PROCESS CHEMISTRY CENTRE

ÅBO AKADEMI UNIVERSITY

Skyrec

December 16th 2009

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FINNISH RECOVERY BOILER COMMITTEE

Skyrec - project

1. High temperature behavior of steels under alkali sulfates and chlorides containing synthetic ashes in reducing atmosphere

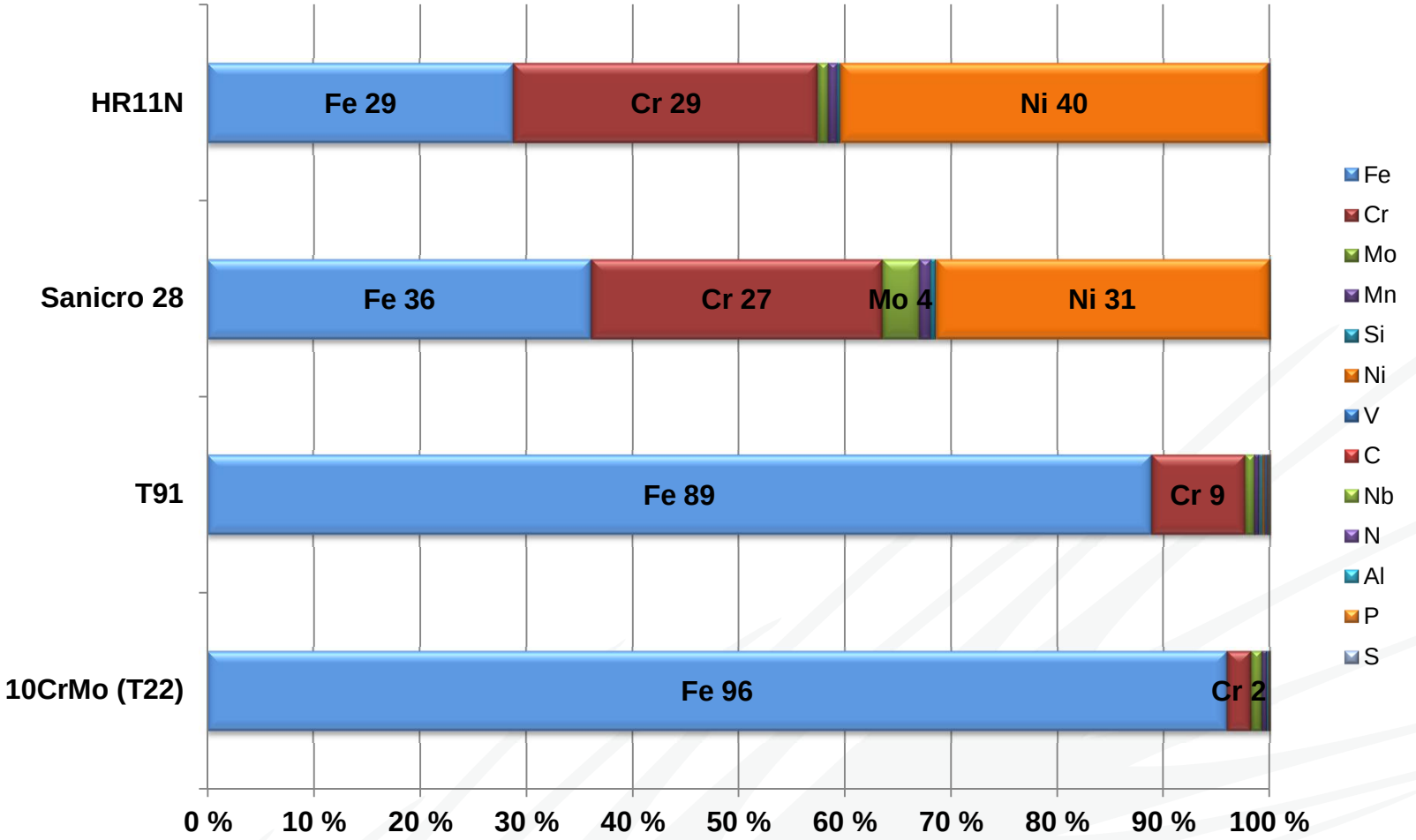
Temperatures: 450°C, 500°C, 550°C, 600°C

Salts:
- Salt 5 - Na_2SO_4
- Salt 8 - Na_2SO_4 + K_2SO_4 + NaCl + KCl
- Salt 9 - Na_2SO_4 + NaCl
- Salt 10 -Na_2SO_4 + K_2SO_4 + KCl

Steels:
10CrMo9-10
T91
S28
HR11N

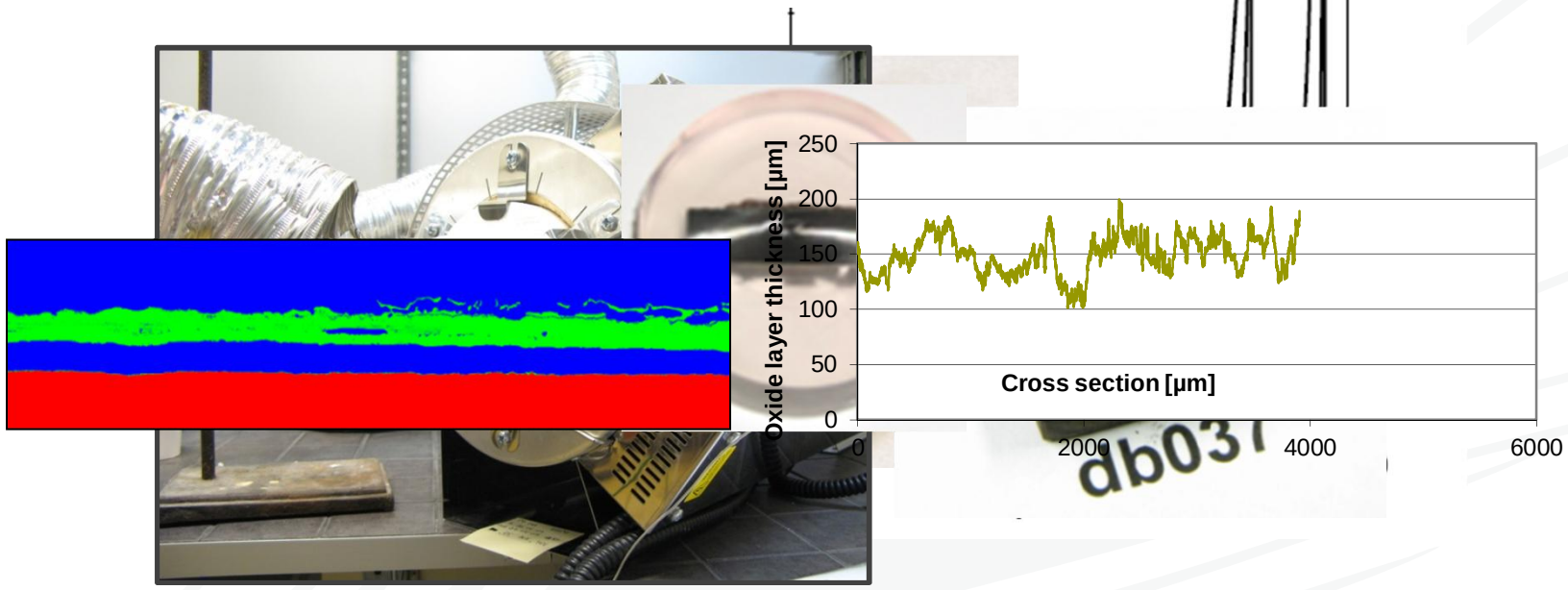
Atmosphere: reducing (5% CO + 95% N_2 – 2 l/min)

Skyrec - tested steels composition

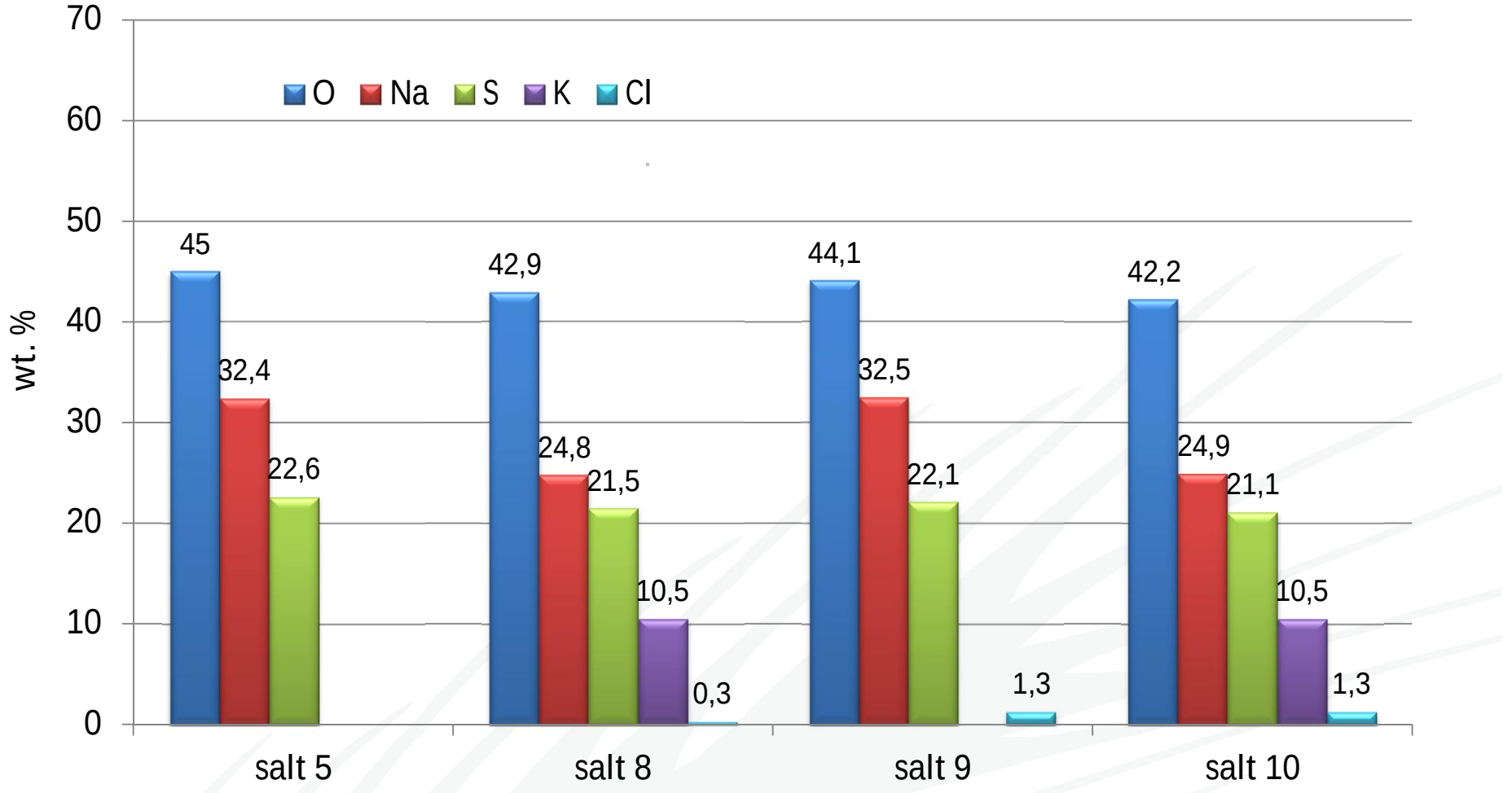


Laboratory method for HT corrosion tests

1. Preparation of salts
2. Preparation of steel samples for the experiment
3. Tube furnace tests
4. Preparation of samples for SEM/EDXA
5. Analysis of SEM results



Skyrec – synthetic ashes composition



Skyrec - corrosion test matrix - Na_2SO_4

	Salt	Steel	Temp	Corrosion products thickness
1	Na_2SO_4	10CrMo	450	
2	Na_2SO_4	T91	450	
3	Na_2SO_4	Sanicro 28	450	
4	Na_2SO_4	HR11N	450	
5	Na_2SO_4	10CrMo	450	
6	Na_2SO_4	10CrMo	500	
7	Na_2SO_4	T91	500	
8	Na_2SO_4	Sanicro 28	500	
9	Na_2SO_4	HR11N	500	
10	Na_2SO_4	T91	500	
11	Na_2SO_4	10CrMo	550	
12	Na_2SO_4	T91	550	
13	Na_2SO_4	Sanicro 28	550	
14	Na_2SO_4	HR11N	550	
15	Na_2SO_4	Sanicro 28	550	
16	Na_2SO_4	10CrMo	600	24
17	Na_2SO_4	T91	600	6
18	Na_2SO_4	Sanicro 28	600	
19	Na_2SO_4	HR11N	600	2
20	Na_2SO_4	HR11N	600	

Salt 5 characteristic:
$T_0 = 884^oC$
No Cl^-
No K^+

Skyrec - corrosion test matrix - Na_2SO_4+NaCl

	Salt	Steel	Temp	Corr prod. thickness
41	Na_2SO_4+NaCl	10CrMo	450	
42	Na_2SO_4+NaCl	T91	450	1
43	Na_2SO_4+NaCl	Sanicro 28	450	
44	Na_2SO_4+NaCl	HR11N	450	
45	Na_2SO_4+NaCl	10CrMo	450	3
46	Na_2SO_4+NaCl	10CrMo	500	2
47	Na_2SO_4+NaCl	T91	500	
48	Na_2SO_4+NaCl	Sanicro 28	500	
49	Na_2SO_4+NaCl	HR11N	500	
50	Na_2SO_4+NaCl	T91	500	
51	Na_2SO_4+NaCl	10CrMo	550	13
52	Na_2SO_4+NaCl	T91	550	
53	Na_2SO_4+NaCl	Sanicro 28	550	
54	Na_2SO_4+NaCl	HR11N	550	
55	Na_2SO_4+NaCl	Sanicro 28	550	
56	Na_2SO_4+NaCl	10CrMo	600	
57	Na_2SO_4+NaCl	T91	600	
58	Na_2SO_4+NaCl	Sanicro 28	600	
59	Na_2SO_4+NaCl	HR11N	600	62
60	Na_2SO_4+NaCl	HR11N	600	

Salt 9 characteristic:
T_0 = 621°C
1.3 wt% of Cl^-
No K^+

Skyrec - corrosion test matrix - Na_2SO_4+NaCl+K_2SO_4+KCl

	Salt	Steel	Temp	Corr prod. thickness
21	Na_2SO_4+K_2SO_4+NaCl+KCl	10CrMo	450	11
22	Na_2SO_4+K_2SO_4+NaCl+KCl	T91	450	9
23	Na_2SO_4+K_2SO_4+NaCl+KCl	Sanicro 28	450	
24	Na_2SO_4+K_2SO_4+NaCl+KCl	HR11N	450	
25	Na_2SO_4+K_2SO_4+NaCl+KCl	10CrMo	450	3
26	Na_2SO_4+K_2SO_4+NaCl+KCl	10CrMo	500	3
27	Na_2SO_4+K_2SO_4+NaCl+KCl	T91	500	
28	Na_2SO_4+K_2SO_4+NaCl+KCl	Sanicro 28	500	
29	Na_2SO_4+K_2SO_4+NaCl+KCl	HR11N	500	
30	Na_2SO_4+K_2SO_4+NaCl+KCl	T91	500	
31	Na_2SO_4+K_2SO_4+NaCl+KCl	10CrMo	550	
32	Na_2SO_4+K_2SO_4+NaCl+KCl	T91	550	
33	Na_2SO_4+K_2SO_4+NaCl+KCl	Sanicro 28	550	
34	Na_2SO_4+K_2SO_4+NaCl+KCl	HR11N	550	
35	Na_2SO_4+K_2SO_4+NaCl+KCl	Sanicro 28	550	
36	Na_2SO_4+K_2SO_4+NaCl+KCl	10CrMo	600	334
37	Na_2SO_4+K_2SO_4+NaCl+KCl	T91	600	
38	Na_2SO_4+K_2SO_4+NaCl+KCl	Sanicro 28	600	
39	Na_2SO_4+K_2SO_4+NaCl+KCl	HR11N	600	
40	Na_2SO_4+K_2SO_4+NaCl+KCl	HR11N	600	

Salt 8 characteristic:

T_0 = 526°C

0.3 wt% of Cl^-

10.5 wt% of K^+

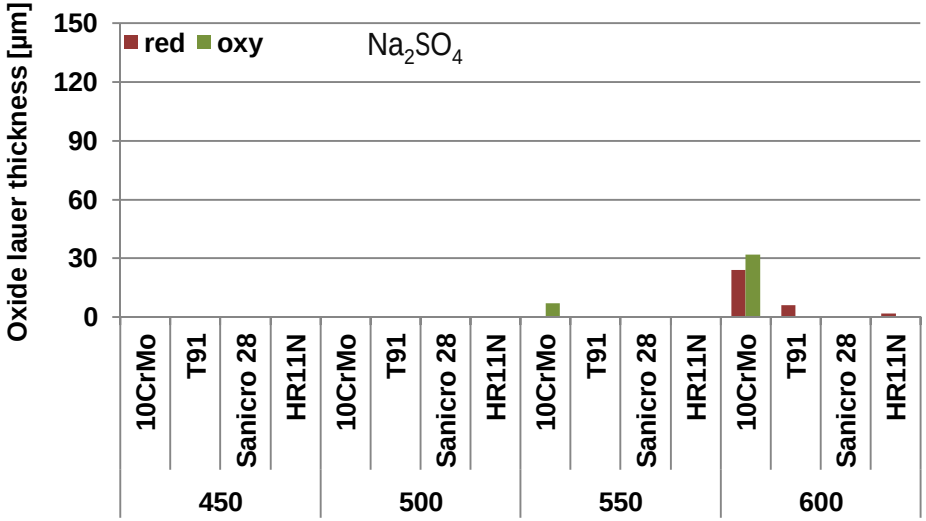
Skyrec - corrosion test matrix - $Na_2SO_4+KCl+K_2SO_4$

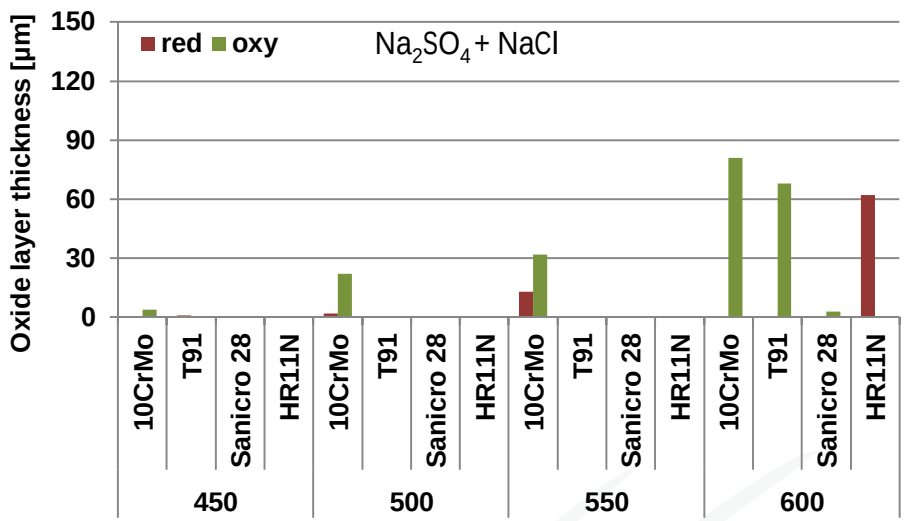
	Salt	Steel	Temp	Corr prod. thickness
61	$Na_2SO_4+K_2SO_4+KCl$	10CrMo	450	
62	$Na_2SO_4+K_2SO_4+KCl$	T91	450	
63	$Na_2SO_4+K_2SO_4+KCl$	Sanicro 28	450	
64	$Na_2SO_4+K_2SO_4+KCl$	HR11N	450	
65	$Na_2SO_4+K_2SO_4+KCl$	10CrMo	450	
66	$Na_2SO_4+K_2SO_4+KCl$	10CrMo	500	
67	$Na_2SO_4+K_2SO_4+KCl$	T91	500	
68	$Na_2SO_4+K_2SO_4+KCl$	Sanicro 28	500	
69	$Na_2SO_4+K_2SO_4+KCl$	HR11N	500	
70	$Na_2SO_4+K_2SO_4+KCl$	T91	500	
71	$Na_2SO_4+K_2SO_4+KCl$	10CrMo	550	2
72	$Na_2SO_4+K_2SO_4+KCl$	T91	550	2
73	$Na_2SO_4+K_2SO_4+KCl$	Sanicro 28	550	2
74	$Na_2SO_4+K_2SO_4+KCl$	HR11N	550	2
75	$Na_2SO_4+K_2SO_4+KCl$	Sanicro 28	550	2
76	$Na_2SO_4+K_2SO_4+KCl$	10CrMo	600	306
77	$Na_2SO_4+K_2SO_4+KCl$	T91	600	54
78	$Na_2SO_4+K_2SO_4+KCl$	Sanicro 28	600	53
79	$Na_2SO_4+K_2SO_4+KCl$	HR11N	600	76
80	$Na_2SO_4+K_2SO_4+KCl$	HR11N	600	24

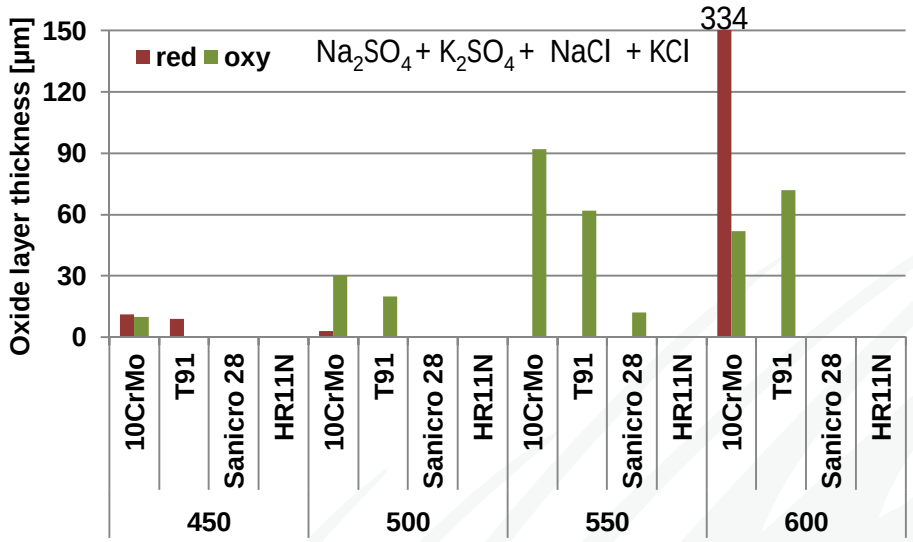
Salt 10 characteristic:
$T_0 = 522^oC$
1.3 wt% of Cl^-
10.5 wt% of K^+

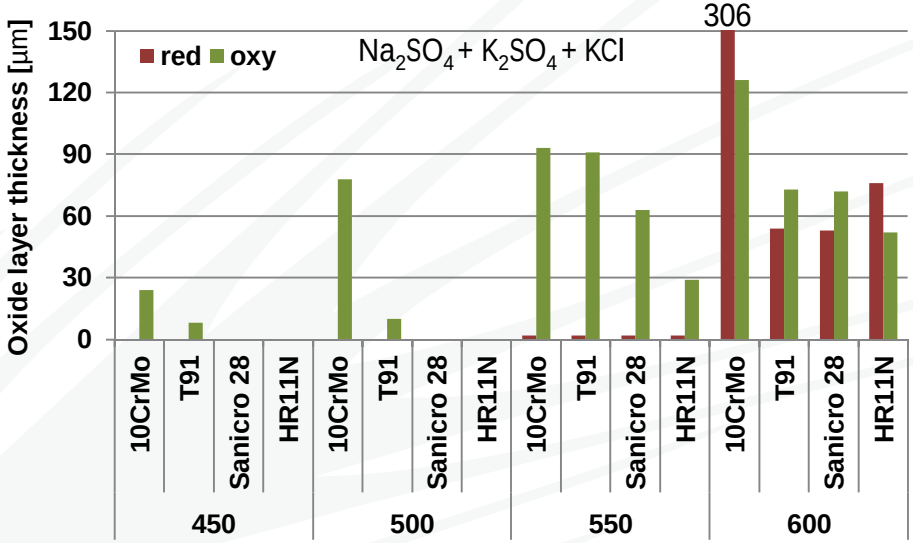
← {Oxide layer + internal attack} thickness

Skyrec – reducing vs ambient atmosphere



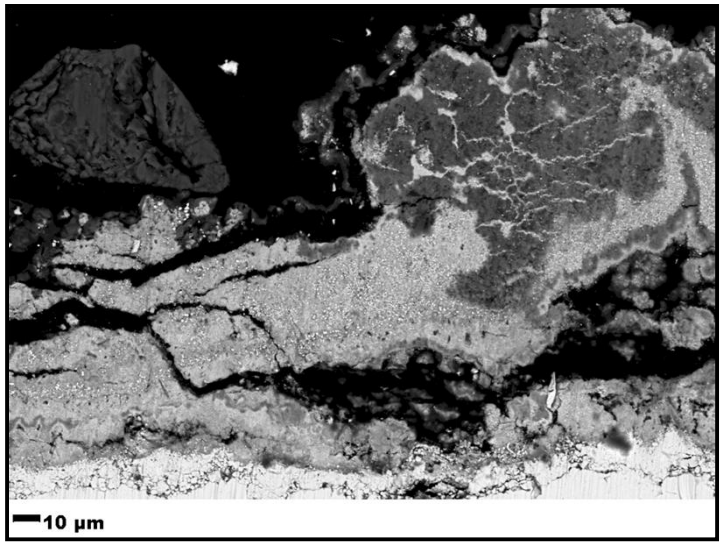


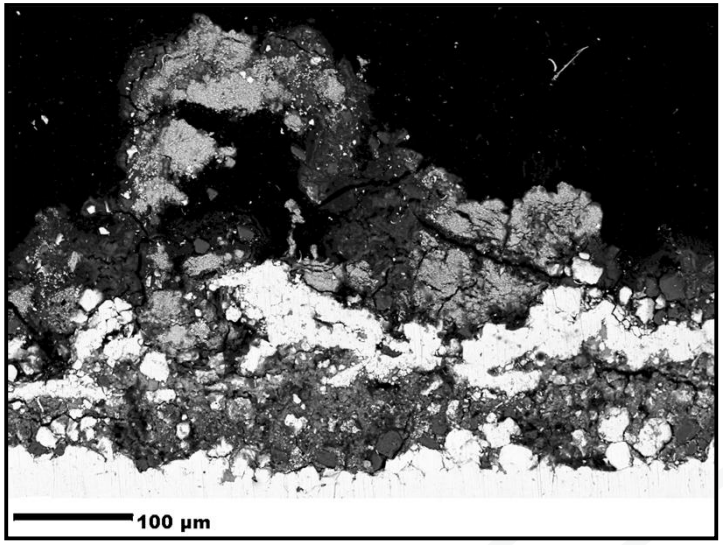




Skyrec – results 10CrMo, 600ºC

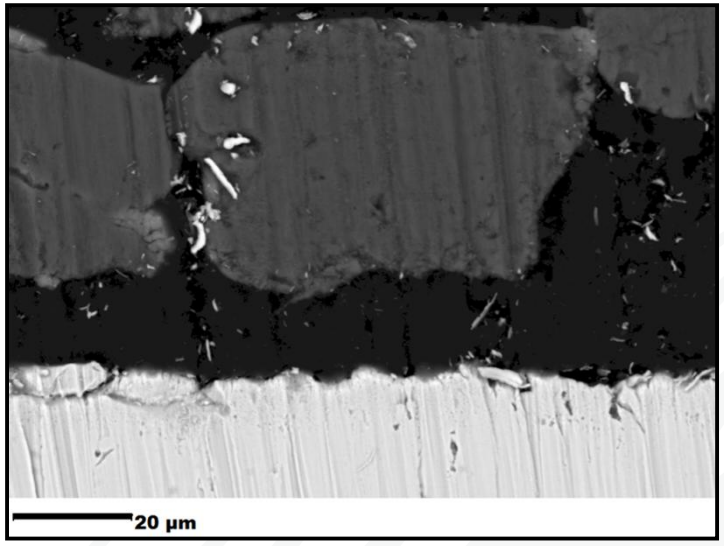
T_0 = 884ºC
No Cl
No K
Salt 5
24 µm

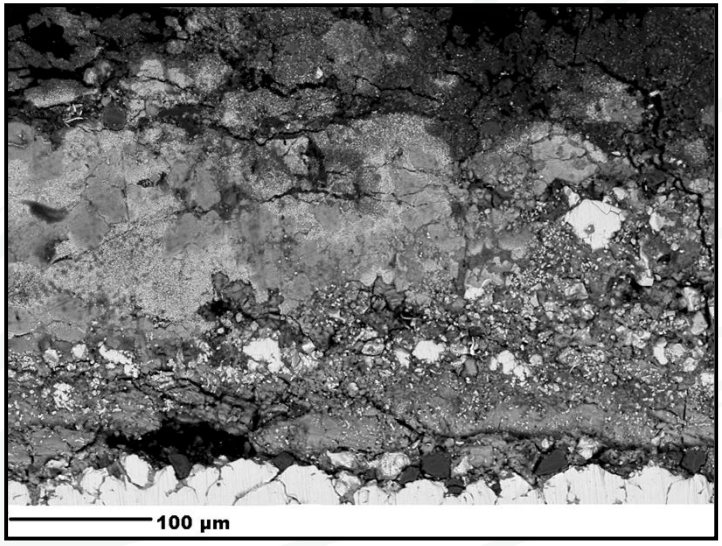




T_0 = 526ºC
0.3 mol% of Cl
13 mol% of K
Salt 8
334 µm

T_0 = 621ºC
1.7 mol% of Cl
No K
Salt 9
0 µm

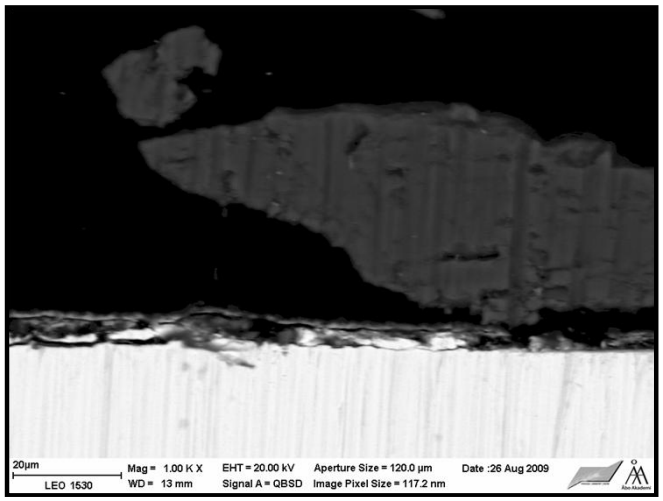


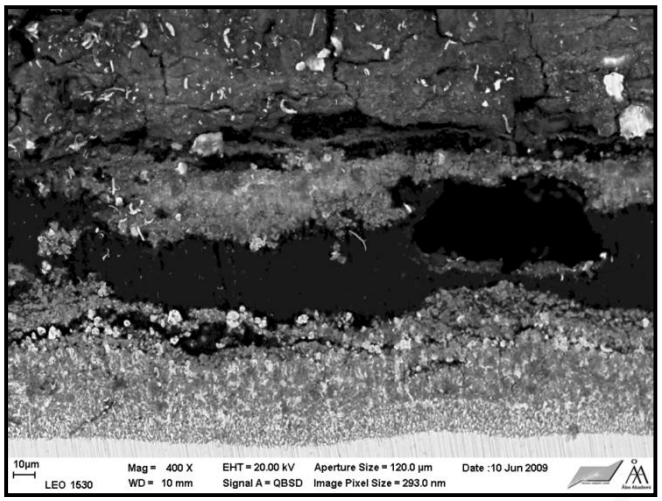


T_0 = 522ºC
1.7 mol% of Cl
13 mol% of K
Salt 10
306 µm

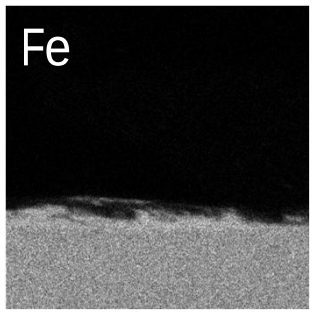
Skyrec – results, 600ºC

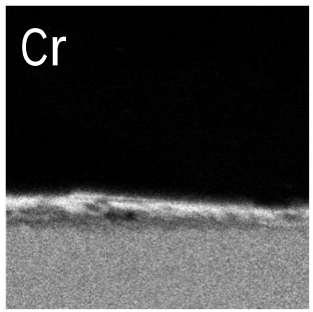
HR11N, red
Na_2SO_4
Salt 5
2 µm

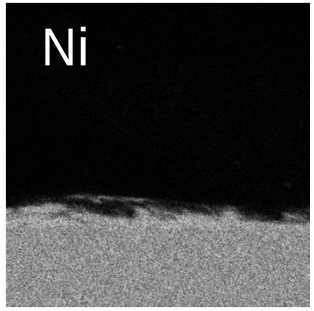


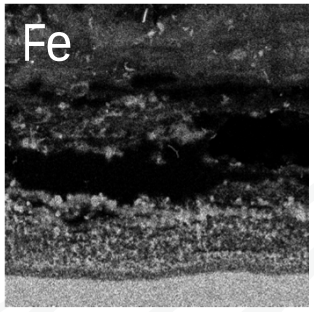


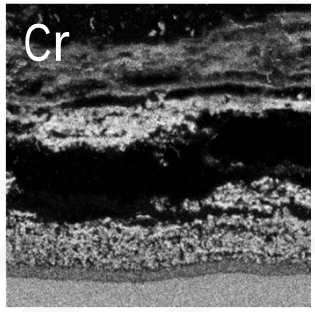
HR11N, red
Na_2SO_4 + NaCl
Salt 9
62 µm

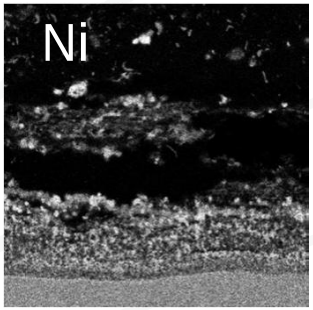


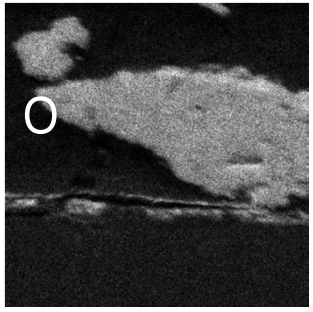


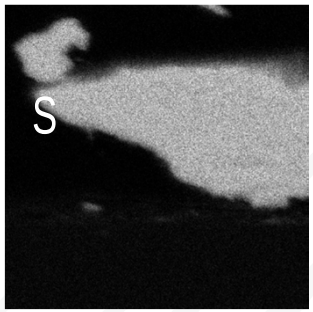


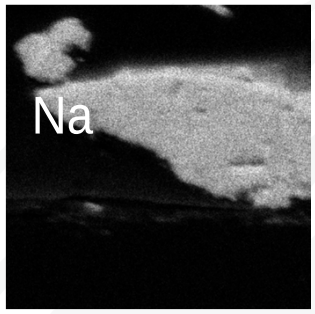


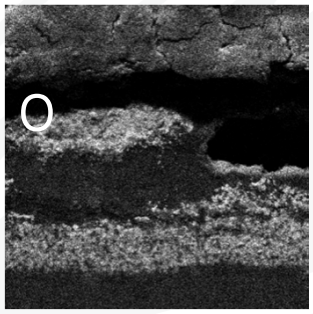


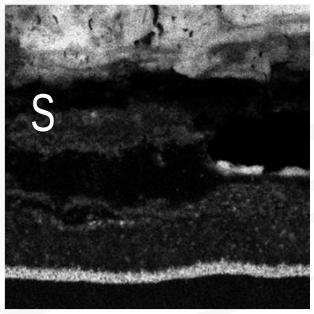


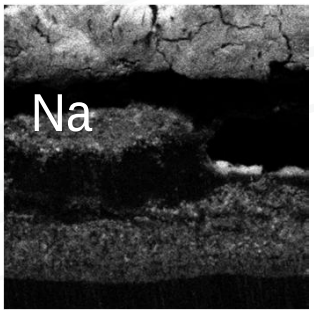








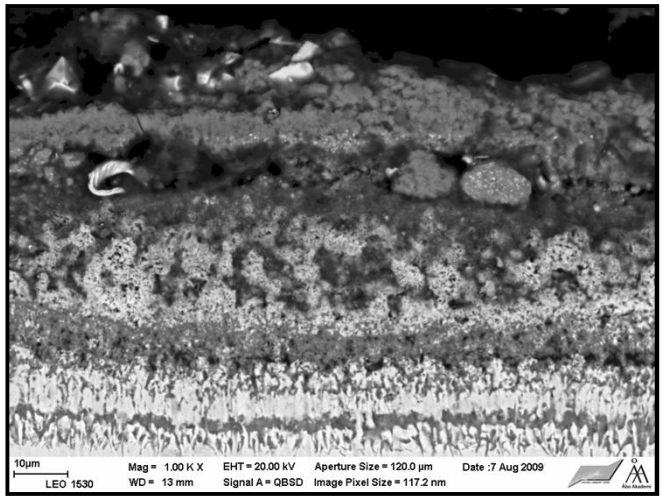


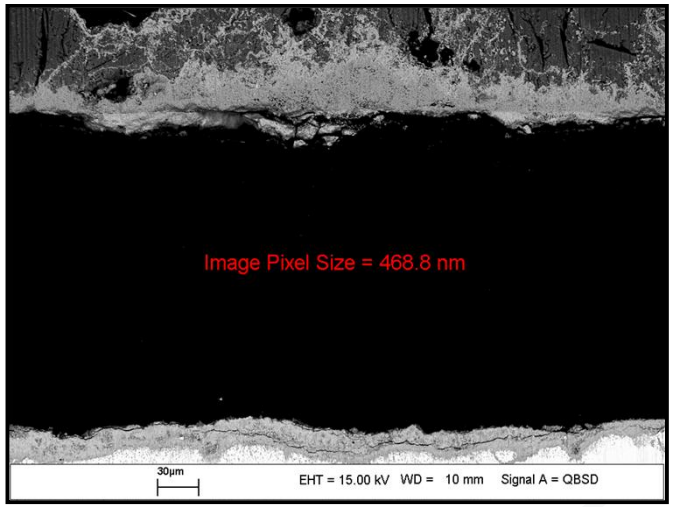


Skyrec – results, 600ºC

S28, red
Na_2SO_4 +
K_2SO_4 + KCl
Salt 10

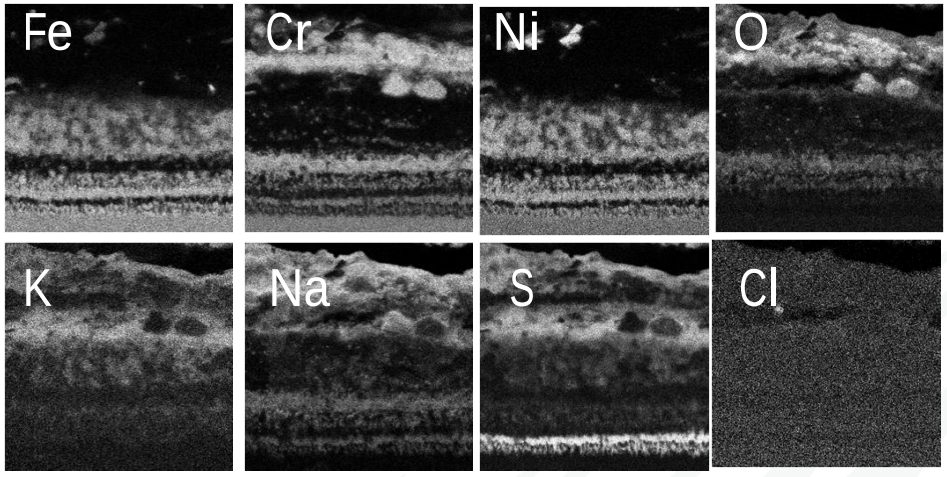
53 µm

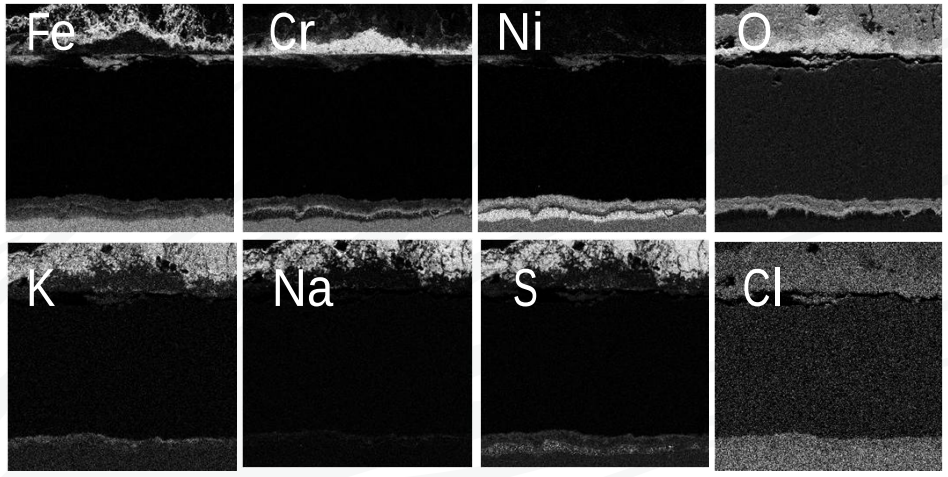




S28, ambient
Na_2SO_4 +
K_2SO_4 + KCl
Salt 10

72 µm

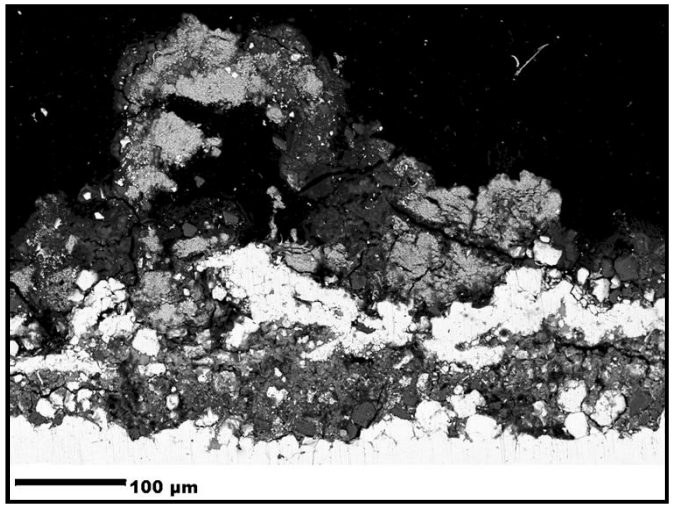


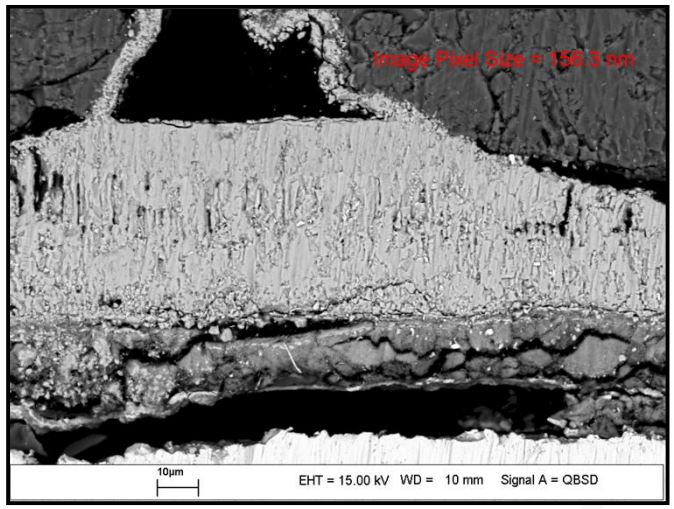


Skyrec – results, 600ºC

10CrMo, red
Na_2SO_4+K_2SO_4
+NaCl + KCl
Salt 8

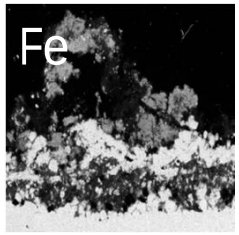
334 µm

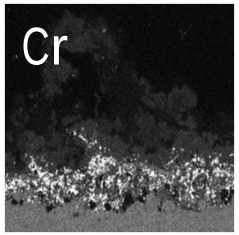


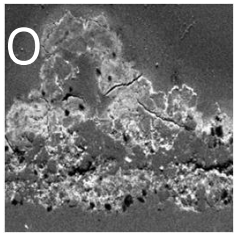


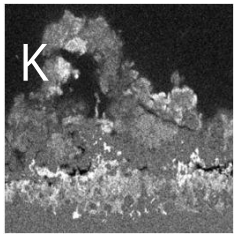
10CrMo,
ambient
Na_2SO_4+K_2SO_4
+NaCl + KCl
Salt 8

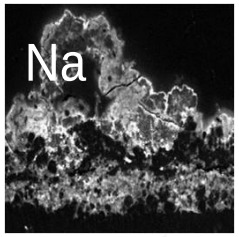
52 µm

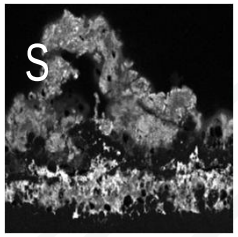


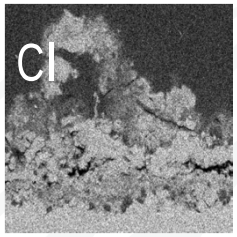


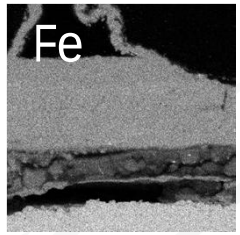


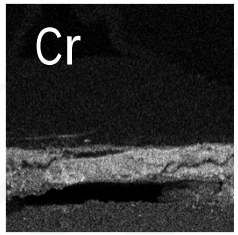


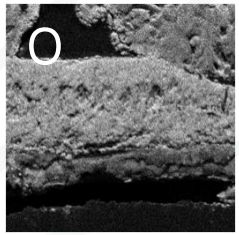


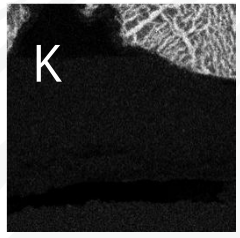


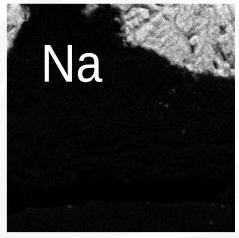


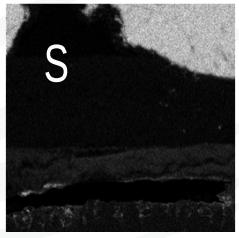


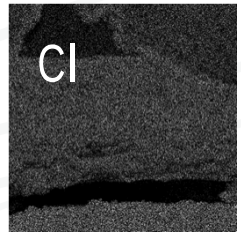






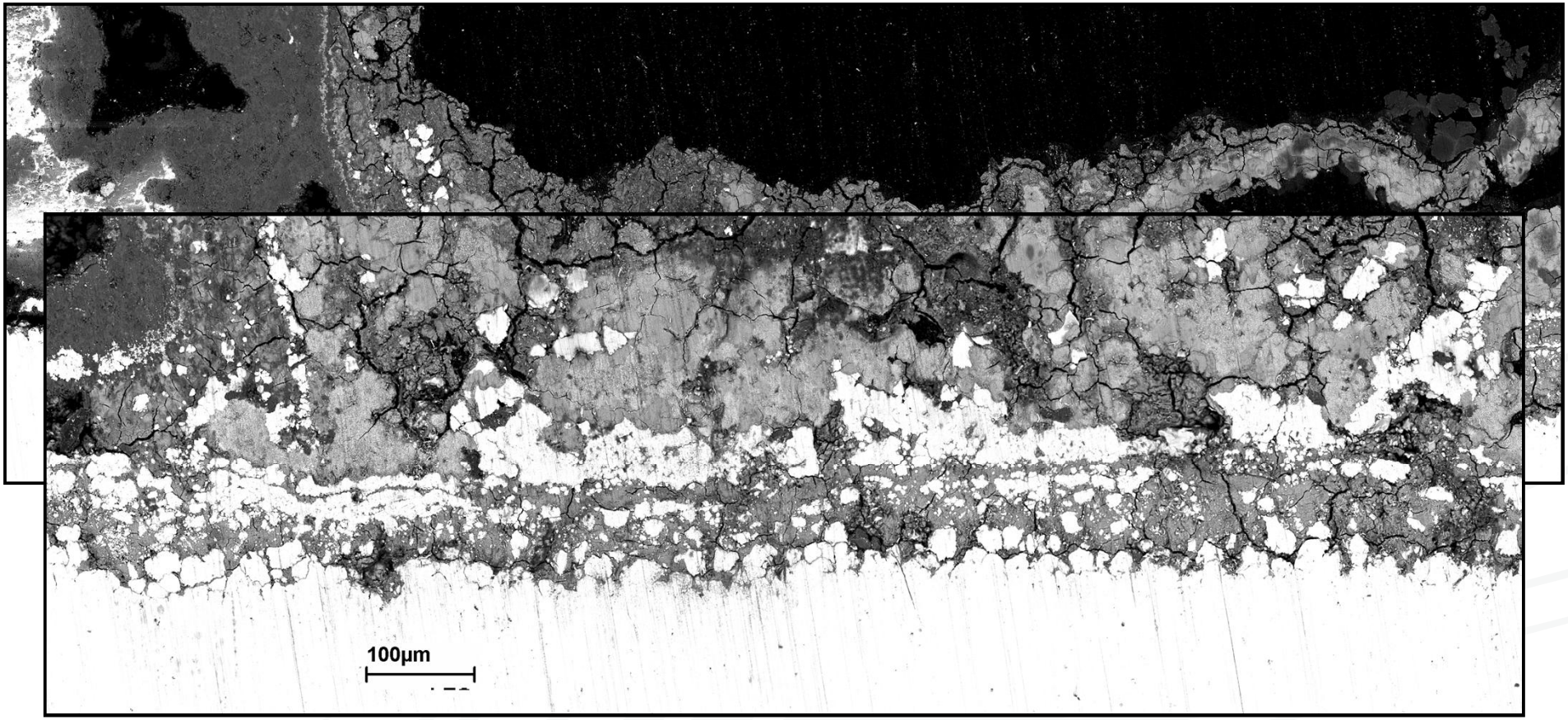






Skyrec – results

10CrMo at 600ºC with salt 8 attacked by the grain boundary corrosion



Skyrec – preliminary conclusions

- Ambient atmosphere seems to be more harmful than reducing under tested temperature and salts

- K containing salts show more detrimental effect
  - especially ≥ 500°C for low grade steels, ≥ 550°C for all steels - at ambient conditions
  - ≥ 550°C for all steels - at reducing conditions

(T_0 of the K containing salts slightly above 500°C)

- In reducing conditions and high temperature:
  - Low grade steels are destroyed mainly by grain boundary corrosion
  - Austenitic steels undergo heavy Cr leaching

- *Sulfur* often found on the corrosion front, deep in the pores

- Reducing conditions induce mainly internal attack of the steel*
- In ambient conditions growth of the oxide layer is promoted*

* Under tested temperatures and salts

Skyrec – To be done

- Final reporting (date to be decided)
- Corroded samples will be reported in a printed version of the report
- All the results (SEM/EDX) will be delivered on the CD