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MECHANICAL PROPERTIES AND CORROSION RESISTANCE OF CANDIDATE MATERIALS FOR SCWRs

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TVO

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IAEA – SCWR

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(SC25) Mechanical properties and corrosion resistance of candidate materials for SCWRs

Joint ICTP-IAEA Course on Science and Technology of SCWRs, Trieste, Italy, 27 June - 1 July 2011

CONTENTS OF SC25

1. Candidate materials
2. Mechanical properties - strength
3. Chemical stability – corrosion
4. Creep – creep oxidation
5. Stress Corrosion Cracking
6. Summary for SCWR candidate materials

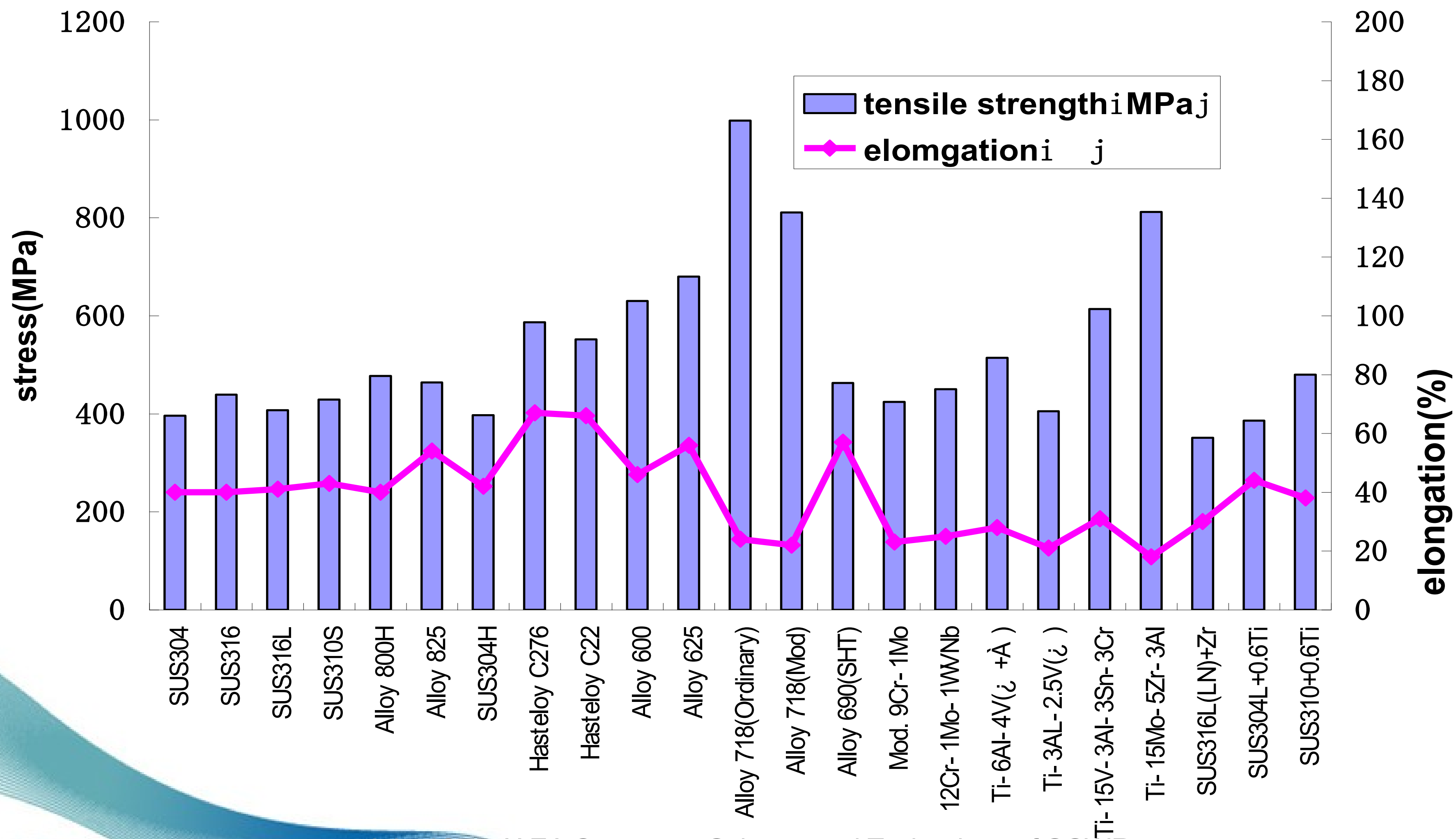
GOALS OF THE LECTURE

To learn about the strength testing of materials for LWRs.
To learn about corrosion types and the potential modes in LWR applications.
To learn about the testing and analysing methods for selection of candidate materials.

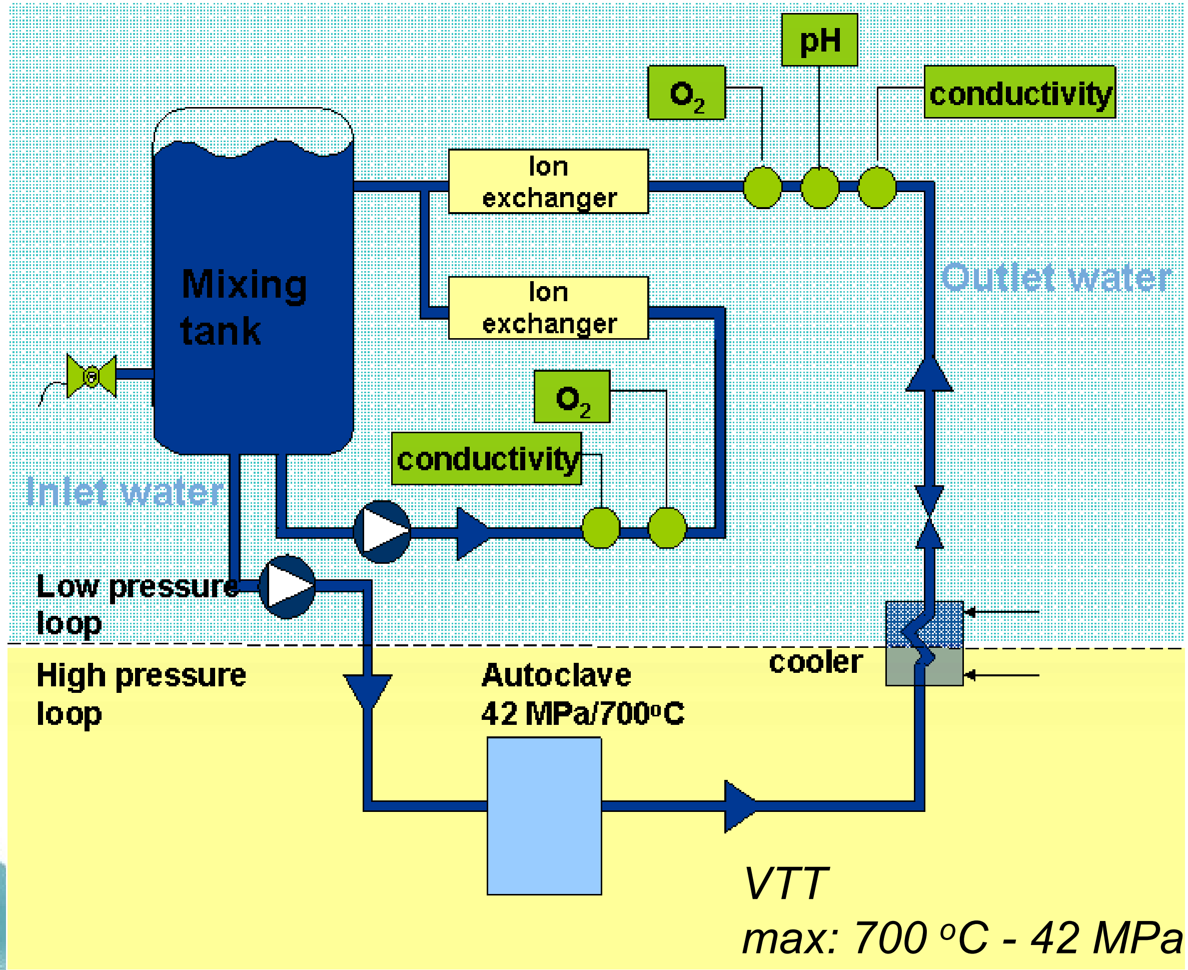
CHEMICAL COMPOSITIONS OF STUDIED ALLOYS (EURATOM PROGRAMME) (WT-%)

		Material	Chemical analysis
F/M	1	P91	0.1Ni 8.3Cr 0.96Mo 0.11C 0.43Mn 0.23V 0.41Si
	2	P92	0.02Ni 8.9Cr 0.49Mo 0.08C 0.42Mn 2.1W 0.22V 0.09Si
	3	HCM12	0.28Ni 11.9Cr 0.34Mo 0.09C 0.62Mn 1.96W 0.25V 0.34Si 0.45Cu
	4	Eurofer 97	---
F/M ODS	5	Eurofer ODS (EU)	0.03Ni 9.2Cr 0.02Mo 0.035C 0.4Mn 1.3W 0.21V 0.03Si
	6	Eurofer ODS (FZK)	0.05Ni 9Cr 0.02Mo 0.021C 0.36Mn 1.3W 0.21V 0.12Si
	7	**PM2000, ODS**	0.03Ni 20.1Cr 0.09Mo 0.005C 0.08Mn 0.03V 0.02Si 0.43Ti
Aust. SS	8	**316NG (LN)**	11.3Ni 16.6Cr 2.11Mo 0.014C 0.8Mn 0.42Si 0.07Co 0.23Cu
	9	321	9-12Ni 17-19Cr 2Mn 1Si 0.08C >5*%C Ti
	10	**TP347H**	10.7Ni 17.6Cr 0.048C 1.8Mn 0.29Si 0.56Nb
	11	Sanicro 28	30.6Ni 26.7Cr 3.34Mo 0.015C 0.065N 1.7Mn 0.41Si 0.87Cu
	12	**BGA4**	15.4Ni 22.9Cr 0.14Mo 0.11C 0.19N 6.1Mn 1.5W 0.31V 0.61Nb 0.49Si 2.7Cu
	13	**15Cr15NiTi (1.4970)**	15Cr 15Ni + Ti
	14	Incoloy 800H	30.8Ni 20.5Cr 0.13Mo 0.06C 0.67Mn 0.36Si 0.36Ti 0.26Al
Ni-base	15	Inconel 625	2.6Fe 22.4Cr 9.1Mo 0.02C 0.05Mn 0.12W 3.3Nb 0.07Si 0.25Ti 0.29Al
	16	Inconel 690	27-31Cr 7-11Fe 0.05C 0.5Mn 0.5Si 0.5Cu

TENSILE TEST RESULTS - LITERATURE



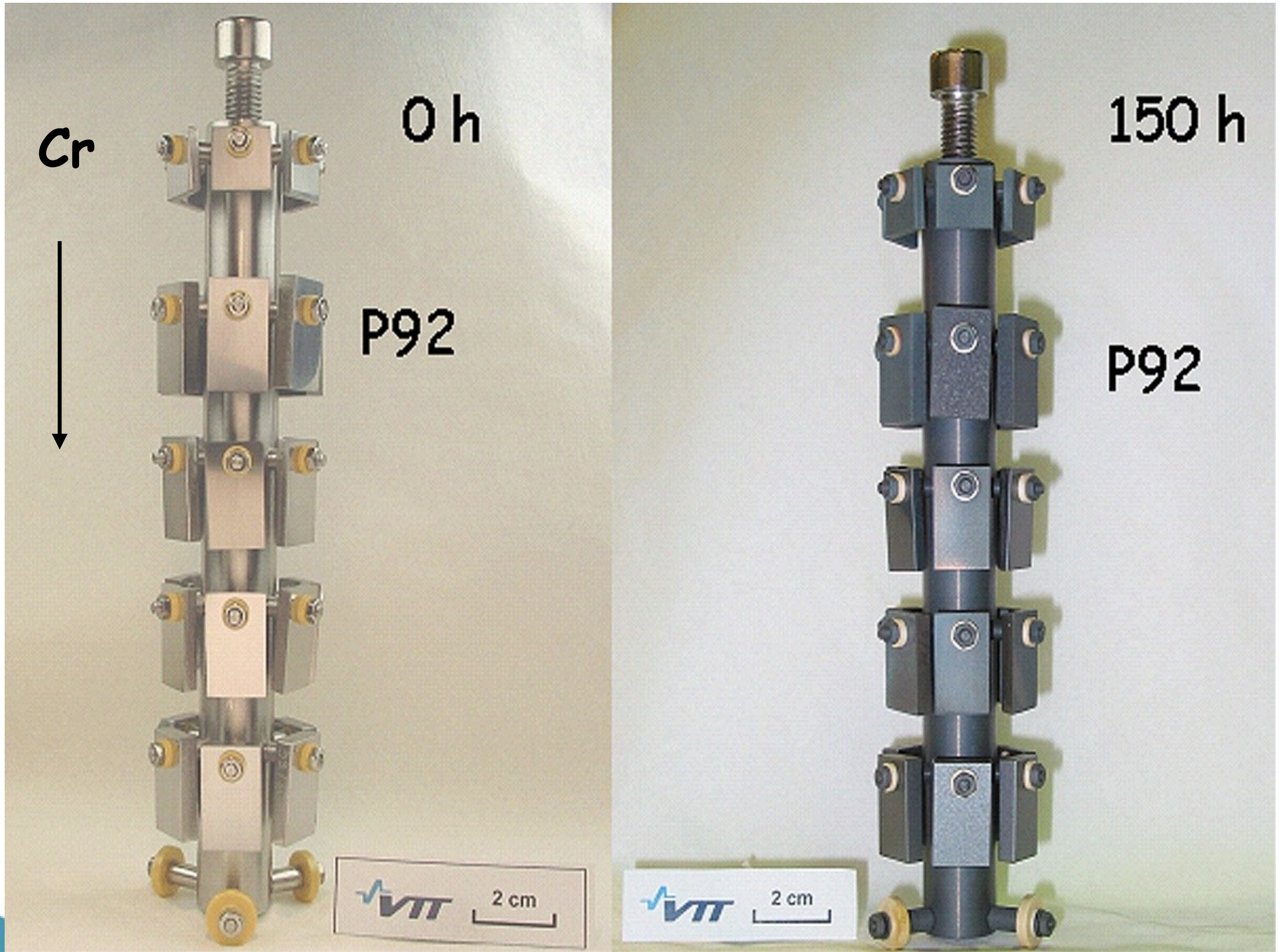
THE SCW AUTOCLAVE EQUIPMENT WITH A WATER LOOP DESIGNED AND CONSTRUCTED AT VTT



Reseach facilities for metal-coolant interaction studies:

- Supercritical autoclave with a water loop (x4)
- Monitoring for SCW chemistry and corrosion phenomenon
- Bellow Loading facilities for creep and SCC tests. [in Novotny presentation]

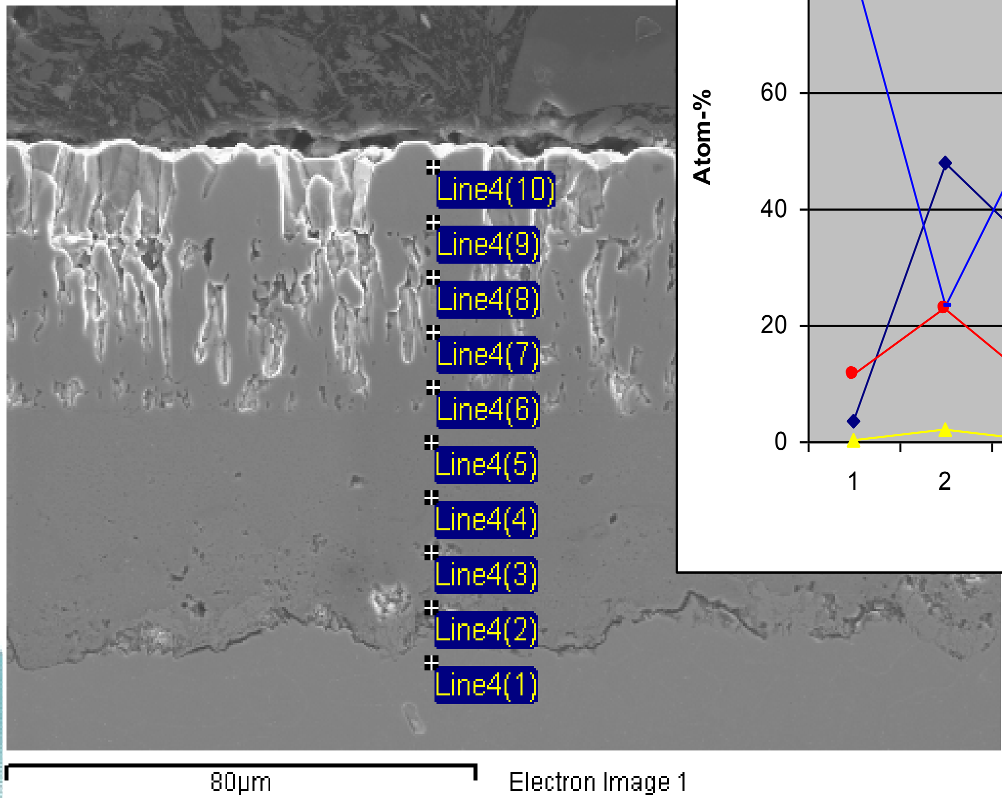
VTT TEST RIG FOR COUPONS: 650 ^{O}C - 30 MPA OXIDATION TESTS

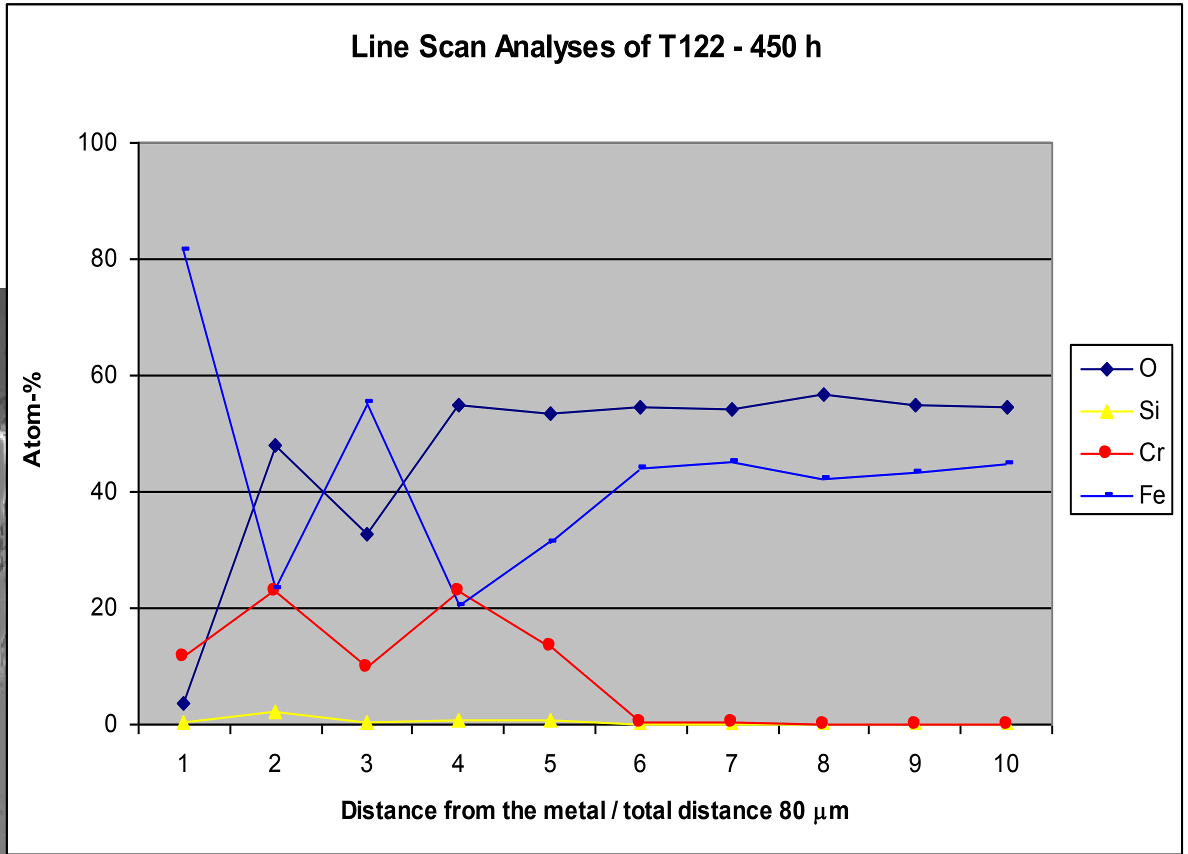


General corrosion - oxidation

Steel HCM12 (T122)

650 °C/30MPa - 450 h

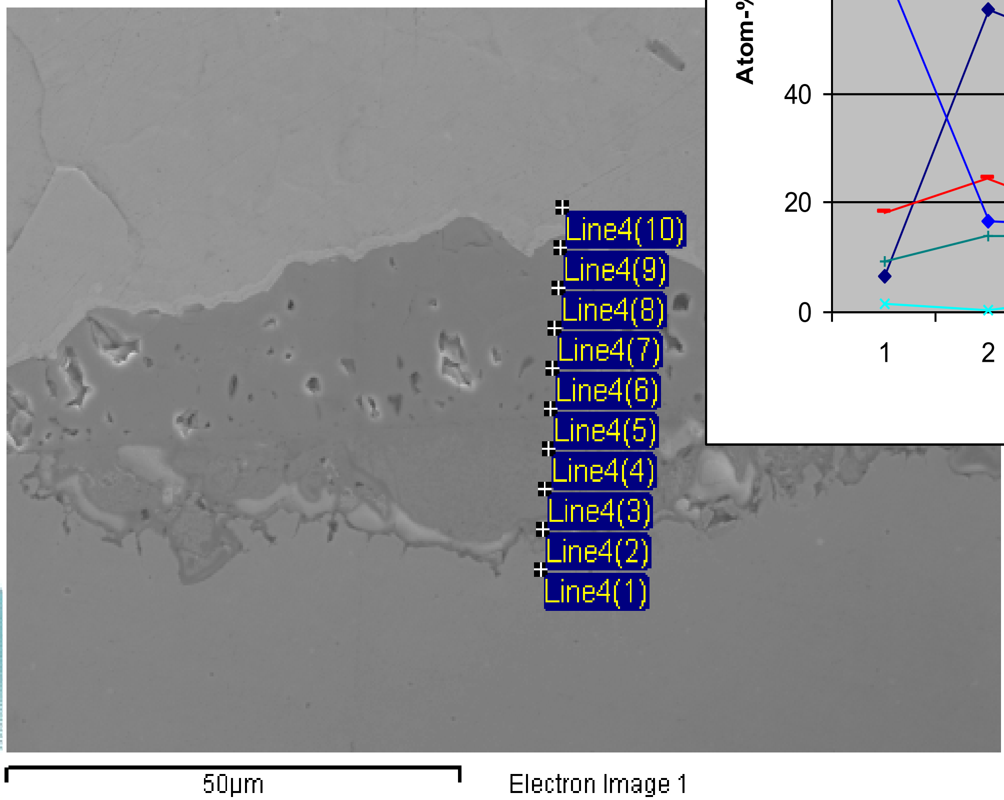


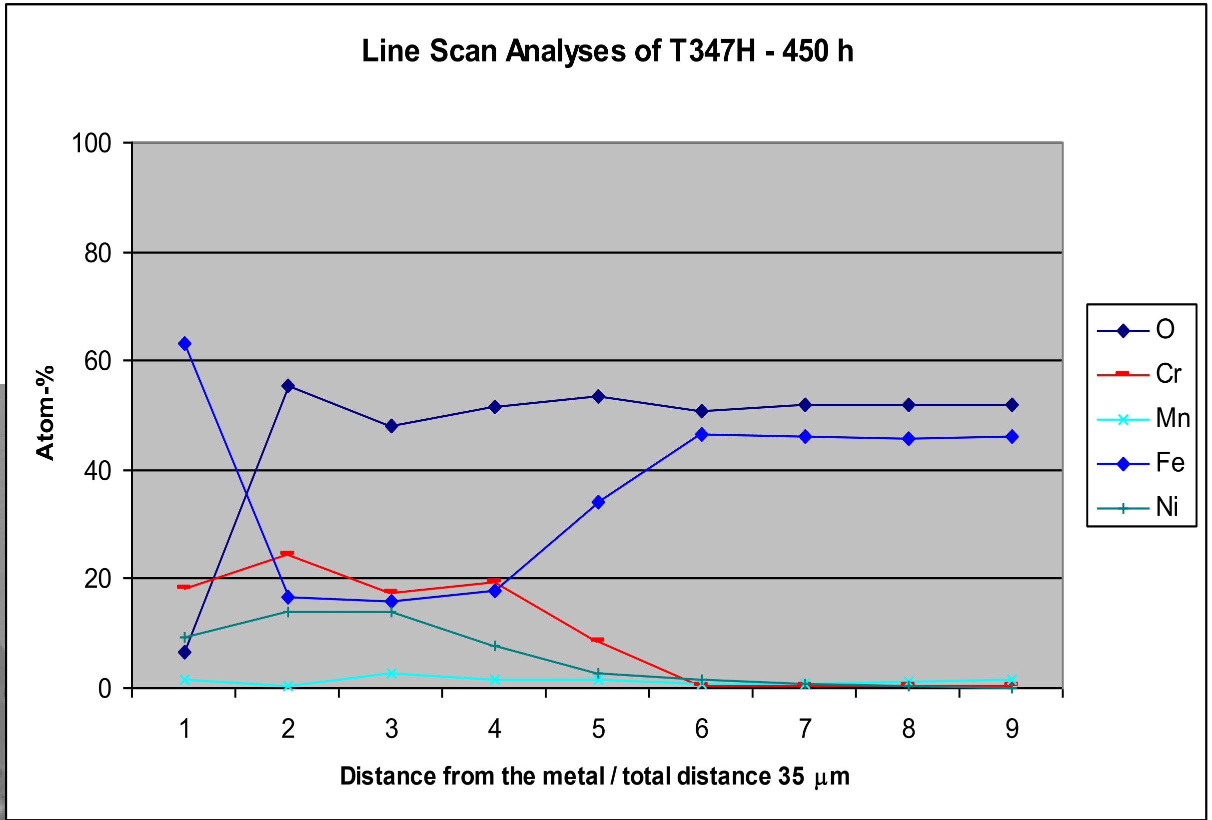


General corrosion – Oxidation

Steel TP347HFG

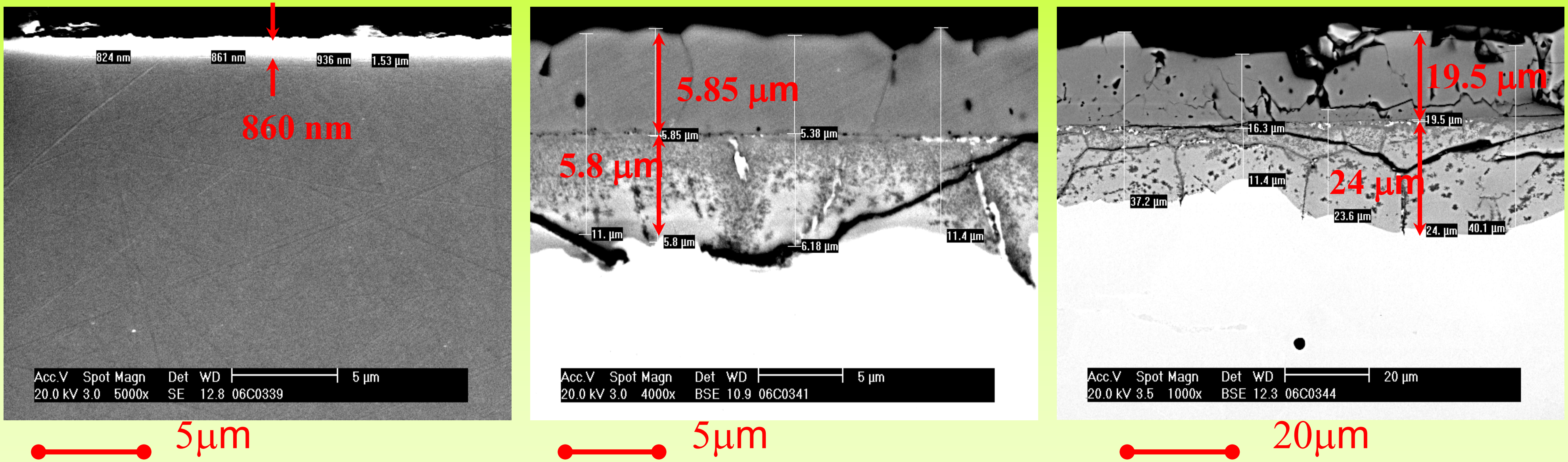
650 °C/30MPa - 450 h



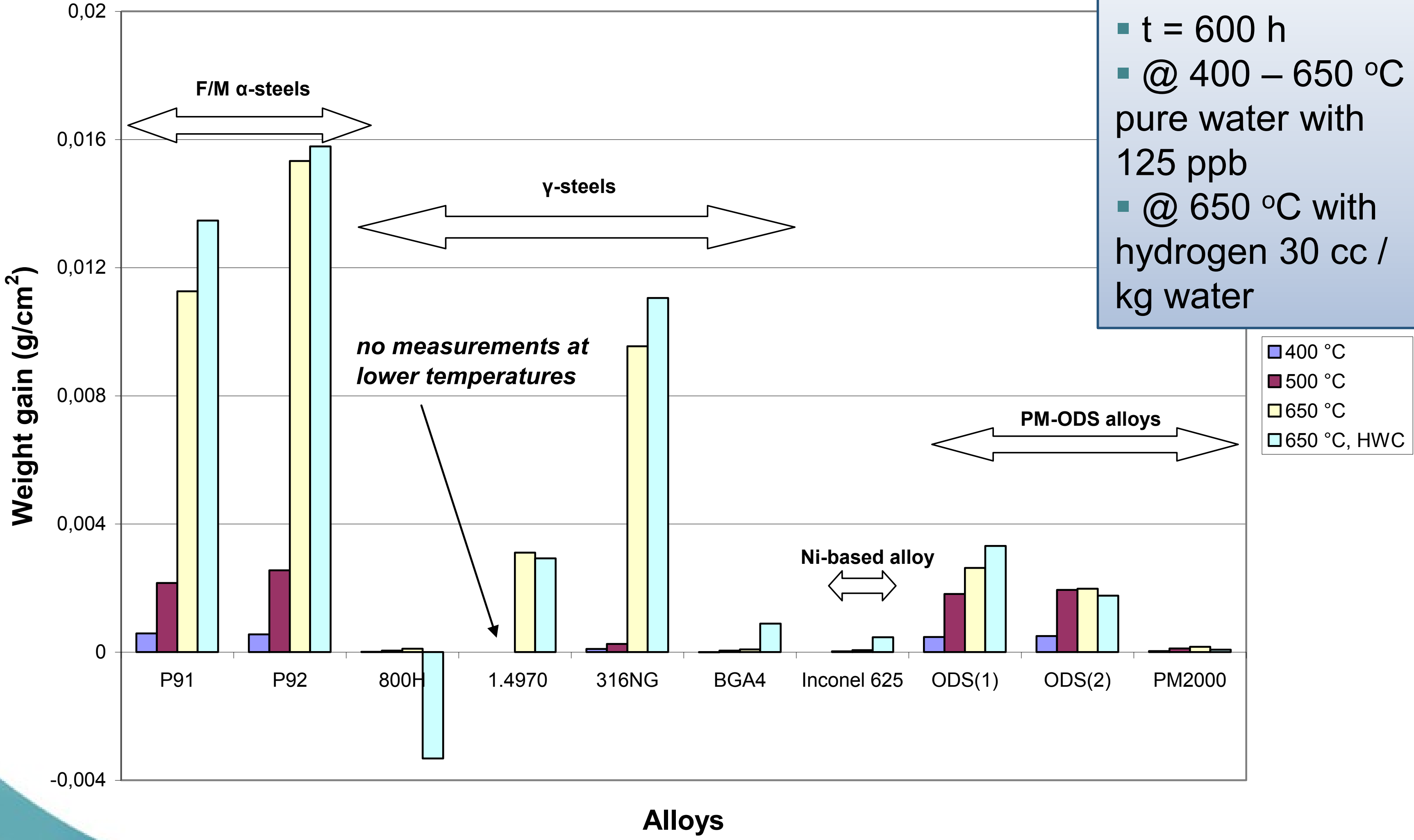


SURFACE MORPHOLOGIES OF OXIDE FILMS ON AISI316 - EXPOSURE FOR 100 H UNDER 30 MPA

500°C | 600°C | 700°C

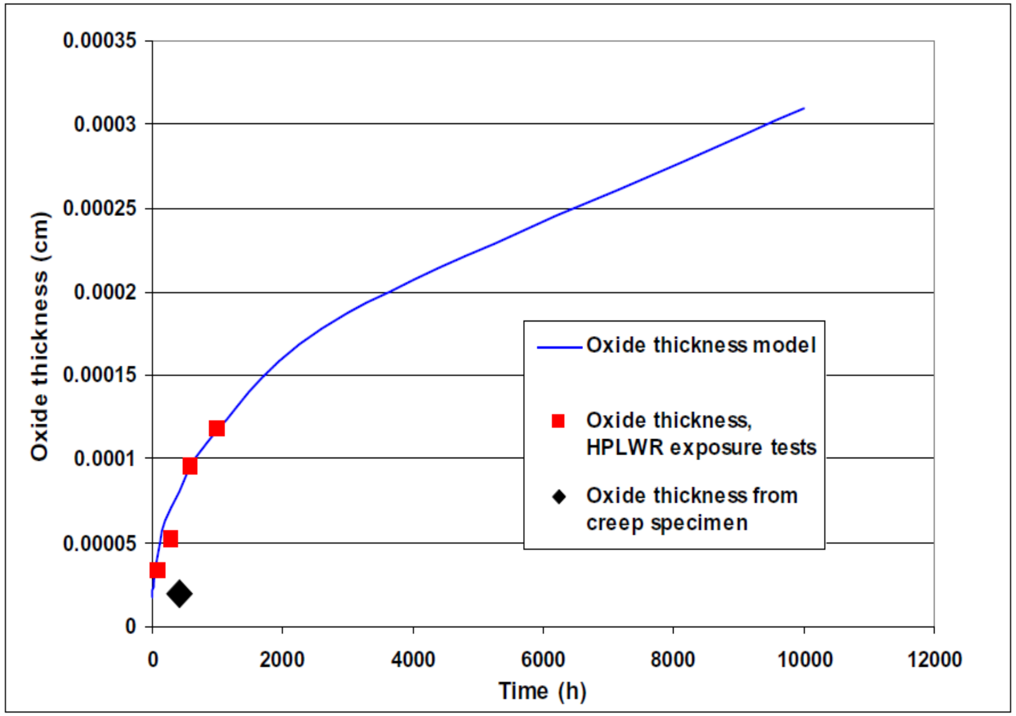


THE PRE-SCREENING TEST RESULTS OF THE HPLWR M&C FOR CANDIDATE IN-CORE MATERIALS



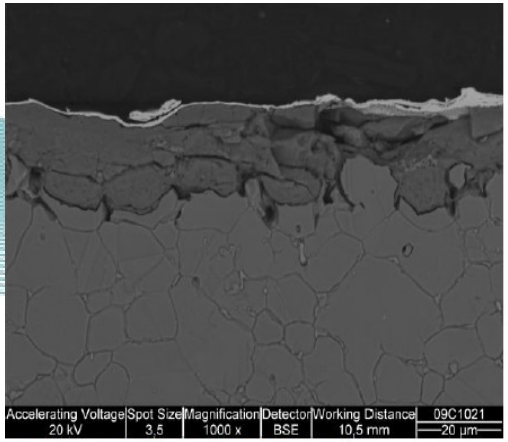
- t = 600 h
- @ 400 – 650 °C pure water with 125 ppb
- @ 650 °C with hydrogen 30 cc / kg water

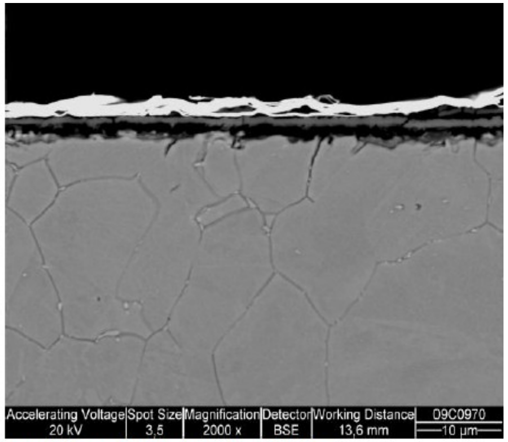
VTT RESULTS: OXIDE THICKNESS MODELING



316NG at 650 C SCW

Oxide thickness data from previous HPLWR tests
Compared to oxide thickness of a creep specimen
Parabolic oxide thickness model fits to data

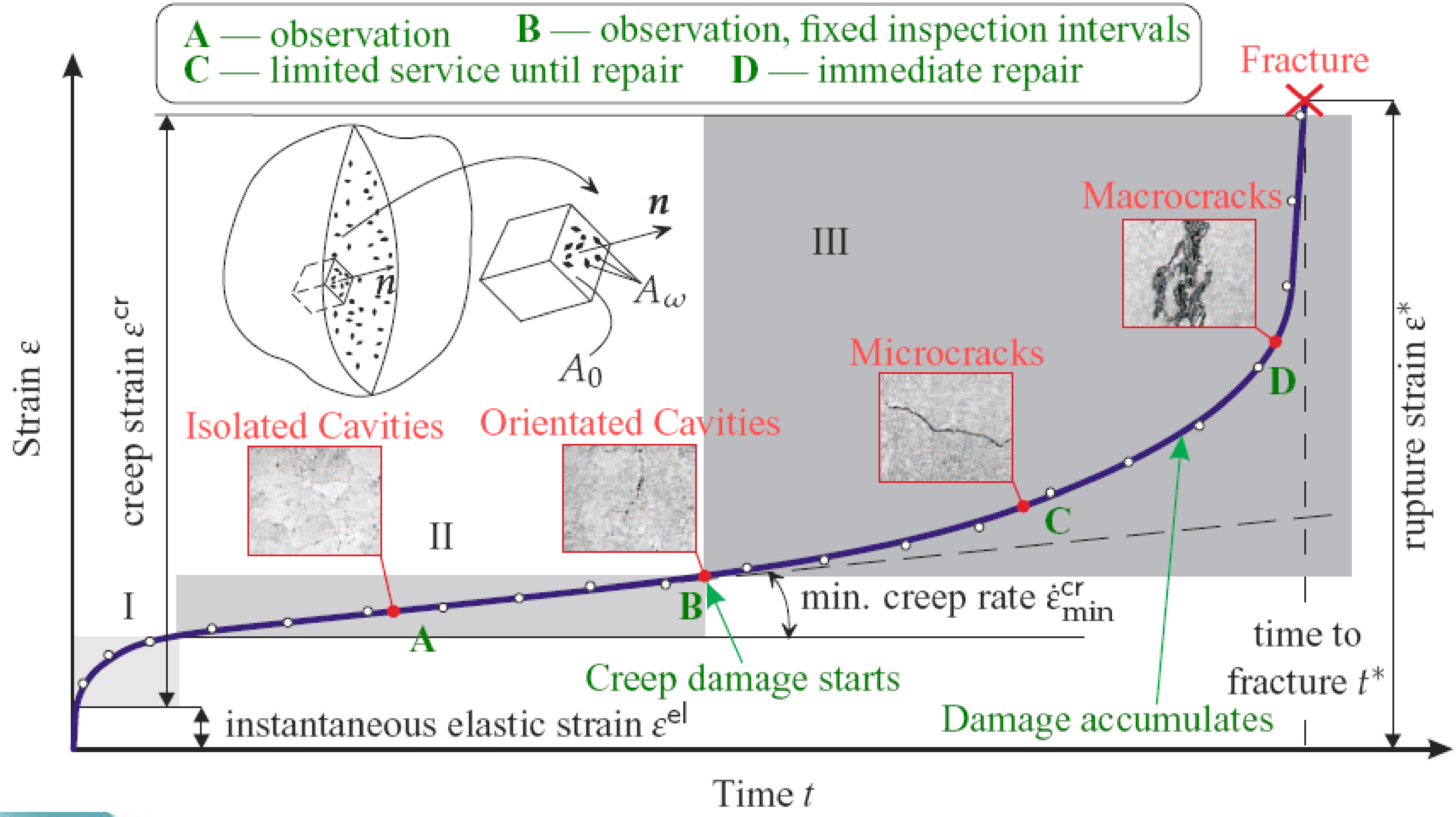




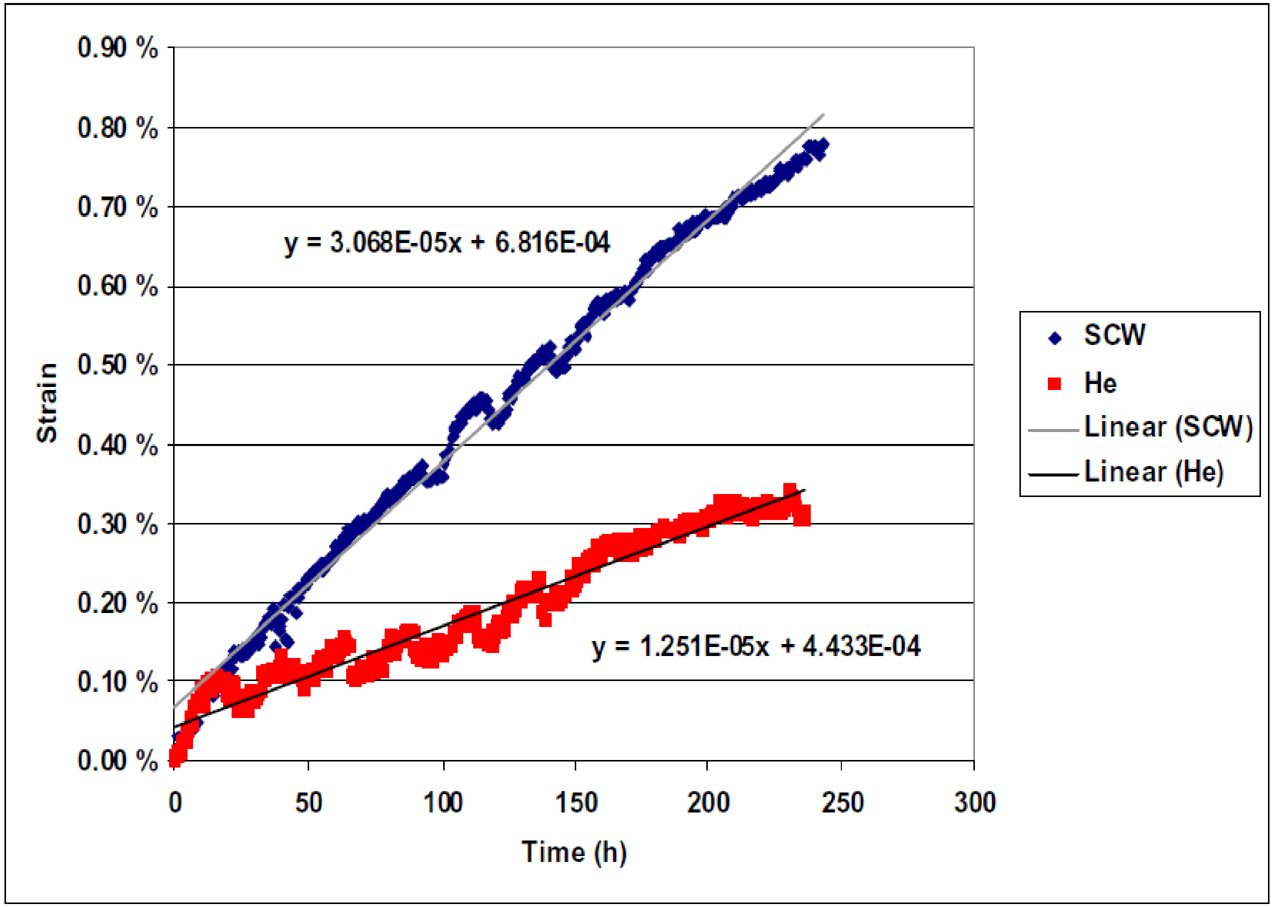
347H at 650 C SCW & He

- Oxide thickness:
  - SCW: 15 µm (ε_{tmax}=5.8%)
  - He: 2 µm (ε_{tmax}=2.4 %)

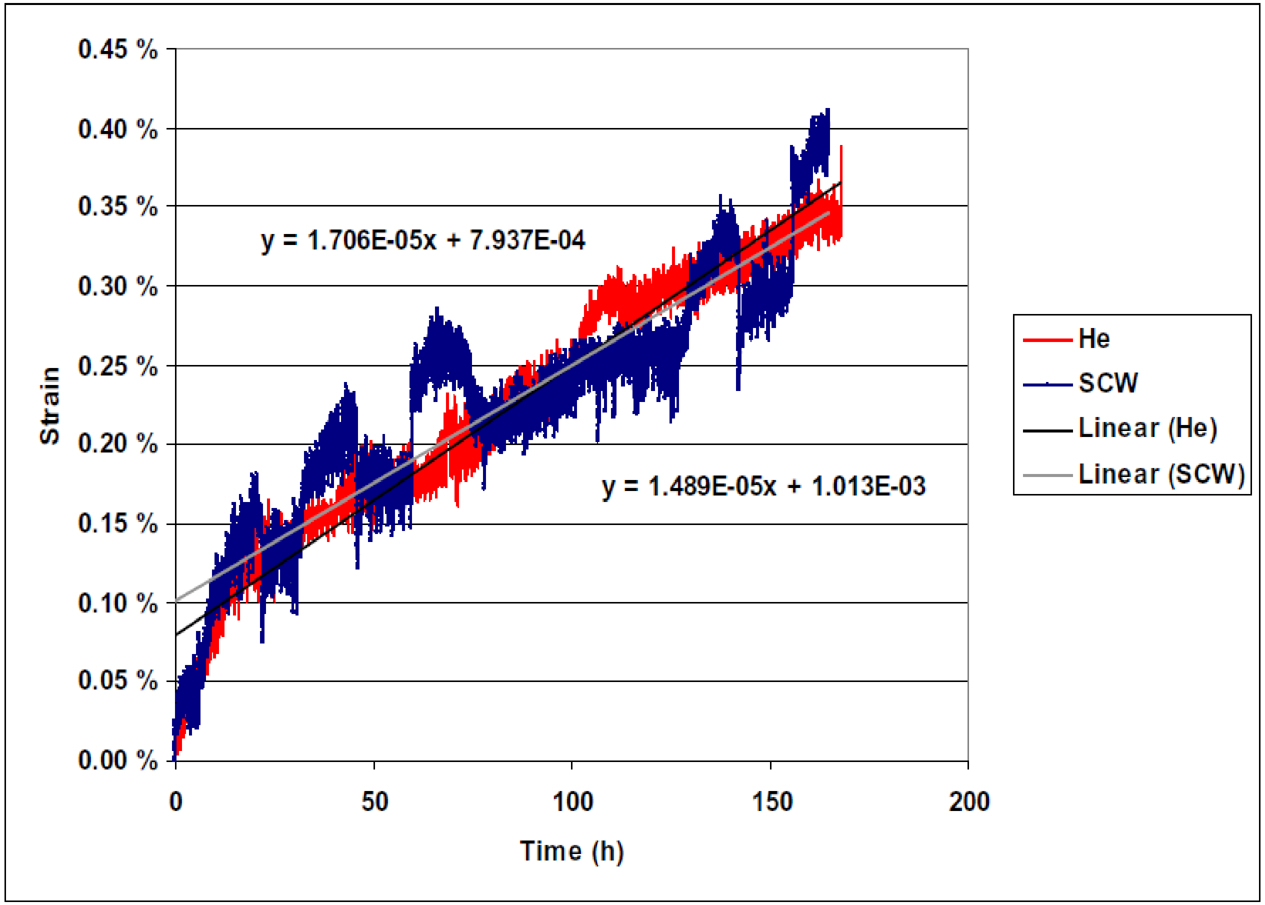
HIGH SERVICE TEMPERATURE => CREEP



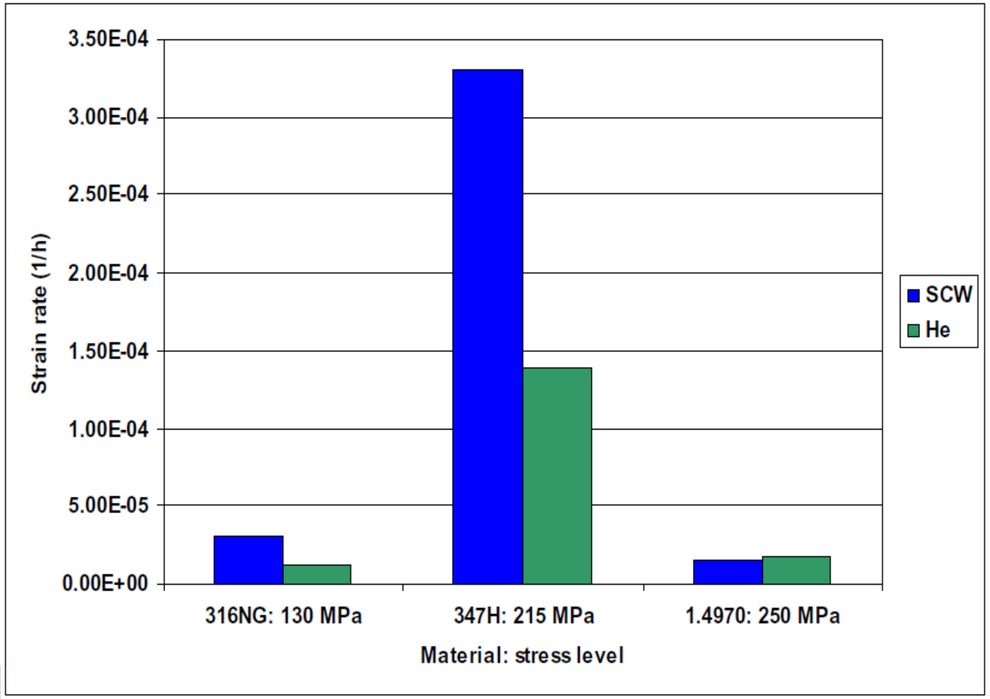
VTT RESULTS: PRIMARY STRAIN RATE DETERMINATION; 316NG (650 C, 130MPA)



VTT RESULTS: PRIMARY STRAIN RATE DETERMINATION 1.4970 (650 C, 250MPA)



VTT RESULT: COMPARISON OF THE PRIMARY STRAIN RATES



650°C	Strain rate SCW/He
316NG: 130 MPa	1.6
316NG: 90 MPa	2.5
347H: 149 MPa	1.2
347H: 215 MPa	2.4
1.4970: 200 MPa	≈ 1
1.4970: 250 MPa	≈ 1

500°C SCW	Strain rate higher σ/lower σ
316NG	1
347H	3
1.4970	1.5

CONCLUSIONS CREEP (VTT)

SCW environment increases strain rate compared to He environment for 316NG and 347H (note short duration tests)

Testing for creep properties usually > 1000 h

→ Must be taken into account in the design

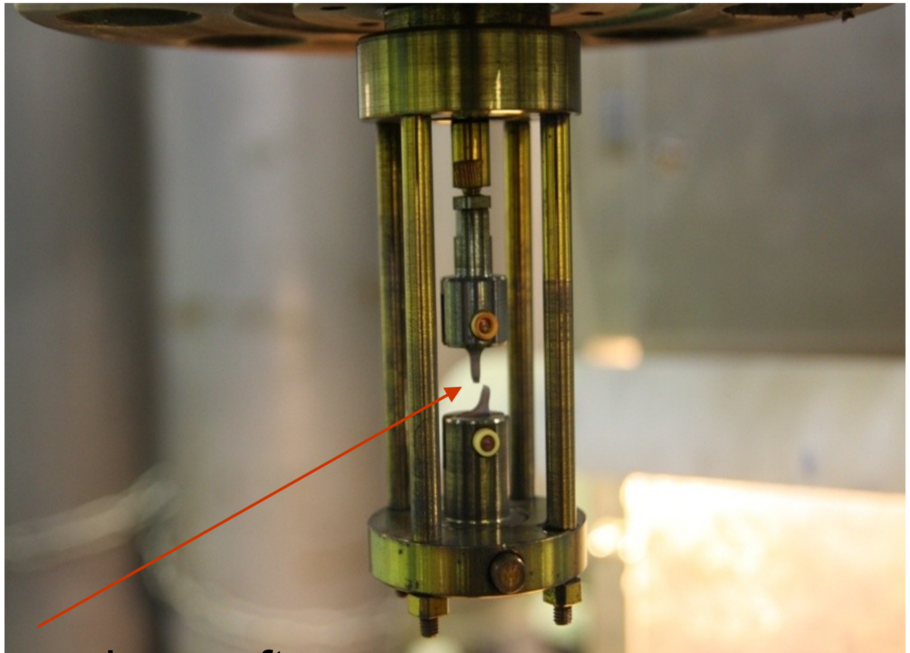
→ Needs more testing

→ The reasons for the increased primary strain rate need to be studied further

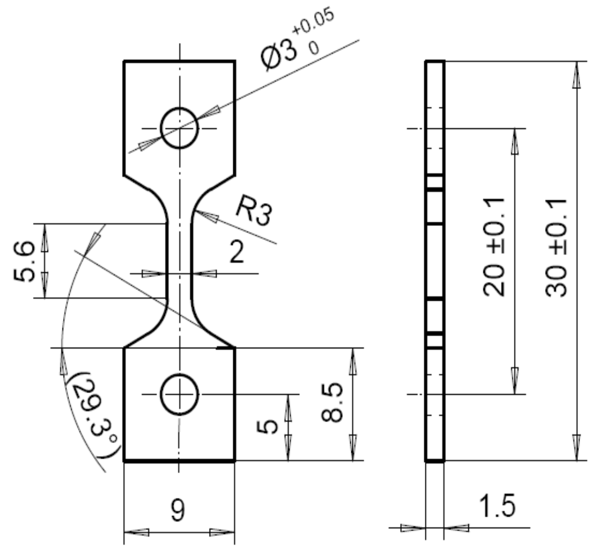
SCC SUSCEPTIBILITY – SSRT (SLOW STRAIN RATE TESTING)

T = 500°C and 650°C, p = 25 MPa and DO_2 = 150 ppb
Deionized water, k < 0.1 μS/cm (inlet)
Strain rate of $3x10^{-7}$ s^{-1}
Materials (VTT):

- **316NG**
- **347H**
- **1.4970**
- **BGA4**
- **PM2000**

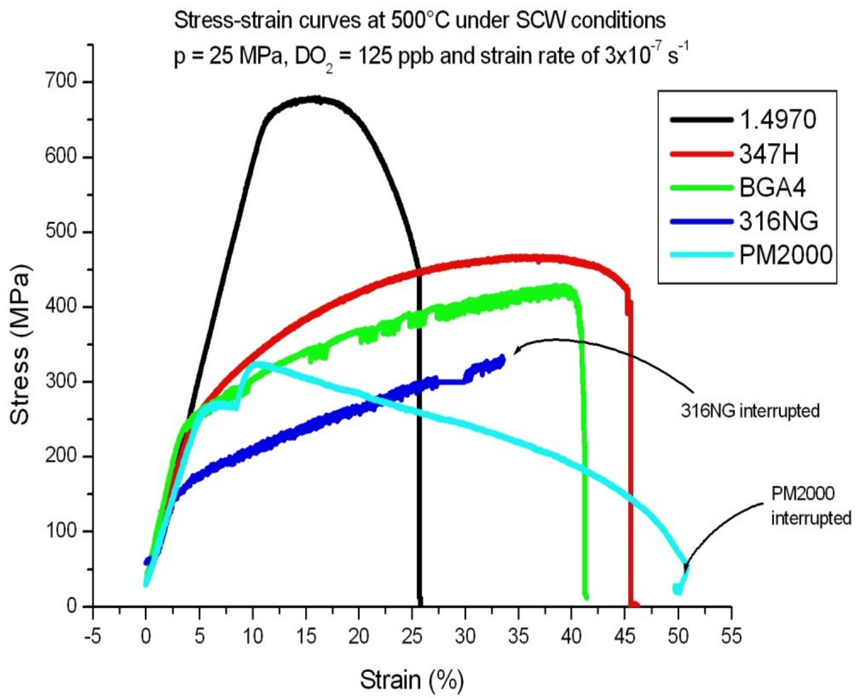


a broken specimen after the SSRT test

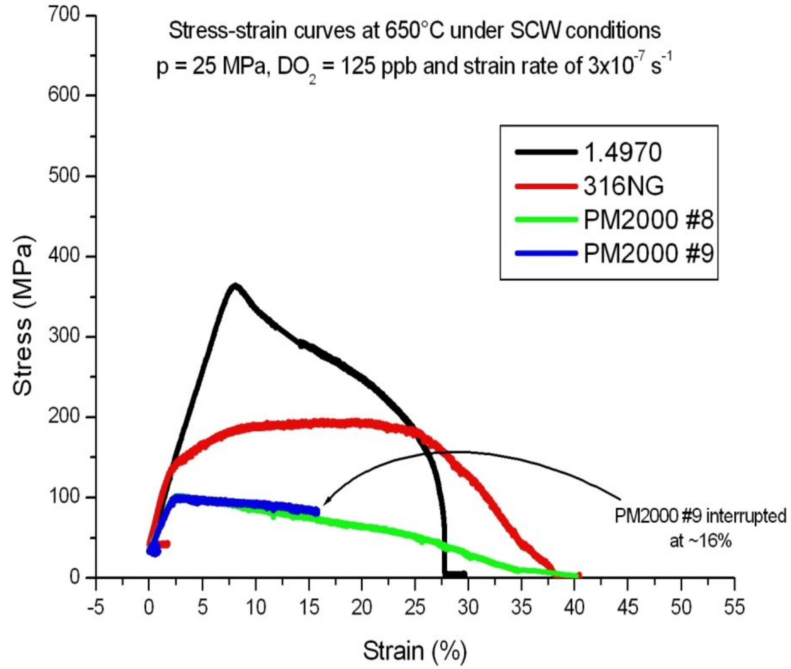


STRESS-STRAIN CURVES FOR THE STUDIED ALLOYS UNDER SCW CONDITIONS AT 500°C AND 650°C

500°C

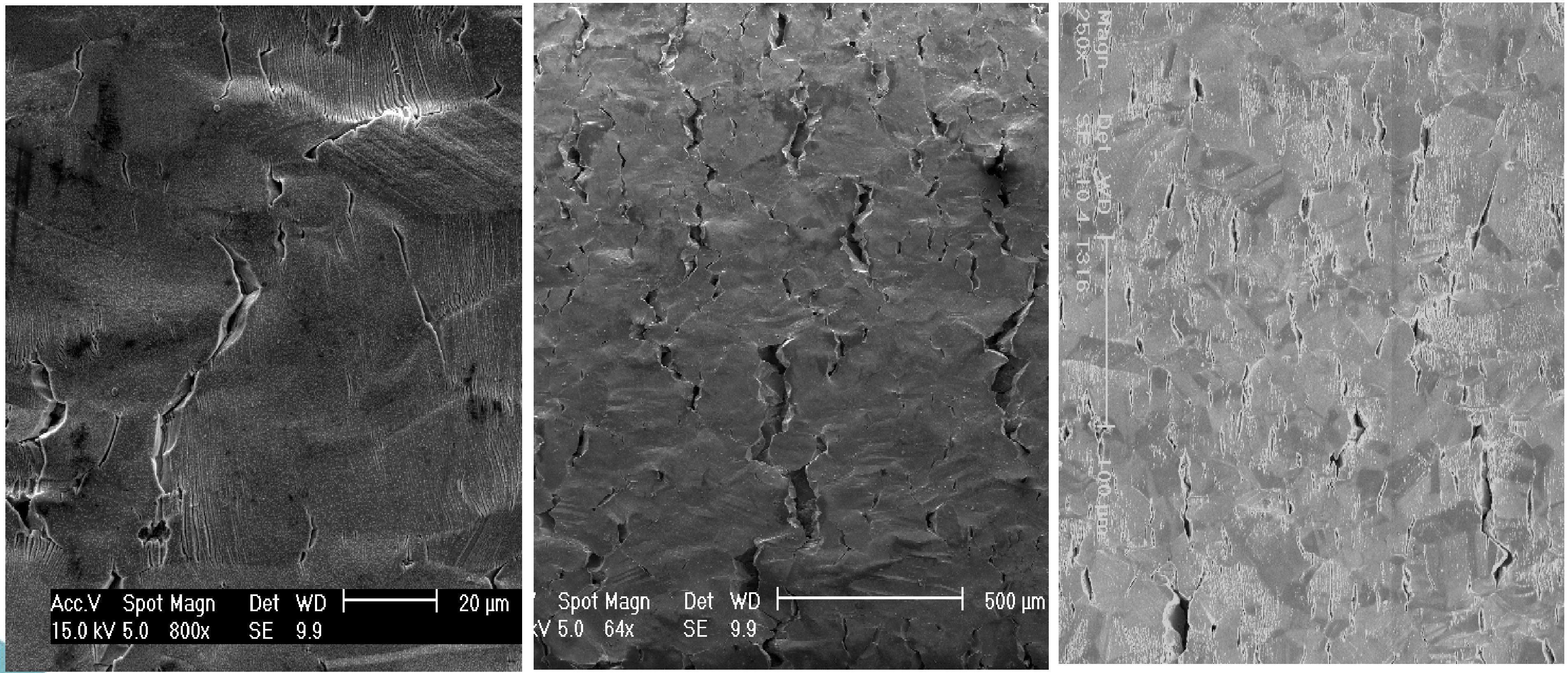


650°C



Gage surfaces after CERT tests on alloy 625 in SCW

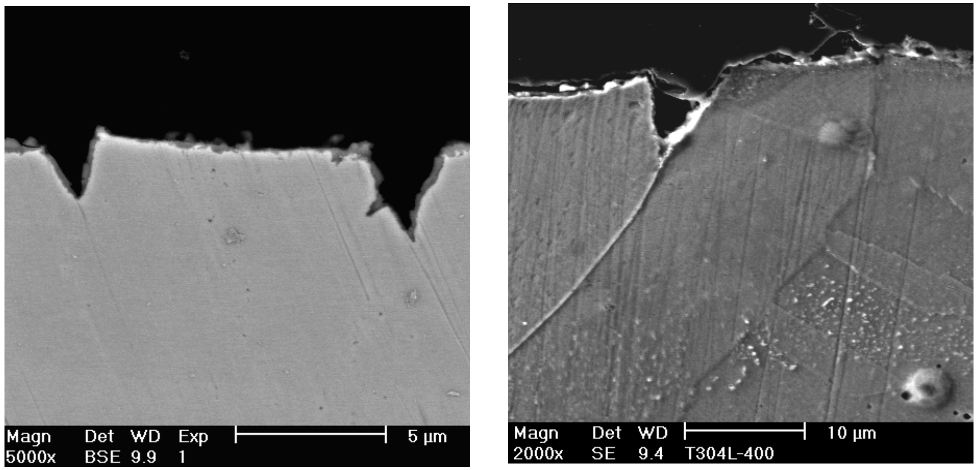
G. Was & al. Univ. Michigan Nov. 2005



400°C 500°C 550°C

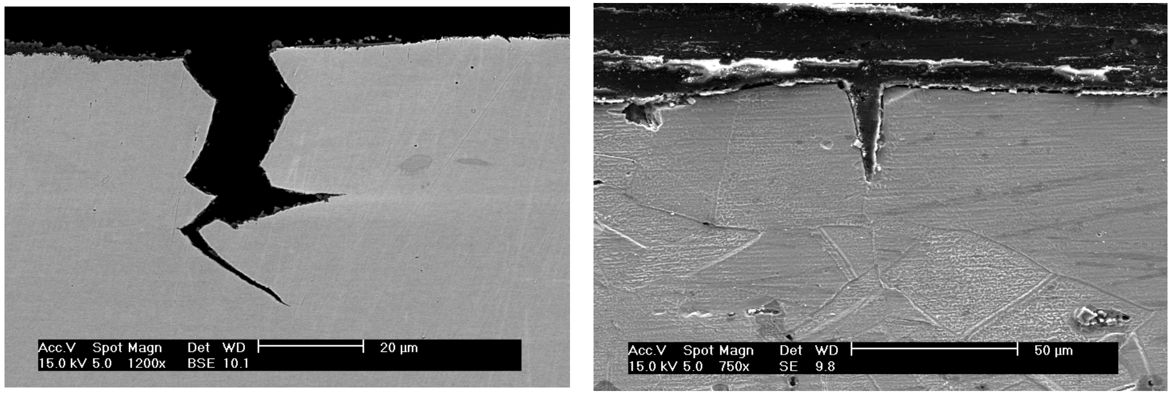
304L

400°C



(a)

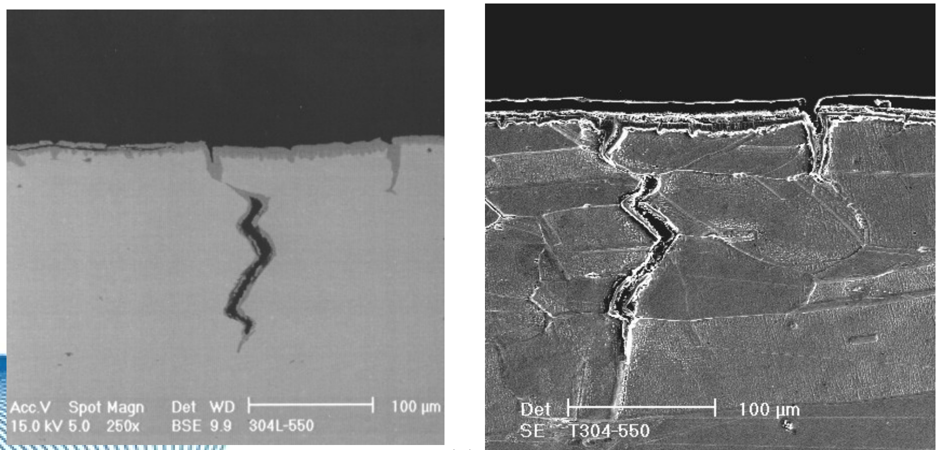
500°C



(b)

G. Was & al. Univ. Michigan Nov. 2005

550°C



(c)

SUMMARY – BASED ON EURATOM PROJECT RESULTS

- The oxidation rate of F/M steels is too high for HPLWR core components even at T < 500 C.
- Thus Austenitic SSs, which have a good enough oxidation, SCC and creep resistance up to ~500 - 550 C have been selected for most HPLWR components.
- 20% Cr ODS steel (PM2000) was selected, at this point, for the HPLWR fuel rod cladding material because of its excellent oxidation resistance even up to 650 C, its SCC resistance and its good creep specifications.

However, Austenitic SSs have been observed to be SCC susceptible in other studies at 500 C!

More studies are needed in the behavior of high Cr F/M ODS steels in supercritical water.

ODS materials are recommended to applications where high strength and oxidation resistance are needed, but only little additional joining is required (fusion welding is a problem).

To be noticed that ferritic alloys with chromium content of above ~14% are susceptible to embrittlement at above 475°C.