Heavy section austenitic stainless steel for the future high-efficient biomass-fired power plants

KME 801

Hugo Wärner
Department of Management and Engineering (IEI)
Division of Engineering Materials

LINKÖPING UNIVERSITY

12 March 2019, KME-HTC Research Symposium 2019

Acknowledgment

SANDVIK

Sumitomo SHI FW

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

Swedish Energy Agency

Energiforsk

[redacted]

Project group

Project manager:

- Mattias Calmunger (Linköping University)

Members:

- Hugo Wärner (Linköping University, PhD student)
- Johan Moverare (Linköping University)
- Guocai Chai (Sandvik Materials Technology/Linköping University)
- Maria Sundqvist (Sandvik Materials Technology)
- Vesna Barišić (Sumitomo SHI FW)
- Kyösti Vänskä (Sumitomo SHI FW)
- Bertil Wahlund (Energiforsk)

Outline

- Background
  - Results from KME 701
- Project plan
  - Materials
  - Main activities
- Project goals

Background to the project

- Future need of more efficient energy production.
- Increasing demand on materials high-temperature performance.

Gärdstadverken Linköping.
Photo Åke E. Lindman

Fuel

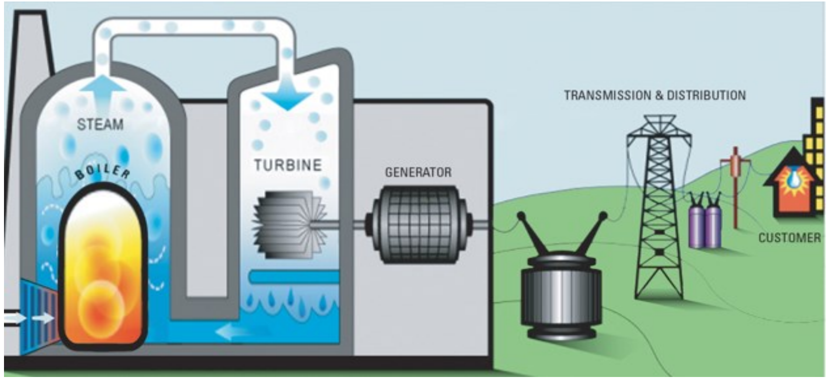


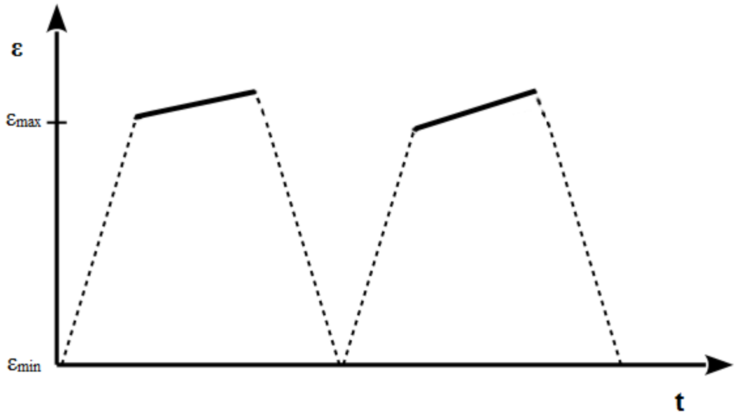
Image from Xcel Energy

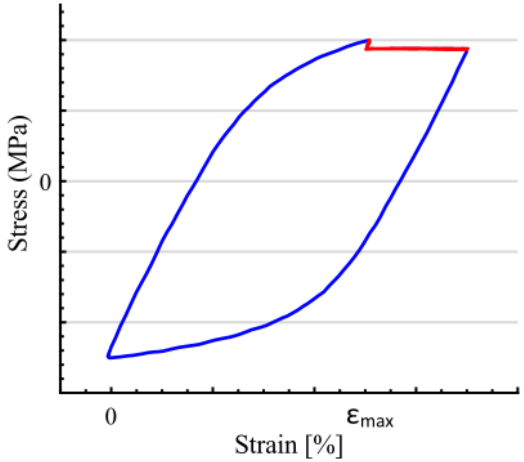
Continuation of KME-501, 521 and 701.

- Creep and fatigue interaction

  – **KME 701**

    - Strain controlled fatigue part
    - Load controlled dwell time
    - Temperature: 700°C
    - Dwell time: 0, 100, 300, 600 and 1800 seconds
    - Strain amplitudes: 0.25%-0.5%
    - Pre-ageing: 700°C for 2000h

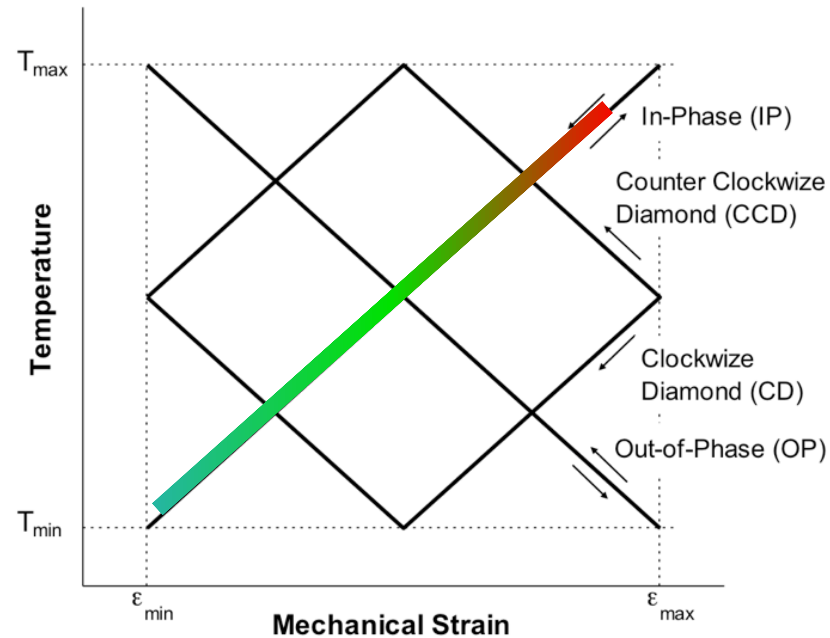




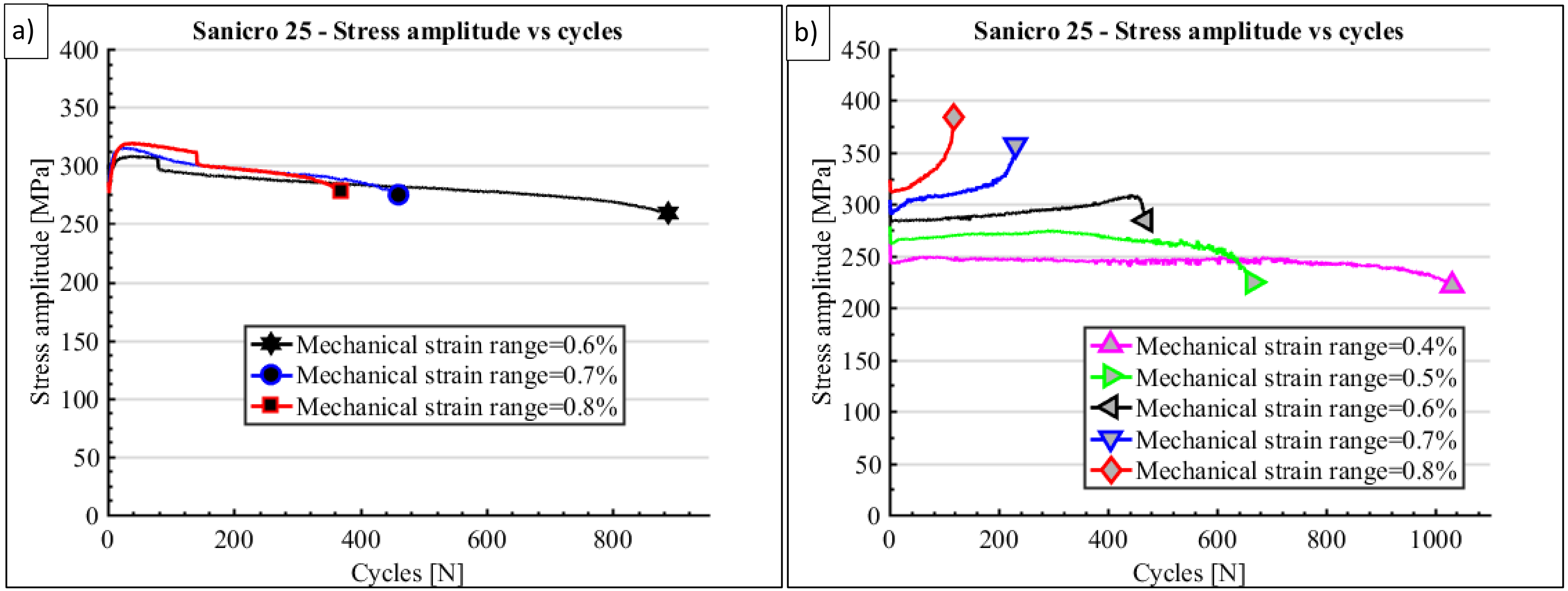
- Thermomechanical fatigue

  - **KME 701**
    - Phase-shift: in-phase (IP)
    - Heating/Cooling rate: 5°C/s
    - Maximum temperature: 800°C
    - Minimum temperature: 100°C
    - Dwell time: 5min

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

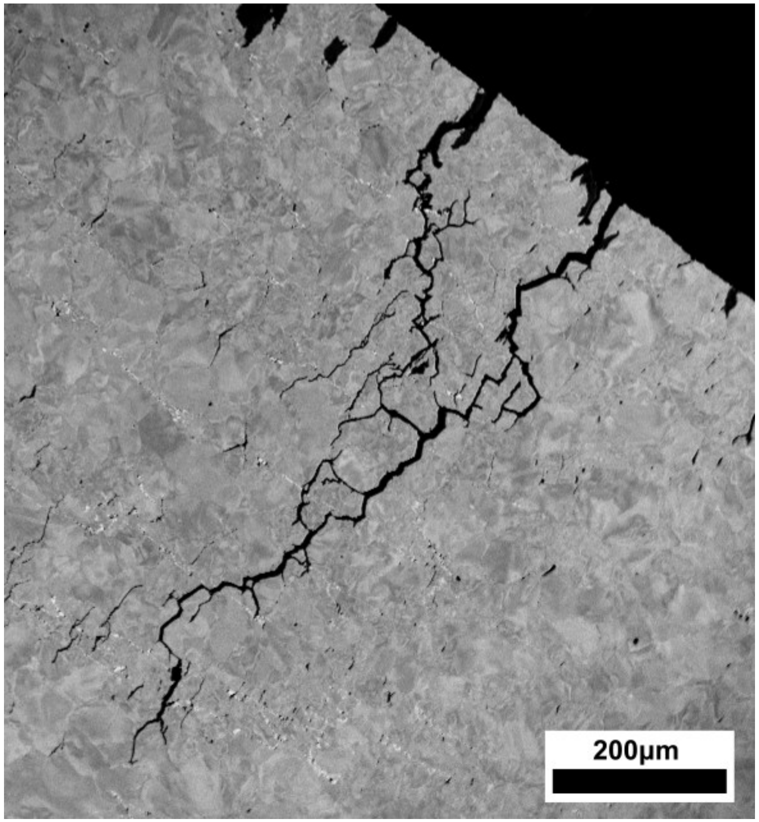


TMF: Sanicro 25

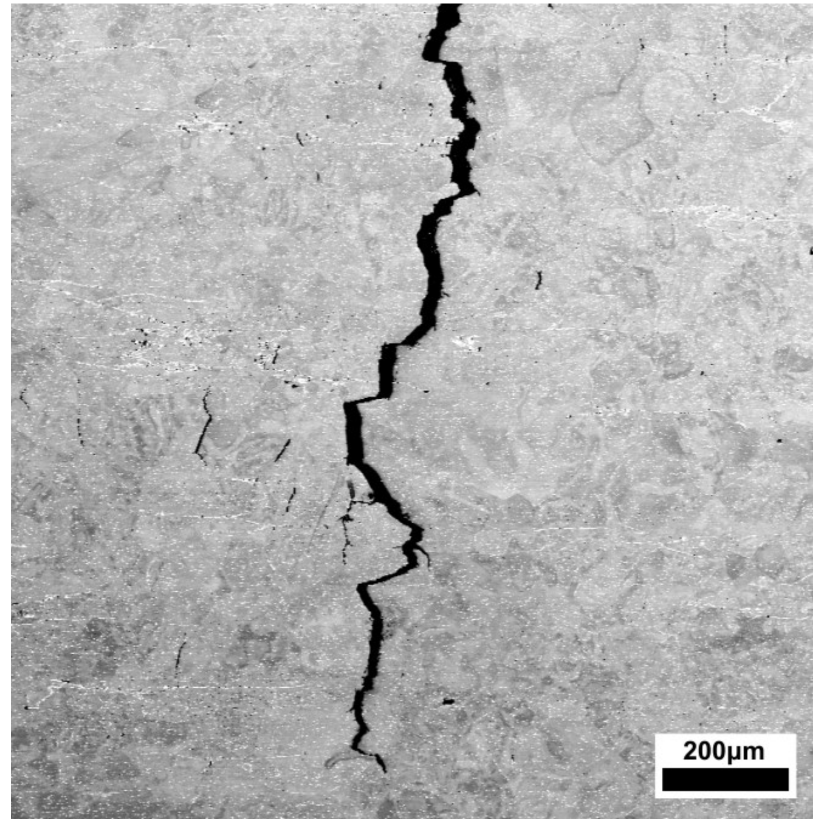


Cyclic hardening/softening curves, for Sanicro 25. a) Virgin material b) Aged material

TMF Testing: Sanicro 25 – Failure mechanisms



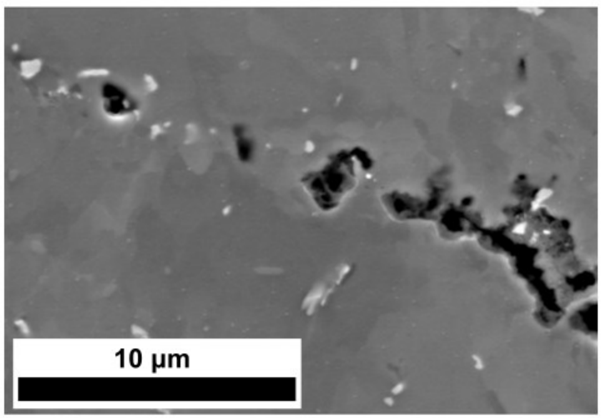
Micrograph of virgin Sanicro 25 with $\Delta\varepsilon_{mech} = 0.8\%$. ~400 cycles.

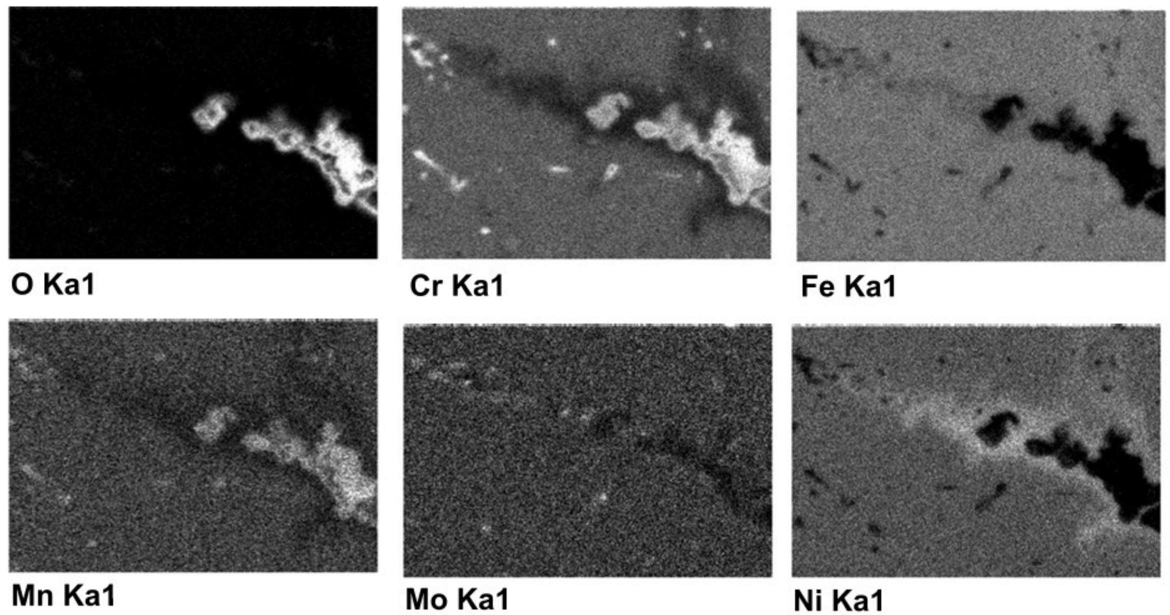


Micrograph of pre-aged Sanicro 25 with $\Delta\varepsilon_{mech} = 0.6\%$.~450 cycles.

[redacted]

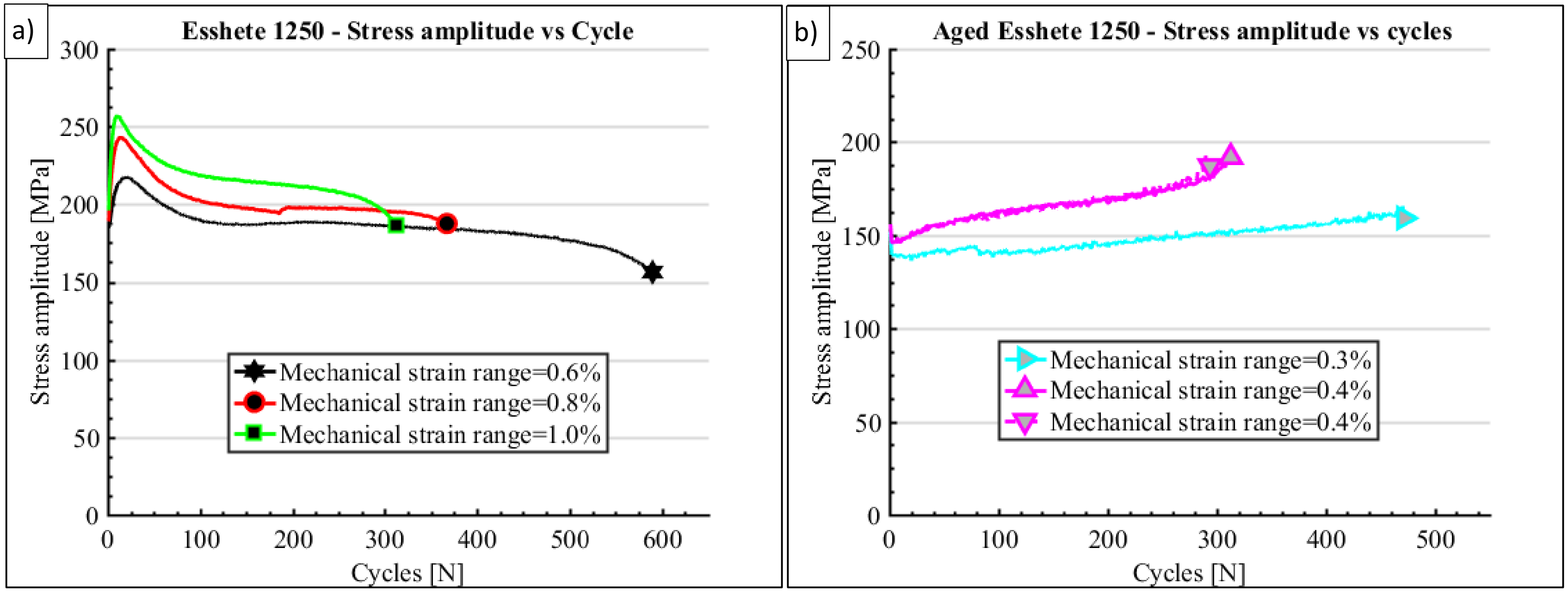
TMF-Testing: Sanicro 25 – Failure mechanisms





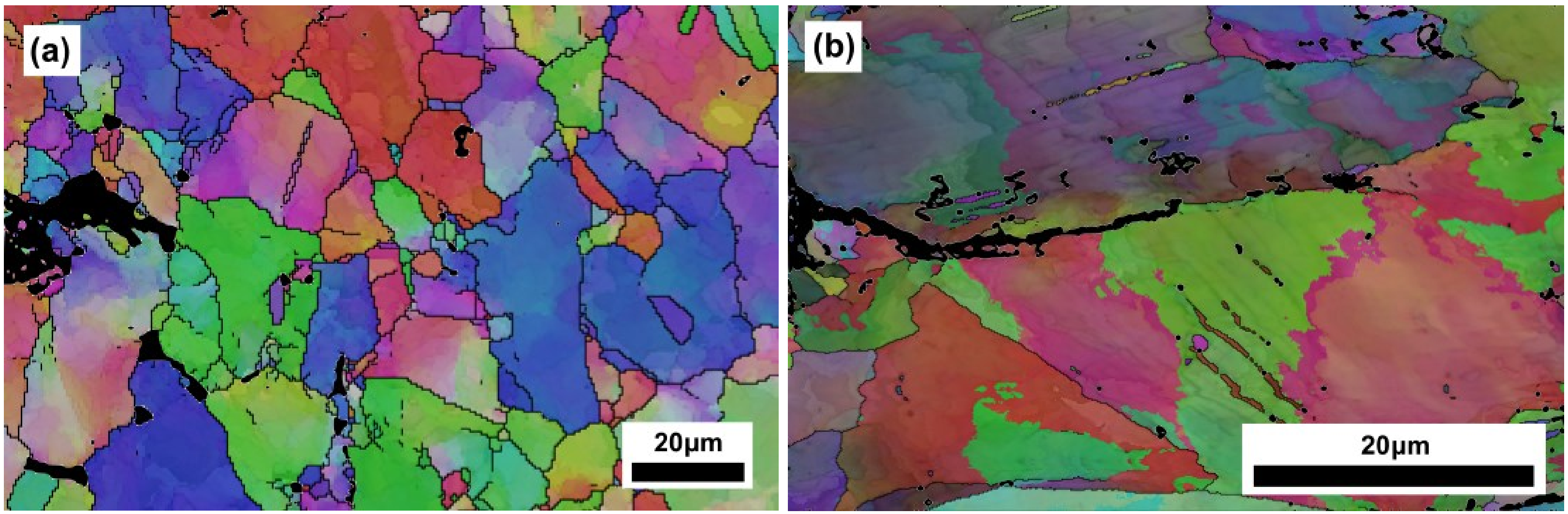
EDS analysis of aged Sanicro 25 with $\Delta\varepsilon_{mech} = 0.6\%$ ~450 cycles.

TMF: Esshete1250



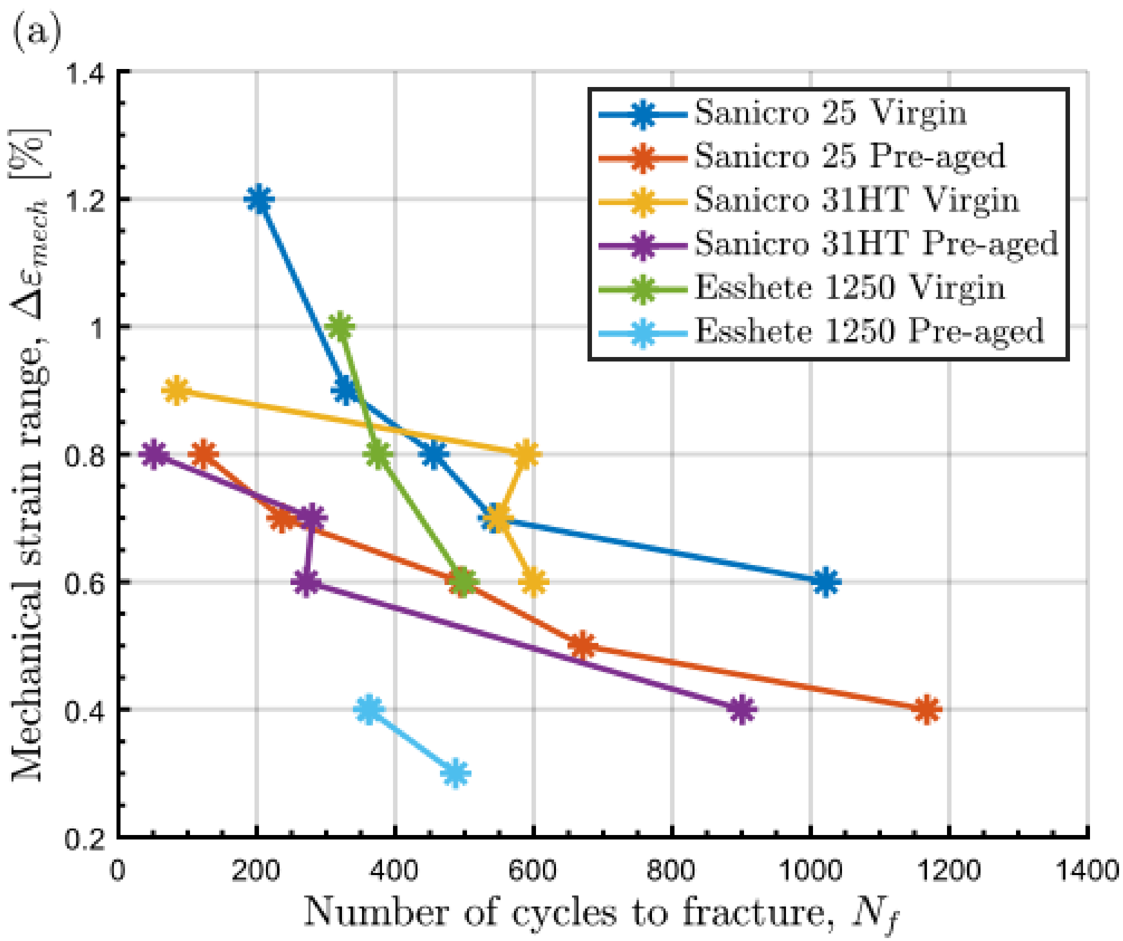
Cyclic hardening/softening curves, for Esshete 1250. a) Virgin material b) Aged material

TMF-Testing: Esshete 1250– Failure mechanisms



Esshete 1250 EBSD mapping (IPF colouring with grain boundary contrast) of main crack (transverse loading direction) for the, (a) virgin specimen (ε_{mech} = 0.6%), (b) pre-aged specimen (ε_{mech} = 0.4%)

[redacted]


(a)
Sanicro 25 Virgin
Sanicro 25 Pre-aged
Sanicro 31HT Virgin
Sanicro 31HT Pre-aged
Esshete 1250 Virgin
Esshete 1250 Pre-aged
Mechanical strain range, $\Delta\varepsilon_{mech}$ [%]
1.4
1.2
1
0.8
0.6
0.4
0.2
0
200
400
600
800
1000
1200
1400
Number of cycles to fracture, N_f

KME 801: Project plan – Materials

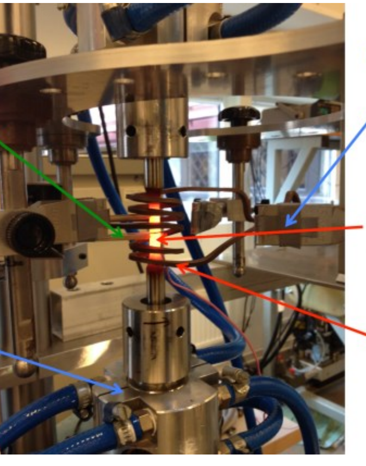
Alloy	C	Mn	Cr	Ni	Mo	Cu	Co	Nb	V	Fe
Sanicro 25	0,07	0,47	22,3	24,9	0,24	2,95	1,44	0,52	-	B
Esshete1250	0,1	6,3	15	9,5	1	-	-	1,0	-	B

B = balance

Sanicro 25 and (Esshete 1250) and one ferritic stainless steel as reference.

Project plan – Main activities

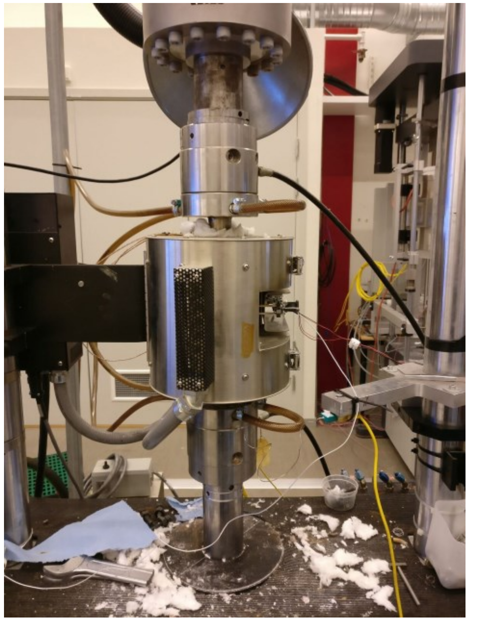
- Part 1: Thermomechanical fatigue testing
  - **Task 1-1: Long term ageing before TMF testing**
    - Temperature: 600°C, 650°C and 700°C
    - Time: up to 10 000 hours
  - **Task 1-2: Thermomechanical fatigue testing**
    - Out-of-phase (OP)
    - Heating/Cooling rate: 5°C/s
    - Maximum temperature: 700°C
    - Minimum temperature: 100°C
    - Dwell time: 5min
  - Microscopy investigation: Light optical microscopy (LOM) and scanning electron microscopy (SEM) techniques (ECCI, EBSD) to analyse the deformation and damage mechanisms



[redacted]

- Part 2: Fatigue behavior and creep resistance

  - **Task 2-1: Long-term ageing before crack propagation and creep testing**
    - Temperature: 600°C, 650°C and 700°C
    - Time: up to 10 000 hours



  - **Task 2-2: Fatigue crack propagation testing**
    - The cracking behaviour due to low cycle fatigue
    - CT-specimens
    - PD-monitoring
    - Temperature: 650°C and 700°C

  - **Task 2-3: Creep testing**
    - High and low load
    - Temperature: 650°C and 700°C

  - Microscopy investigation: Light optical microscopy (LOM) and scanning electron microscopy (SEM) techniques (ECCI, EBSD) to analyse the deformation and damage mechanisms

- Part 3: Influence of welding and ageing on toughness

  - **Task 3-1: Long-term ageing before crack propagation and creep testing**
    - Temperature: 600°C, 650°C and 700°C
    - Time: up to 10 000 hours
    - Condition: Virgin and welded material

  - **Task 3-2: Influence of welding and long-term ageing on toughness**
    - Temperature: 25°C (RT)
    - Impact testing: Charpy V
    - Fracture toughness testing: CTOD (Crack tip opening displacement)

  - Microscopy investigation: Light optical microscopy (LOM) and scanning electron microscopy (SEM) techniques (ECCI, EBSD) to analyse the deformation and damage mechanisms

- Part 4: Design feasibility study
  - **Task 4-1: Stress analysis comparison**
    - Stress analysis results from Sanicro 25 and Esshete 1250 compared to ferritic stainless steel
    - FE models of the application

Project goals

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

1) To **evaluate thermo-mechanical fatigue properties** of new materials of critical components for safety and life evaluation since the biomass-fired power plants can start/shutdown quite often during service for energy saving and flexibility purposes in the future.

2) To **evaluate the fatigue crack propagation behavior** of new materials used in safety and reliability considerations since the material of critical components can undertake low cycle fatigue during the service.

3) To **evaluate the creep resistance** of new materials used in safety and reliability considerations since the material of critical components can undertake creep during the service.

4) To **evaluate the structure stability and the toughness of welded and aged material** after long term service at high temperatures for safety analysis.

5) To **evaluate the new candidate material compared to currently used materials using FE-models** of the applications.

Thank you for your attention!

www.liu.se

LINKÖPING UNIVERSITY

Publication list KME 501 and KME 701

1. Deformation behaviour in advanced heat resistant materials during slow strain rate testing at elevated temperature
Theoretical and Applied Mechanics Letters, 2014, 4(041004), .

2. Mechanical Behaviours of Alloy 617 with Varied Strain Rate at High Temperatures
Materials Science Forum, 2014, 783-786, 1182-1187.

3. Influence of deformation rate on mechanical response of an AISI 316L austenitic stainless steel
Advanced Materials Research, 2014, 922, 49-54.

4. Long Term High-Temperature Environmental Effect on Impact Toughness in Austenitic Alloys
Key Engineering Materials, 2015, 627, 205-208.

5. Damage and Fracture Behaviours in Aged Austentic Materials During High-Temperature Slow Strain Rate Testing
Key Engineering Materials, 2014, 592-593, 590-593.

6. Advanced Microstructure Studies of an Austenitic Material Using EBSD in Elevated Temperature In-Situ Tensile Testing in SEM
Key Engineering Materials, 2014, 592-593, 497-500.

7. Influence of High Temperature Ageing on the Toughness of Advanced Heat Resistant Materials
13th International Conference on Fracture (ICF13), June 16-21, Beijing, China, 2013.

8. Damage and Fracture Behaviours in Advanced Heat Resistant Materials During Slow Strain Rate Test at High Temperature
13th International Conference on Fracture (ICF13), June 16-21, Beijing, China, 2013.

9. Influence of Dynamic Strain Ageing on Damage in Austenitic Stainless Steels
19th European Conference on Fracture (ECF19), August 26-31 2012, Kazan, Russia, 2012.

[redacted]

Cont. Publication list

10. Surface Phase Transformation in Austenitic Stainless Steel Induced by Cyclic Oxidation in Humidified Air
Corrosion Science, 2015, 100, 524-534.

11. Creep and Fatigue Interaction Behavior in Sanicro 25 Heat Resistant Austenitic Stainless Steel
Transactions of the Indian Institute of Metals, 2016, 69, 337-342.

12. Local surface phase stability during cyclic oxidation process
Materials Science Forum, 2017, 879, 855-860

13. Influence of dynamic strain ageing and long term ageing on deformation and fracture behaviors of Alloy 617
Materials Science Forum, 2017, 879, 306-311

14. Toughening Behavior in Alloy 617 with Long Term Ageing
Solid State Phenomena, 2017, 258, 302-305

15. Creep-fatigue interaction in heat resistant austenitic alloys
MATEC Web of Conferences 2018, 165, 05001

16. Fracture and Damage Behavior in an Advanced Heat Resistant Austenitic Stainless Steel During LCF, TMF and CF
Procedia Structural Integrity, Volume 13, 2018, Pages 843-848

In addition, two Master thesis *Thermal mechanical fatigue behaviour of aged heat resistant austenitic alloys* (Wärner, 2016) and *The Influence of Dynamic Strain Aging on Austenitic Stainless Steels* (Calmunger, 2011), two Licentiate thesis *High-Temperature Behaviour of Austenitic Alloys* (Calmunger, 2013) and *High-Temperature Fatigue Behaviour of Austenitic Stainless Steel: Influence of Ageing on Thermomechanical Fatigue and Creep-Fatigue Interaction* (Wärner 2018) and one PhD thesis *On High-Temperature Behaviours of Heat Resistant Austenitic Alloys* (Calmunger, 2015) have been produced within KME 501 and 701.

[redacted]