

Challenges of Flexible Power Plant Operation: Damage mechanisms and inspection methods

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Operational Regime of Coal-Fired Plants: in the Past

- › Regularly the plants had more than 7,000 full load operational hours per year → full load plant as per design
- › Plants were only shut down for maintenance
- › Creep was the main damage mechanism on the components
- › Number of starts in correlation to the operational hours was low nearly no impact on lifetime consumption



Operational Regime of Coal-Fired Plants: over the Years

- › Number of (cold) starts in correlation to the operational hour is increasing
→ more flexible operation, more cyclic exposure
- › Operational hours clearly decreasing in the last decade at all locations
→ less creep exposure / damage
- › Number of starts very dependent on plant location
- › Lifetime consumption due to cyclic exposure becomes more dominant at some locations
- › Lifetime consumption at many locations is not significantly influenced due to reduced operation

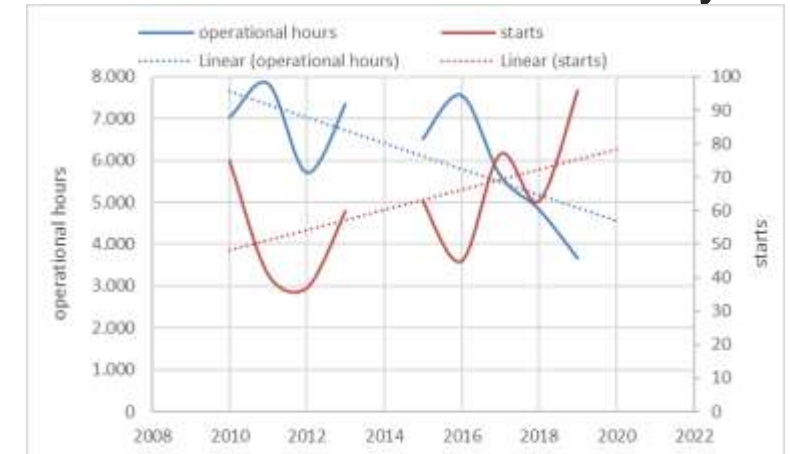
Plant A: North of Germany



Plant B: Middle of Germany



Plant C: South of Germany



Consequences for Maintenance 1/2

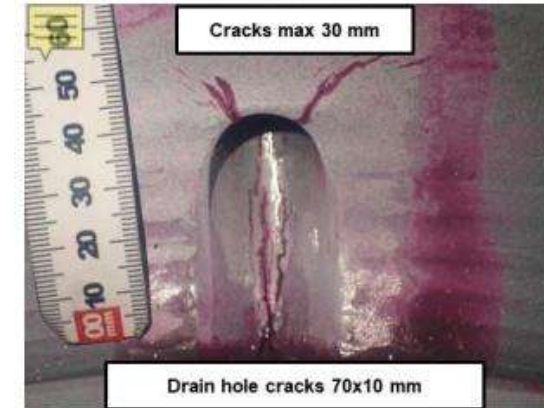
- Lifetime consumption particularly related to cycling fatigue stress – new inspection methods are needed to detect damages
- Implementation of condition monitoring systems that calculate the lifetime consumption based on metal temperature measurements (e.g. boiler fatigue monitoring)
- Higher lifetime consumption due to higher switching rate of actuators such as big electric motors – more frequent inspections are required
- Higher likelihood of damage (erosion) to steam valves, as they are operated more frequently in wet state



Wear and tear at a HP bypass valve;
source: vgbe member company

Consequences for Maintenance 2/2

- Increased risk of cracks in hot thick-walled components like main stop valves, main control valves and reheat combined valves due to thermal stress and condensation
- More frequent inspections are required, e.g. every two to three years instead of every 50,000 hours
- More attention needs to be paid to components that are not designed for longer operation (e.g. turbine turning gear)
- Spare part management needs to be adjusted accordingly



Strain-induced corrosion cracks in main stop valve body

source: vgbe member company

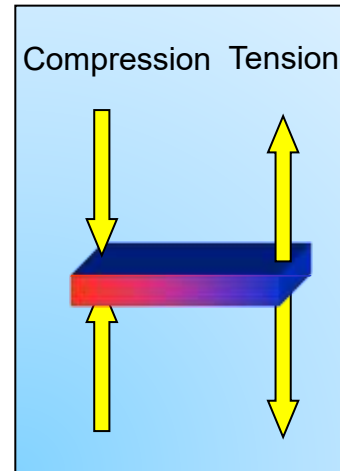
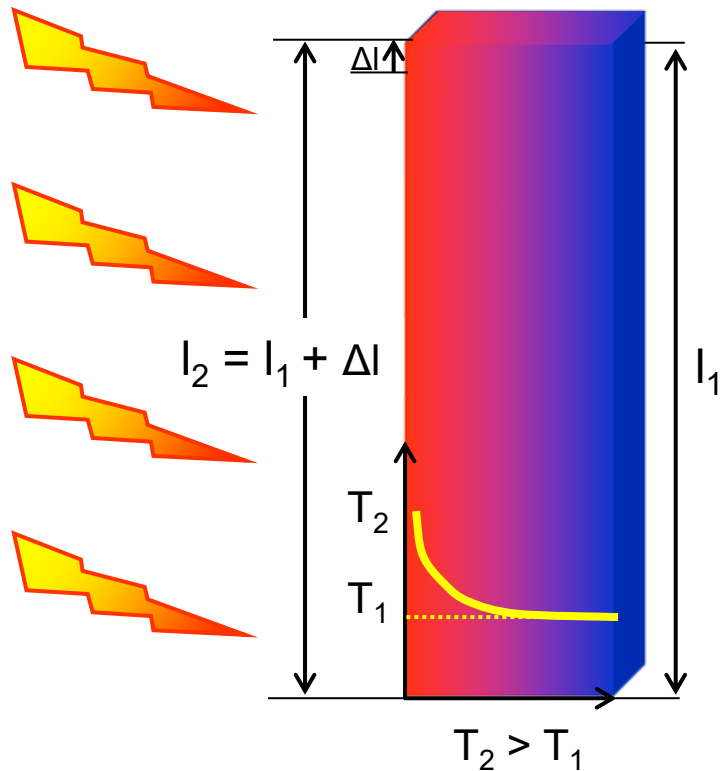
- › Consequences are very plant depended and can differ
- › Operational parameter to be individually checked
- › For many plants no negative effect on the “yearly” lifetime consumption expected → expected to reach year 2035 without “flexibility” damage
- › Longer periods of non-operation → **preservation concepts**
- › Cycling operation requires:
 - generally more complicated **lifetime monitoring**
 - **different inspection methods**
- › Up to now no significant increase in damages due to cyclic operation observed → however some specific failure occurred



Damage Mechanisms potentially caused by Cyclic Operation

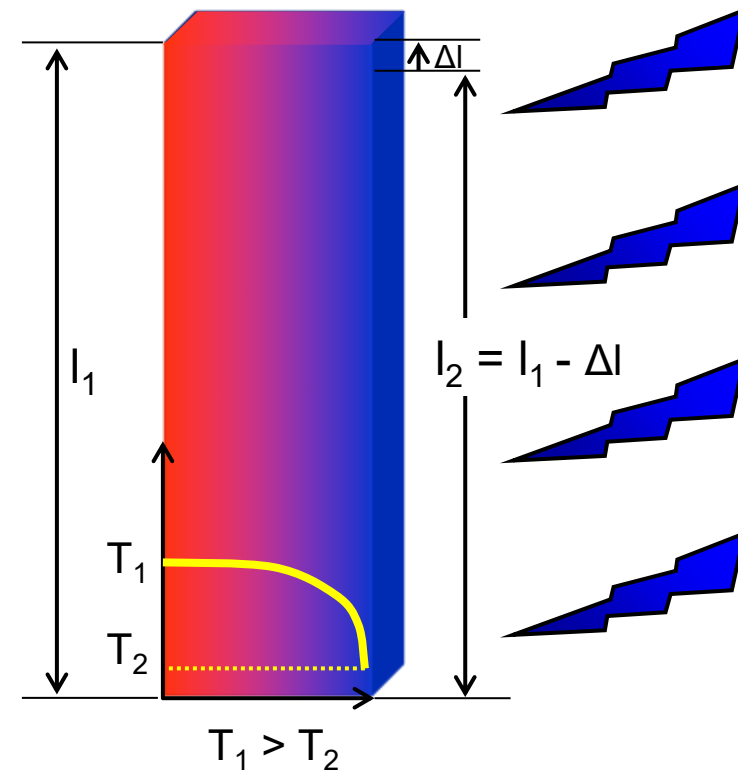
One-sided “shock-like” heating

$$\Delta l = l_1 \alpha (T_2 - T_1)$$

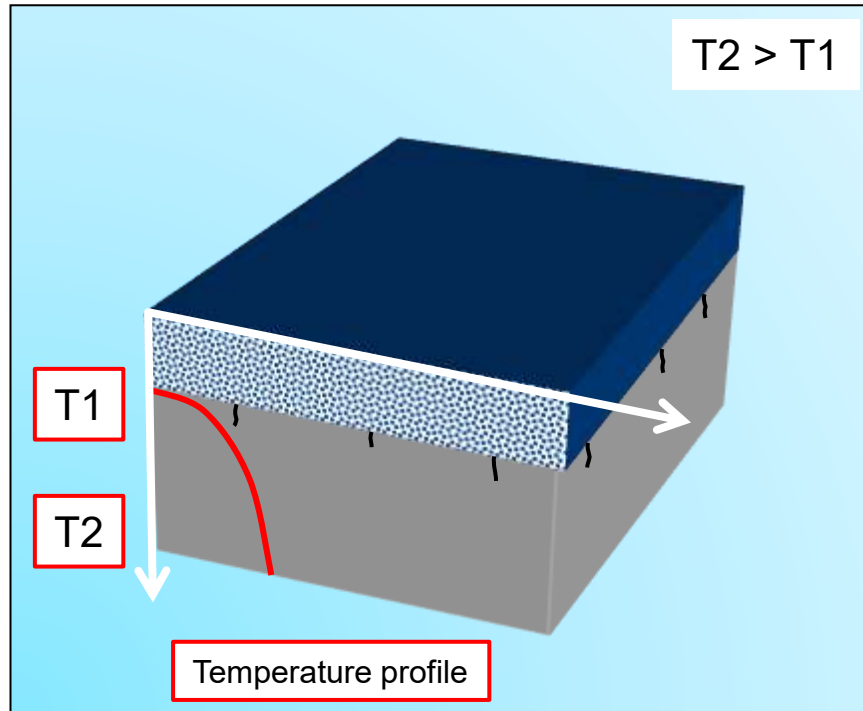


One-sided “shock-like” cooling

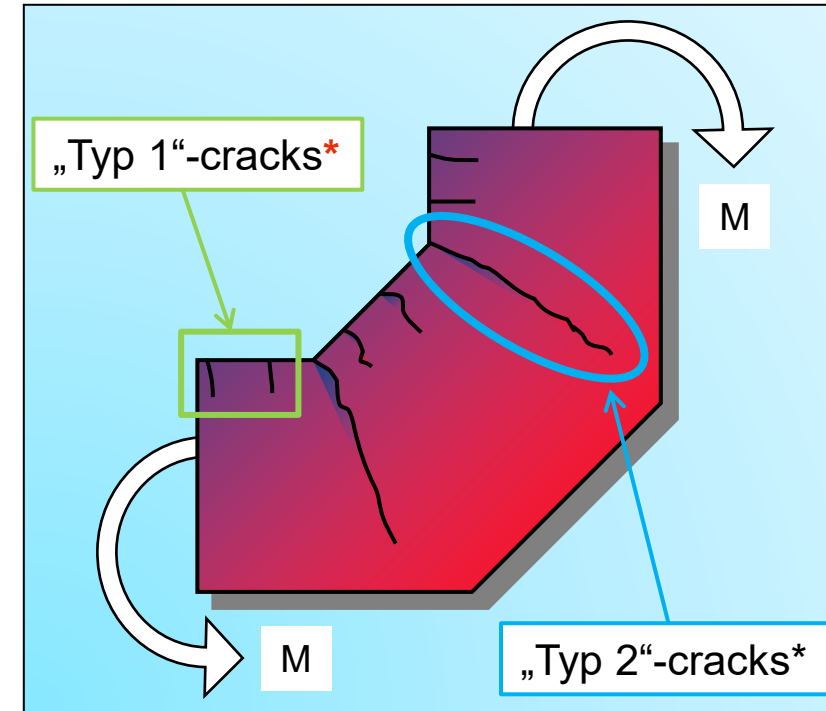
$$\Delta l = l_1 \alpha (T_1 - T_2)$$



Thermal Shock / Thermal Fatigue Cracks



One-sided “shock-like” cooling of a flat plate with constant thickness and “infinite” extent

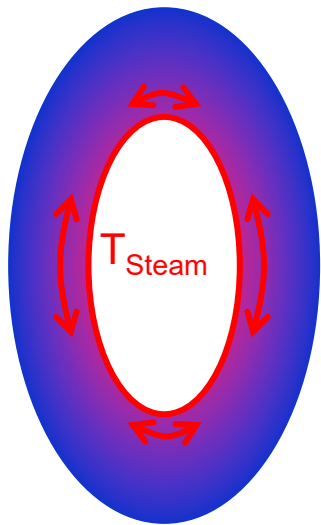


One-sided “shock-like” cooling of a more complex geometry with additional external loading

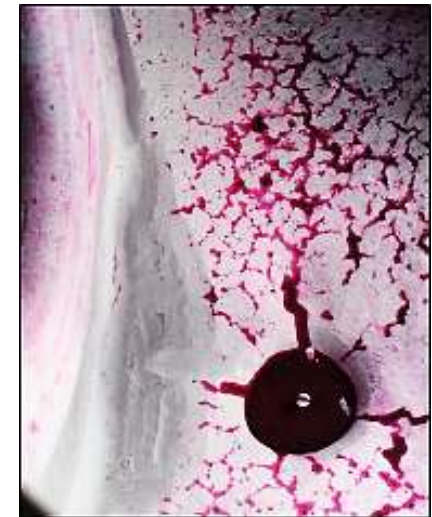
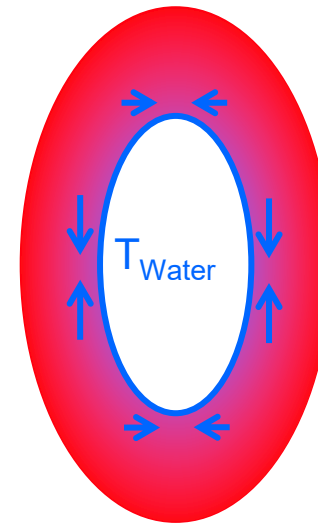
**The classification into “Type 1” and “Type 2” cracks is not a generally binding designation*

Example: Turbine and Turbine Valve Casings

Temperature gradient within the component wall led to constrained thermal expansions
→ (tensile) or (compressive) stresses, which are, however, relieved by plastic deformation once the yield strength is reached

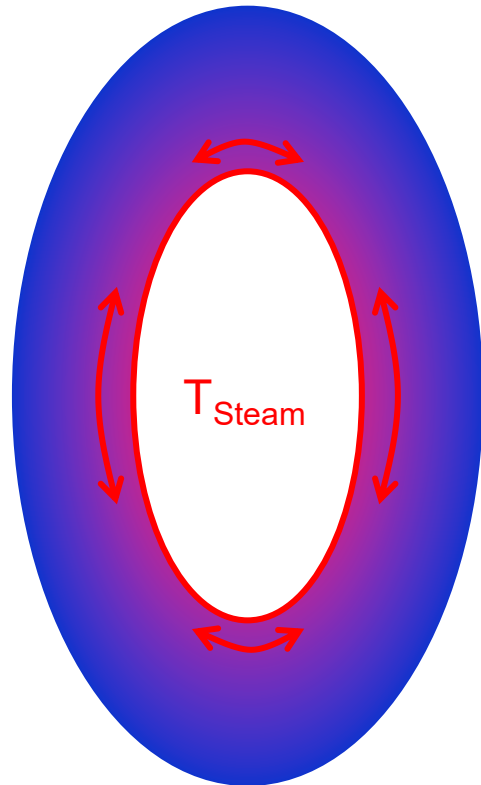


Left Image:
Cracks on the inner surface of the casing exposed to the high-pressure steam flow



Right Image:
Crack network in the area of the drainage nozzle (condensate)

Example: Turbine Valve Casing during Start-Up with excessive Heating Rate



The hot area of the inner casing surface expands (red arrows). This expansion is restrained by the still cold areas of the outer component surface; as a result:

- **Compressive stresses** occur on the inner surface
- **Tensile stresses** occur on the outer surface

Cracks may form on the outer surface, or existing cracks may continue to grow

On the inner surface, the compressive stresses are reduced by plastic deformation; during cooling, tensile stresses develop as a result, leading to

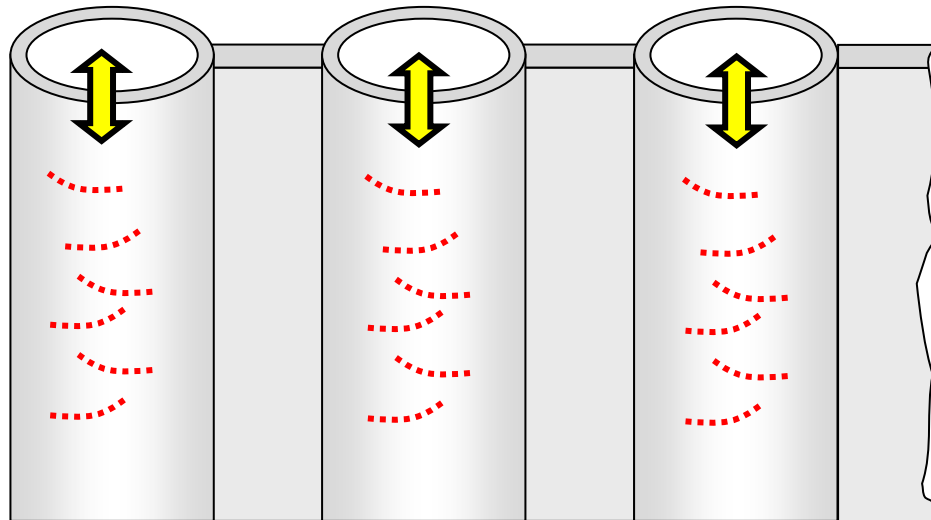
- the formation of cracks, or the growth of existing cracks

Avoid damage by:

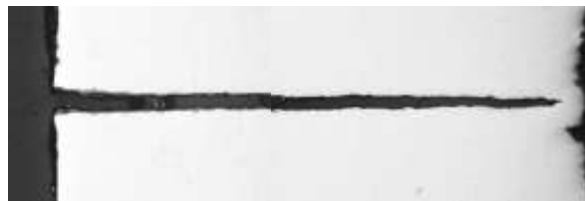
- **Defining challenging but decent ramp rates**
- **Design changes if necessary and sensible**

Thermal Fatigue / Membrane Wall Tubes 1/6

Transverse cracks originating from the inner surface of the tube on the furnace-facing half-shell



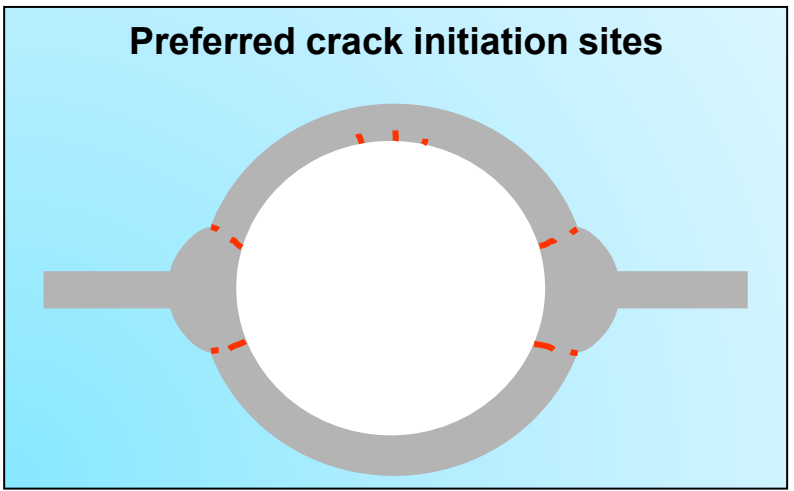
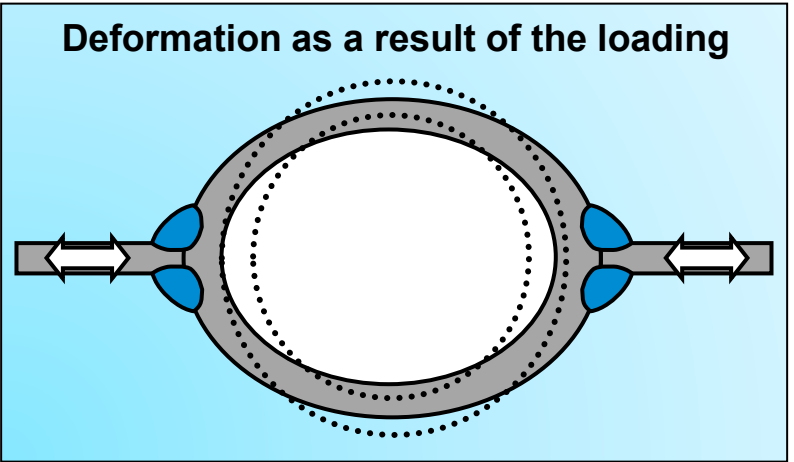
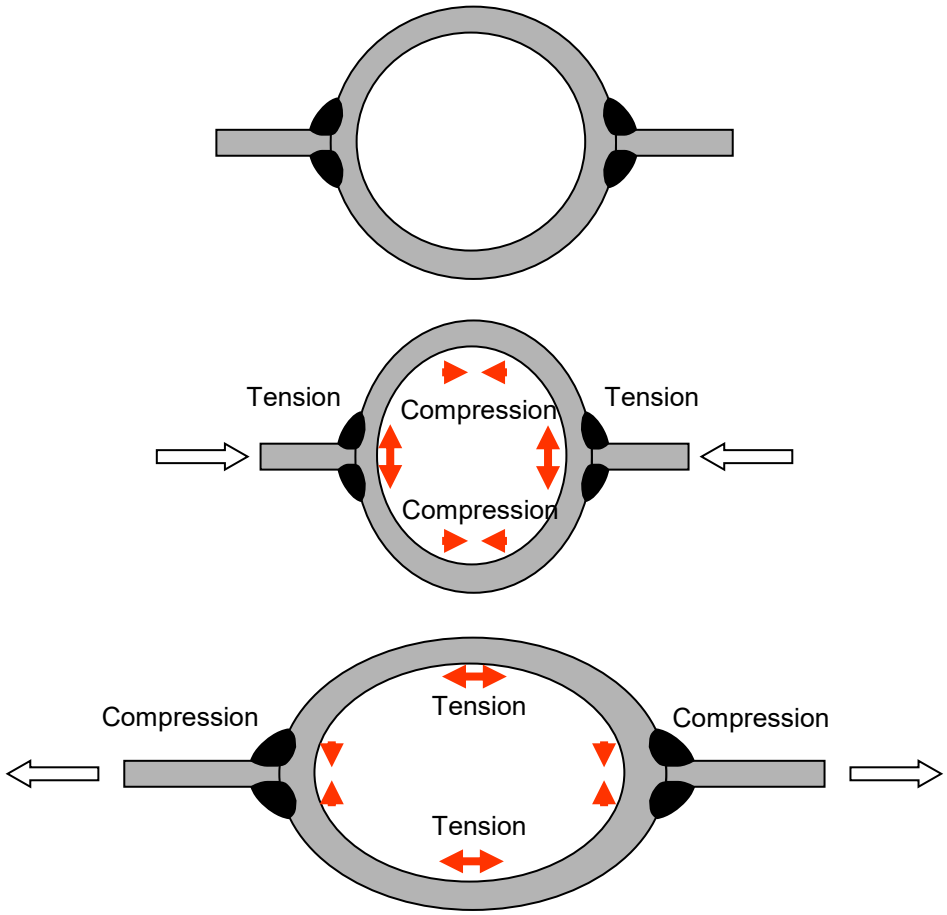
Inner tube Surface

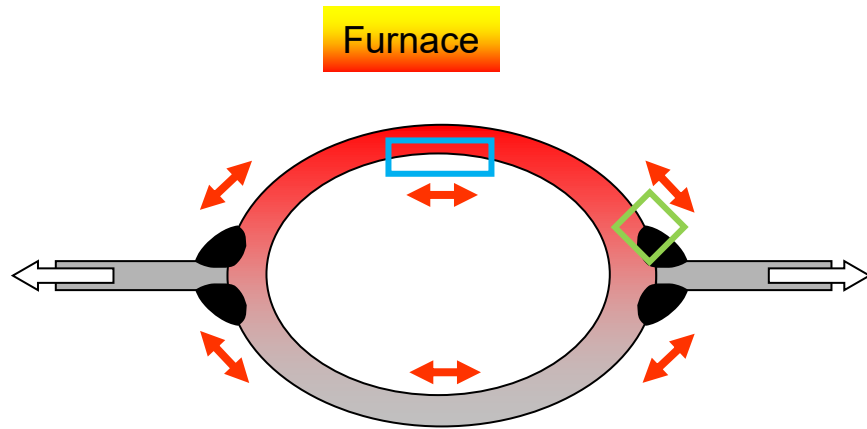


Outer tube surface

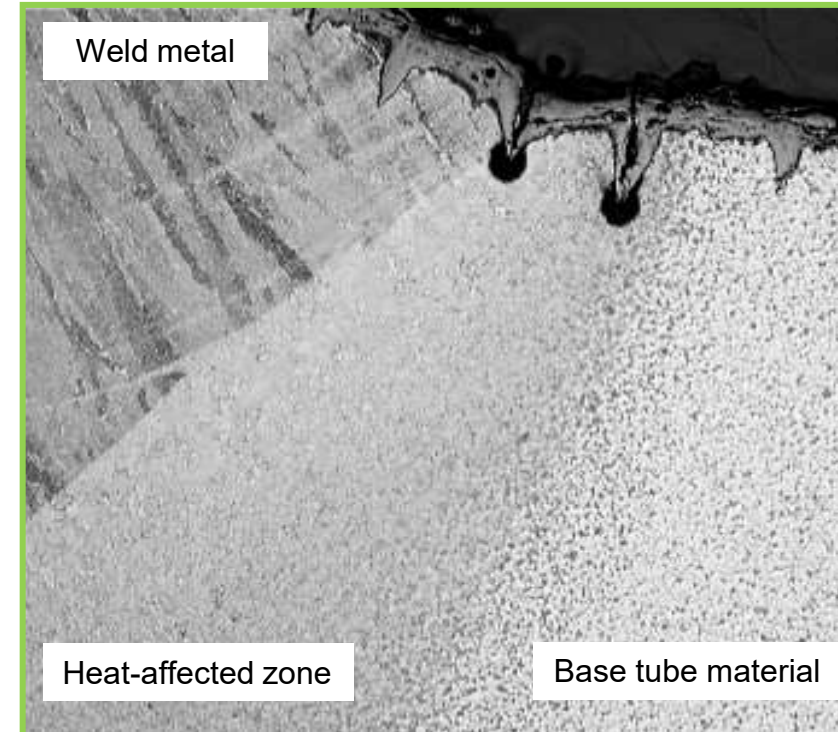
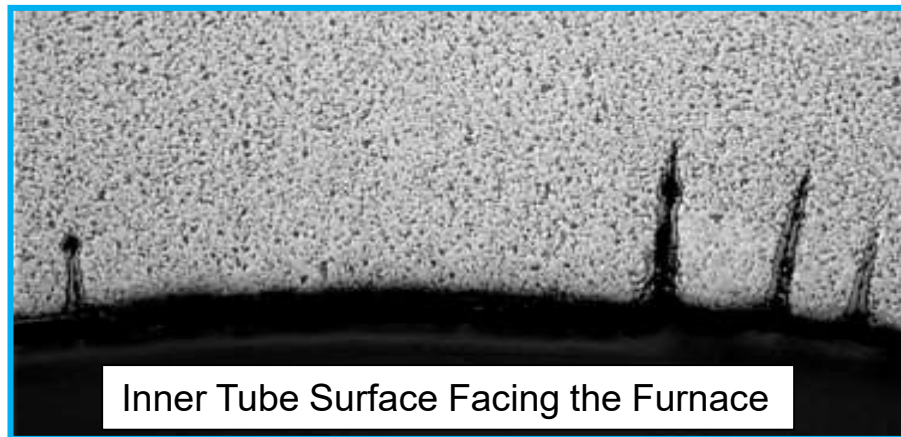


Cyclic Loading as a result of constrained thermal expansion caused by massive heat imbalances



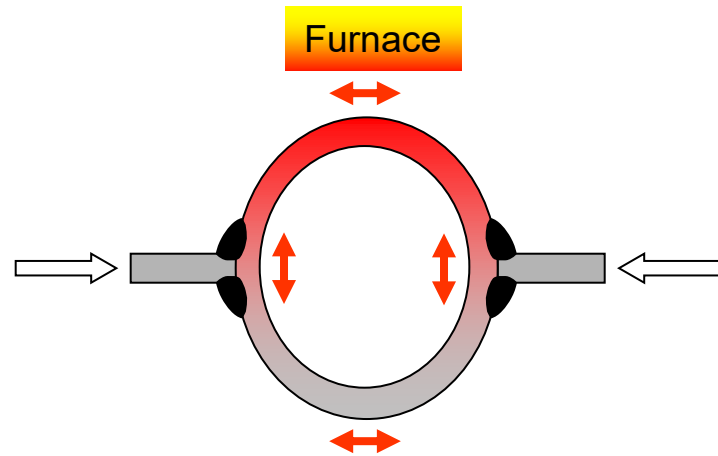


Example of relatively minor damage

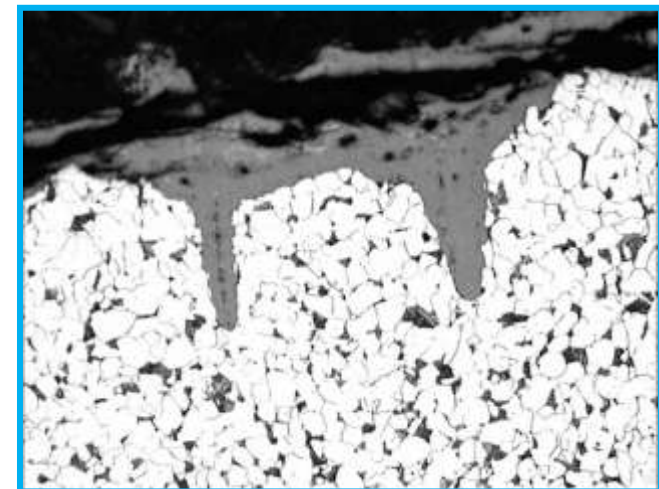
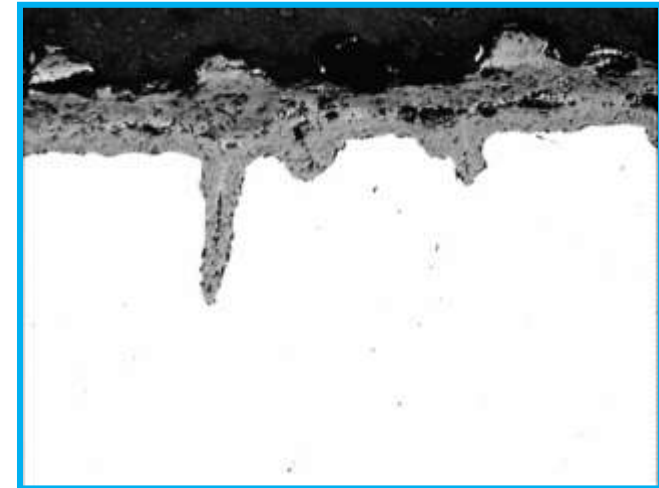
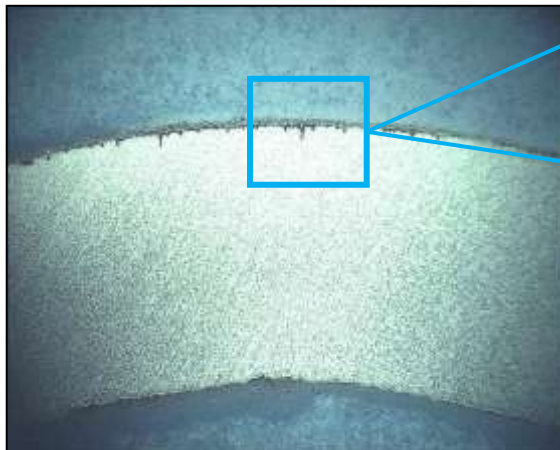


Crack initiation due to local tensile stresses supported by:

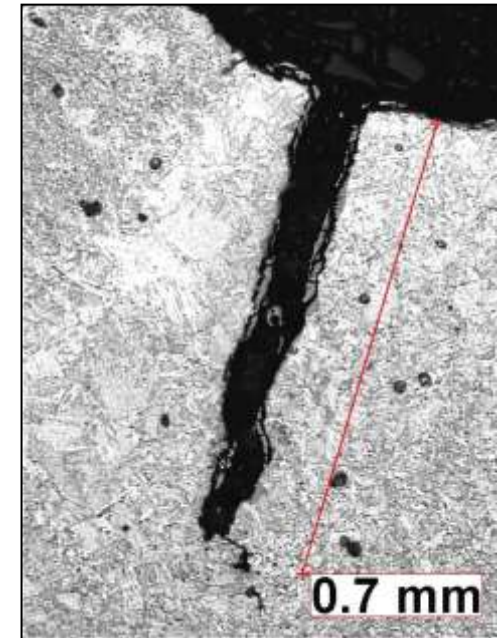
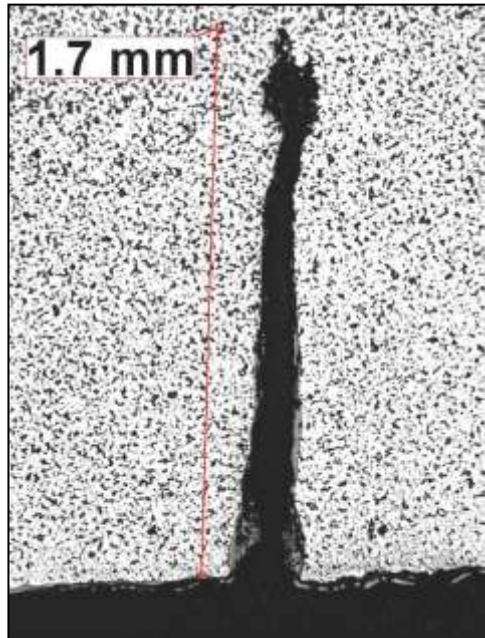
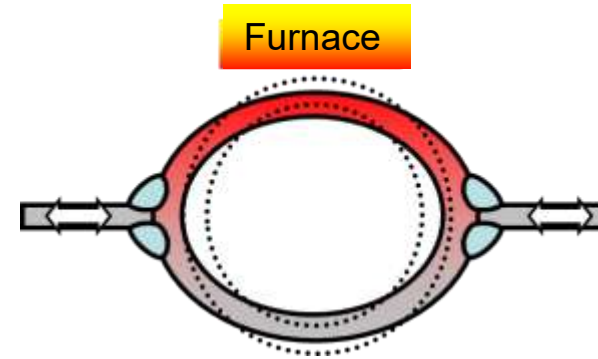
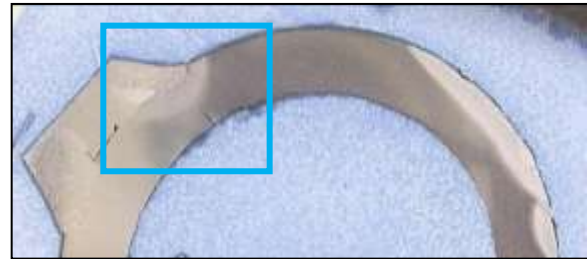
- steam-side corrosion
- flue gas-side corrosion
- notch stresses



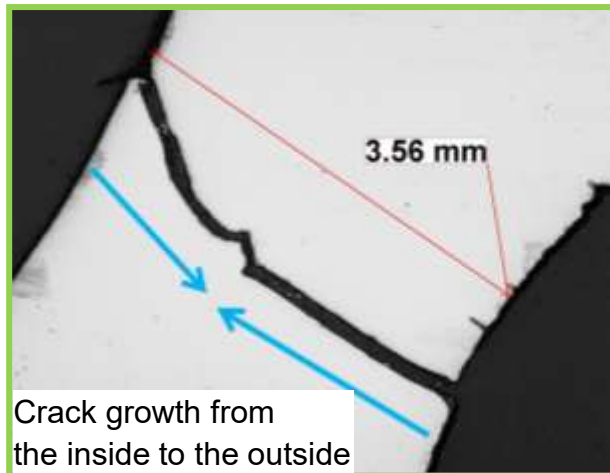
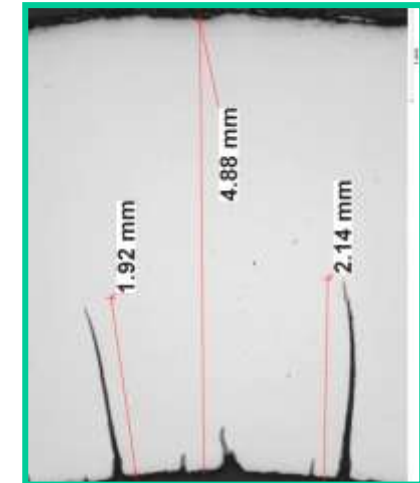
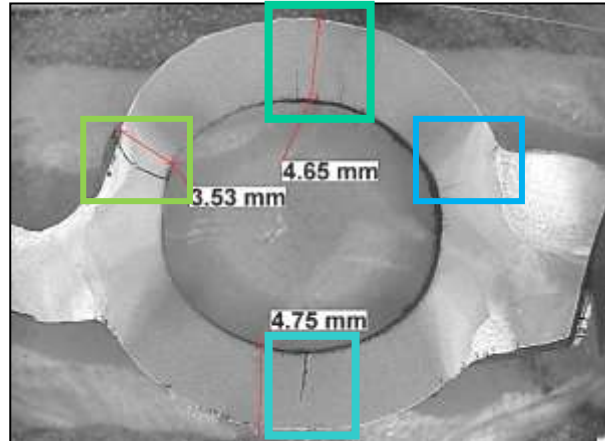
Example of relatively minor damage



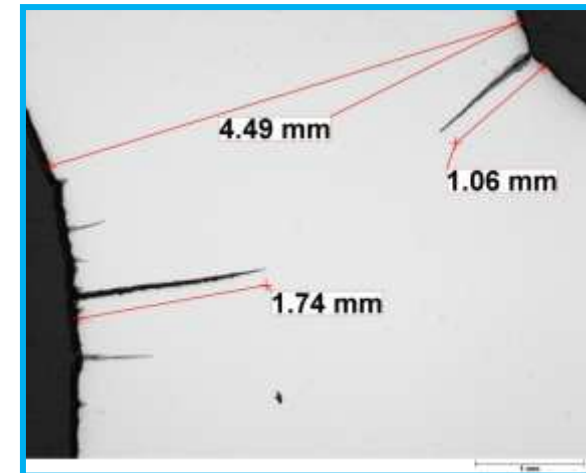
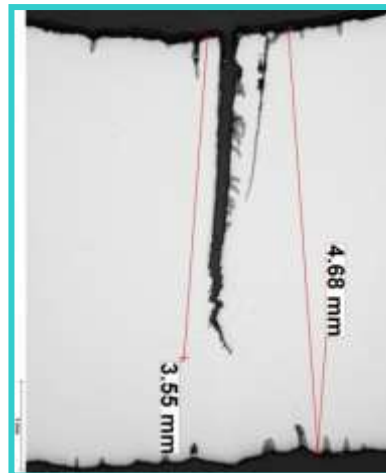
Thermal Fatigue / Membrane Wall Tubes – Longitudinal Cracks 5/6



Example of very severe damage

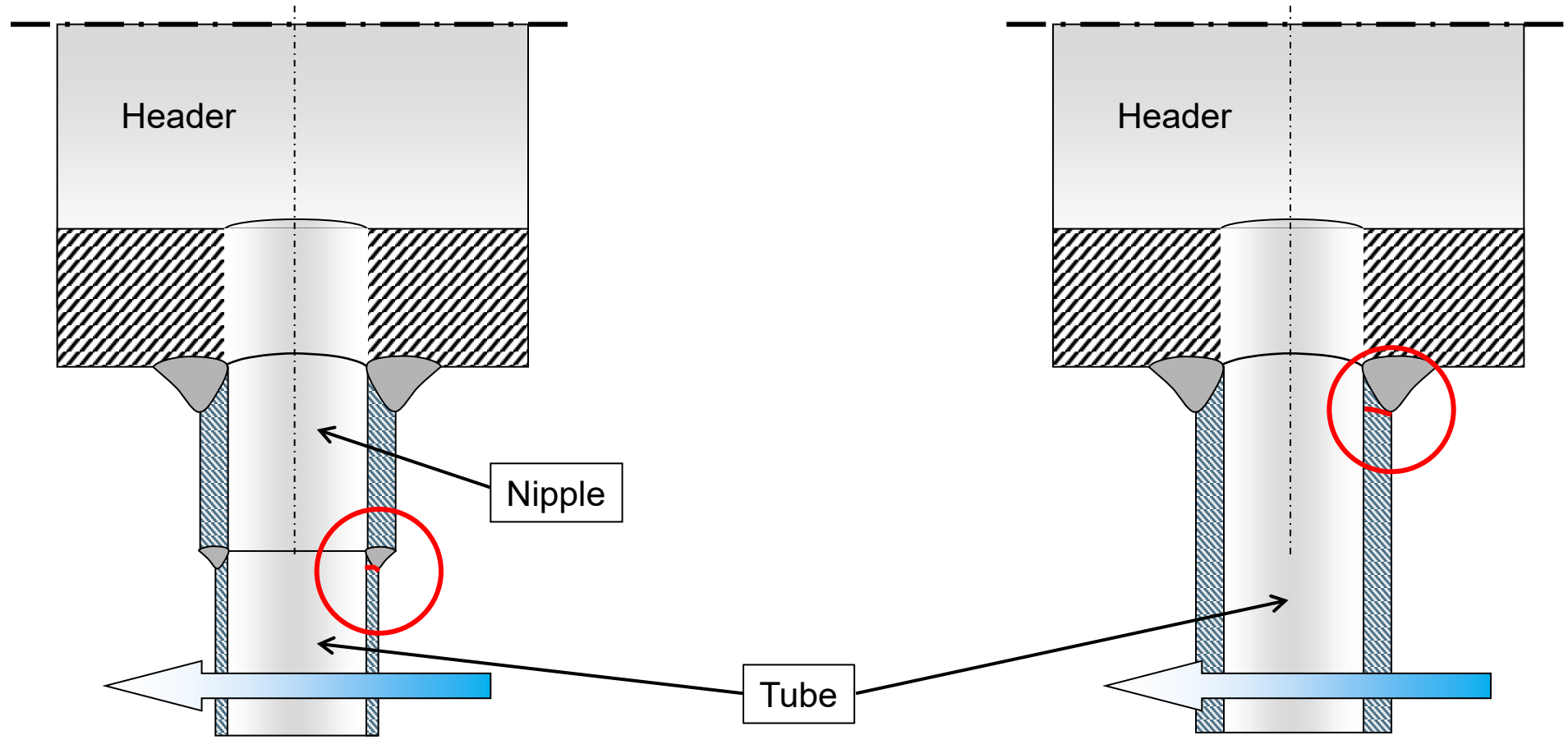


Crack growth from the inside to the outside

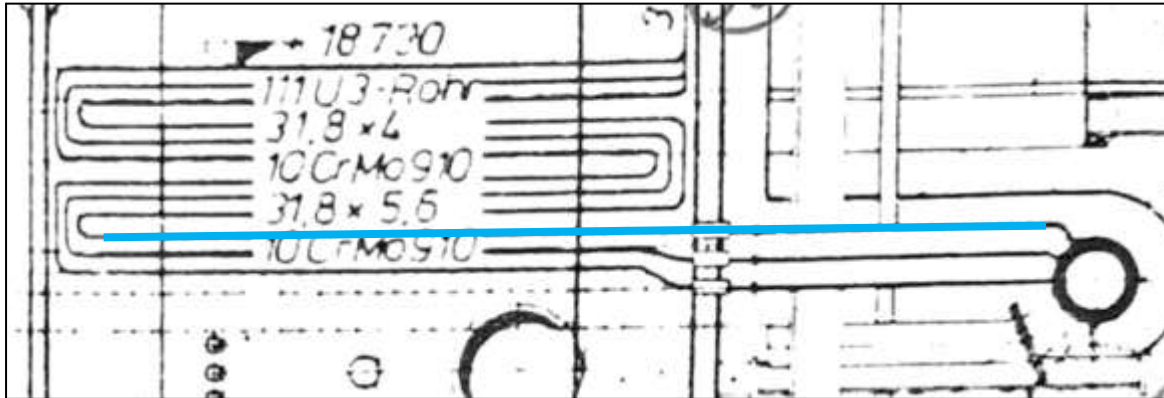


Thermal Fatigue / Nipple-to-Tube Connection (Header)

Crack formation always from outside to the inside!!!



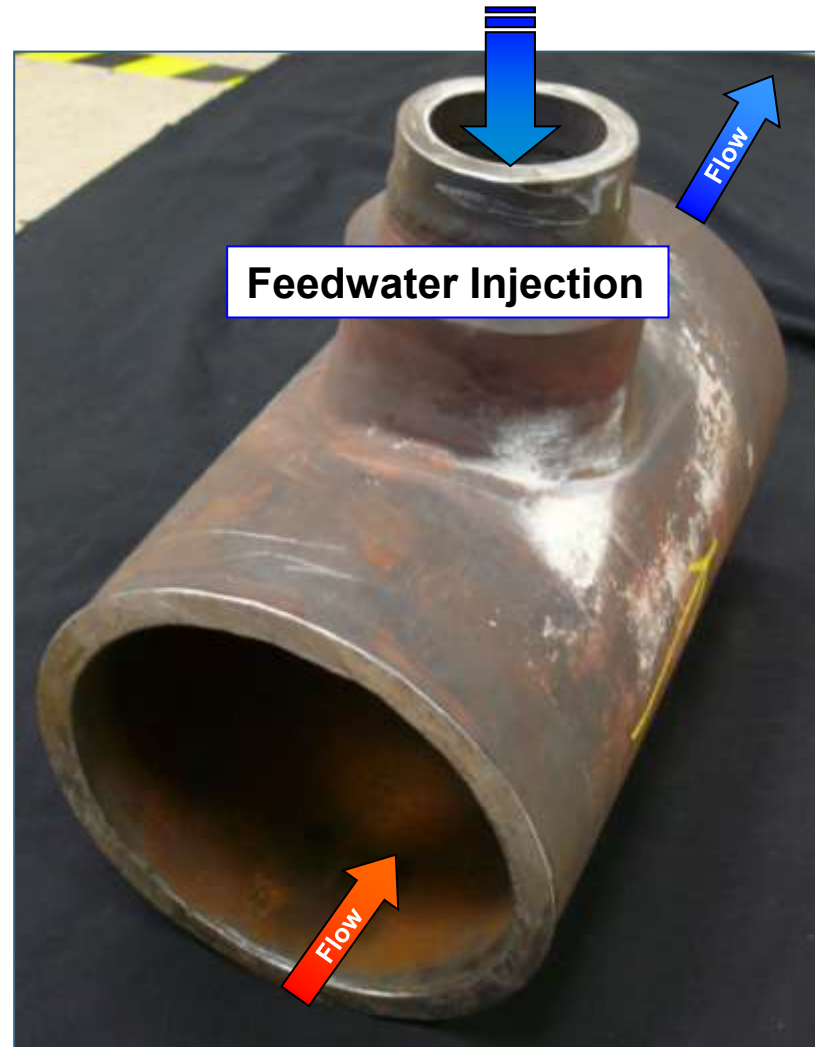
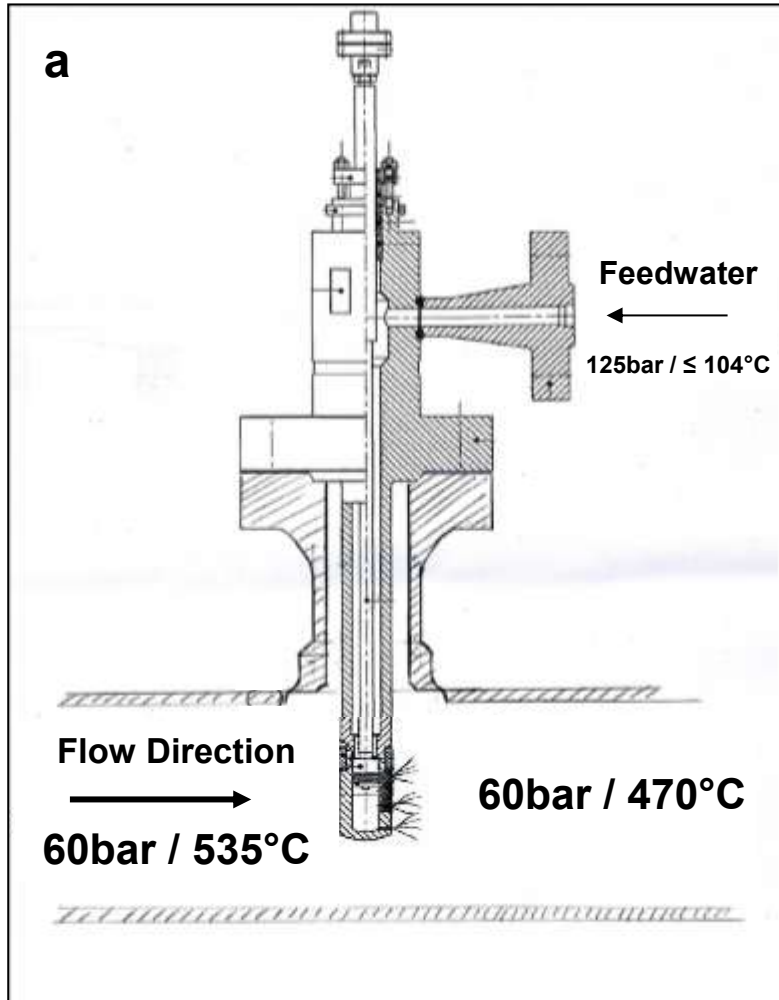
Thermal Fatigue / Tube to Header Connection



22 of 37 tubes showed indication



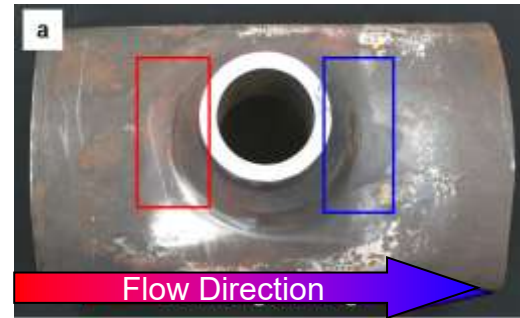
Thermal Fatigue / Shock - Desuperheater



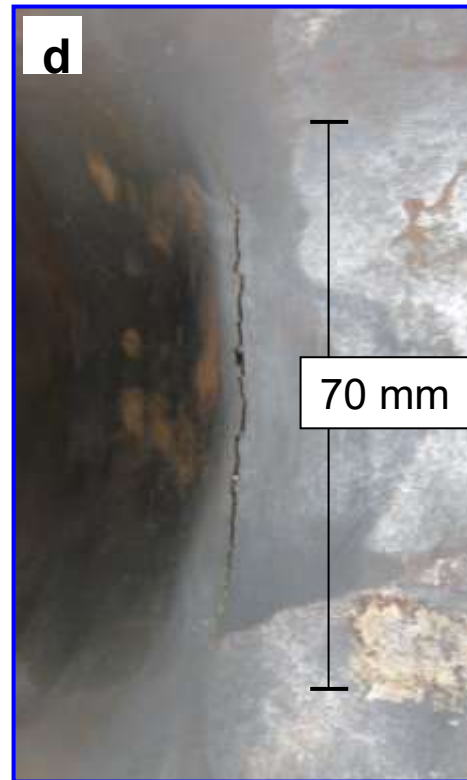
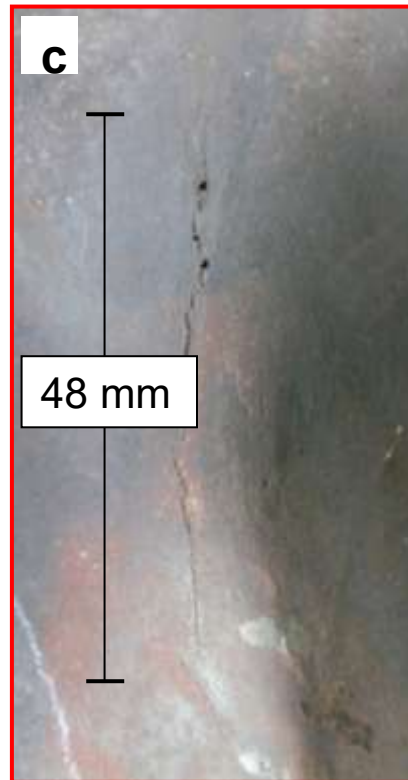
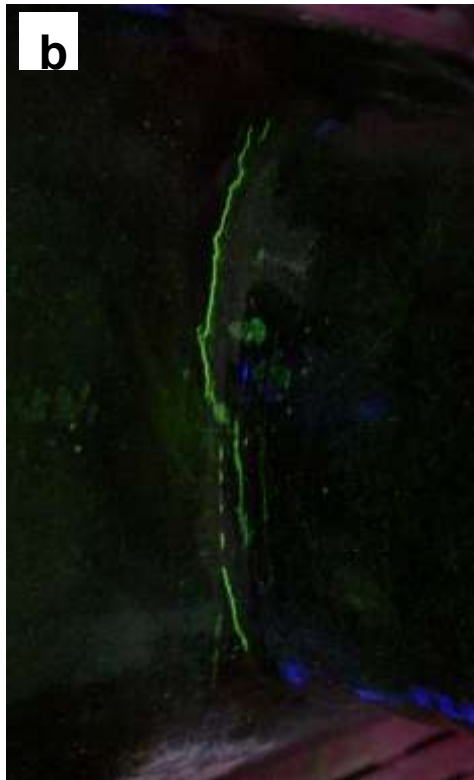
Desuperheater HP - Line

Tube:	10CrMo9-10
Nozzle:	13CrMo4-5
Operating Temperature	from 535 to 470°C
Operation Pressure	60bar

Thermal Fatigue / Shock - Desuperheater

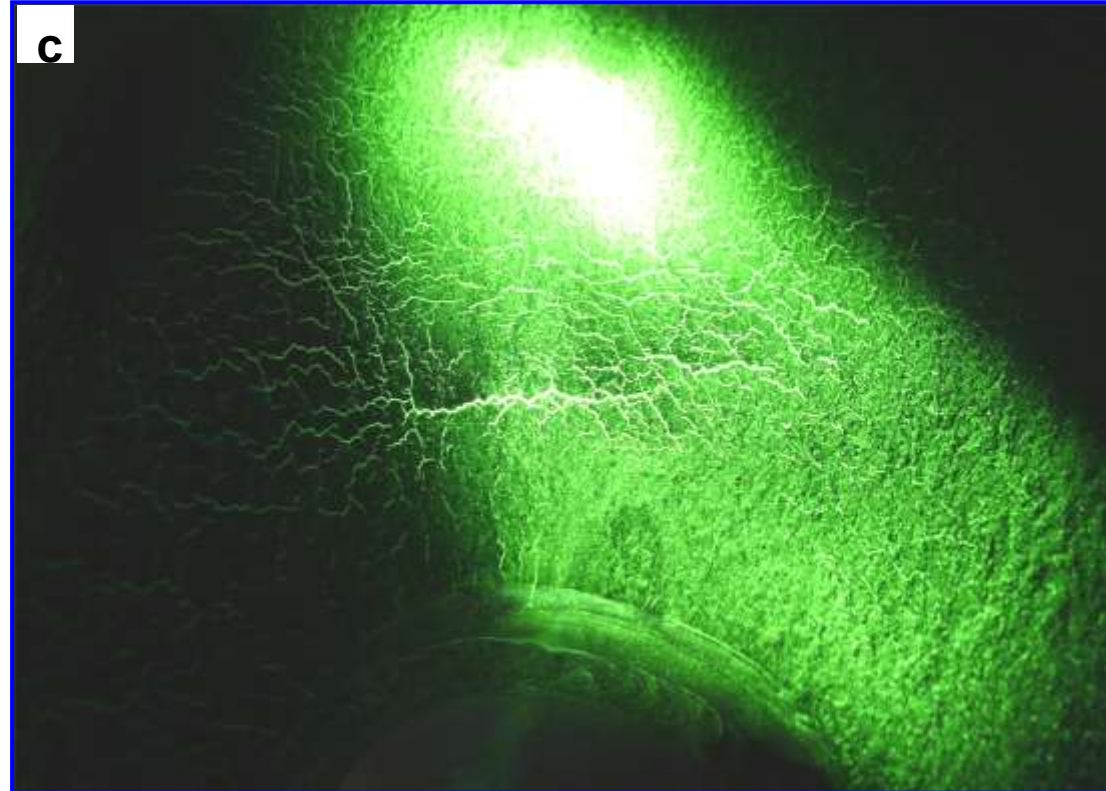
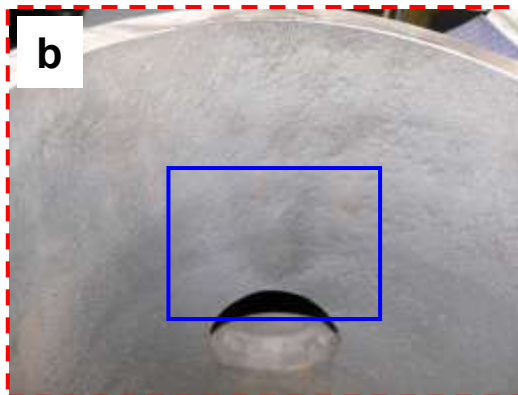
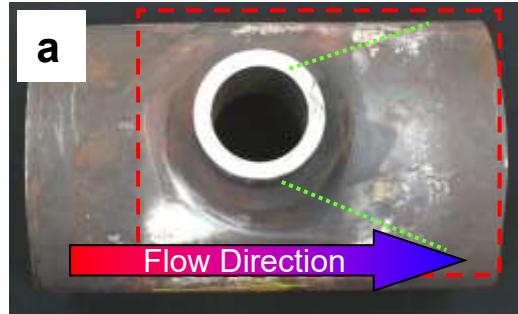


Crack formation on both sides of the nozzle (geometry-related)



Thermal Fatigue / Shock - Desuperheater

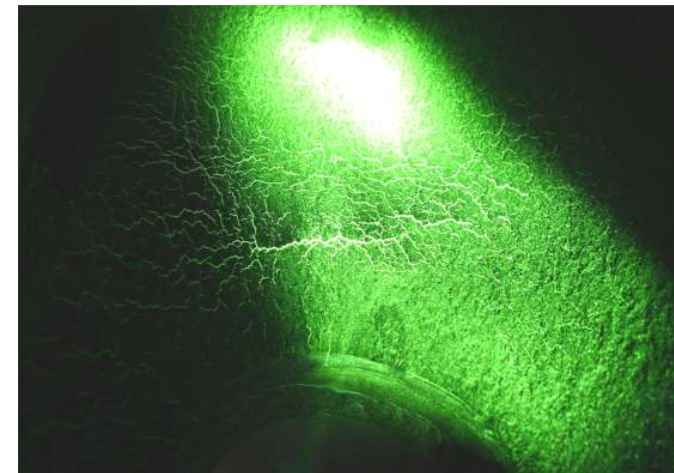
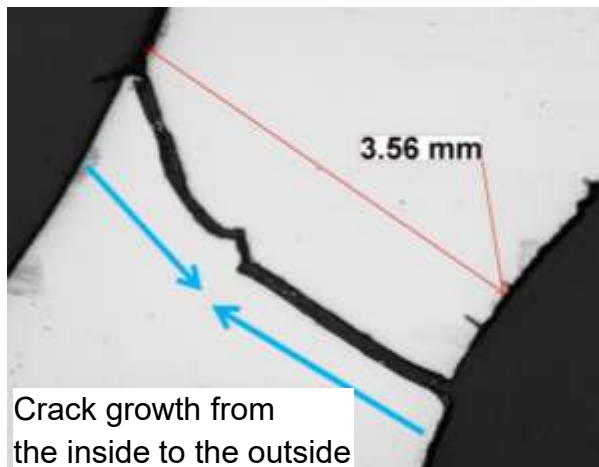
Thermal shock in spray direction



Damage caused by thermal shock and followed by thermal fatigue

Thermal Fatigue – avoiding damage

- Defining minimum load of the boiler with acceptable heat imbalances in membrane wall and heating surfaces
 - To be defined in individual test runs
 - Measurement of tube temperature during test run
- Defining decent ramp rates to equally heat up
- Defining and controlling the process parameter more accurately and adjust them (e.g. spray water)



- Flexible operation can cause challenges in terms of damage evaluation and mechanism
 - Identification of critical components
 - Understand different damage mechanisms
 - Apply correct testing method and lifetime models

- A massive accumulation of additional damages was so far not observed
 - In Germany the operational hours were at the same time significantly reduced
 - Ramp rates given by OEMs were in most cases not exceeded
 - Some plants decided for minor design optimization to apply faster ramping
 - Generally the design margins especially in older plants was quite high

Thank you for your attention

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