Influence of high-temperature environments on the mechanical behaviours of high-temperature austenitic stainless steels

KME 701

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Acknowledgment

KME
CONSORTIUM MATERIALS TECHNOLOGY
for development and demonstration
of thermal energy processes

Swedish Energy Agency

SANDVIK

Project group

Project leader

- Mattias Calmunger (LiU) 2016-06 – 2018
- Sten Johansson (LiU) 2014 – 2016-06

Members

- Guocai Chai (SMT/LiU)
- Johan Moverare (LiU)
- Hugo Wärner (LiU, PhD student)

Outline

- Background
- Goals
- Main activities
- Future work

Background to the project

- Future power generation needs to more efficient and flexible.
- Increasing demand on mechanical properties of the materials in critical components.

Gärdstadverken Linköping.
Photo Åke E. Lindman

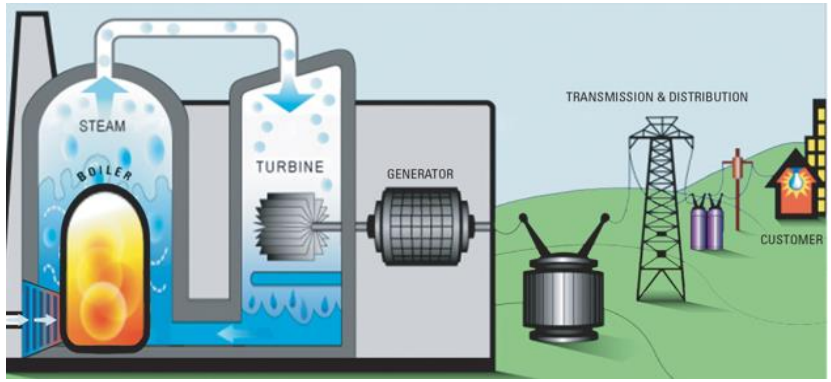


Image from Xcel Energy

Project goals

The main purposes of this project are to evaluate the mechanical behaviours for structure safety and integrity analysis, namely:

- To evaluate the creep and LCF interaction diagram and integrity analysis since the boiler materials can undertake both creep and low cycle fatigue during the service. Ongoing

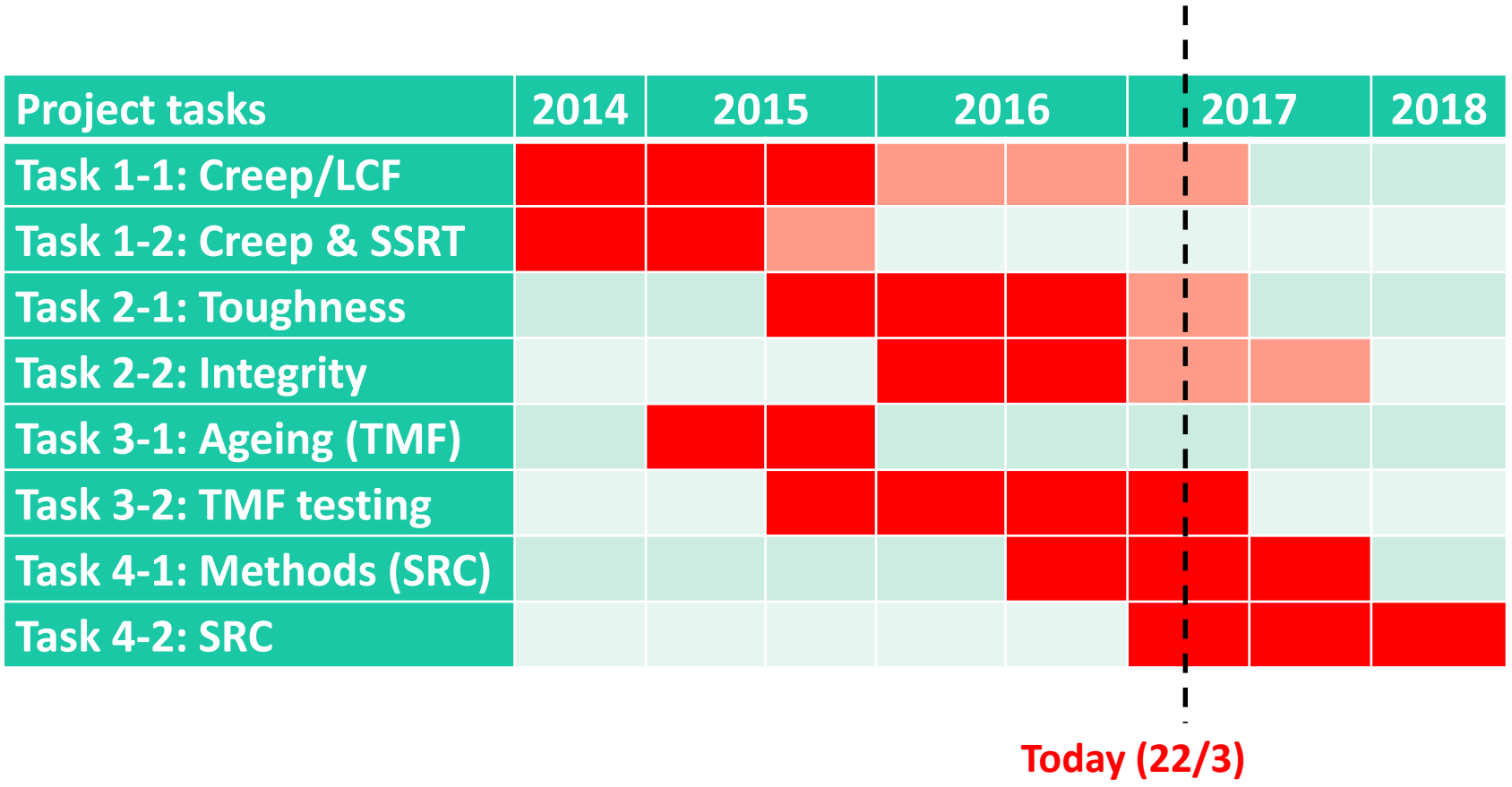
- To evaluate the structure stability and the toughness after long term service at a elevated temperature for safety analysis. Ongoing

- To evaluate thermo-mechanical fatigue properties of the boiler materials for safety and life evaluation since the power plants can start/shutdown quite often during service for energy saving and flexibility purposes in the future. Ongoing

- To evaluate the stress relaxation cracking behaviour of the boiler material. It is critical problem for some boiler materials. Just started

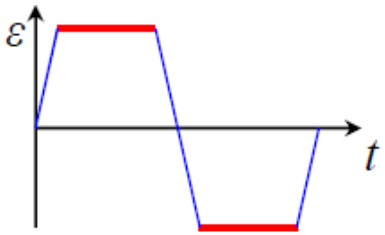
Main activities

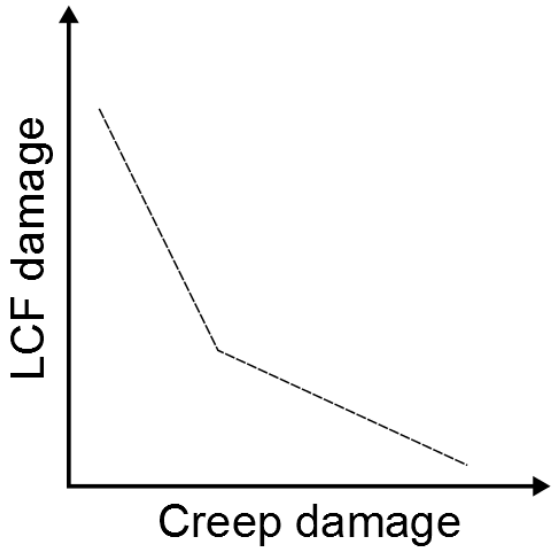
Time schedule

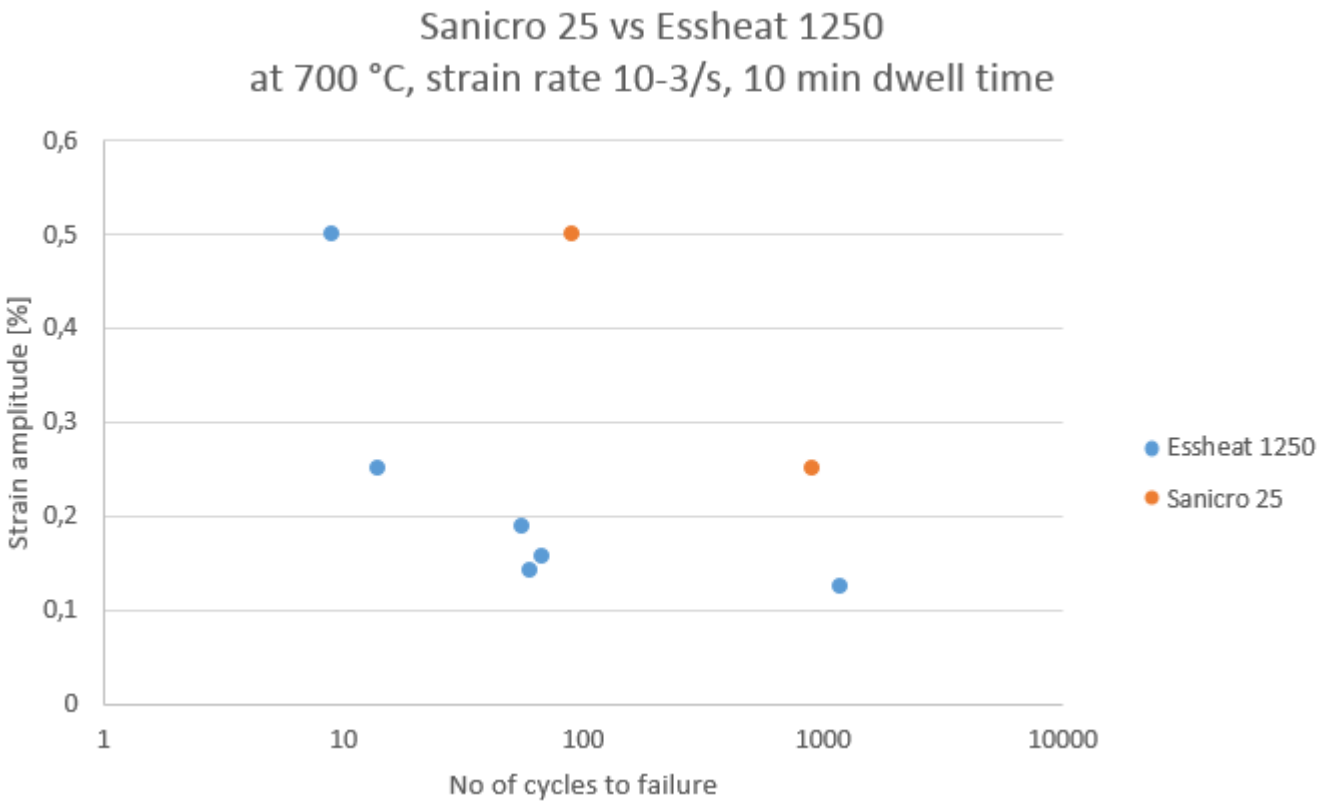


- Task 1: Creep and low cycle fatigue interaction and very slow strain rate testing and creep

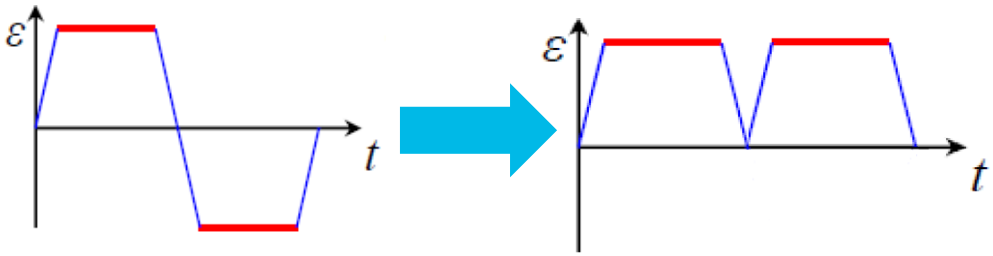
  - Task 1-1: Creep and LCF interaction behaviour
    - Temperature: 700 °C
    - Strain rate: 10^{-3}/s
    - Hold time: 10 and 30 min
    - Strain and load controlled

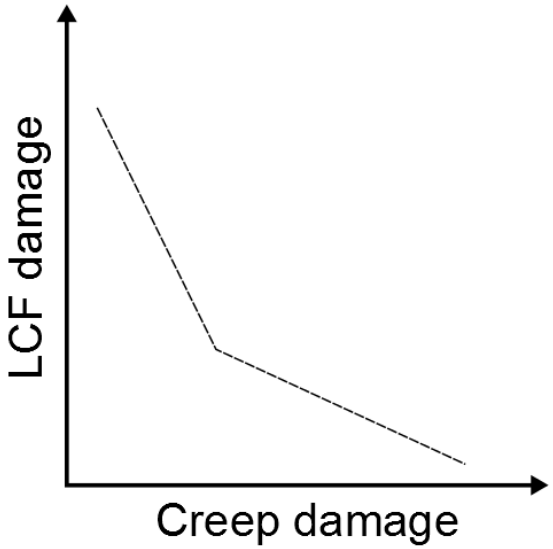




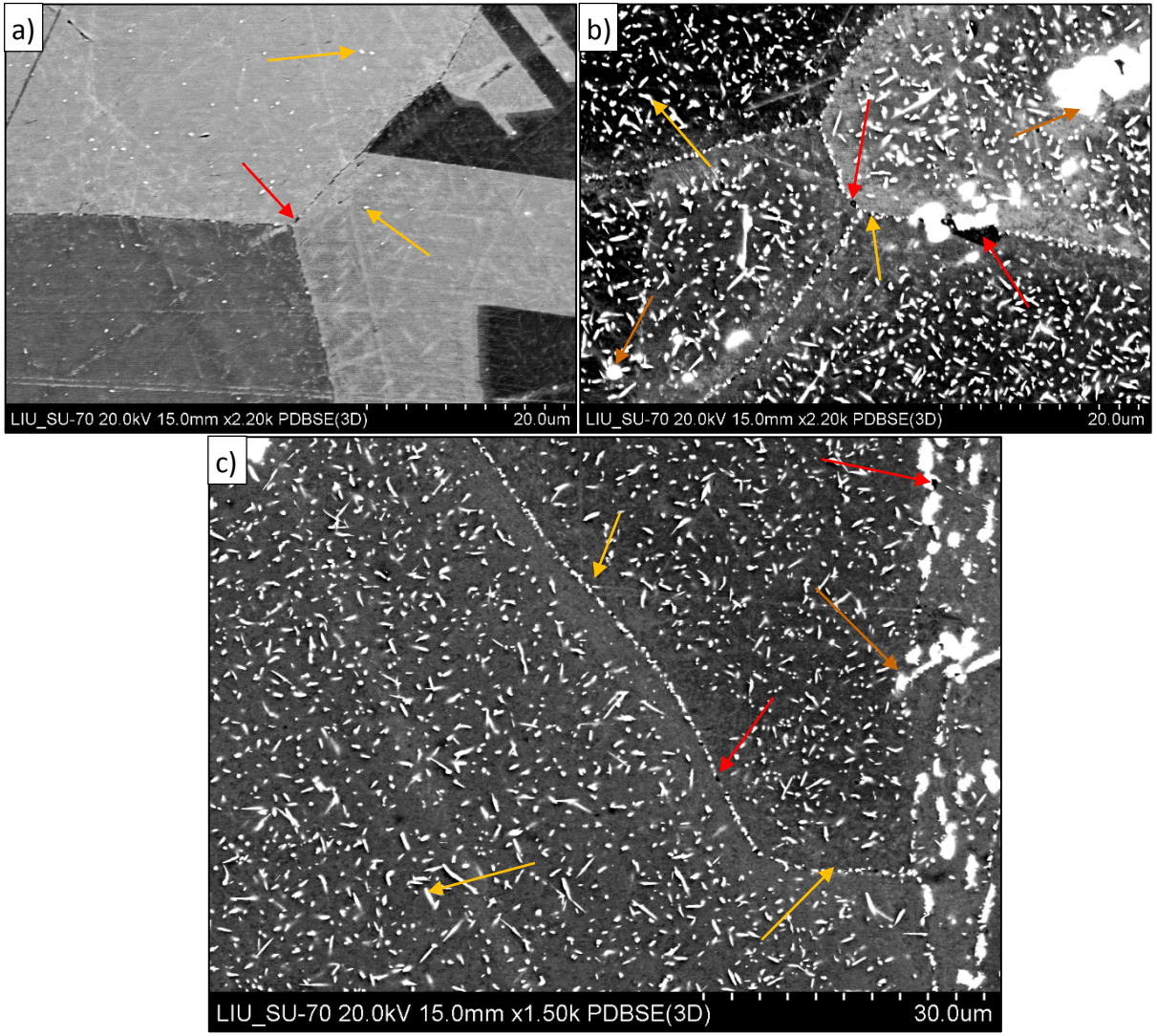

Sanicro 25 vs Essheat 1250
at 700 °C, strain rate 10-3/s, 10 min dwell time
Strain amplitude [%]
0,6
0,5
0,4
0,3
0,2
0,1
0
1
10
100
1000
10000
No of cycles to failure
Essheat 1250
Sanicro 25

- Continuation on task 1-1
  - Task 1-1: Creep and LCF interaction behaviour
    - Temperature: 650 and 700 °C
    - Strain rate: 10^{-3}/s
    - Hold time: 0, 5, 10 and 30 min
    - Strain controlled fatigue-part (0.15%, 0.25%, 0.35%, 0.5%)
    - Load controlled dwell time
    - Aged samples: 2000h, 650°C and 700°C

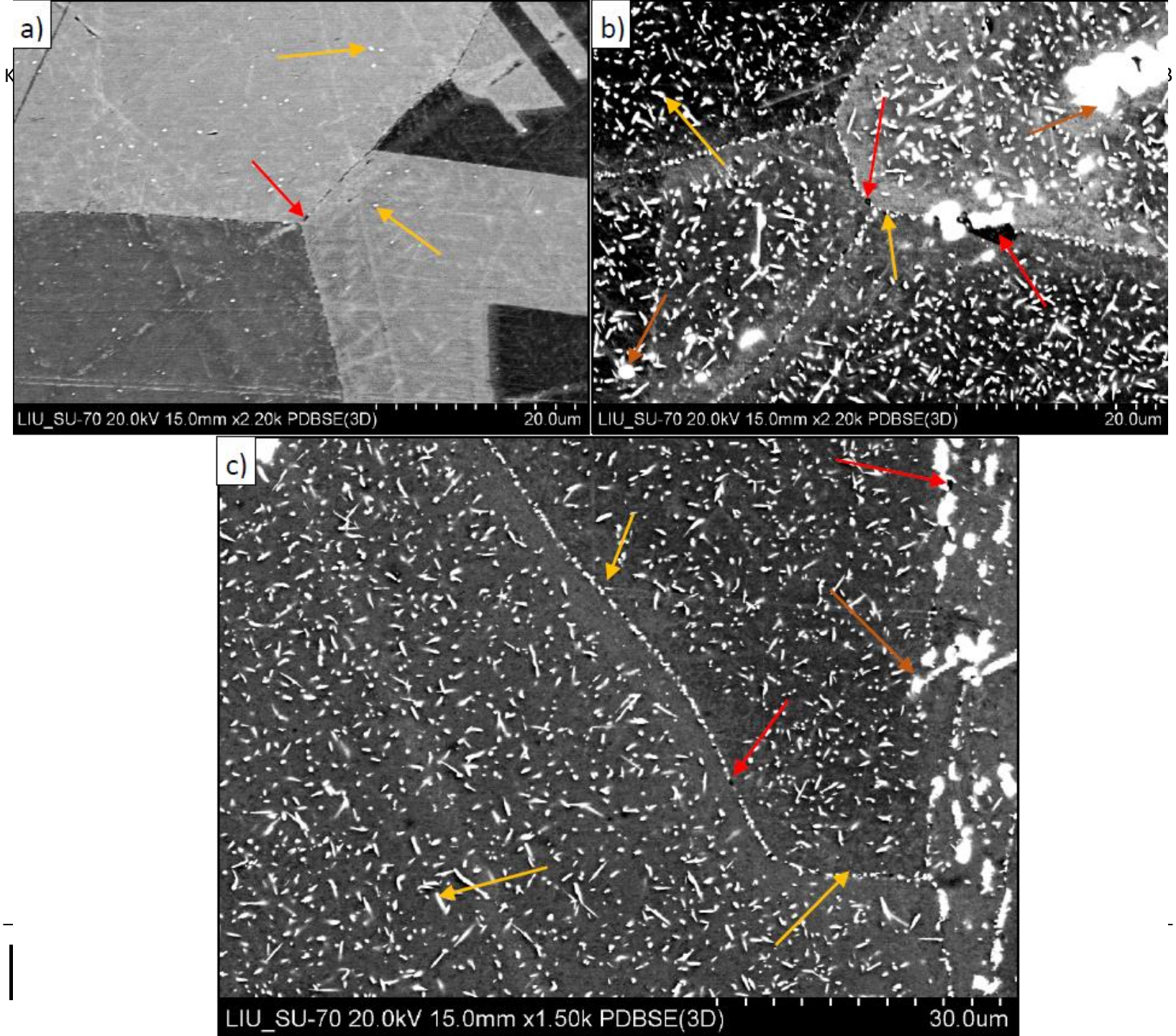




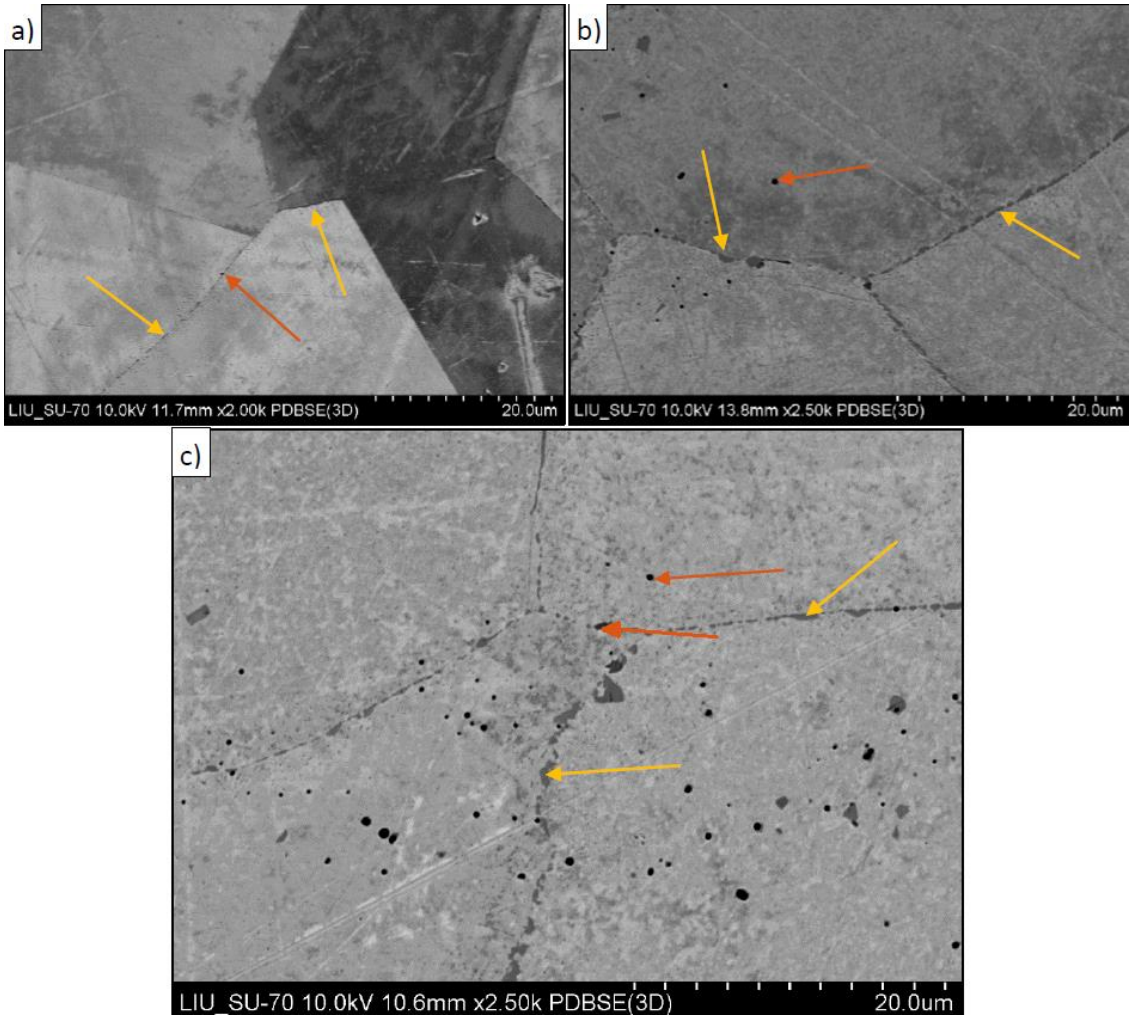
- Task 2: Long-term ageing
  - Task 2-1: Influence of long-term ageing on toughness
    - Temperature: 650 and 700 °C
    - Time: 20 000 (*done*) and 30 000 hours (*done*)
    - Impact (*done*) and fracture toughness testing (*to do*)
    - Materials: (from KME 501) AISI 304 and 310M, Sanicro 25 and 28, Alloy 617 and 800HT.
  - Task 2-2: Structure integrity evaluation (*to do*)
    - Using *failure assessment diagram* and the long-term ageing results from task 2-1 and KME 501, the influence of long-term exposure in high-temperature environments on structural integrity of the heat resistant materials will be evaluated.



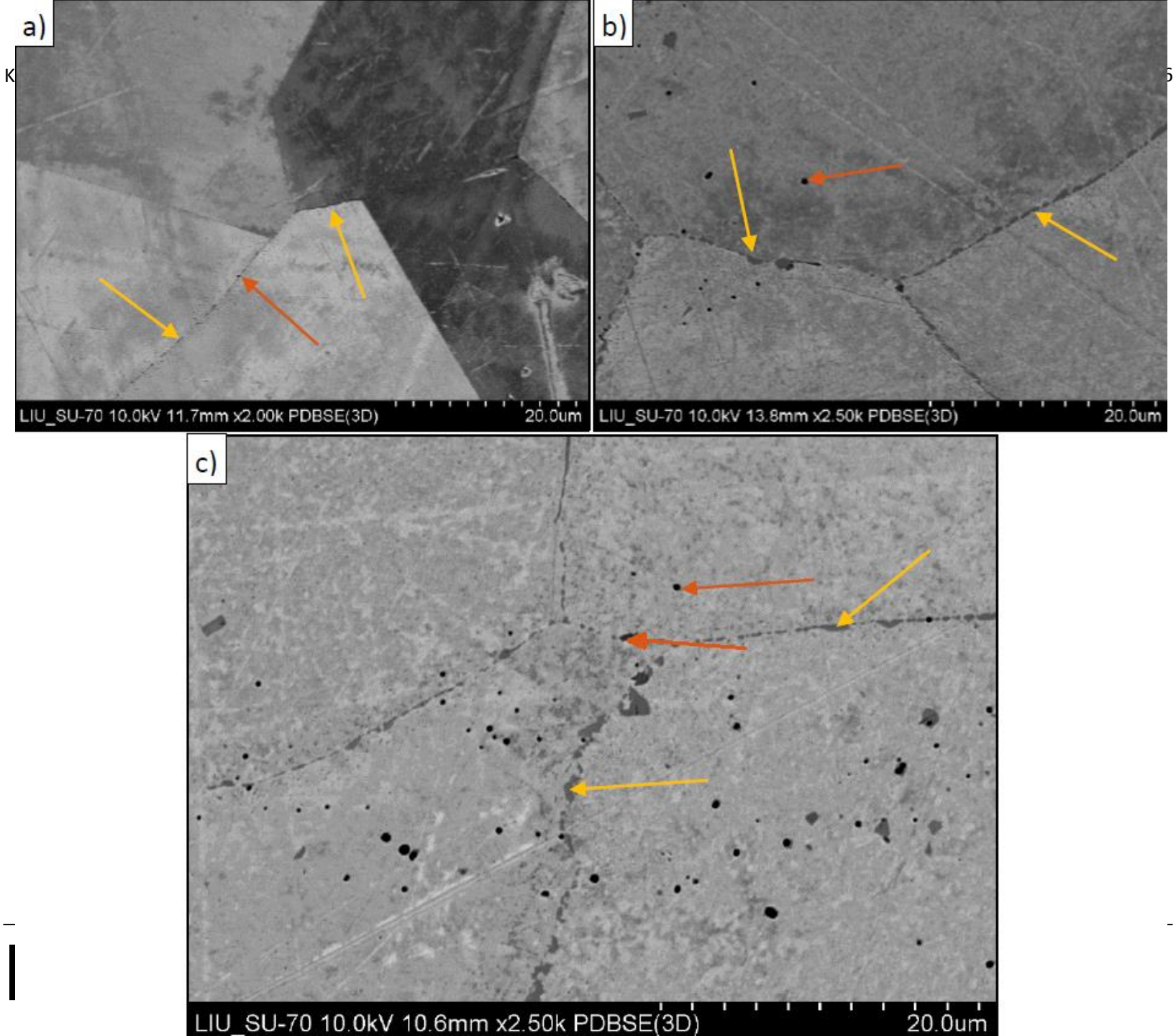
Sanicro 25 at 700˚C. a) after 1000h, b) after 10 000h, c) after 20 000h


a)
LIU_SU-70 20.0kV 15.0mm x2.20k PDBSE(3D)
20.0um
b)
LIU_SU-70 20.0kV 15.0mm x2.20k PDBSE(3D)
20.0um
c)
LIU_SU-70 20.0kV 15.0mm x1.50k PDBSE(3D)
30.0um

Material	Type of precipitation	Estimated identification
Sanicro 25	The big white ones, had increased amount of niobium, nitrogen and carbon (Brown arrow in the figures).	Z-phase
	The black ones on the grain boundaries, with increased amount of chromium and carbon (red arrow in the figures).	$M_{23}C_6$ carbide with chromium as M. But could also be identified as sigma-phase at increased ageing time.
	The small pointy white precipitates, around and on the grain boundaries, had increased amount of tungsten and iron (orange arrow in the figures) .	Laves-phase (Fe_2W).

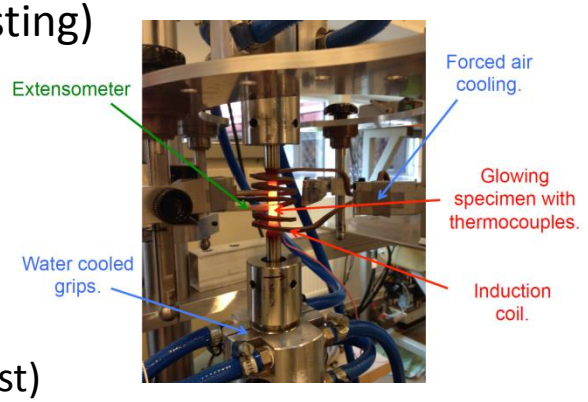


Sanicro 31HT at 700˚C. a) after 1000h, b) after 10 000h, c) after 20 000h


a)
LIU_SU-70 10.0kV 11.7mm x2.00k PDBSE(3D)
20.0um
b)
LIU_SU-70 10.0kV 13.8mm x2.50k PDBSE(3D)
20.0um
c)
LIU_SU-70 10.0kV 10.6mm x2.50k PDBSE(3D)
20.0um

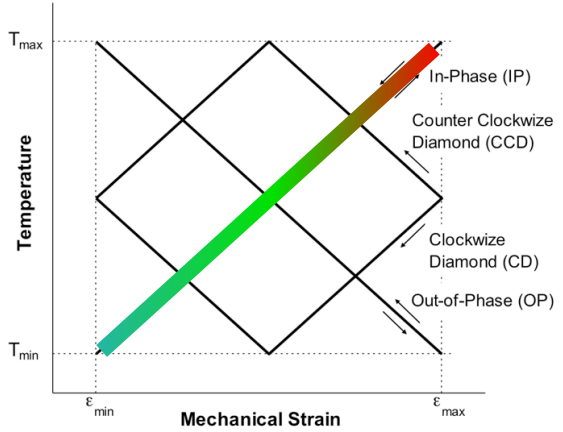
Material	Type of precipitation	Estimated identification
Sanicro 31HT	The small grey ones around and on the grain boundaries, had an increased amount of chromium and carbon (orange arrow in the figures).	$M_{23}C_6$ carbide with chromium as M.
	The black ones, had an increased amount of titanium and carbon (brown arrow in the figures).	Titanium carbide (TiC)

- Task 3: Thermo-mechanical fatigue testing (TMF testing)

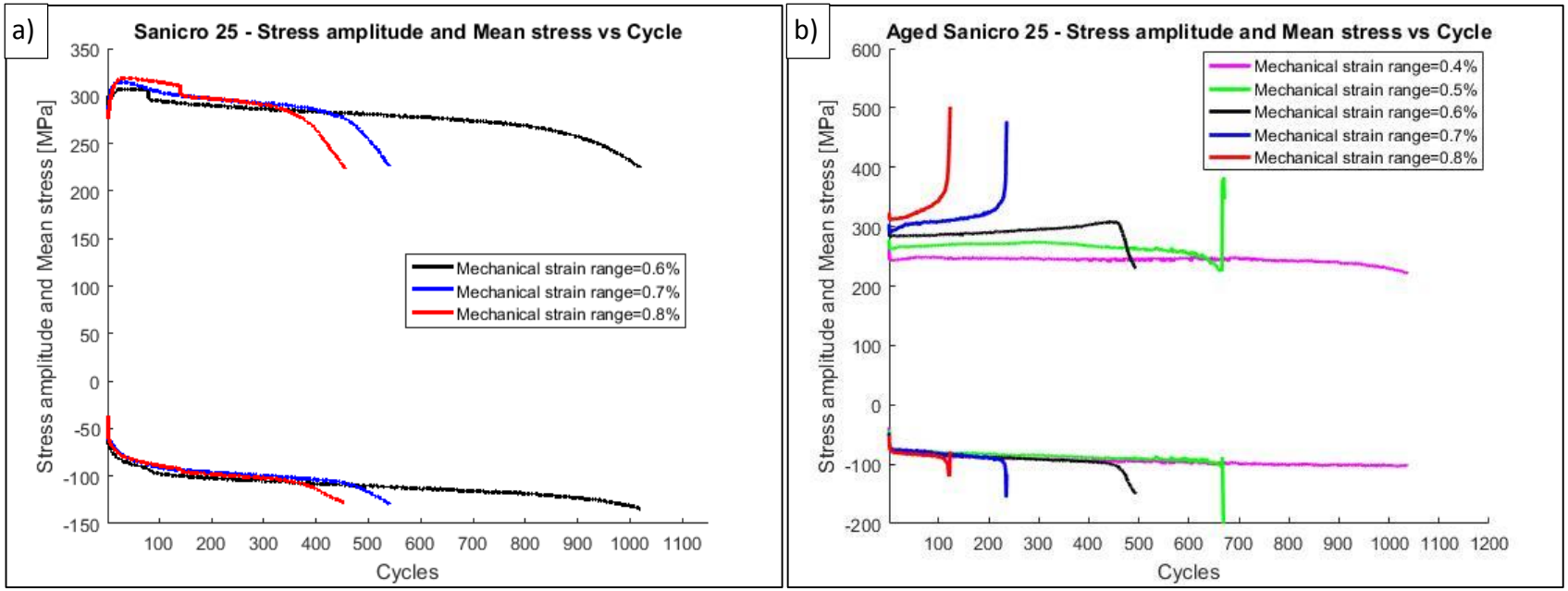


  - Task 3-1: Long-term ageing before TMF testing
    - Temperature: 800 °C
    - Time: 2 000 hours

  - Task 3-2: Thermo-mechanical fatigue testing (TMF-test)
    - Phase-shift: in-phase (IP) and Out-of-phase (OP)
    - Strain controlled
    - Heating/Cooling rate: 5°C/s
    - Maximum temperature: 800°C
    - Minimum temperature: 100°C
    - Dwell time: 5min

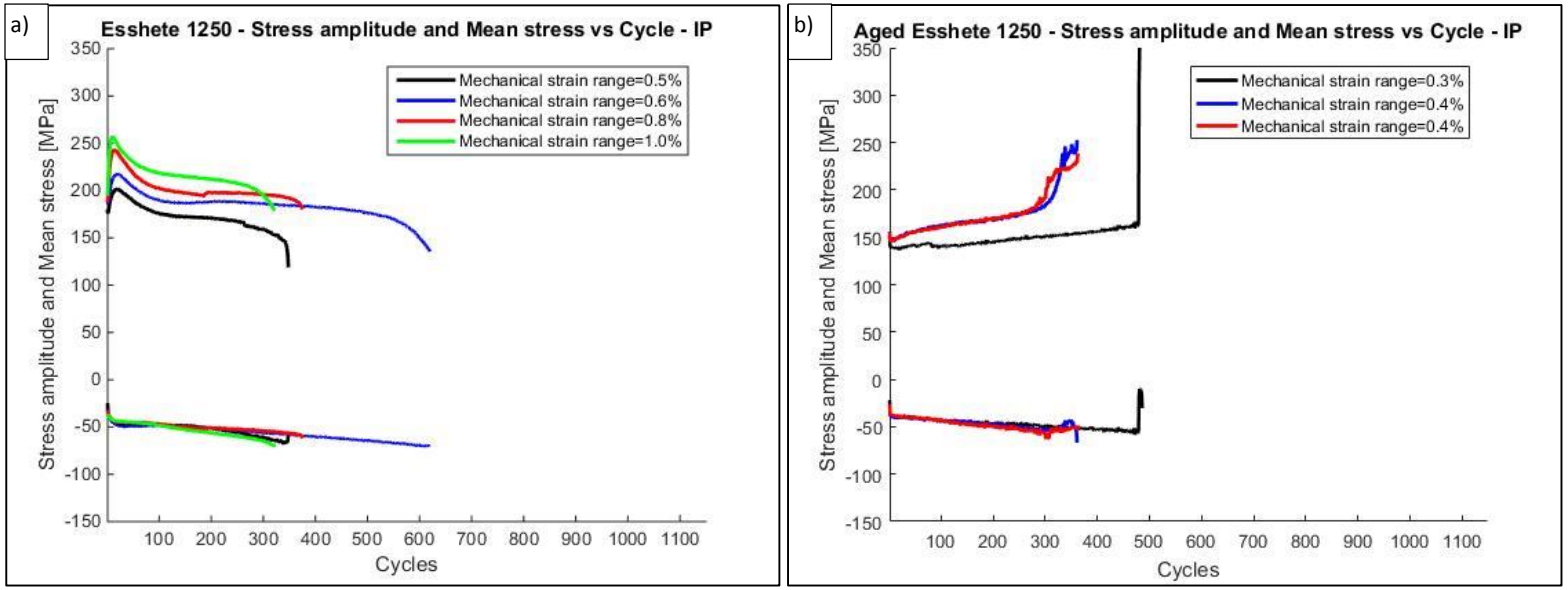


TMF-Testing: Sanicro 25



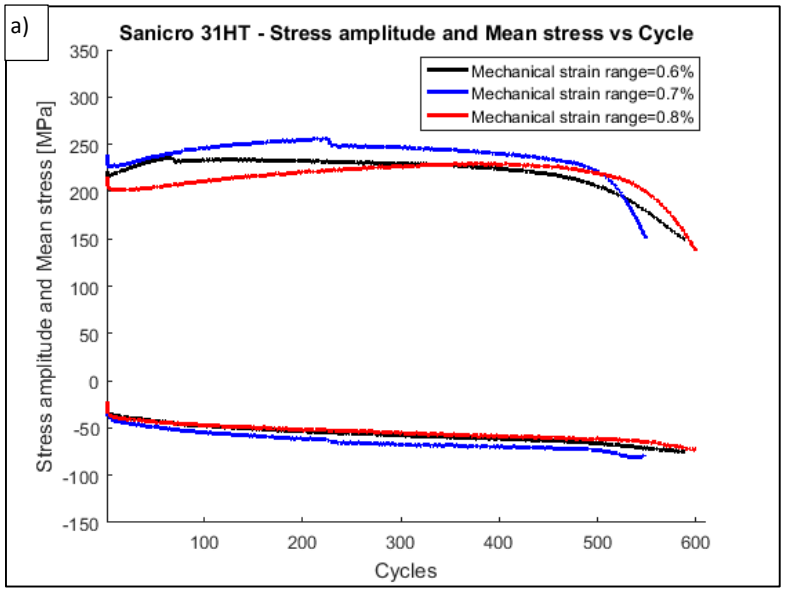
Cyclic hardening/softening; stress amplitude and mean stress vs. cycles, for Sanicro 25. a) virgin specimens, b) aged specimens (2000h).

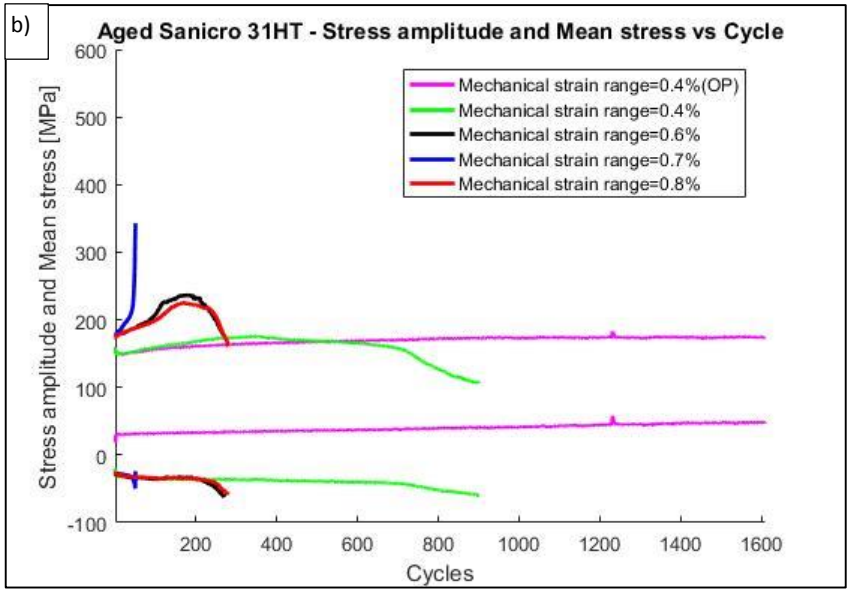
TMF-Testing: Esshete 1250



Cyclic hardening/softening; stress amplitude and mean stress vs. cycles, for Esshete 1250. a) virgin specimens, b) aged specimens (2000h).

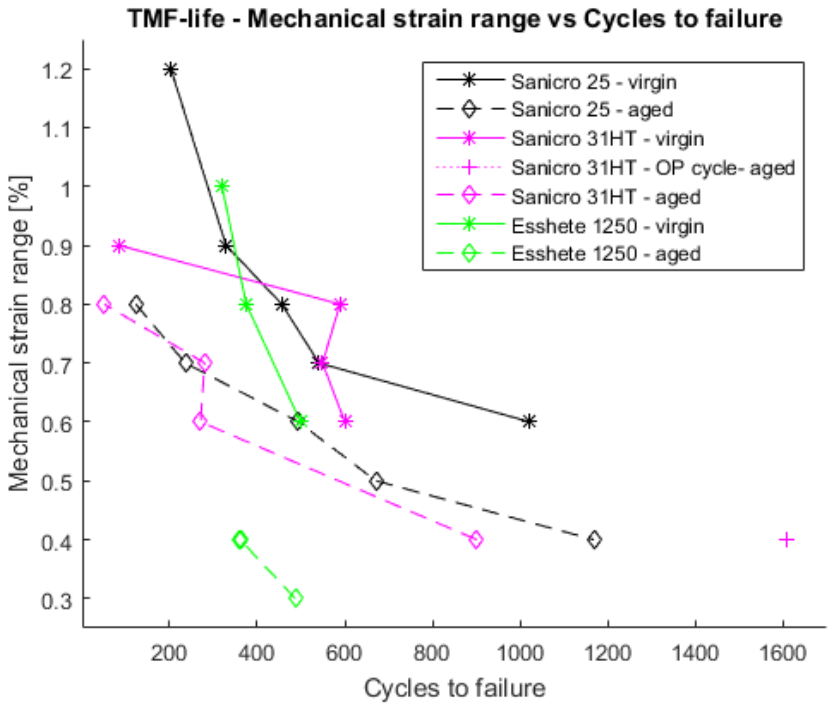
TMF-Testing: Sanicro 31HT



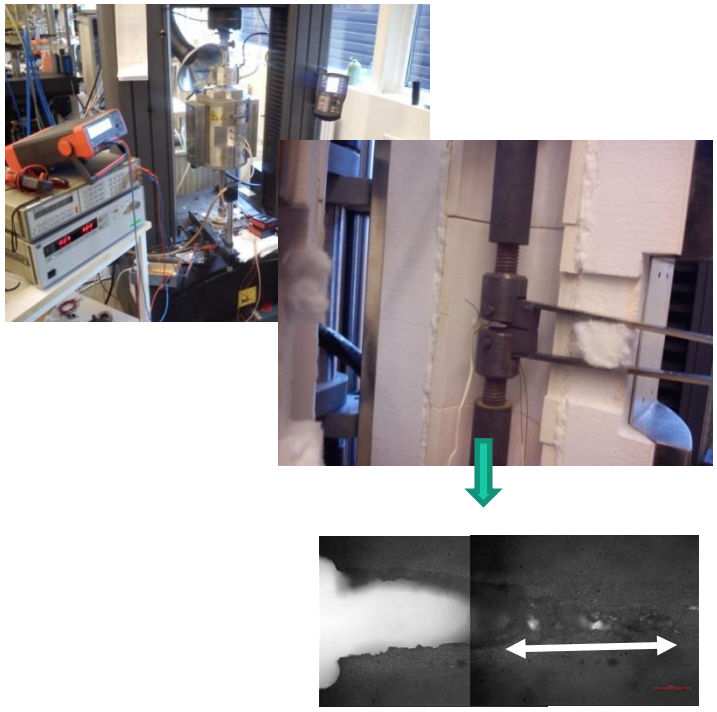


Cyclic hardening/softening; stress amplitude and mean stress vs. cycles, for Sanicro 31 HT. a) virgin specimens, b) aged specimens (2000h).

- The aged materials showed more of a brittle behaviour during TMF-testing.
  - Precipitation at/on grain boundaries is thought to enhance the brittle behaviour, but further investigations is needed.
  - Higher stresses but fewer TMF-cycles.
  - Sanicro 25 performs best, then Sanicro 31HT and last Esshete 1250.

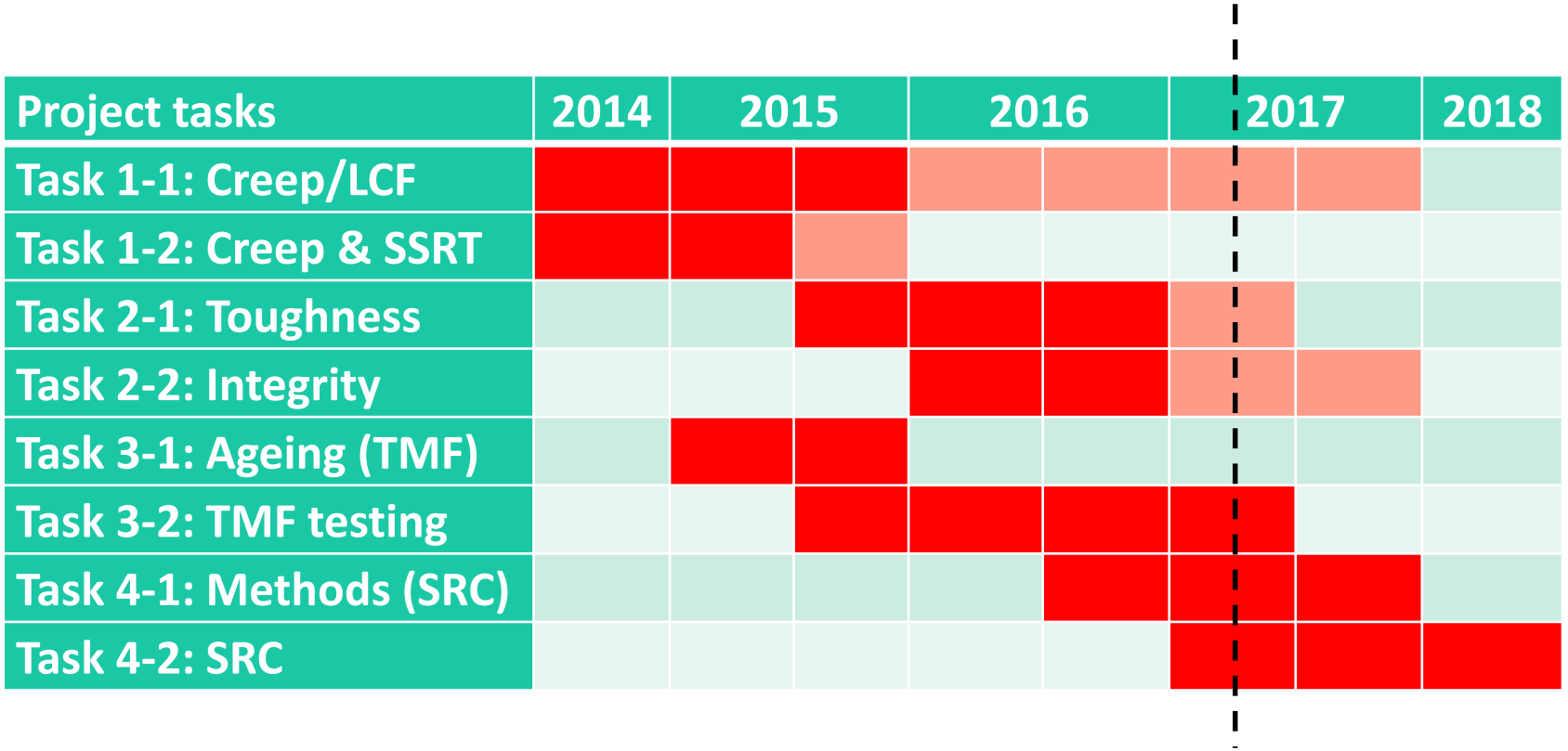


- Task 4: Stress relaxation cracking
  - Task 4-1: Method development
    - Screening method
    - CTOD- testing
  - Task 4-2: Stress relaxation cracking behavior of heat resistant materials
    - Testing
    - Microstructural evaluation



Future work

Time schedule



Thank you for your attention!

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