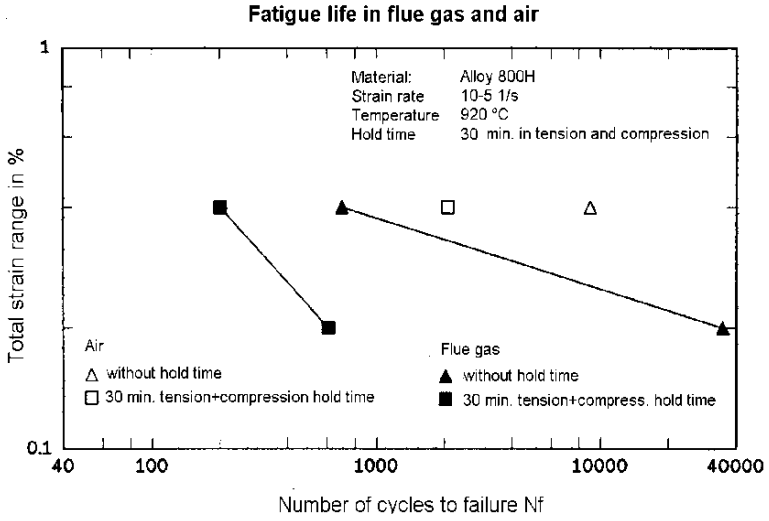
- HT corrosion
- creep
- spallation
- cyclic loading/fatigue

all these issues (and their interactions) need to be considered when assessing the performance of materials

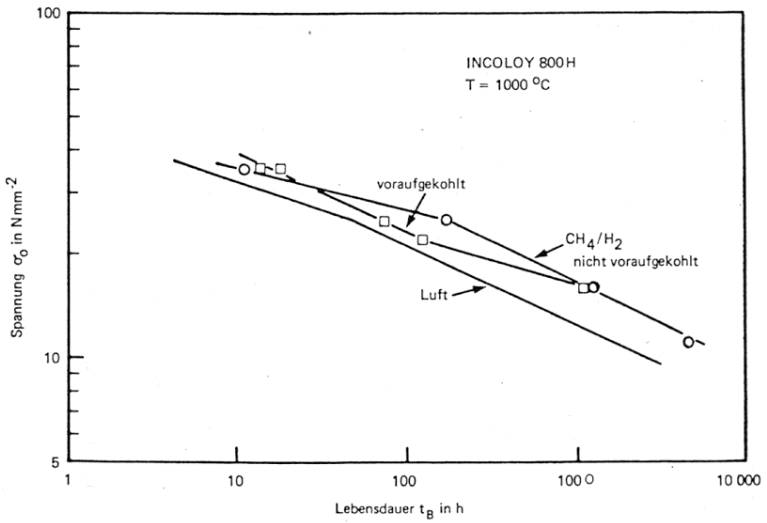
Interactions of atmosphere and mechanics

Possible interactions of atmosphere attack and mechanical loads include e.g.:

- cracking and spalling of layers with severe local oxidation/corrosion
- formation of pits and notches in the surfaces that act as sites for early crack initiation
- accelerated crack propagation due to corrosive attack
- enhanced oxidation/corrosion kinetics in presence of cracks
- Modification of the microstructure, like formation of carbides etc.



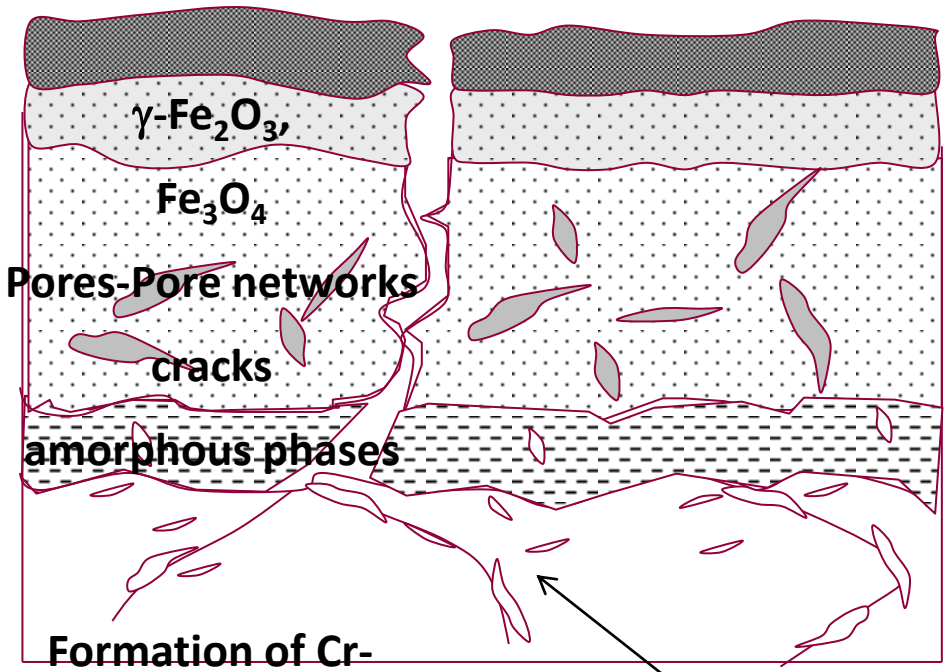
Klingelhöffer, PhD thesis, 1994: Reduced fatigue life in flue gas



Bürgel, PhD thesis, 1981: Enhanced creep resistance in CH4

For example the potential damage observed in an experimental simulation of corrosion under oxygen /coal firing conditions (without ash layer)

Typical Scale on 9-12 % Cr-steel in Coal fired power plants and oxyfuel-technology



Fe-Oxide and $Fe_{X(}SO_4)_Y$;

$(Fe,Cr)_3O_4$ +
$FeCr_2O_4$ + Cr_2O_3 +
Phases with Si, in case
Si is available

Open $FeCr_2O_4$ layer+
amorphous phase (Fe, S, Cr)

$FeCr_2O_4$ +
Base material

Diff. C

$(Cr,Fe)_{23}C_6$

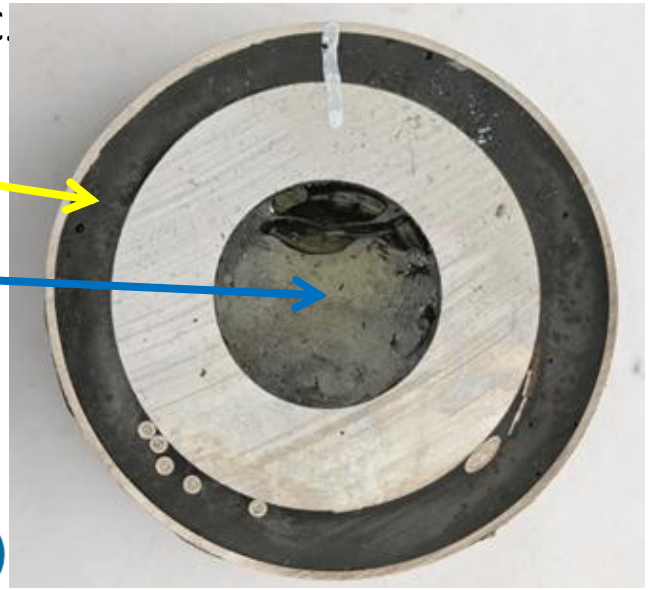
Formation of Cr-Carbides declines Cr mobility

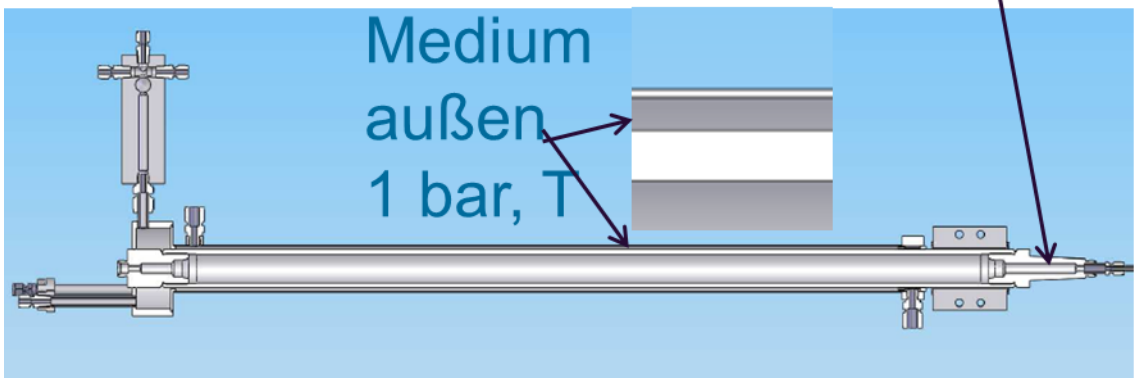
Grain boundary carbides
Local corrosion

Tubular Corrosion samples with 275 bar internal pressure.
Material temperature at failure position 620 °C – 625 °C.

Flue gas: 70 CO_2 – 27 H_2O – 2 O_2 – 1 SO_2

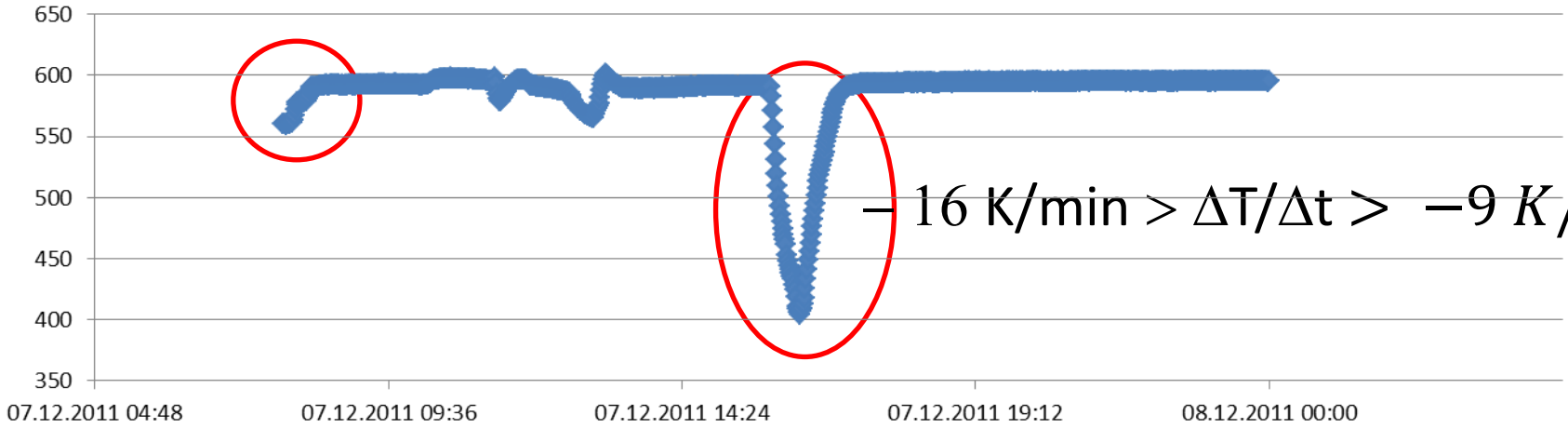
Steam: 275 bar

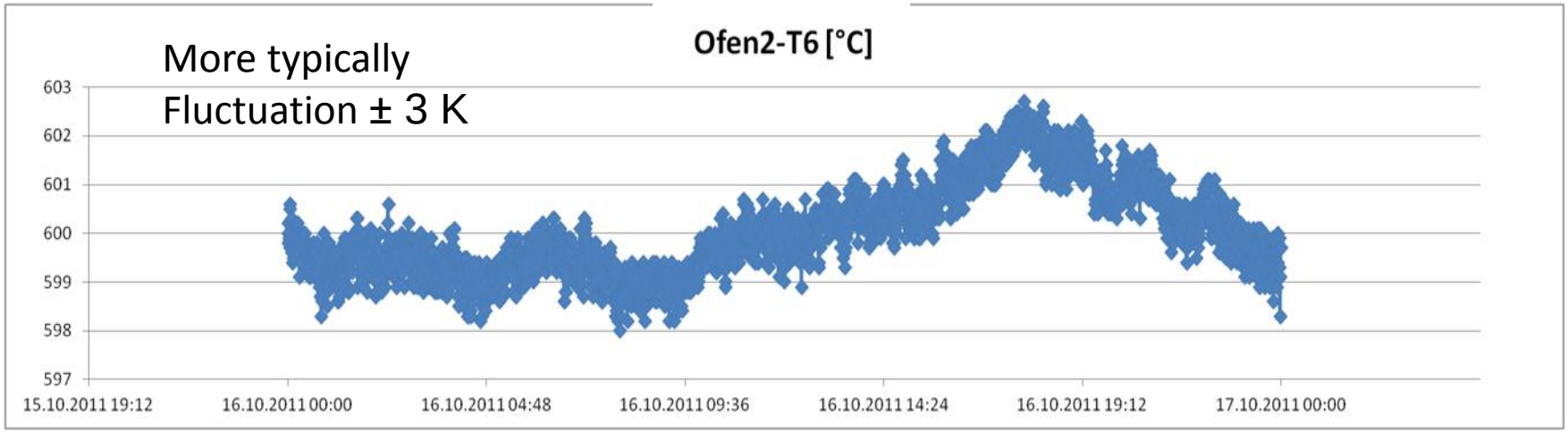




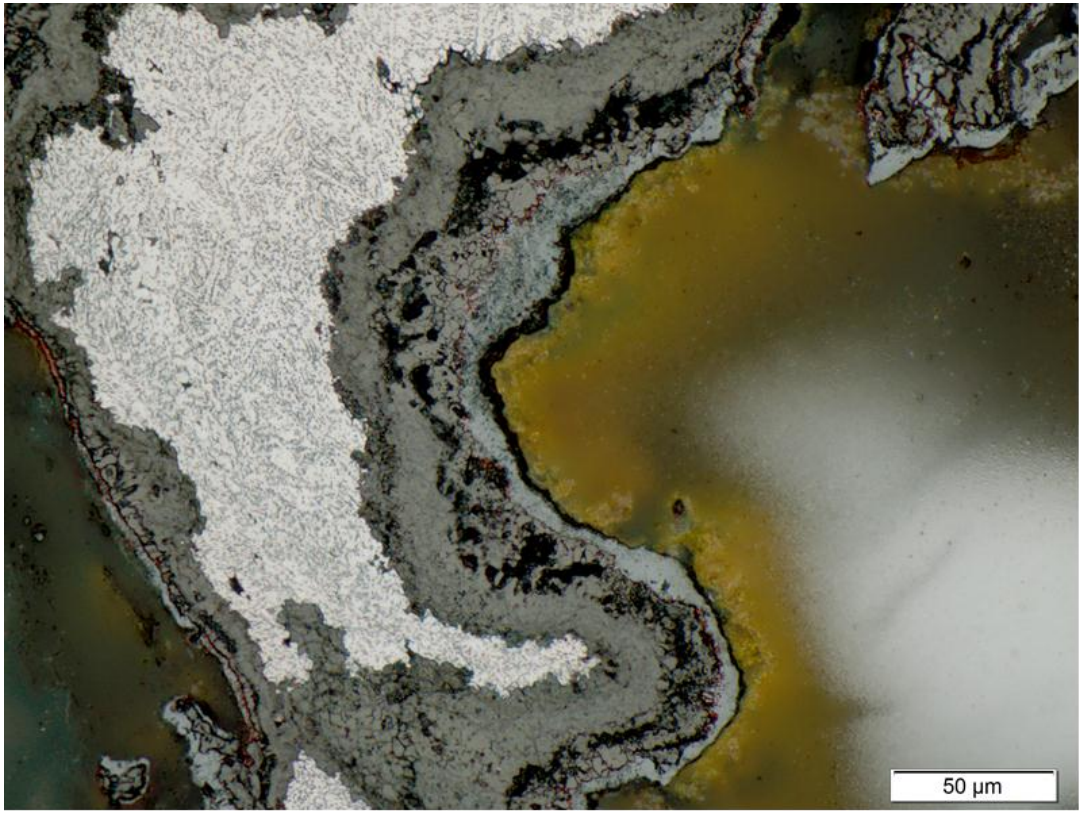
Not very much cycles (less than 100 times – 50 K, 8 times > - 50 K)

2 examples of a 24 h Temperatur data recording of the failed tube)

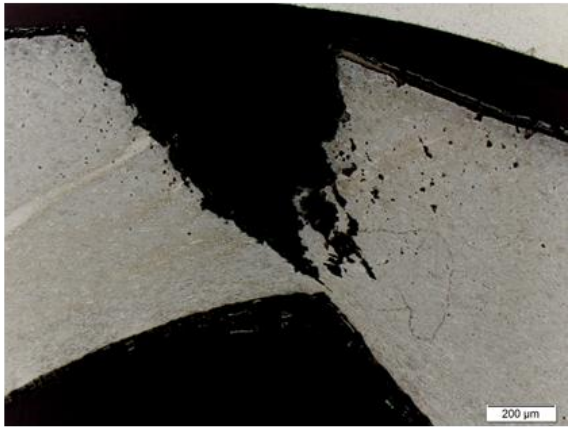




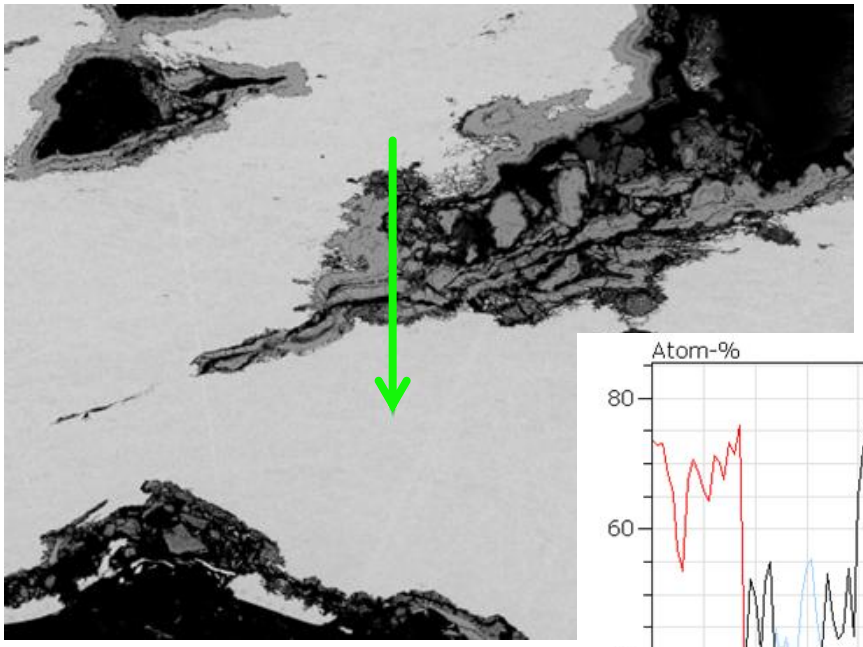
Crack formed on the outer surface under the influence of Oxyfuel atmosphere.



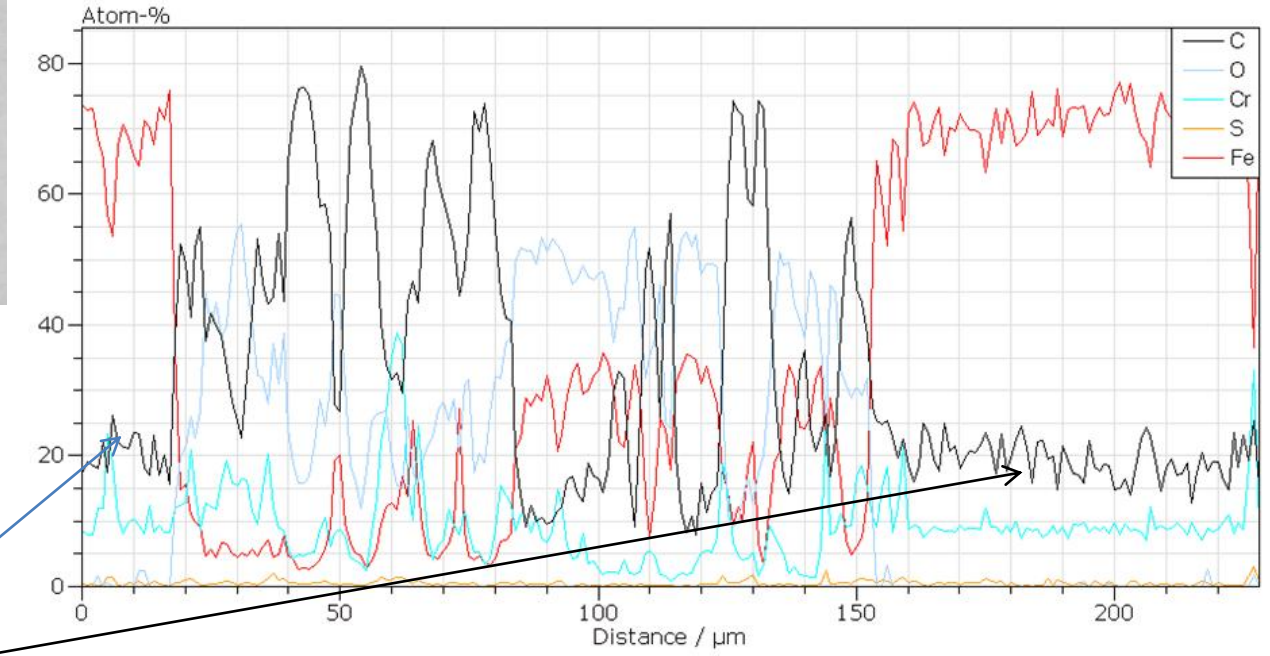
Magnification 50x1



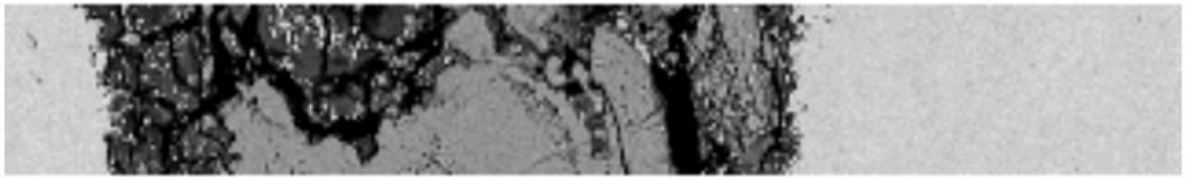
Sulfur was analysed in the complete crack surface in this cross section.



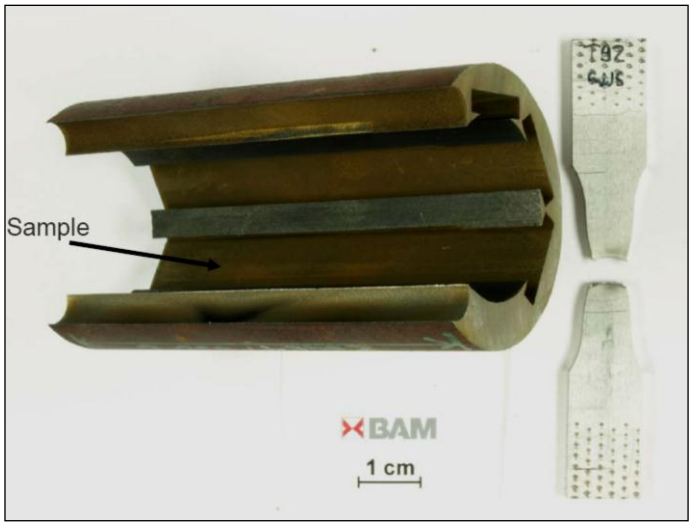
Energy-dispersive X-ray mincroanalytic line scan cross a crack surface near region.

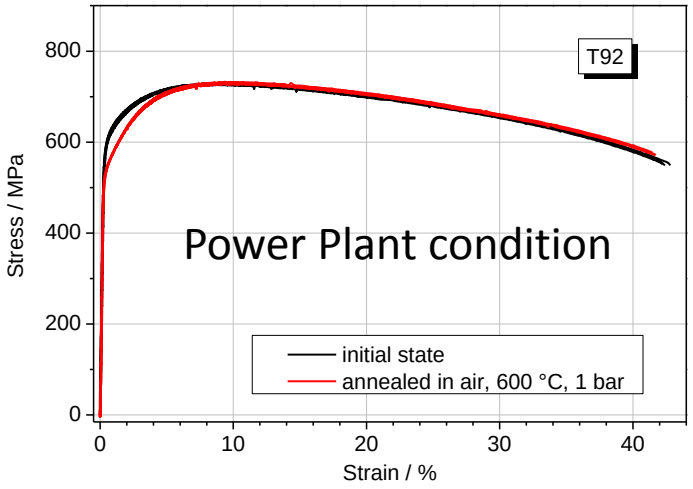


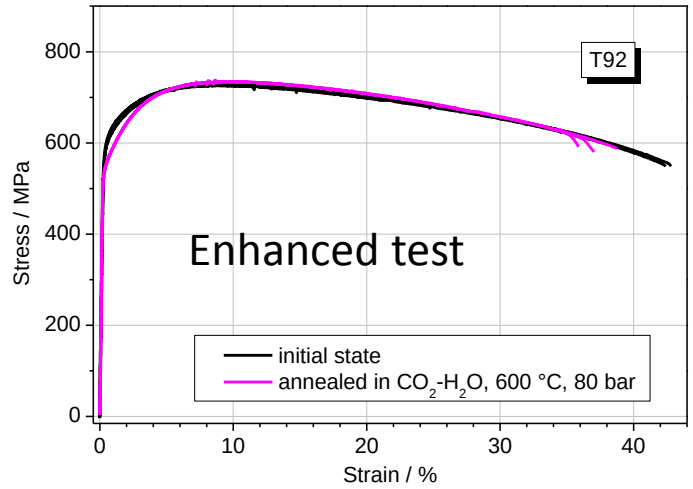
Carbon uptake



Specimen tests for surface near microstructure changes – hierin carburization.

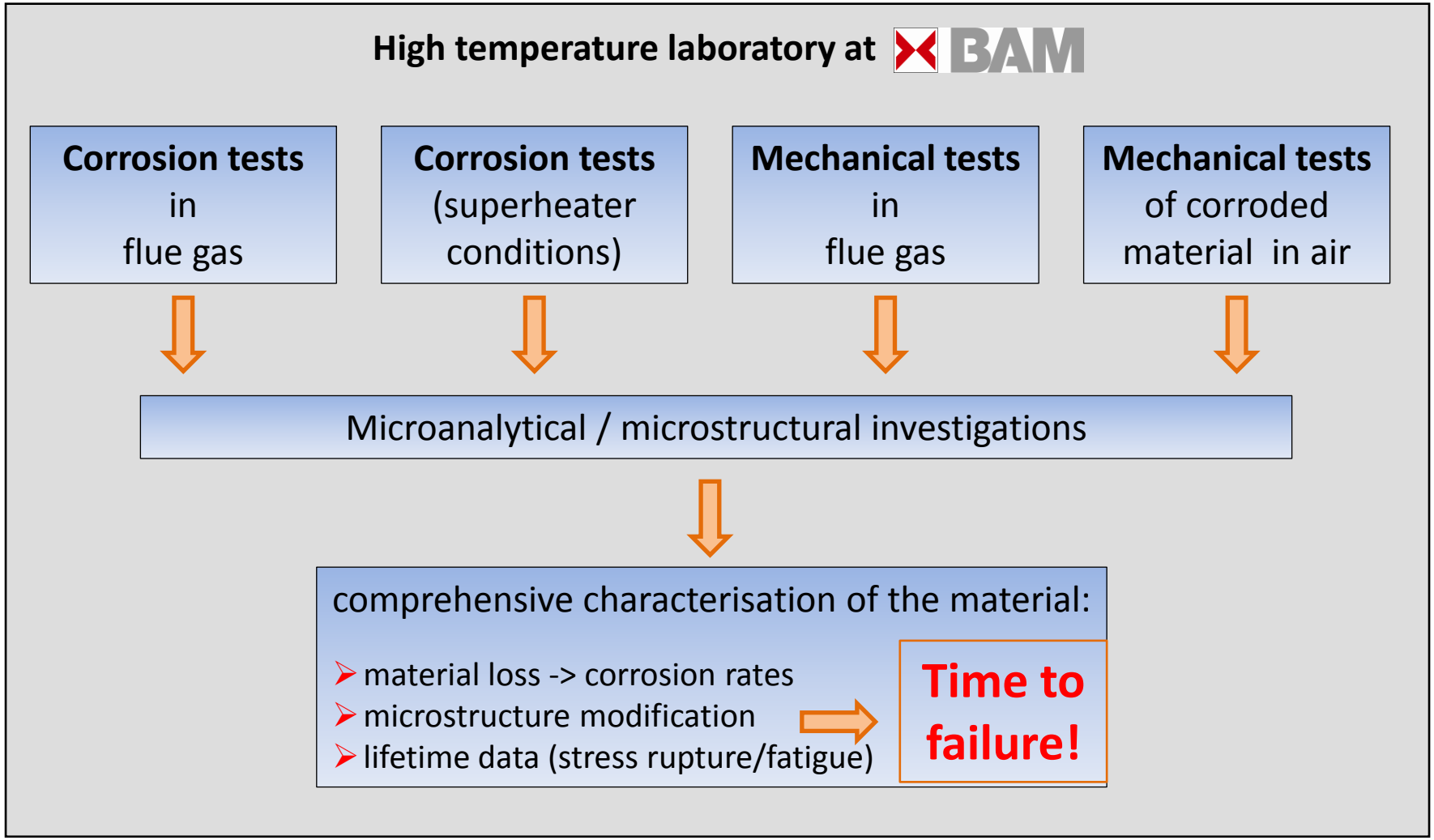






- obvious reduction of elongation at fracture, indicating an influence of the CO_2 rich test atmosphere on the ductility of T92
- very short exposure time (1000 h) compared to typical component lifetimes

Comprehensive characterisation
-> combination of working condition simulation and mechanical tests.



Corrosion test facilities for boiler tubes and tubular heat exchangers

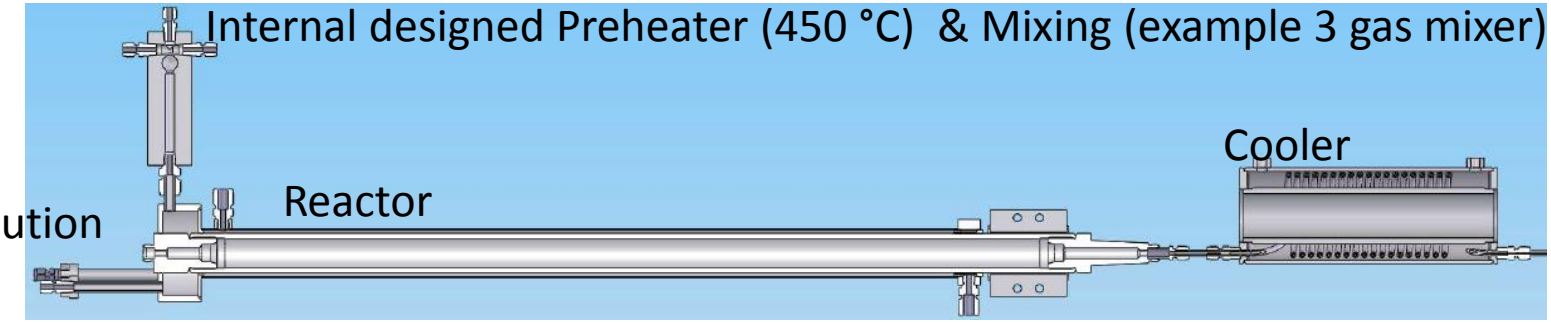
- test environments:

  Mixture of 5 gases (SO_2, CO_2, H_2O, O_2, N_2, CO, …)

  Pressurized CO_2, H_2O
- pressure: 1 atm, 30 – 320 bar

  (inside tubular specimen)
- temperature: RT - 750 °C
- time: 100 h - > 4000 h

Corrosion lab view



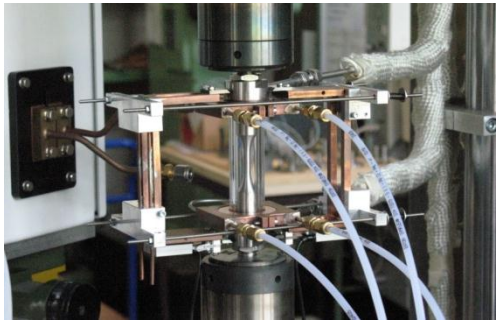
Details of the reactor

Mechanical testing in atmospheres

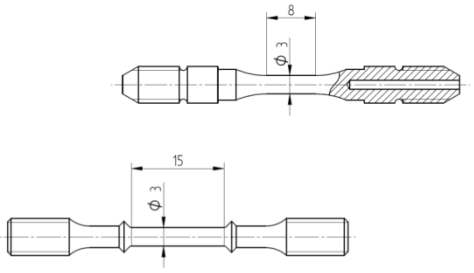
Mechanical test facilities

HT-LCF and creep/stress rupture tests in flue gas

- damage mechanisms in combustion atmosphere
- structure of the oxide layers grown under load
- check the importance of interactions between loading and HT corrosion for power plant materials
- creep and fatigue life data under near service conditions



Fatigue test setup



Extraction of miniature specimens from super heater pipes

Final remarks

- Material performance in extreme conditions is governed by a multi-factorial set of parameters with individual share of impact.

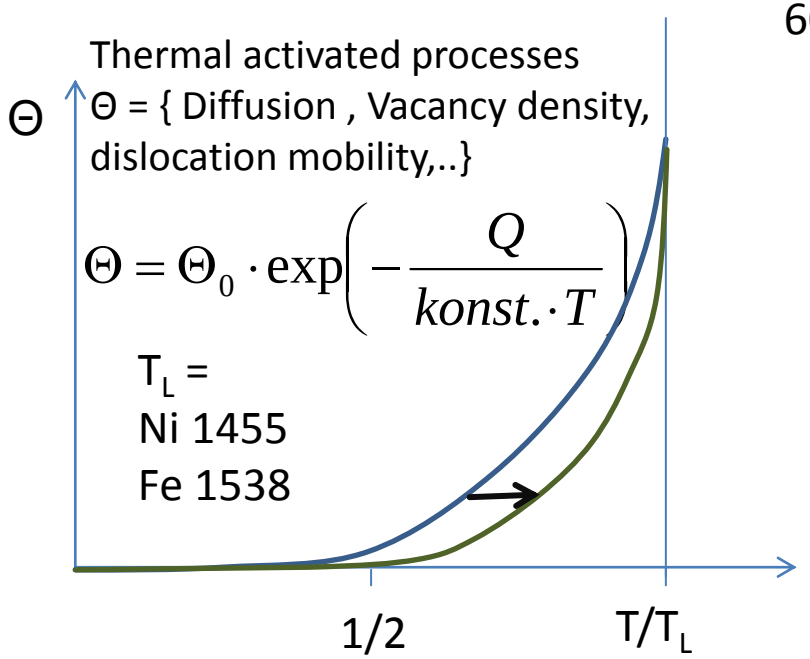
  - Mechanical loads
  - Superimposition of thermal and mechanical cycles in corrosive atmosphere
  - Influence of microstructure modifications on the life time
  - Microstructure damages (carburized grain boundaries, local corrosion, sulfur corrosion) and crack formation.
  - ……

- Test under simulated working conditions may be important to verify life time models
- Attention should be paid to the interactions of these processes as they may be crucial for component lifetimes.
- Microstructure stability under corrosion superimposed with stress has to be considered.

Just remarks on materials technology for the 700 °C power plant!

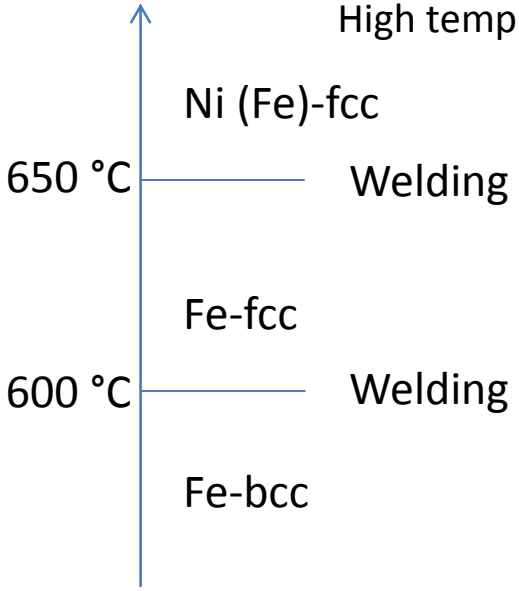
High temp. material development

Phase (Precipitation) stability:
- Solubility and dissolution kinetics
- Nucleation and growth
- Stability of nano-precipitates
- Coatings? – Separate mechanical and corrosion requirements



Material development
⇔ Influence Q

High temp. material development



Firing:
Avoid -
- hot spots
- Low oxygen partial pressure
- ….

Improve -
- O_2-fuel mixture
- ….

Requirements for further material developement are tests under working conditions, investments in solid research in the field of kinetic and thermodynamic processes and constitution of materials .

Thank you for your kind attention!

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