F/M Steels and High Ni Alloys in SCW and Their Corrosion Products

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Layout

- Introduction to Gen IV SCWR & Its Candidate Materials
- Experiments
- SCW Corrosion Test Result of F/M Steels
- SCW Corrosion Test Result of High Ni Alloys
- Characterization of Corrosion Product Layers
- Summary

Comparison of Plant Parameters

	ABWR	PWR	SCFP	SCWR
Electric Power, MW	1350	1150	1000	1700
Thermal Efficiency, %	34.5	34.4	41.8	44.0
Rx Pressure, MPa	7.2	15.5	24.1	25
Coolant Inlet Temp, ^oC	269	289	289	280
Coolant Outlet Temp, ^oC	286	325	538	508
Fuel	UO_2	UO_2	-	UO_2
Cladding Material	Zircaloy	Zircaloy	-	?

Y. Oka 2000

Candidate Materials for Gen IV SCWR

System	Cladding	Structural Material	
		In-Core	Out-of-Core
SCWR (Thermal or Fast)	F-M (12Cr, 9Cr, etc.) (Fe-35Ni-25Cr-0.3Ti) Incoloy 800, ODS Inconel 690, 625, & 718	Same as Cladding Options	F-M

F-M : Ferritic-Martensitic stainless steels (typically 9 to 12 wt% Cr)

ODS : Oxide dispersion-strengthened steels (typically ferritic-martensitic)

(from Technology Roadmap, Dec 2002)

Experiment: Corrosion Test in SCW

Sample Material

F/M Steels: T91, T92, T122

High Ni Alloys: Alloy 625, 690, 800H

Sample: 10*10*2 mm

Test condition : 350, 400, 500, 550°C / 25 MPa

Test duration : 100, 200, 500hr

Test media : de-ionized, distilled H_2O (D.O: 8ppm & 100 ppb)

SCW Corrosion Test Results of F/M Steels

High Cr Steels 10^5hr Creep Rupture Strength at 600 ^oC

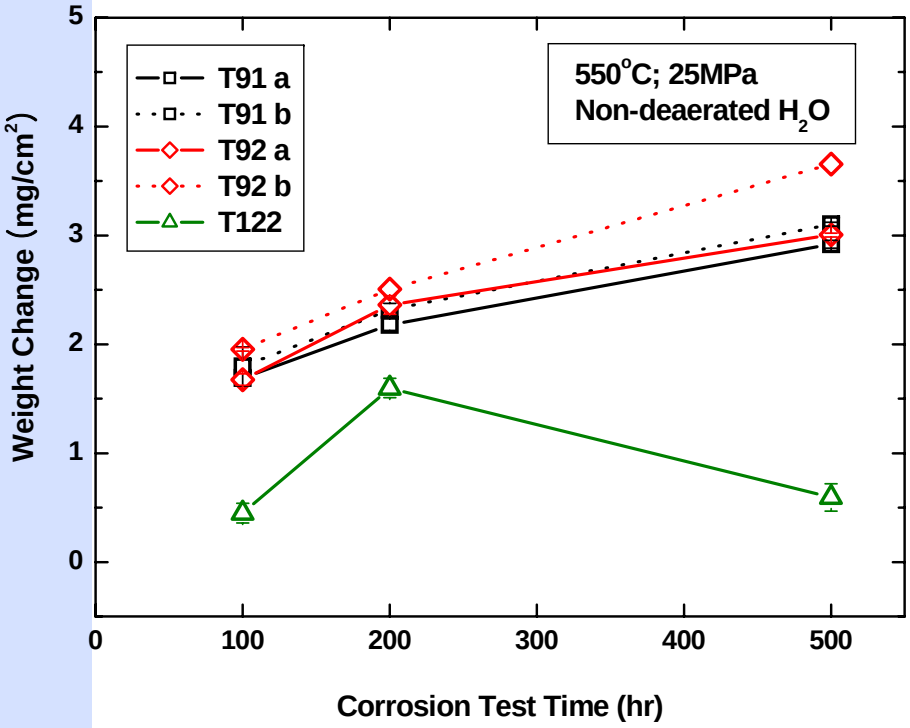
60 MPa		100 MPa	140 MPa	180 MPa
9Cr-2MoVNb *EM 12*				
9Cr-1MoVNb	(V, Nb Optimized)	9Cr-1MoVNb *T 91* *STBA 21*	9Cr-0.5Mo-1.8WVNb *NF 616, T 92* *STBA 29*	
12Cr-0.52Mo			12Cr-0.5Mo-1.8WVNb *TB 12*	12Cr-WCo-NiVNb *NF 12*
12Cr-1MoV *HT 91*	12Cr-1MoWV *HT 9*	C 12Cr-1Mo-1WVNb *HCM 12*	12Cr-0.5Mo-2WCuVNb *HCM 12A* *T 122*	12Cr-WCoVNb *SAVE 12*

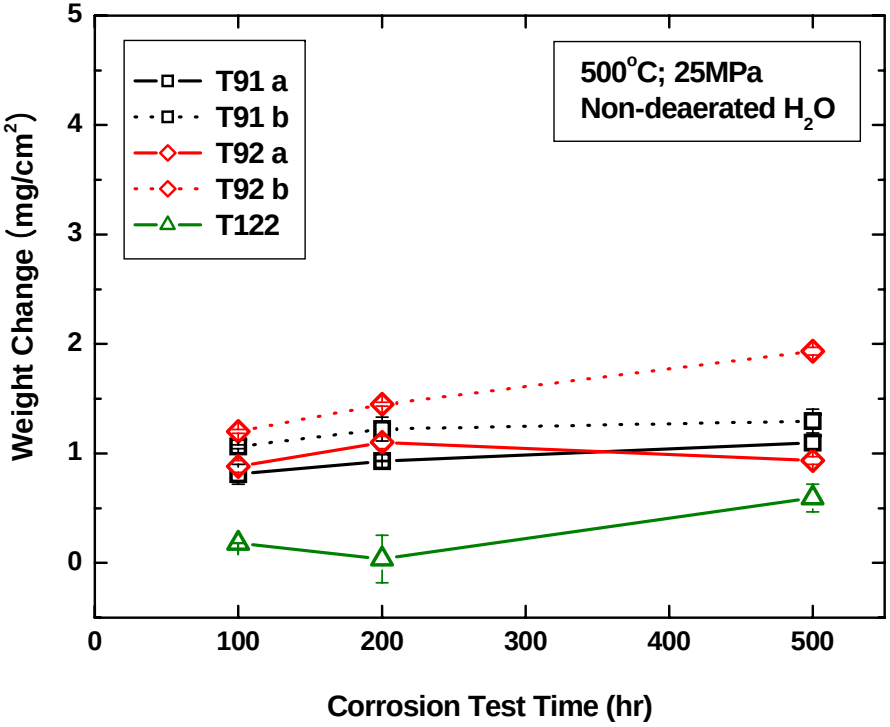
Chemical Composition of F/M Steel Specimens

	Fe	C	Mn	Ni	Cr	Mo	W	Cu	V	Al	Nb	N
T91 a	Bal	0.085	0.38	0.10	9.38	0.91	-	0.080	0.189	0.032	0.080	0.042
T91 b	Bal	0.10	0.45	0.21	8.37	0.90	-	0.17	0.216	0.022	0.076	0.048
T92 a*	Bal	0.7	0.45		9.0	0.5	1.8		0.20		0.05	0.060
T92 b	Bal	0.11	0.43	0.12	8.91	0.47	1.67	-	0.19	0.004	0.06	0.043
T122	Bal	0.10	0.58	0.35	12.12	0.35	1.84	0.83	0.19	0.014	0.06	0.070

* Nominal composistion

SCW Corrosion Results of F/M Steels at 550 & 500°C

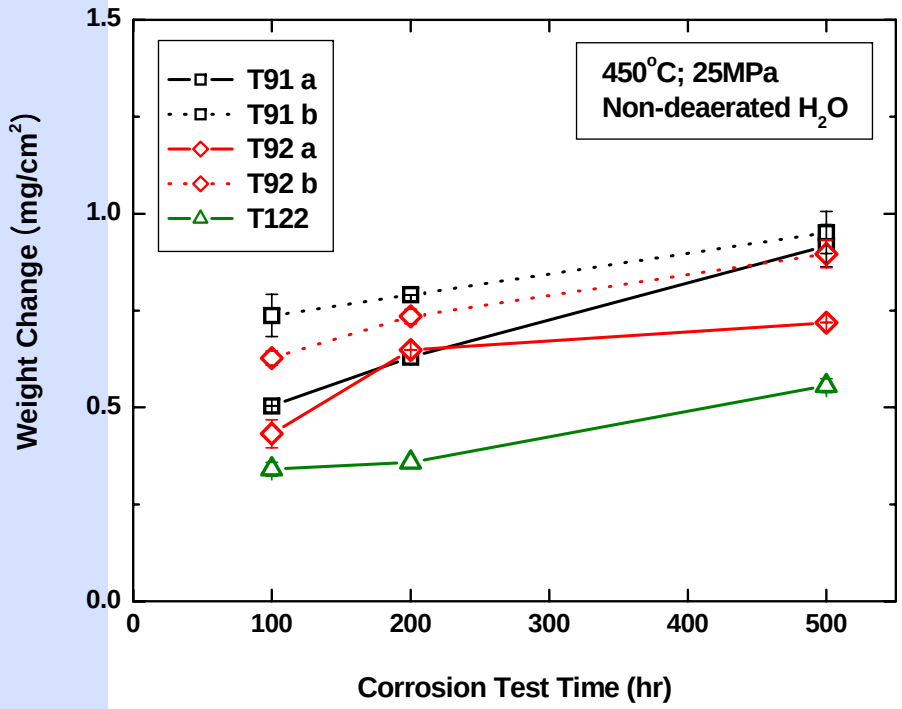


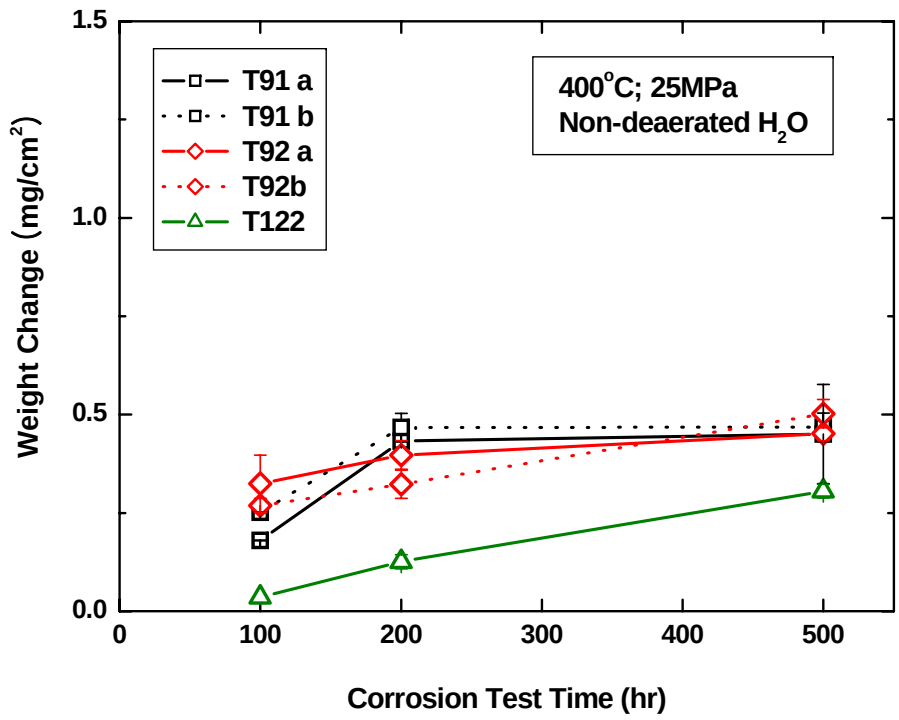


At 550 & 500°C T91 & T92 behaved with similar manner in aerated SCW.

On the other hand T122 showed distinctively lower corrosion rate than 9% Cr steels but irregular behavior presumably due to the unstable or uneven corrosion products.

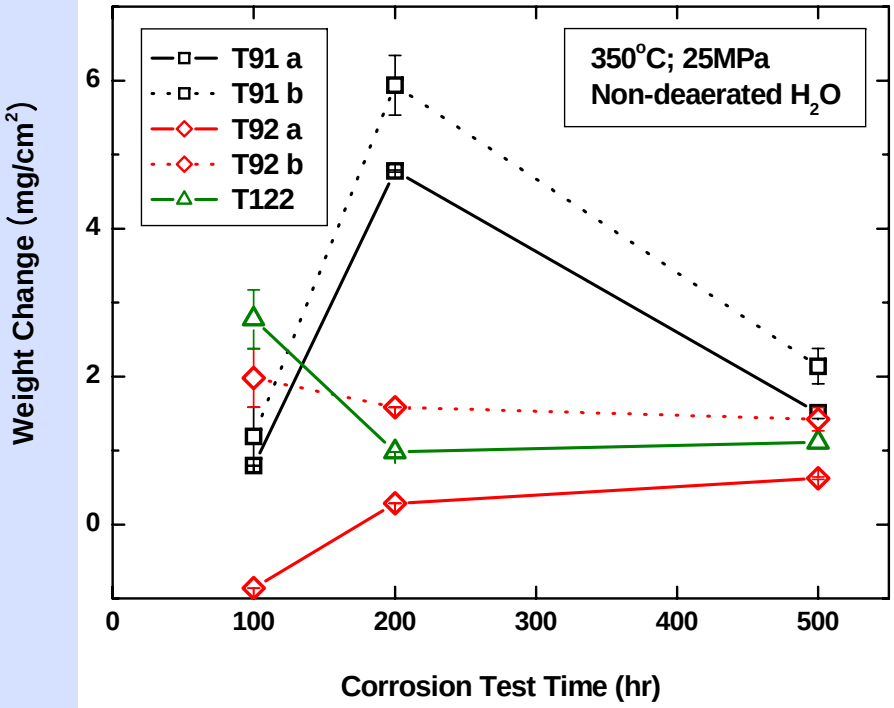
SCW Corrosion Results of F/M Steels at 450 & 400°C





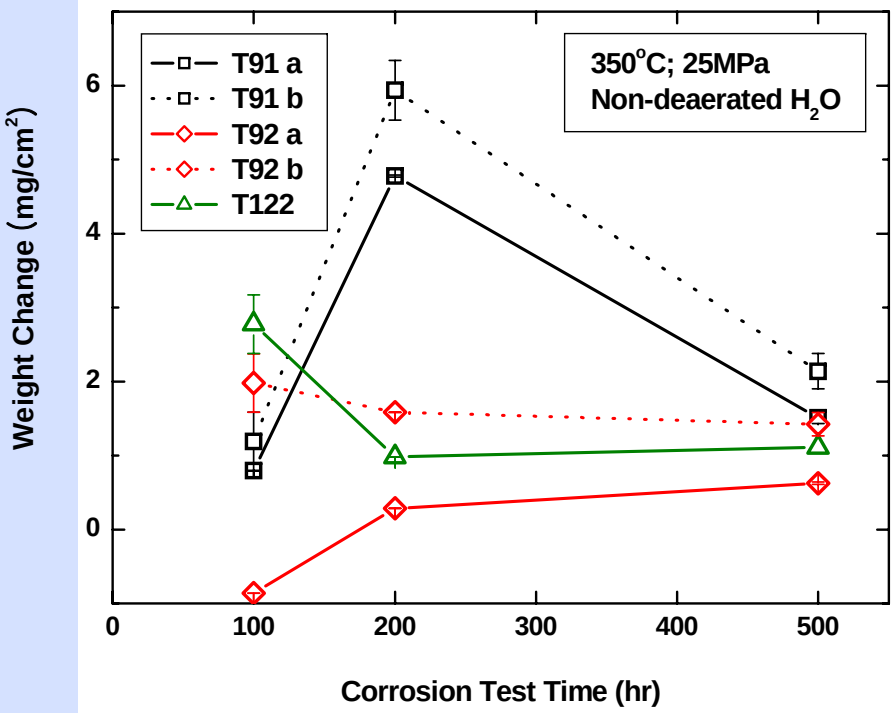
At 450 & 400°C all F/M steel specimens behave in a similar manner as at 550 or 500°C, but with much lower corrosion rates.

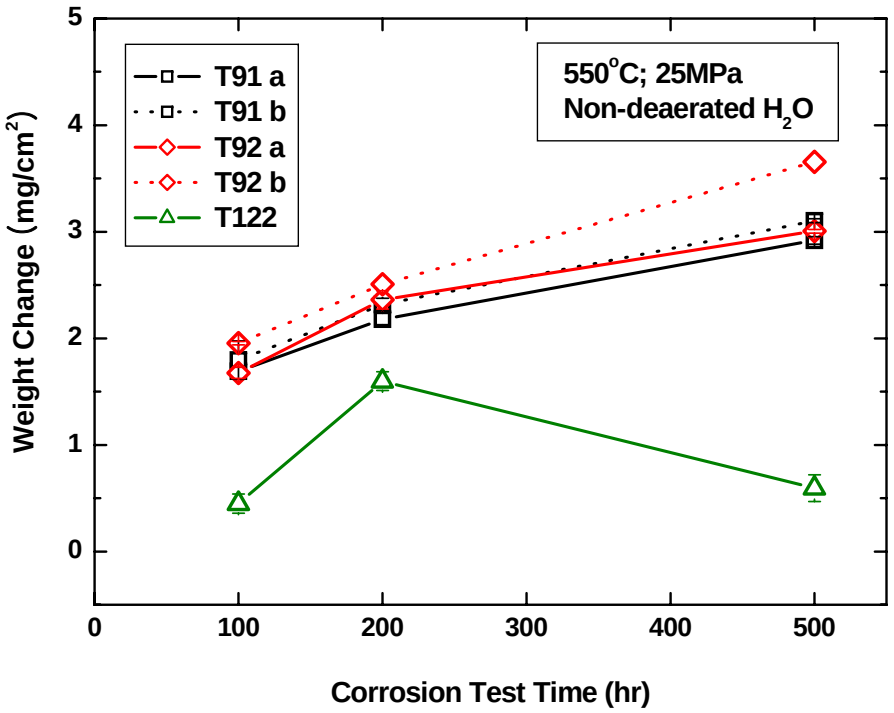
SCW Corrosion Results of F/M Steels at 350°C



At 350°C that is within the subcritical region rather than the supercritical, all the specimens showed very high corrosion rates in an irregular manner. This would be attributed to the phase change of the water at this region.

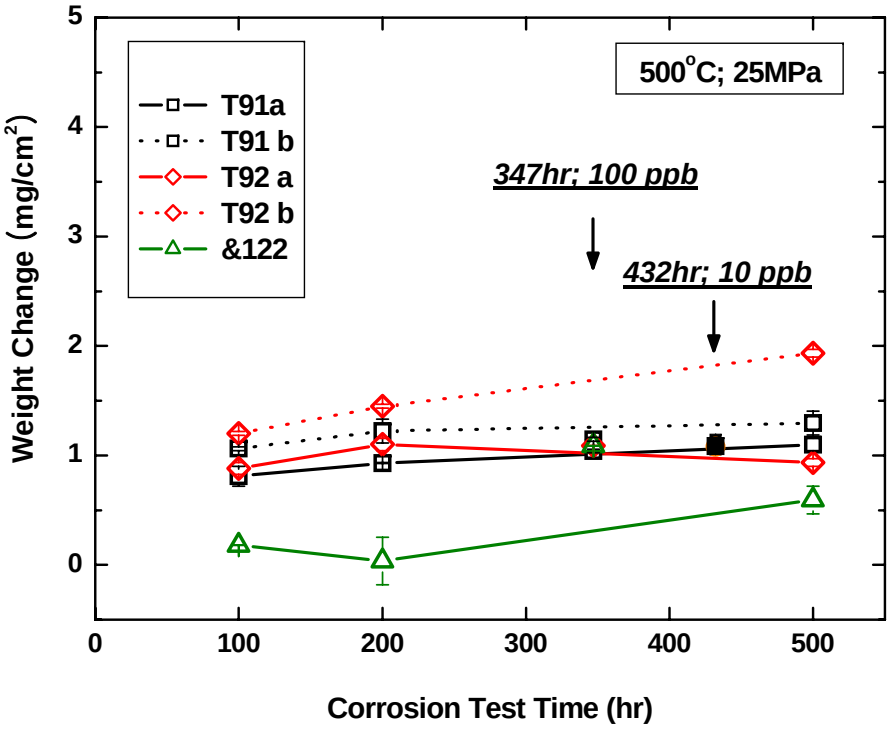
SCW Corrosion Results of F/M Steels at 350 & 550°C





In addition to the comparable or higher corrosion rates at 350°C to those at 550°C, the irregular manner at 350°C seems to more significant because some in-reactor components would be put across this transient temperature range.

SCW Corrosion Results of F/M Steels at 500°C with Two Different D.O Levels



In deaerated SCW (D.O: 100 or below 10 ppb)

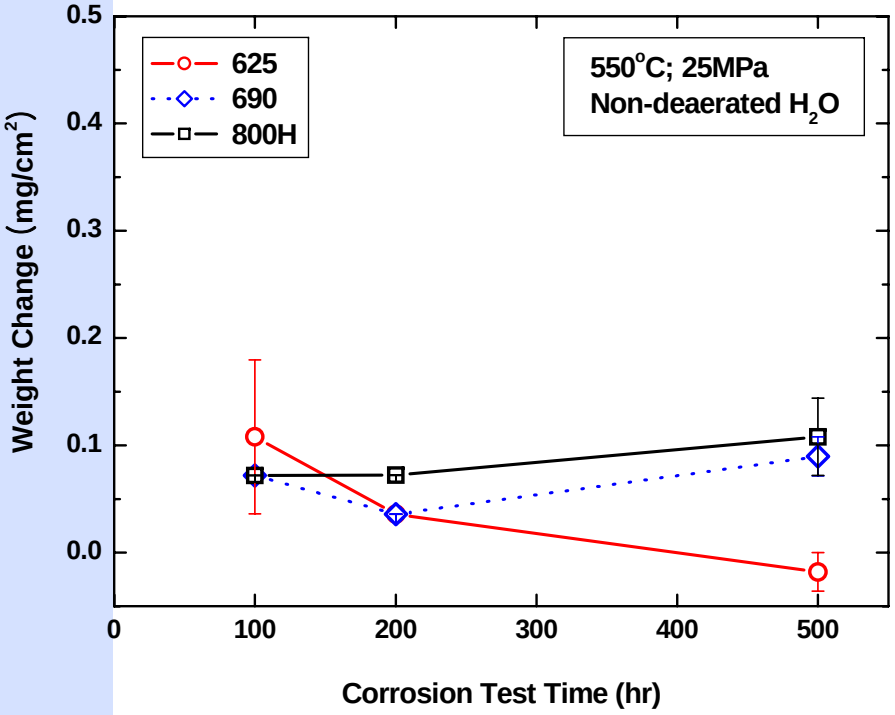
the corrosion behavior of all the specimens seems to converge at an extent.

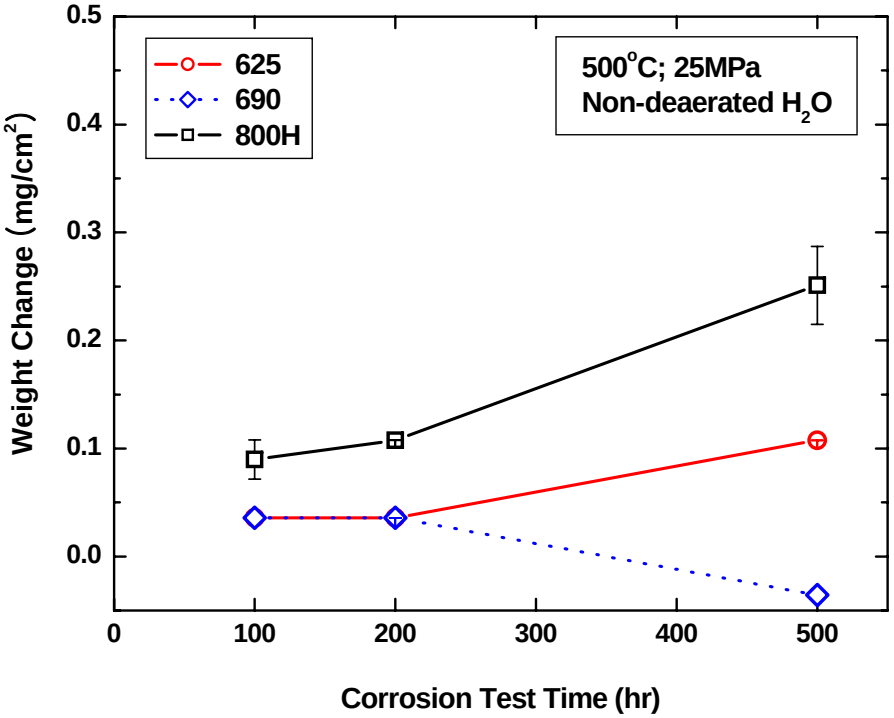
SCW Corrosion Test Results of High Ni Alloys

Chemical Composition of High Ni Alloy Specimens

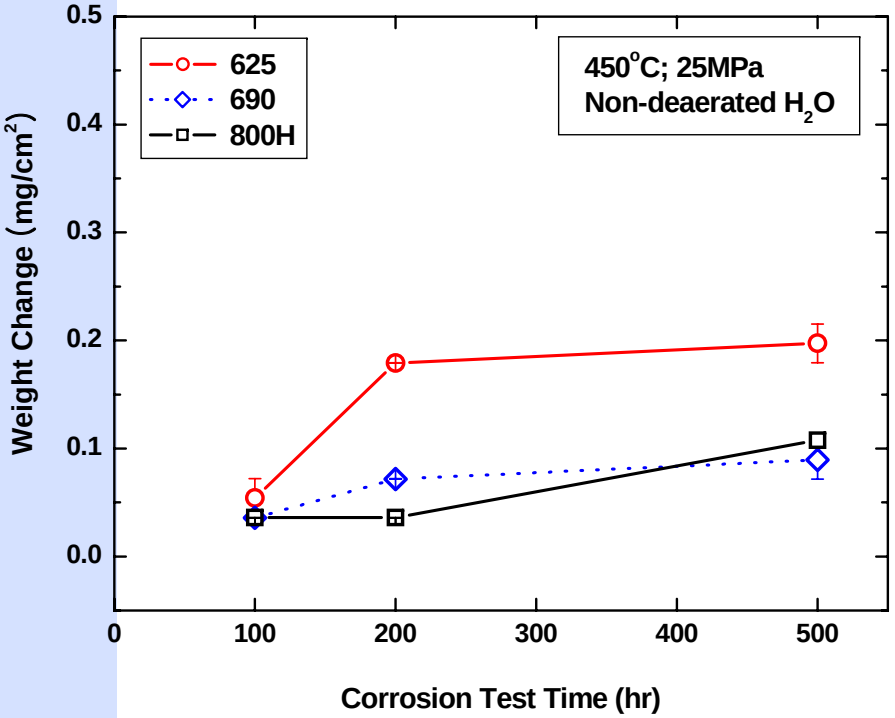
	Ni	C	Mn	Cr	Fe	Mo	W	Cu	V	Al	Nb	Co
Alloy 625	Bal	0.02	0.10	21.75	4.52	9.02		0.08		0.20	3.62	0.20
Alloy 690	Bal	0.021	0.28	29.81	10.68	0.013		0.01		0.022	-	-
Alloy 800H	Bal	0.07	0.74	19.39	47.59	-		0.10		0.23	-	0.05

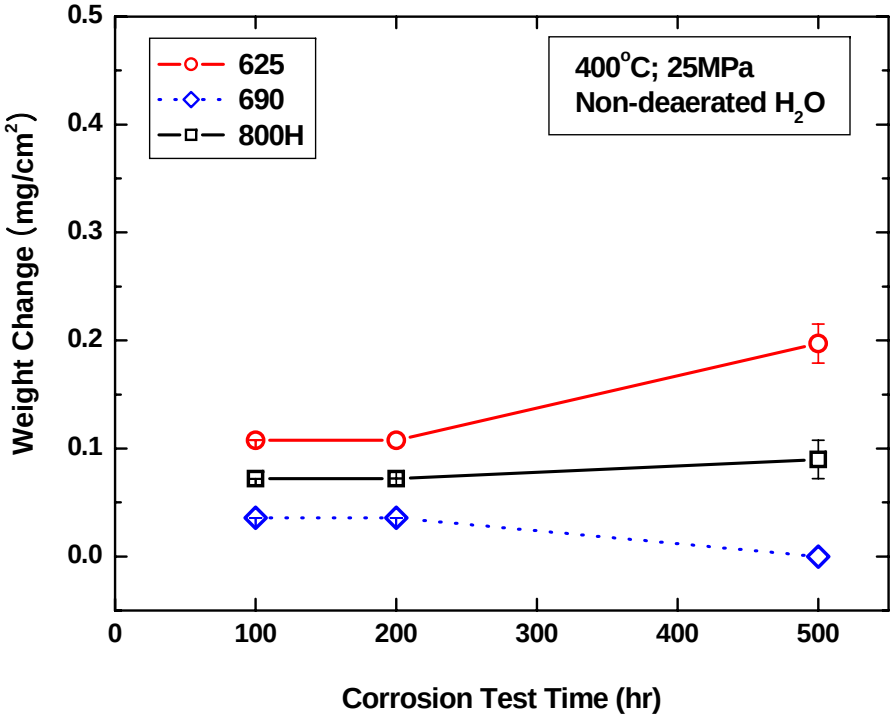
SCW Corrosion of High Ni Alloys at 550 & 500°C



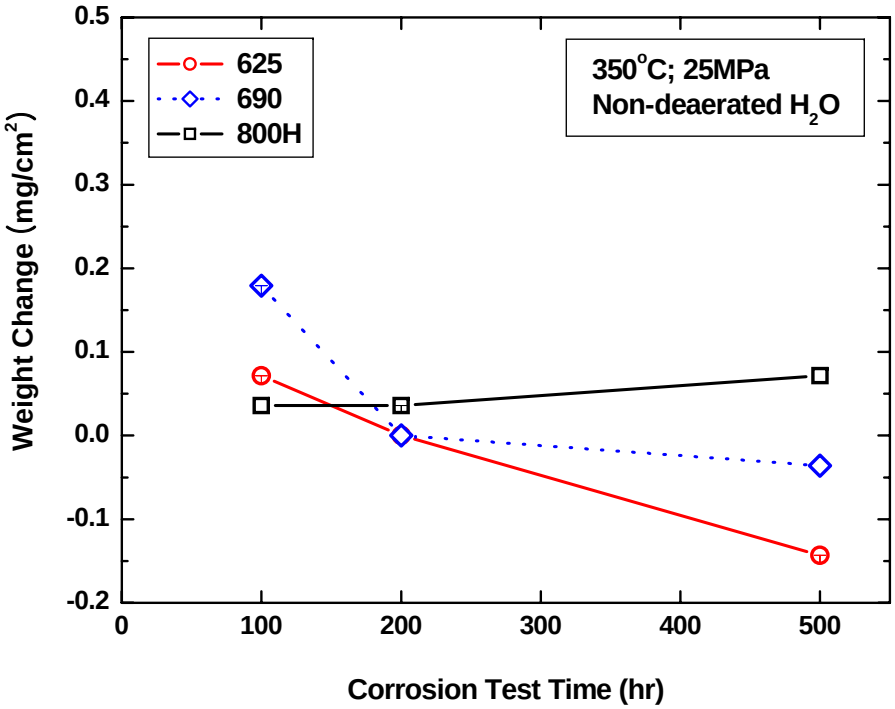


SCW Corrosion of High Ni Alloys at 450 & 400°C

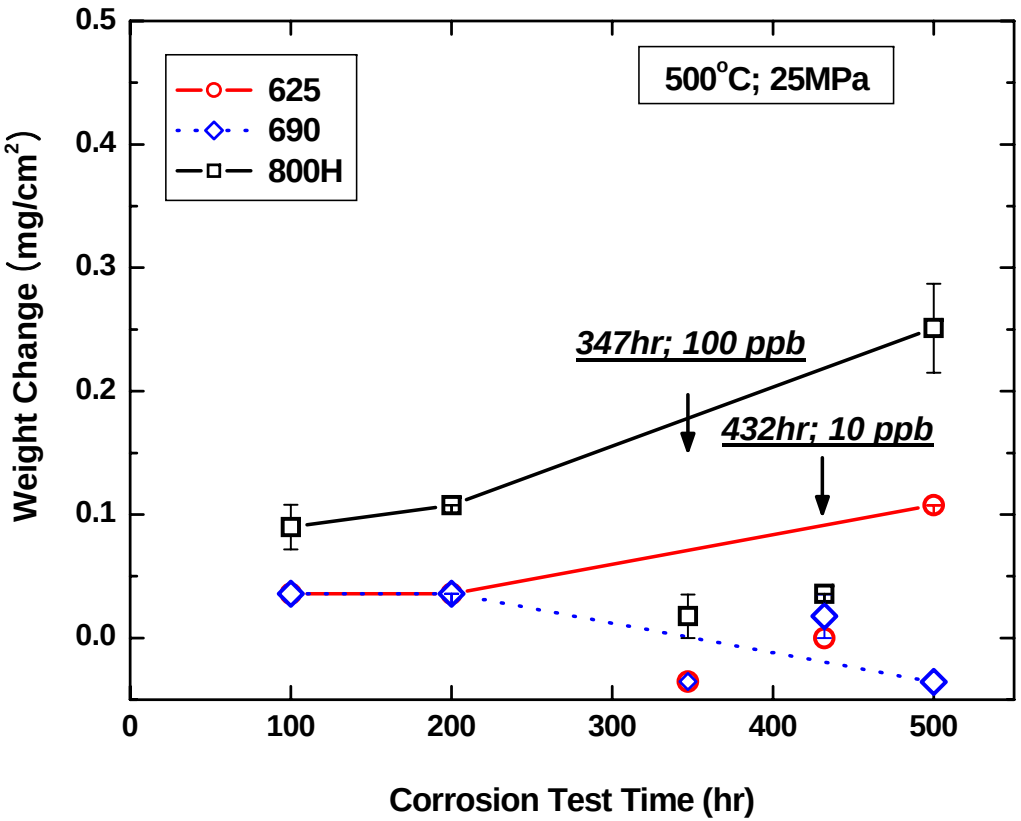




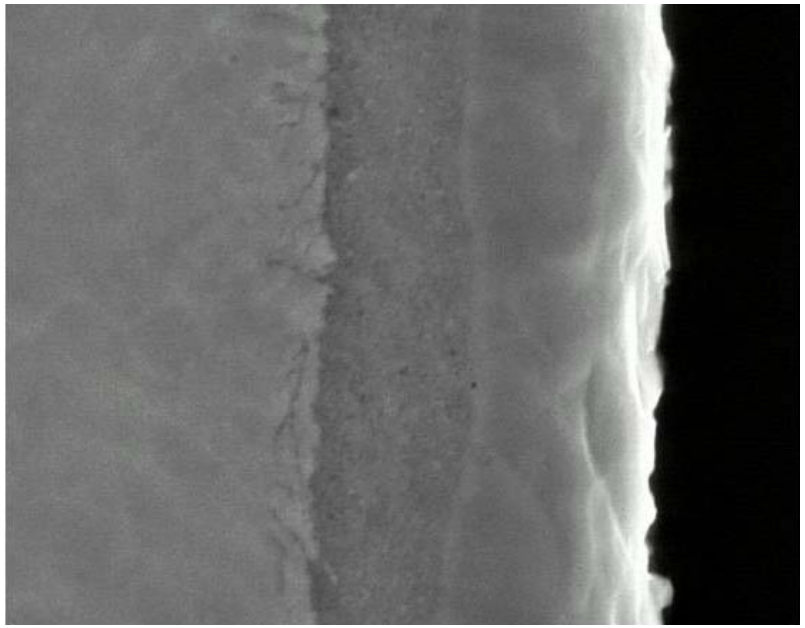
SCW Corrosion of High Ni Alloys at 350°C

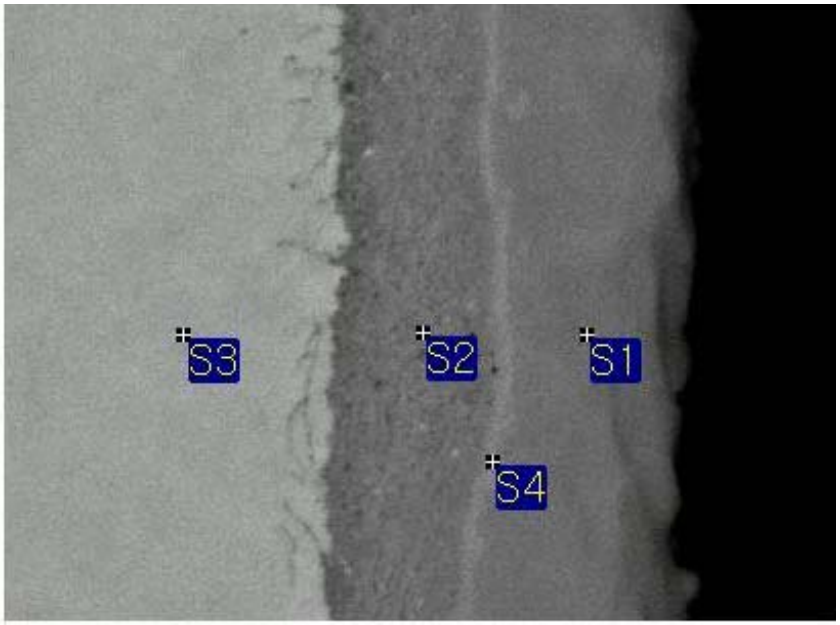


SCW Corrosion of High Ni Alloys at 500°C with Two Different D.O Levels



SEM Micrographs of T91
after 437hr at 500°C in SCW (D.O 10 ppb)





5 micron

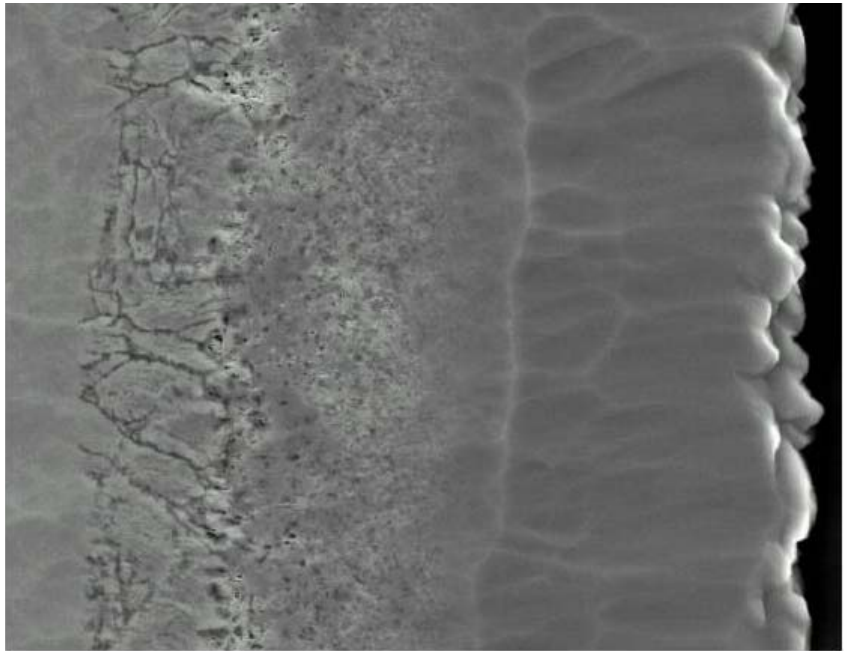
	O	Si	Cr	Fe	Mo
1	32.5		0.6	67.0	
2	25.9	0.82	14.6	58.7	
3			9.4	90.6	
4	28.4		3.6	63.3	2.4

The outer layer: Fe_2O

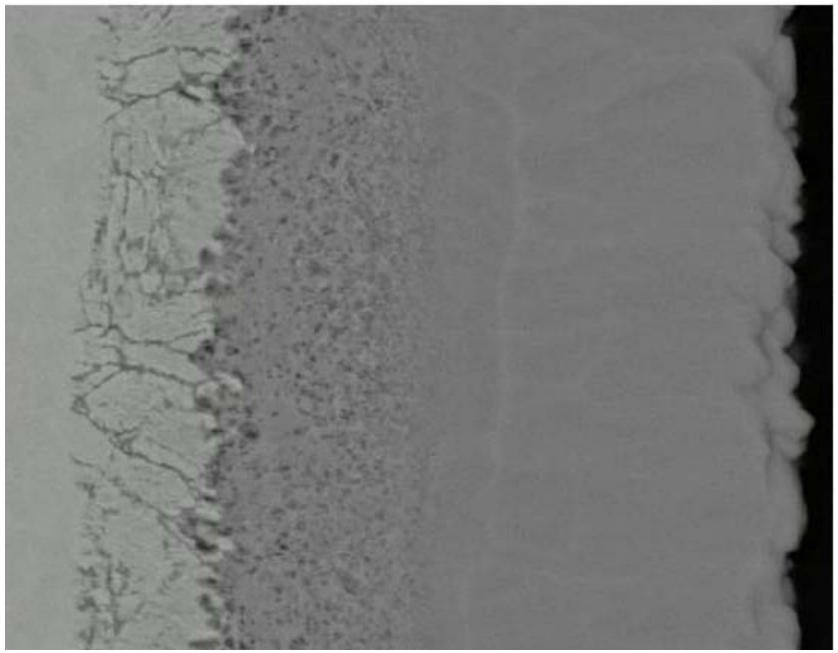
Inner Layer: $(Fe,Cr)_2O$

Internal Oxidation Zone

SEM of T91 Cross Section after SCW Corrosion Test 200 hr at 627 ^{o}C / 25MPa



SEI



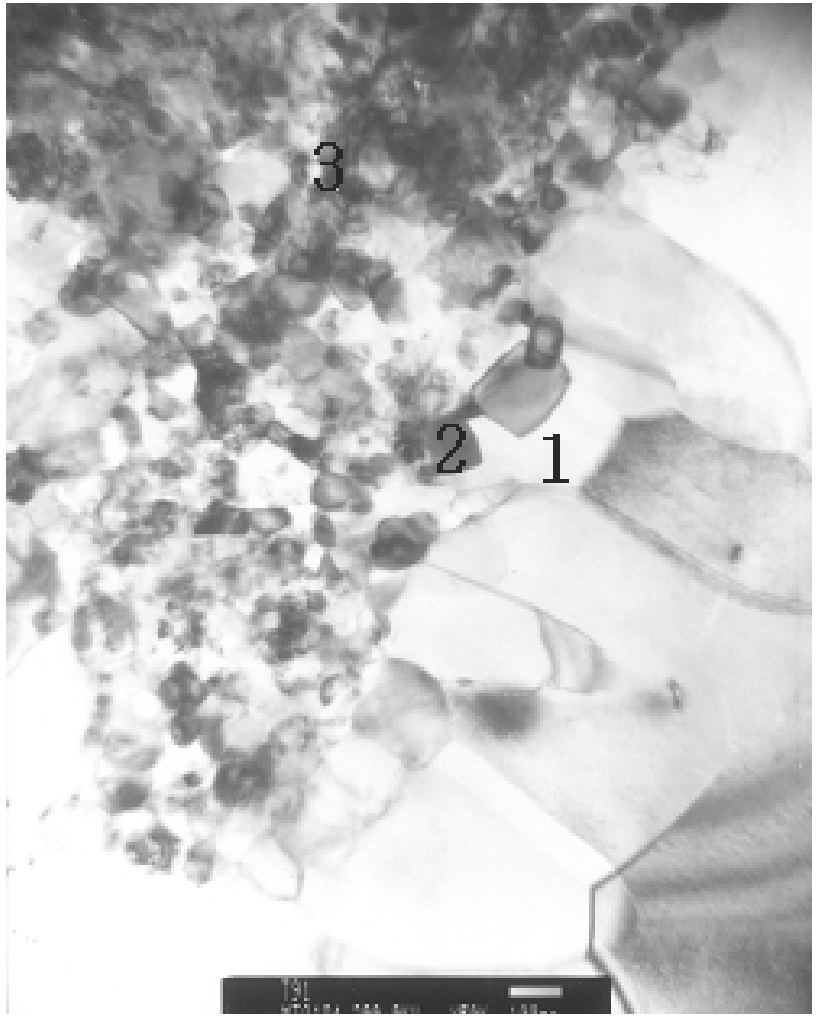
BEI

10 micron

Three distinctive layers were revealed;

the outer layer as a coarse columnar structure with ~ 35 micron thickness, an agglomerate of fine crystallites with ~ 15 micron thickness, and an internal oxidation zone with 10 micron thickness.

XTEM of Oxide Layers of T91 after 200 hr at 627 ^{o}C / 25MPa

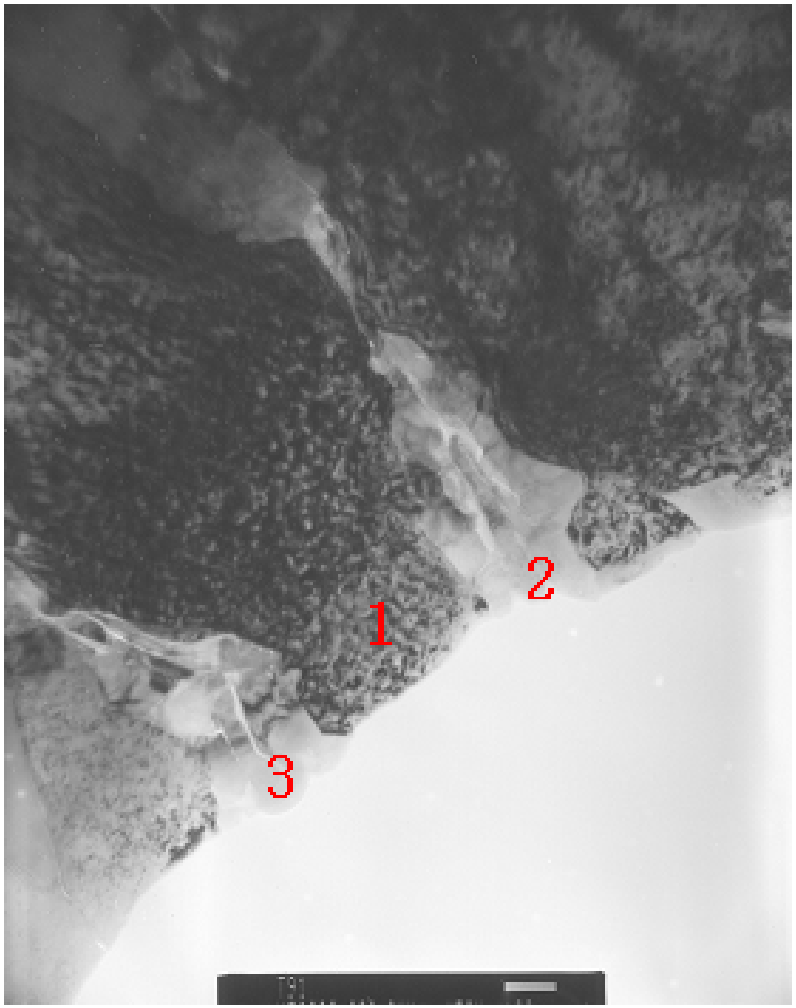


200 nm

	Fe	Cr	Si	Mn	O
1	Bal	4.5	0.2	1.1	49.5
2	Bal	6.2	0.2	0.9	50.0
3	Bal	10.4	1.1	0.4	52.4

Outer columnar layer was composed with Fe_3O_4; more Cr atoms seem to be partitioned into the fine crystallites structure in the inner layer

XTEM of Internal Oxidation Zone of T91 after 200 hr at 627 ^{o}C / 25MPa

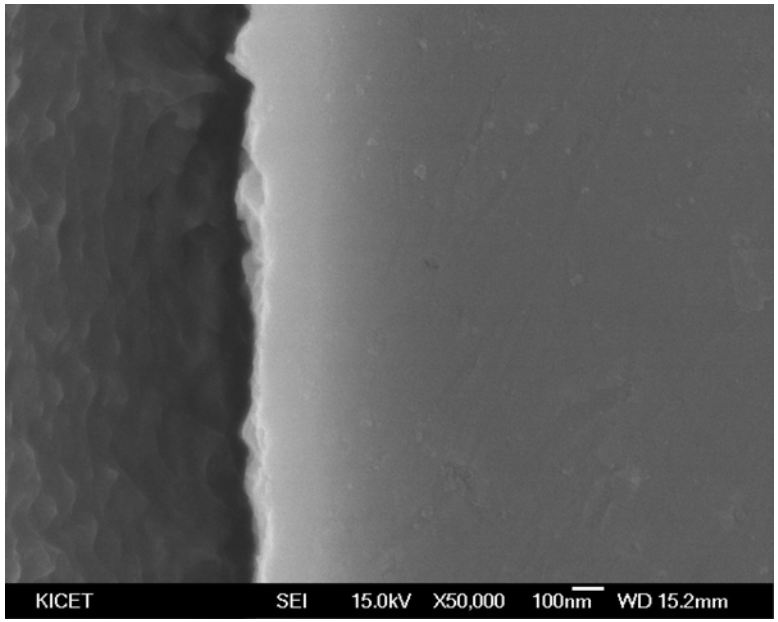


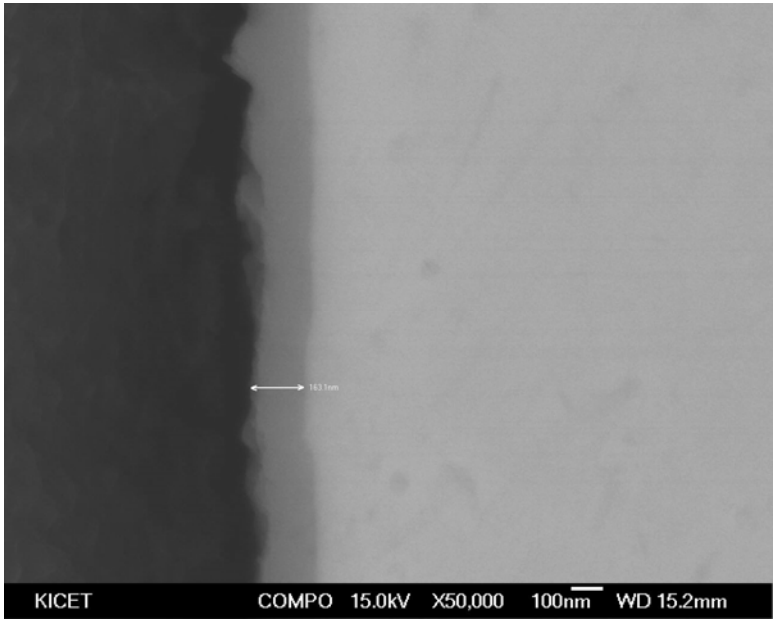
200 nm

	Fe	Cr	Si	Mn	O
1	Bal	0.2	0.01	1.5	-
2	Bal	30.8	1.12	-	65.8
3	Bal	21.0	3.46	-	60.0

Internal oxidation regions was composed with $(Fe,Cr)_2O_3$ & $(Fe,Cr)_3O_4$.

SEM Micrographs of Alloy 800H after 200hr at 500°C in SCW (D.O 10 ppb)





SEI **200nm** **BEI**

Oxide layer on high Ni alloys was usually composed of one thin Cr oxide phase (e.g. about 160 nm thick; alloy 800H) after 200hr at 500°C in deaerated SCW.

Summary

1. The corrosion rate of F/M steels at 350°C was not less than those at 550°C; rather higher and in a very irregular manner.
2. Weight change of 9Cr F/M steels in the deaerated SCW was about one half of those in the aerated SCW water.
3. Corrosion product on T91 in the deaerated SCW at 500°C was similar with that in the aerated SCW at 627°C which was composed of three layers; but the outer columnar structure with Fe_2O rather than Fe_3O_4 in the aerated SWC and an agglomerate of fine (about 10 nm in diameter) particles of $(Fe,Cr)_2O$, $(Fe,Cr)_3O_4$ and the same IOZ along the prior austenite grain and the lath boundaries.
4. Corrosion product on high Ni alloy specimens in SCW at 500°C was composed of just one Cr oxide layer with about several tens to 160nm thickness.