Small Scale Combustion

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Project members

- Janfire
- NIBE
- Sandvik Heating Technology
- Swerea IVF
- Chalmers

Background

- In the combustion of bio-based fuels the critically exposed burner parts in small boilers are typically uncooled and are usually made of FeCr or FeCrNi alloys.
- These materials can suffer attack from the ashes because of the formation of alkali chromate.
- The reaction depletes the protective oxide in chromia, leading to accelerated corrosion.
- This ultimately results in failure of the boiler unit and/or is limiting the service life of critical burner components.

Goals

- To develop practically oriented knowledge about HTC in small and medium sized plants fired mainly by pellet based bio-fuels
- Apply this knowledge and assist the SME producers with current urgent problems
- Increasing lifetime of selected critical components by a factor of 2-3 and decreasing failure complaints to below 5%

Status and time plan

Year	*Activity*
2014	Planning and production of materials to be investigated
2015	Cyclic lab exposures (Sandvik Kanthal) 850°C
	Analysis of exposed materials at Swerea IVF
2016	Cyclic lab exposures (Sandvik Kanthal) 600°C
	Analysis of exposed materials at Swerea IVF
	Field exposures ~800°C (Janfire)
	Analysis of exposed materials at Swerea IVF
2017	Cyclic lab exposures with elevated Cl-content at 600°C (Planned)
	Analysis of exposed materials at Swerea IVF

Production of model alloys

- Performed at Kanthal site in Hallstahammar
- Coupons were prepared from reference and model alloys

Lab scale vacuum melting and hot rolling

Testing – Ranking test, thermal cycling

- Performed at Kanthal Site in Hallstahammar
- Cycling, 1 hour hold time at high temperature, 30 minutes at RT
- 850°C (2015) and 600°C (2016 and 2017)
- Reference wood pellets ash (Janfire) was manually placed on the samples. Ash was replaced each 10th cycle in order to maintain its corrosiveness.

Cyclic test furnace

Samples, general appearance

At start

After 60 cycles

Field test – Ranking test, thermal cycling

- Performed by Janfire and exposed at commercial installation

Samples

Field exposure test set-up

850°C Analysed samples (2015 – 2016)

No.	Material	No. of cycles	Fe	Ni	Cr	Al	Other
2	model	50			5	4	2 Si
4	model	50			10	4	2 Si
7	253MA	50	Bal	11	21		RE
8	Kanthal D	60	Bal		21	4.8	RE
9	Kanthal APMT	50	Bal		21	5	Mo 3, RE
11	Kanthal APMT + CS repeated dipping*	50	Bal		21	5	Mo 3, RE
21	Nikrothal PM58	60	18	Bal.	20	5	RE
22	Inconel 625	60		58	21	0.4	Mo 9, Nb 3-4

* CS = colloidal silica

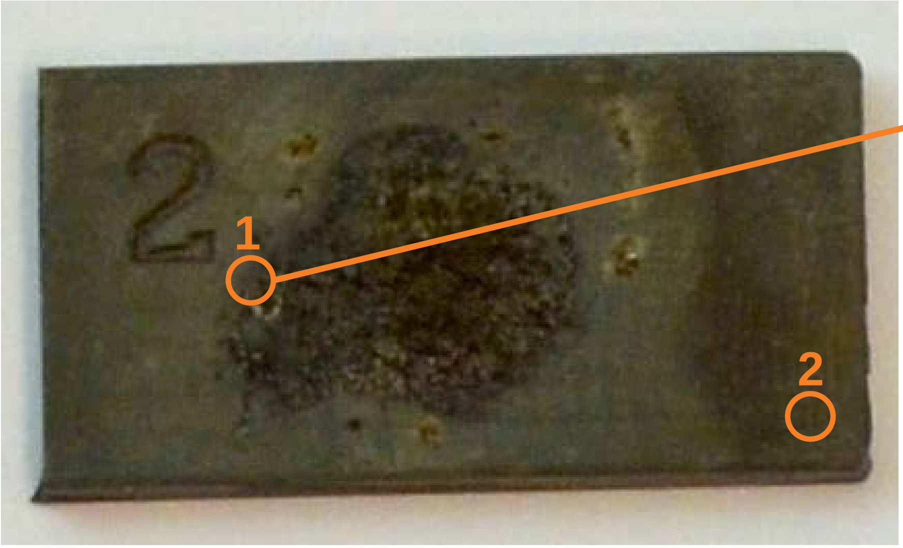
600°C Analysed samples (2016)

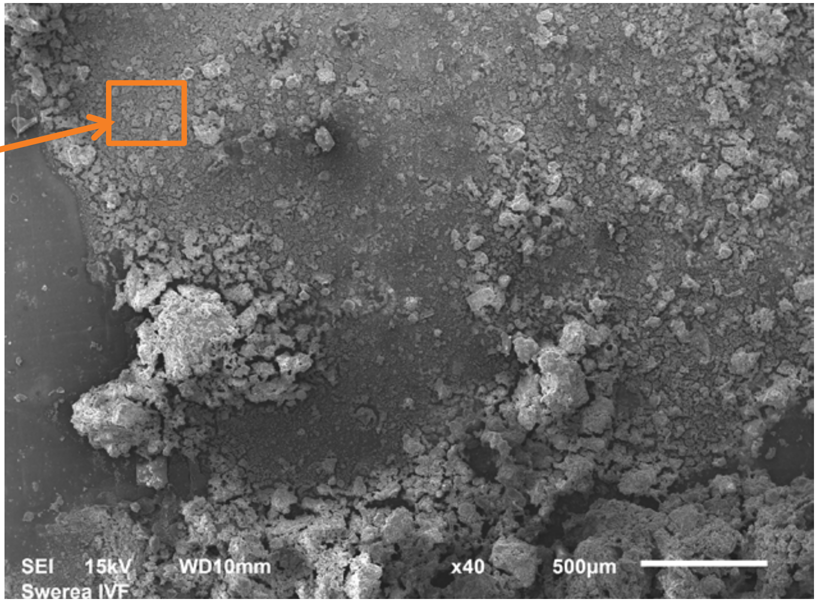
No.	Material	Fe	Ni	Cr	Al	Si	Note
1	model	Bal.		5	4		
3	model	Bal.		5	4	2	
6	model	Bal.		10	4		
7	model	Bal.		10	4	2	
15	model	Bal.		21	3	2	
16	model	Bal.		15	3	2	
19	model	Bal.		10	3	2	
23	model	Bal.		10	4	2	
NiCrAl	Nikrothal PM58	18	Bal.	20	5		
FeCrAl	Kanthal AF	Bal.		21	5		
FeCrAlMo	Kanthal APMT	Bal.		21	5		

- Model alloys with potential for alumina protection
- Model alloys have variations in Cr, Al and Si
- Model Alloys compared to advanced commercial HT alloys
- Model alloys are Fe-base and relatively lean for sustainable performance

SEM top view

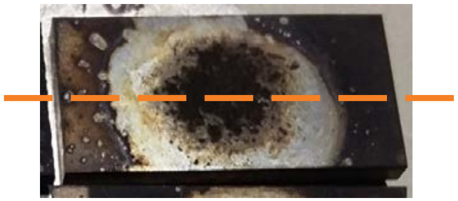
- Topographical contrast, magnifications: (x120), x300, x1000 och x3000. Pictures in two areas, see below.
  - Analysis on two positions
    - 1: close to the rim of the ash deposited area
    - 2: close to the edge of the coupon



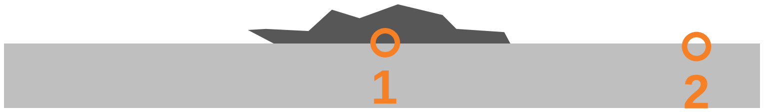


SEM cross sections

- The whole sample was molded in epoxi resin and then cut to the center (in order to protect the surfaces during subsequent cutting and and grinding/polishing)



- Then again the sample was molded into epoxy resin and finally the cross section was ground and polished for investigation



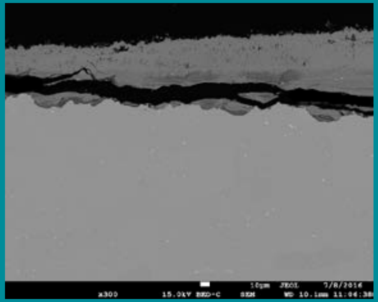
- Investigation was done mainly on two positions:
  - 1: in the middle of the ash deposited area
  - 2: close to the edge of the coupon surface
- Elemental analysis (with EDS):
  - Mapping in x1000 (centre)
  - In other areas in case of interesting features

Summary, reaction products on surface

No.	Total layer	Composition (Layer thickness)		
		Inner	Center	Outer
1	50-80 µm	Al, Cr, (20-30 µm)		Fe (30-40 µm)
3	2-30 µm	Al, Cr, Si (2-5 µm)		Fe (5-40 µm)
6	0-50 µm	Al, Cr, Fe (10-20 µm)		Fe (20-30 µm)
7	0-3 µm	Al (<3 µm)		
15	2-10 µm	Al (+Fe, Cr, ej oxid)		
16	0-35 µm	Al, Cr (2-8 µm)		Al, Fe (5-30 µm)
19	2-40 µm	Al, Cr, Fe (25-40 µm)		
23	0-30 µm	Al, Cr, Si (1-5 µm)		Fe (5-30 µm)
NPM58	1-20 µm*	Ni (5 µm)	Al, Cr (1-4 µm)	Al, Ca, Fe (7-20 µm)
AF	1-30 µm**	Al, Cr (1-10 µm)		Al, Ca, Fe, K (5-20 µm)
APMT	0-2 µm	Al (<2 µm)		

* Grain boundary attack 5-10 µm deep in the centre of the sample
** Spotwise small grain boundary attacks

Overview, section in centre, all samples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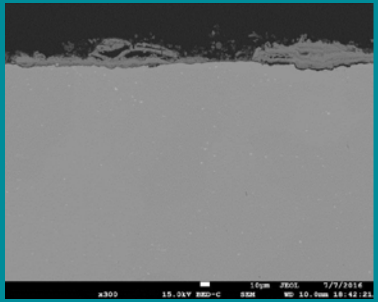
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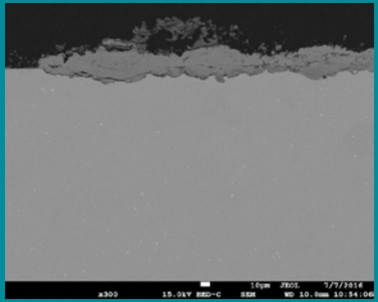
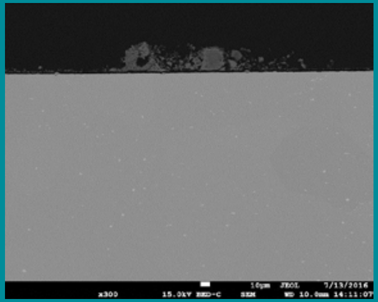

Model 6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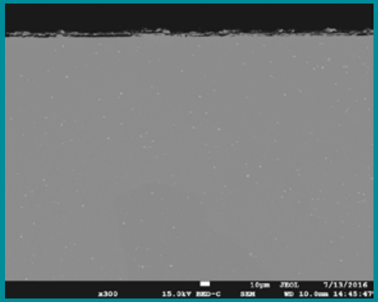
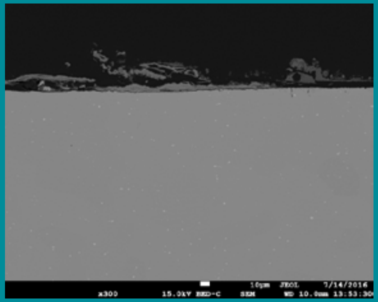
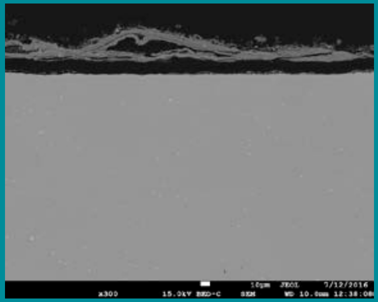
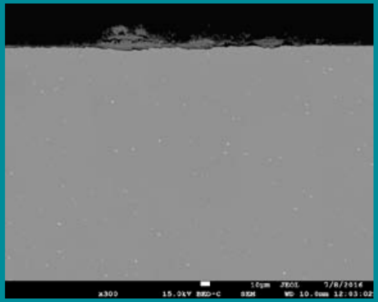
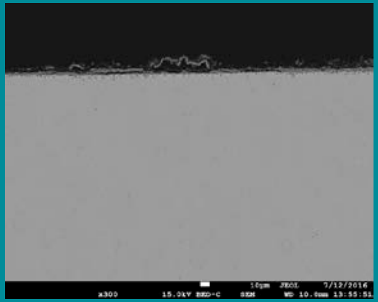
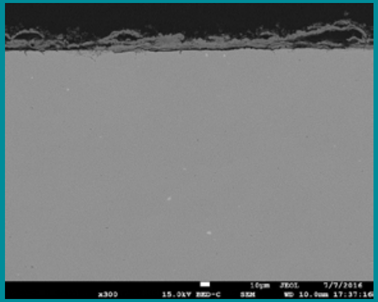

Model 15

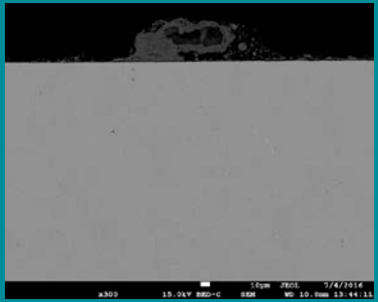

Model 16


Model 19


Model 23

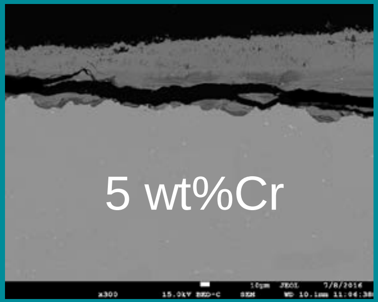

Nikrothal PM58


Kanthal AF

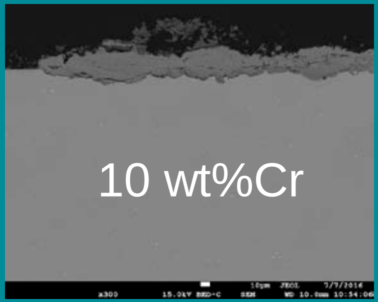

Kanthal APMT

Magnification: x300

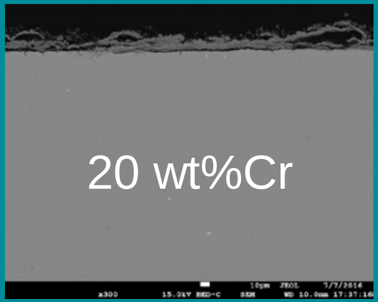
Role of Cr content (without Si)



Model 1



Model 6



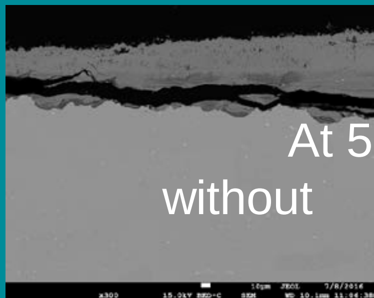
Kanthal AF

Magnification: x300

Role of 2 wt%Si addition

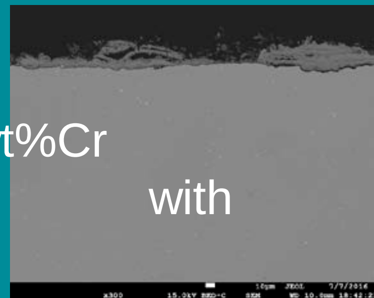
At 5 wt%Cr

without



Model 1

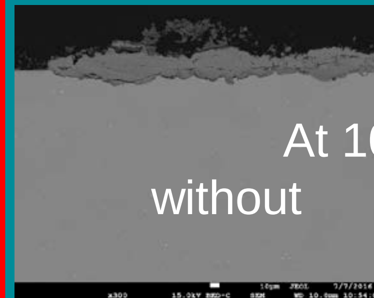
with



Model 3

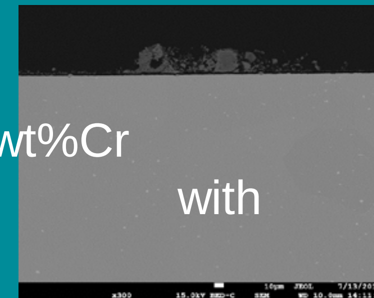
At 10 wt%Cr

without



Model 6

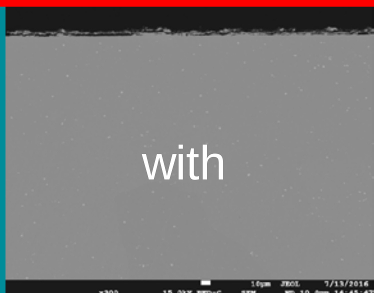
with



Model 7

At 20 wt%Cr

with



Model 15

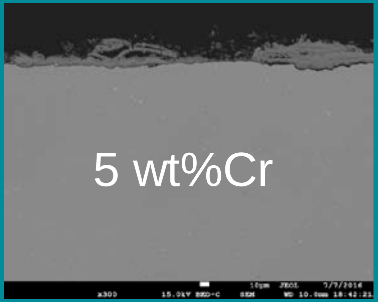
without

Kanthal AF

✓

Magnification: x300

What about Cr content with 2% Si?



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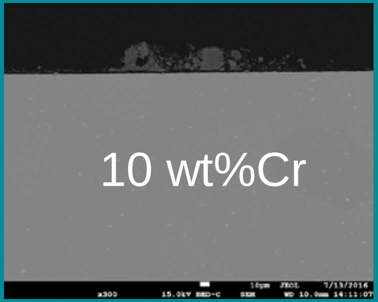
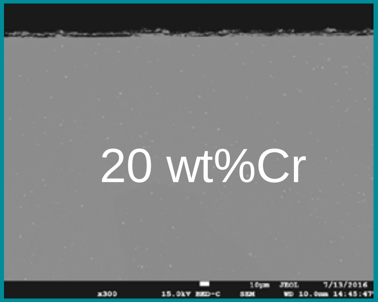
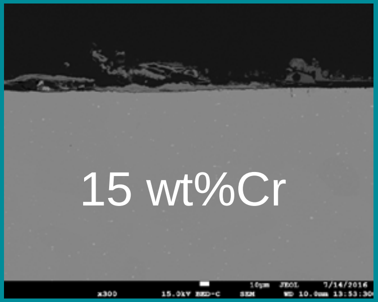


Model 7



Model 15

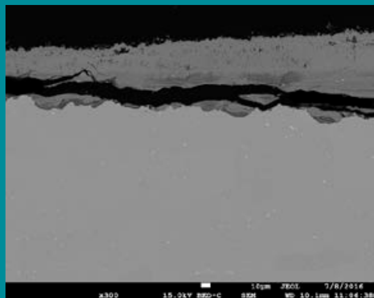


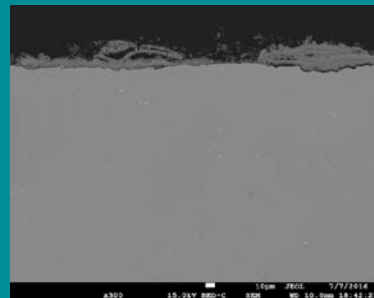
Model 16

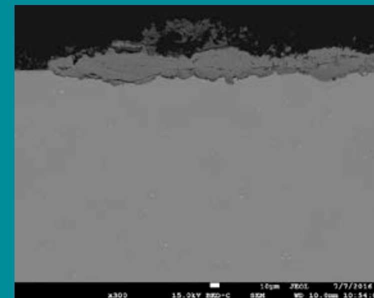
?

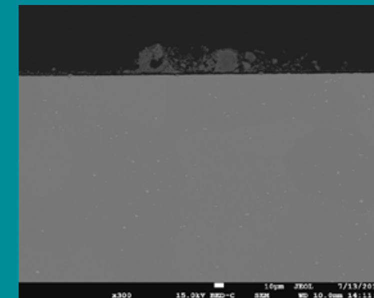
Magnification: x300

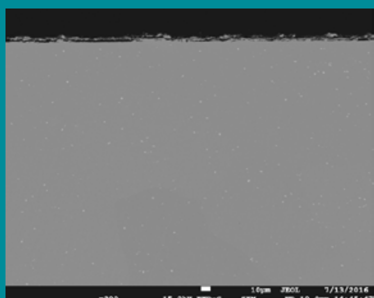
Overview, section in centre, all samples

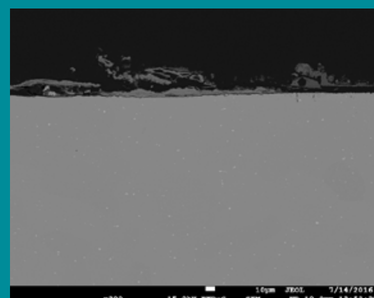

Modellegering 1

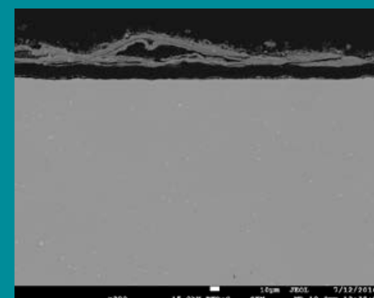

Modellegering 3

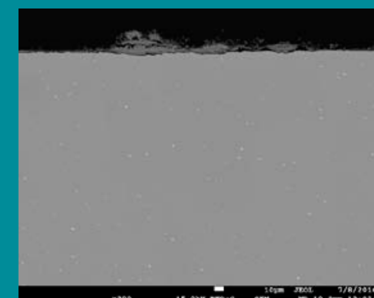

Modellegering 6

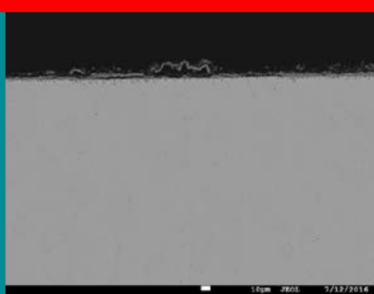

Modellegering 7

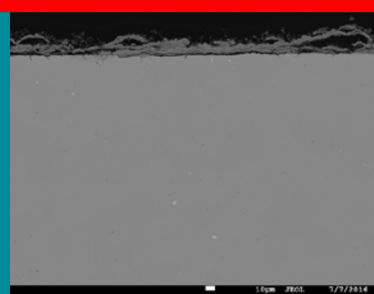

Modellegering 15

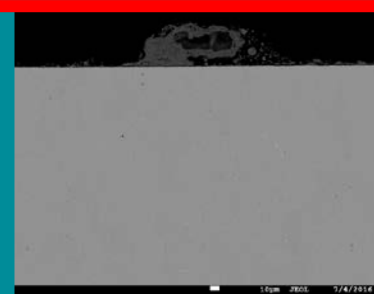

Modellegering 16


Modellegering 19


Modellegering 23

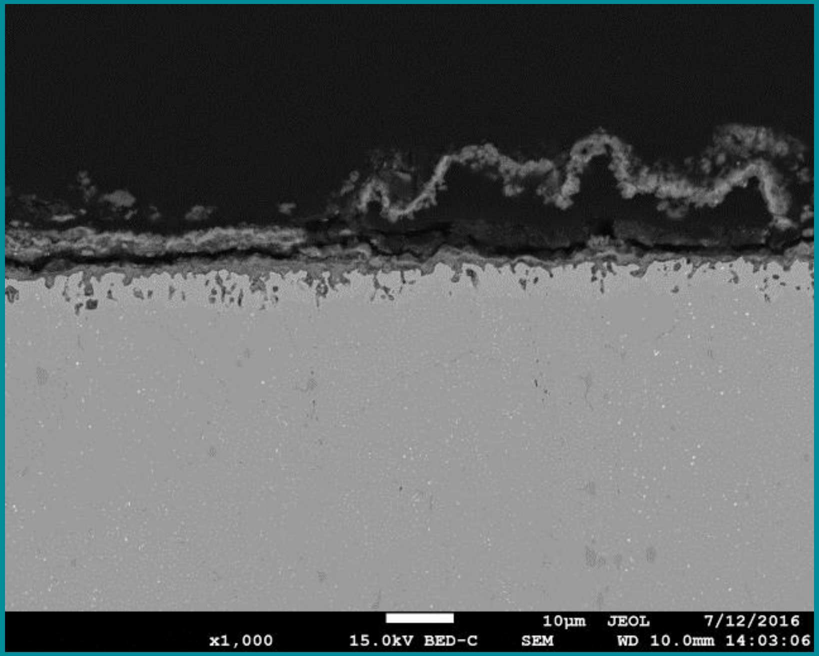

Nikrothal PM58

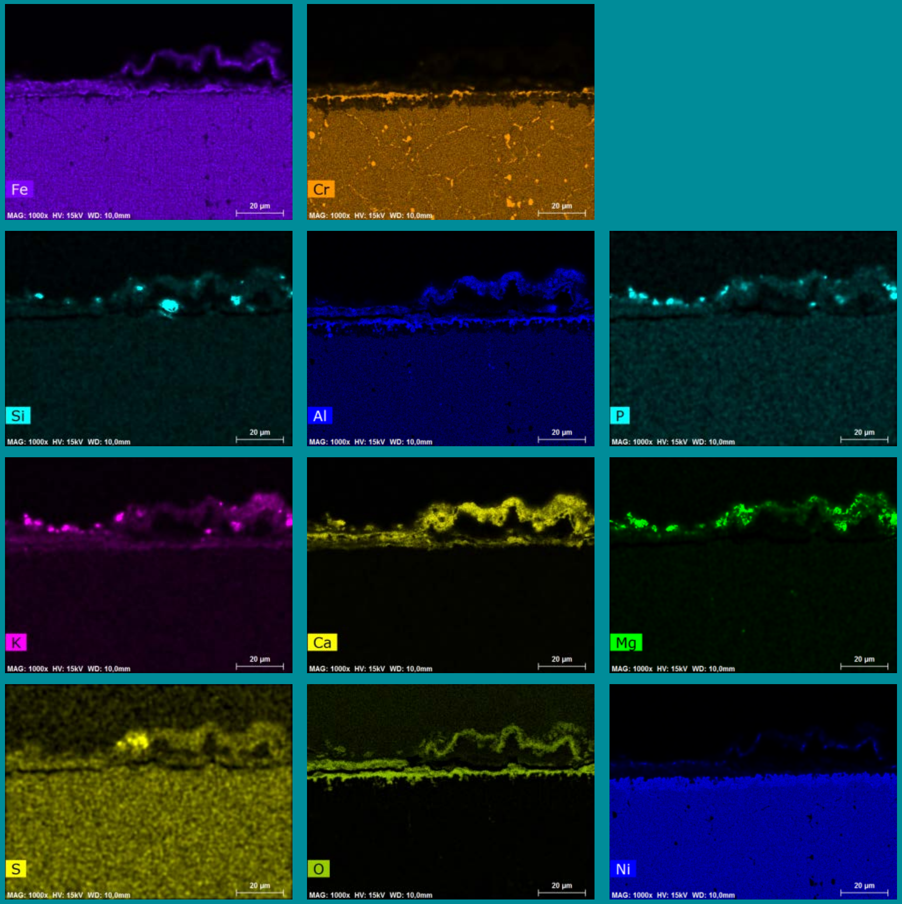

Kanthal AF


Kanthal APMT

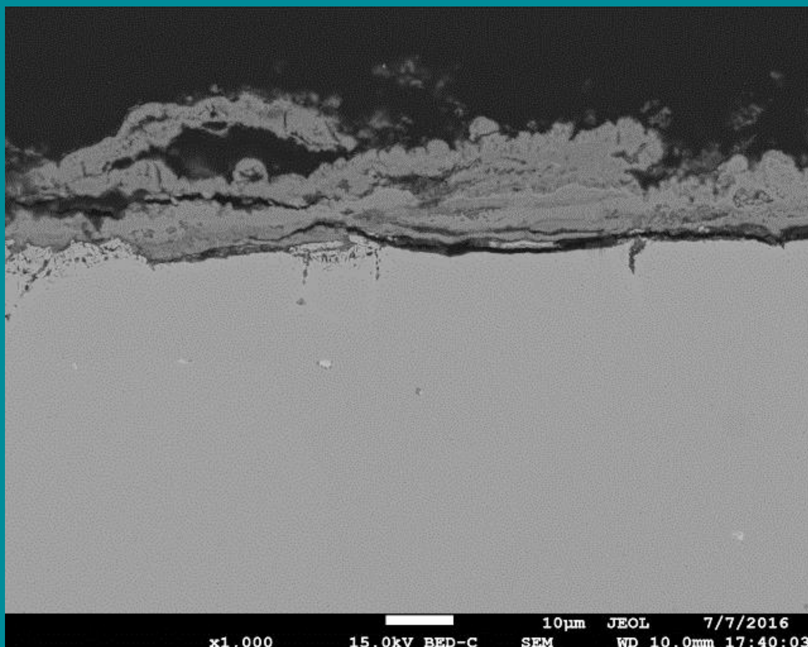
Magnification: x300

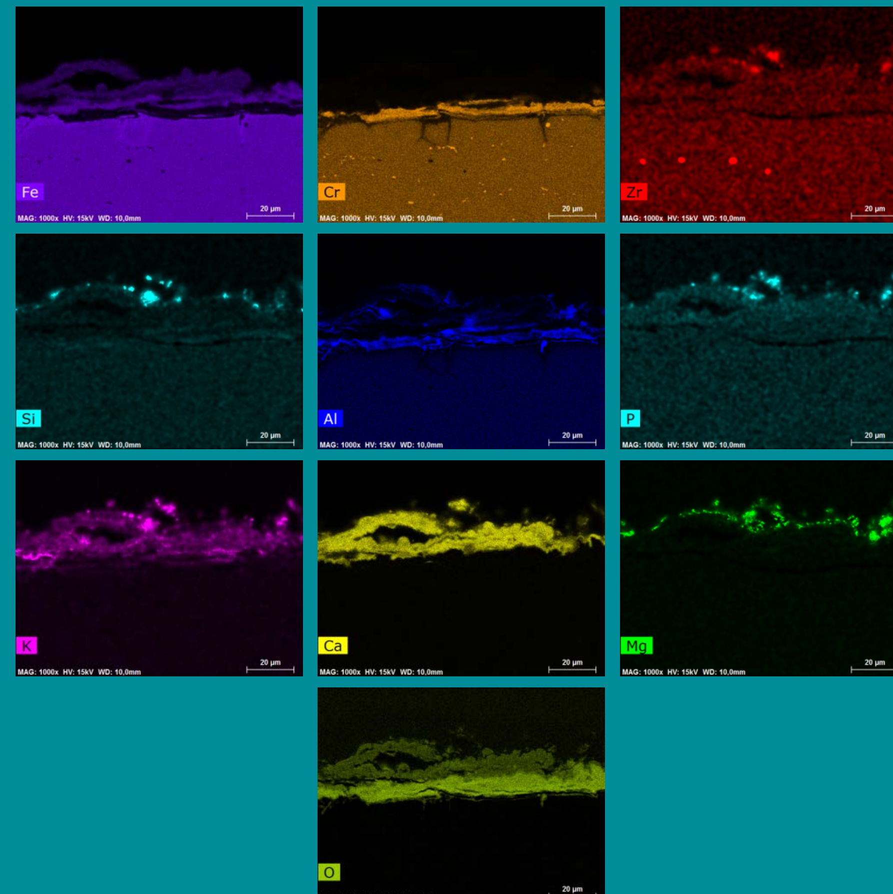
Nikrothal PM58:
Cross section, centre, EDS-analysis



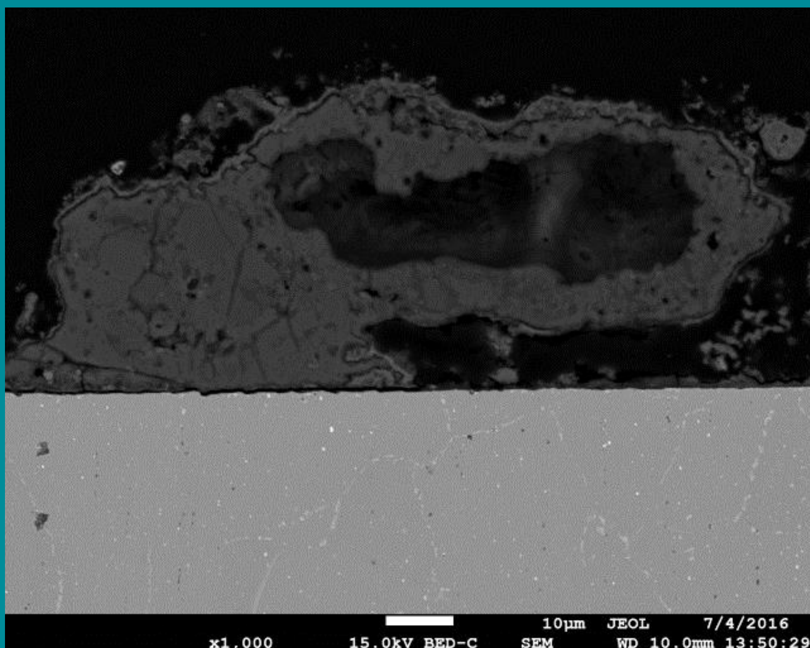


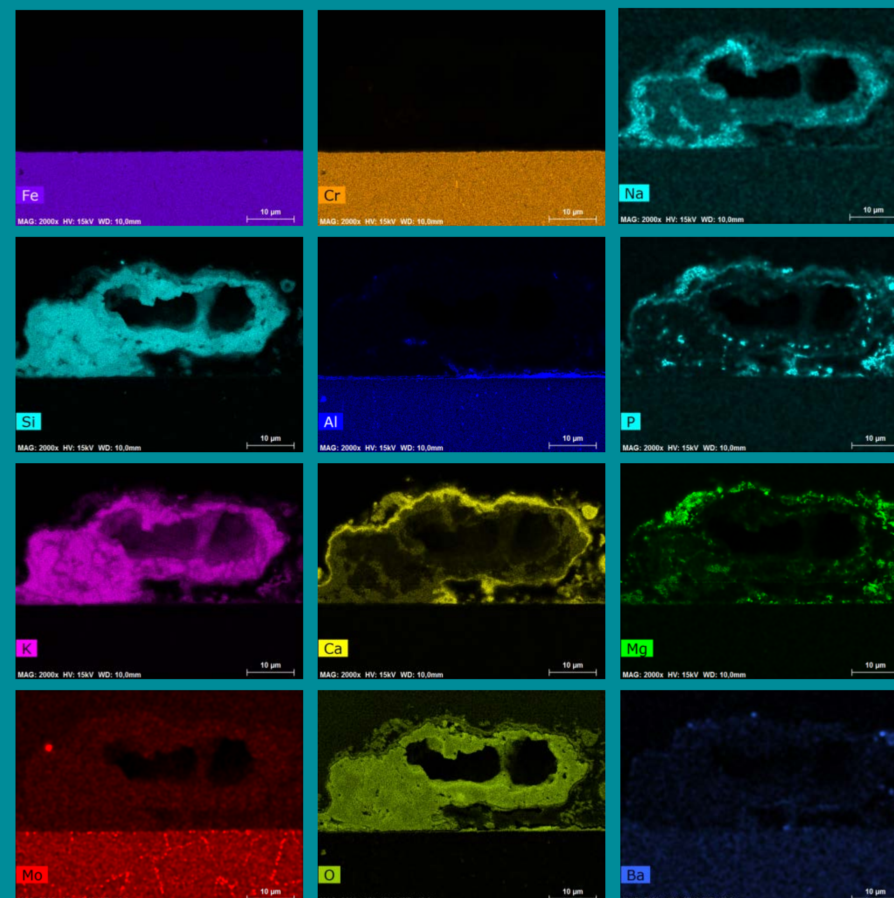
Kanthal AF (21Cr, 5Al):
Cross section, centre, EDS-analysis





Kanthal APMT (21Cr, 5Al, 3Mo): Cross section, centre, EDS-analysis





Field exposure Janfire, temperature up to 800°C

Start
150930

End
160307

Materials:
1. 253 MA
2. Nikrothal N60
3. Kanthal D
4. Kanthal APMT
5. Kanthal AF
6. Model alloy 7

Exposed samples

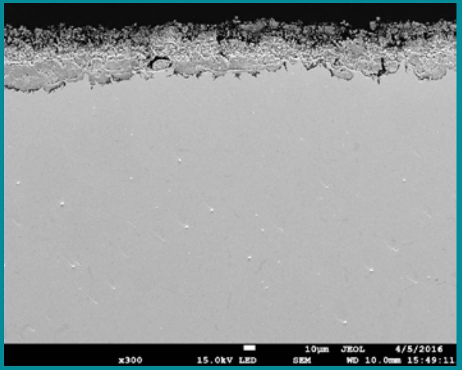
Nominal composition

No.	Material	Ni	Cr	Al	Si	Other
1	253 MA	11	21		1	
2	Nikrothal 60	60	15		1	
3	Kanthal D		21	4.8		
4	Kanthal APMT		21	5		Mo 3
5	Kanthal AF		21	5.3		
6	Model alloy 7		10	4	2	

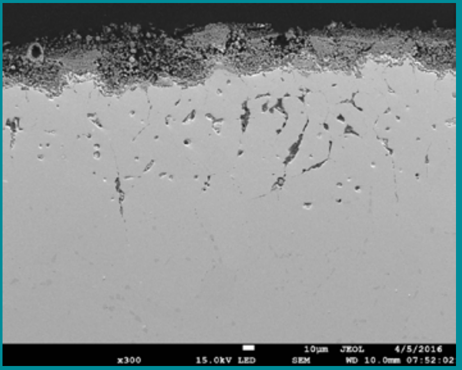
Summary of results

No.	Material	Oxide thickness	Layered oxide		
			Inner	centre	Outer
1	253 MA	30-50 µm	Islands of Si	Cont. Cr inner (1-2 µm) / Cr-Ca (+Ni-particles)	Si-Ca
2	Nikrothal 60	20-50 µm	Varying oxide layers:		
			Cr (1-2 µm)	-	Cr-Fe-Ca
			Si (0-2 µm)	-	Si-Ca
3	Kanthal D	20-50 µm	Al (< 1 µm)	Al-Ca	Si-Ca
4	Kanthal APMT	5-25 µm	Al (1-4 µm)	Al-Ca	Si-Ca
5	Kanthal AF	20-80 µm	Al (1-4 µm)	Al-Ca	Si-Ca
6	Model alloy 7	20-50 µm	Al (0,5-3 µm)	Al-Ca	Si-Ca

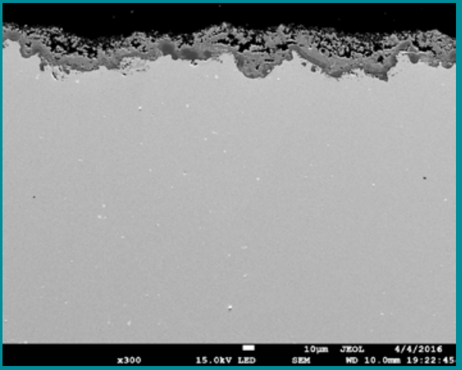
Results, visual



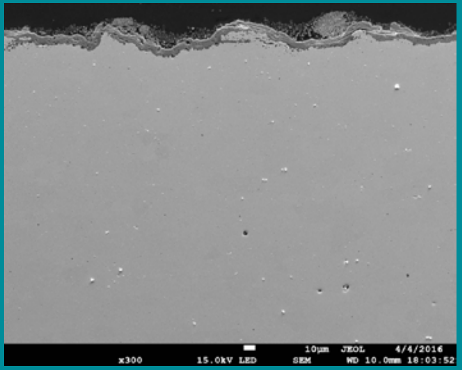
253 MA



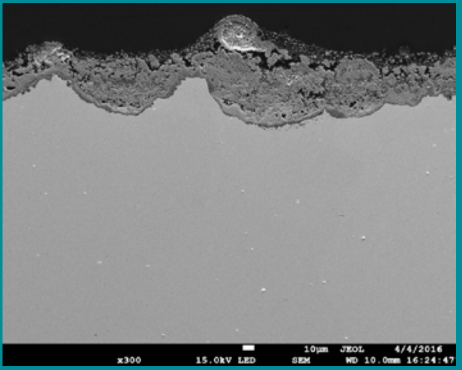
Nikrothal 60



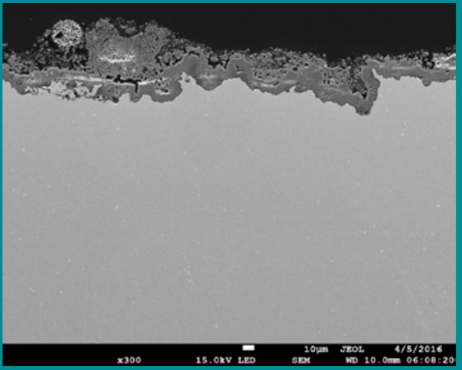
Kanthal D



Kanthal APMT



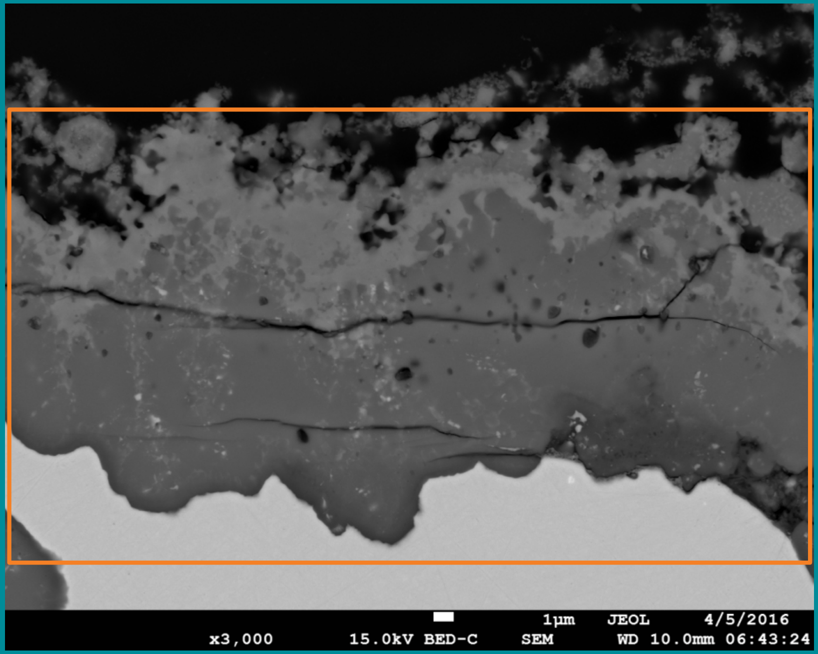
Kanthal AF

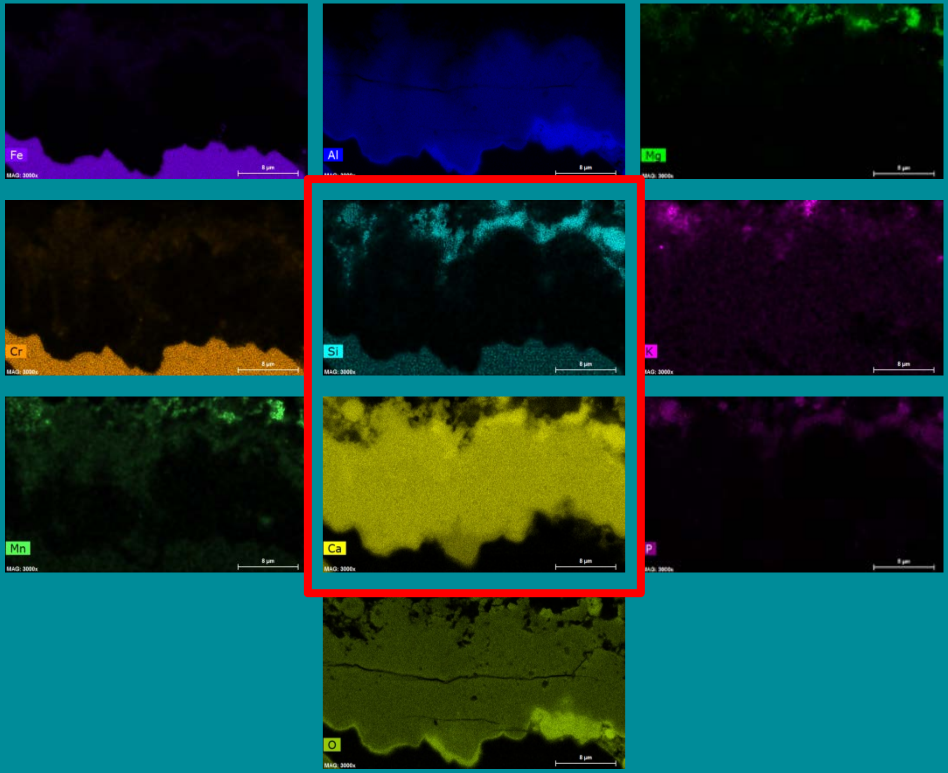


Model Alloy 7

Magnification: x300

Example, model alloy 7
Cross section at centre





Conclusions

- Useful results from lab ranking test is possible
- Deposits in the field exposure differs from the ash used in lab testing
- Further work to clairify the mechanisms is needed
- Specifically the role of elevated Cl contents need investigation
- Model alloy system seems to have potential for further development

Vi arbetar på vetenskaplig grund för att skapa industrinytta.
www.swerea.se