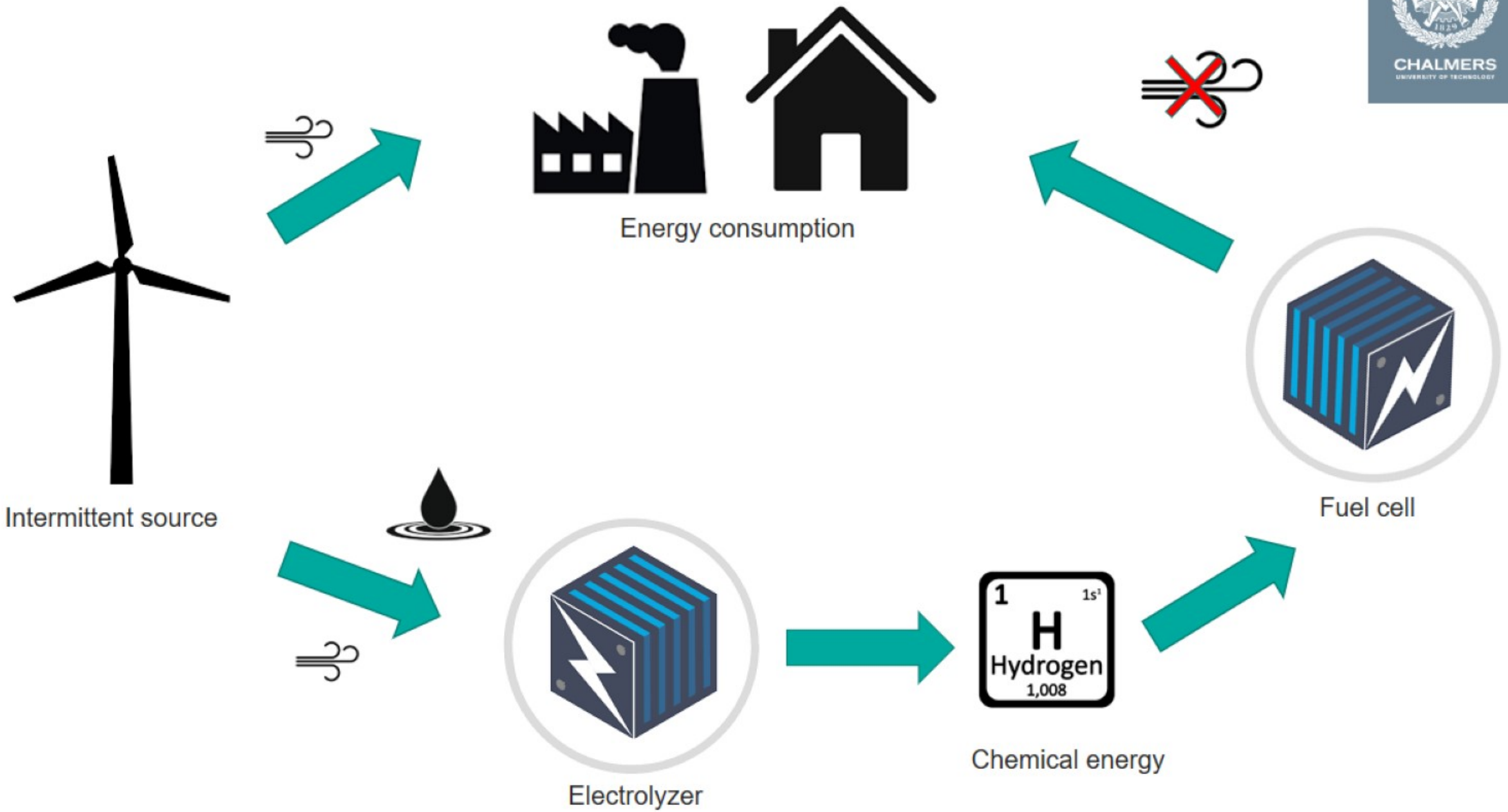
Corrosion and oxidation of FeCr alloys for solid oxide fuel cells, SOFC and solid oxide electrolysis cells , SOEC

Alberto Visibile, Özgür Kerem Gündüz, Claudia Göbel, Jan Froitzheim, Jan-Erik Svensson

Introduction:



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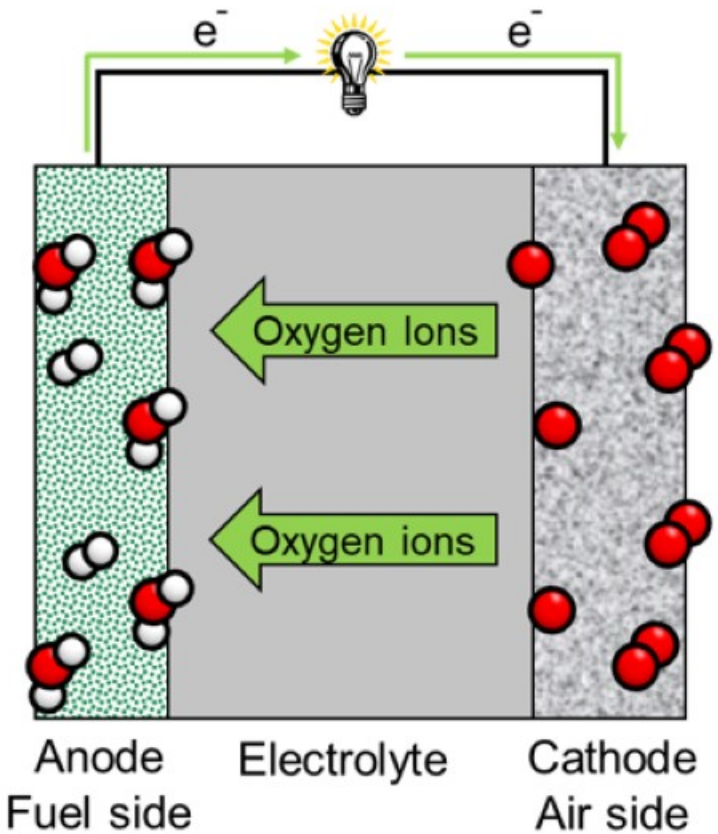

Cathode: $O_2 + 4\ e^- \rightarrow 2\ O^{2-}$

Anode: $2\ O^{2-} + 2\ H_2 \rightarrow 2\ H_2O + 4\ e^-$

Total reaction: $O_2 + 2\ H_2 \rightarrow 2\ H_2O$

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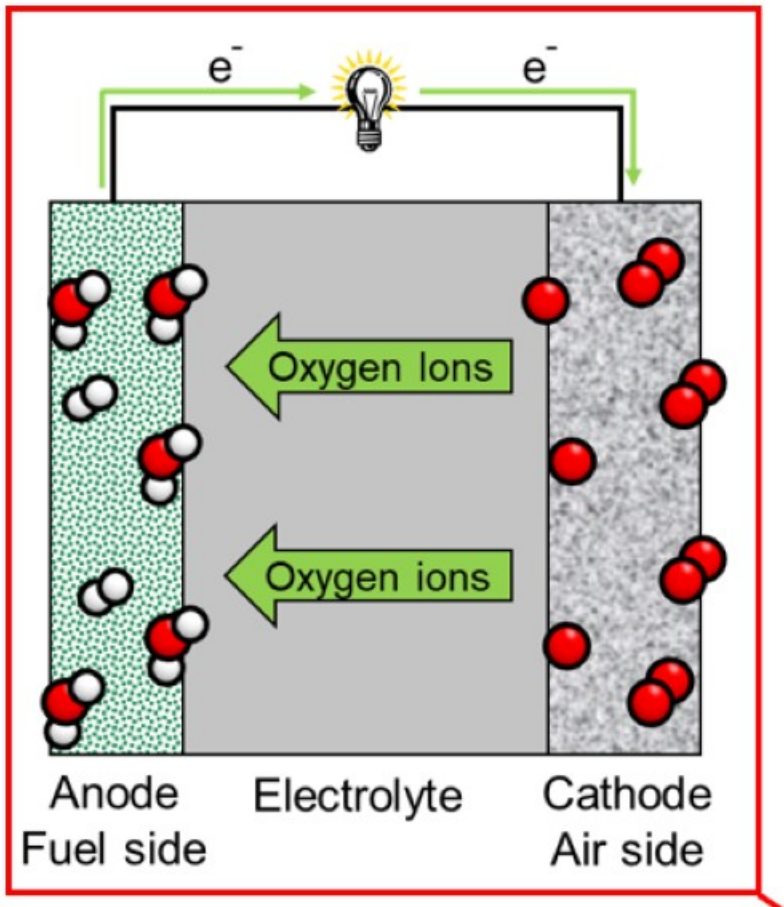

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U < 1V

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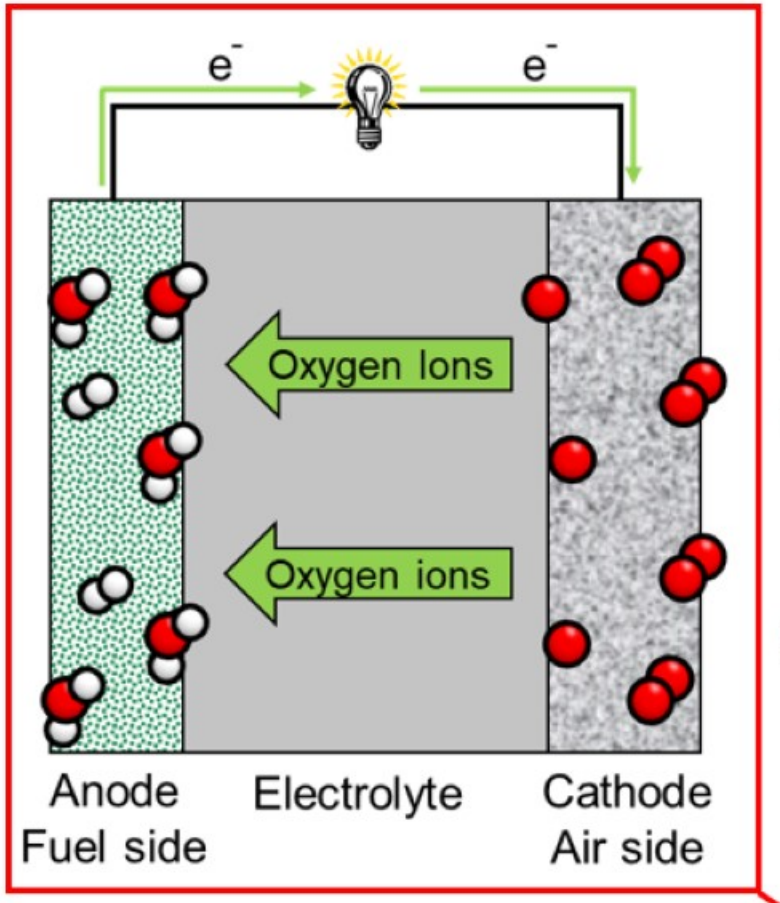
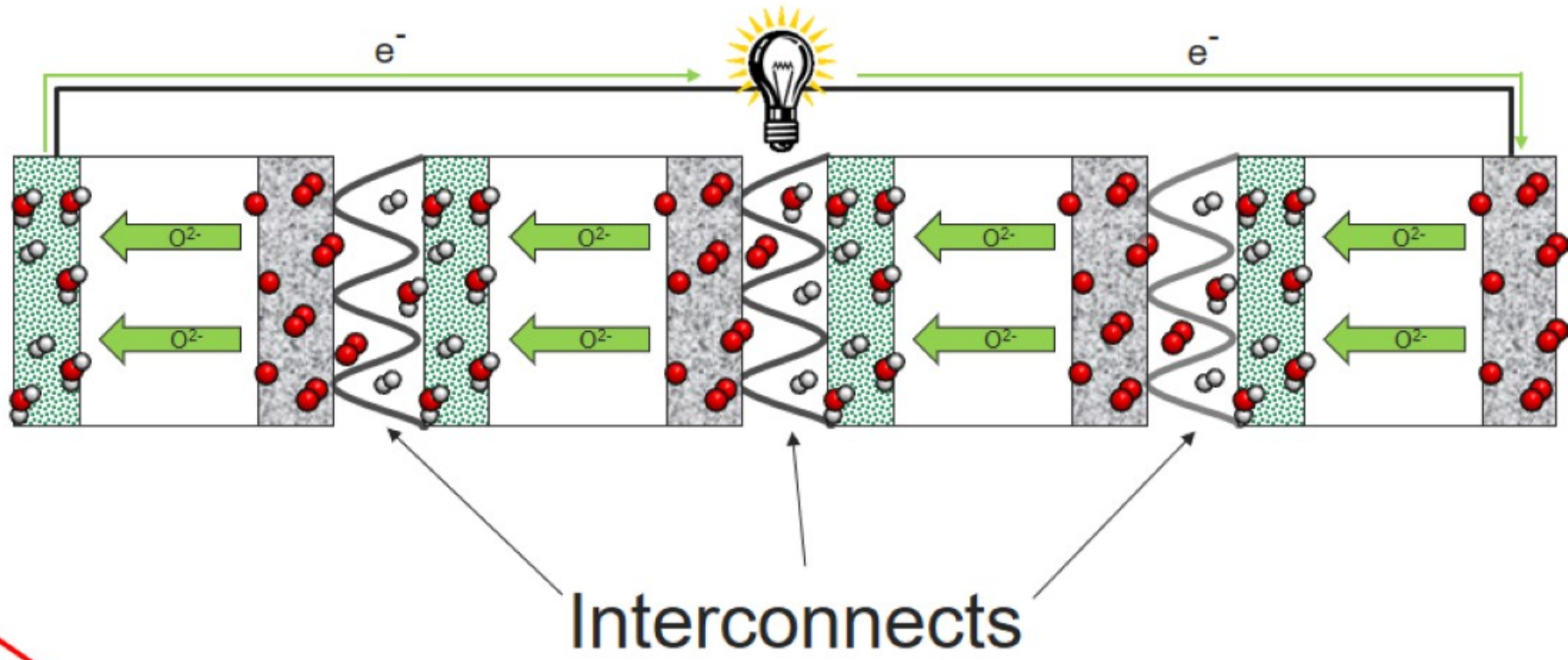


Solid Oxide Fuel Cell Stack



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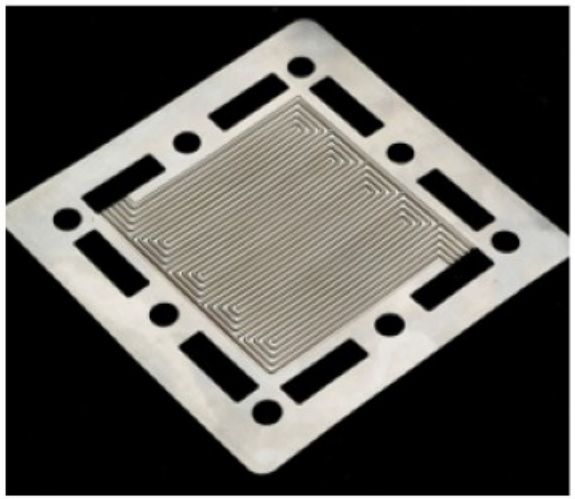


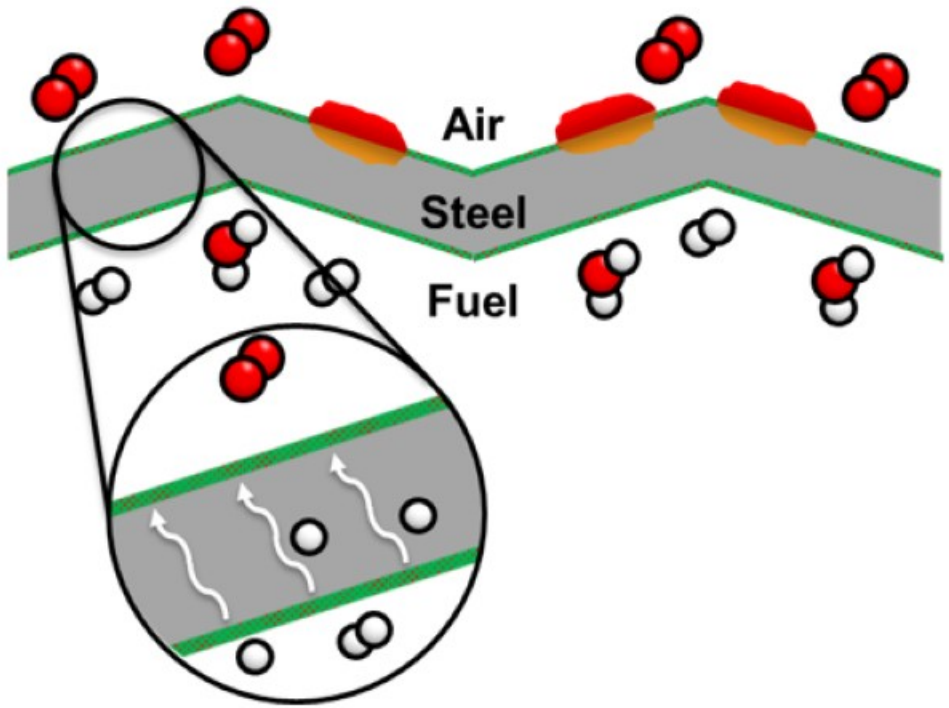
Ferritic Stainless Steel Interconnects

- Similar thermal expansion as the ceramics used in SOFC
- Good electrical conductivity
- Formability, etc.
- Cheap price

But...

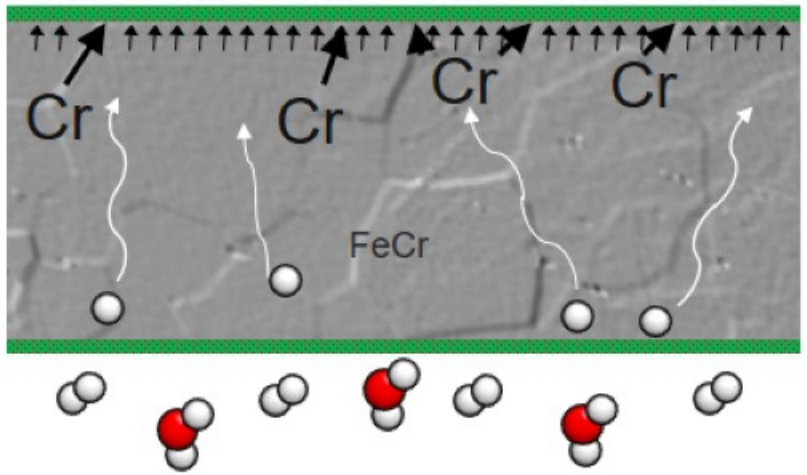
- They suffer from severe corrosion in contact with dual atmosphere

Dual atmosphere effect

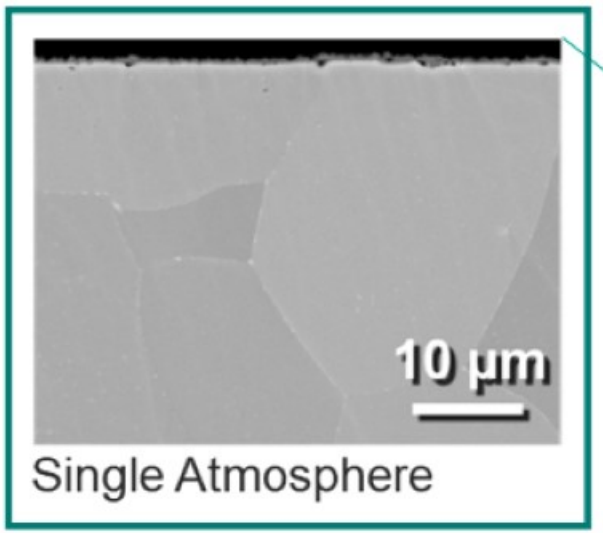


Condition to maintain a protective scale

n_{Cr} (consumption) < n_{Cr} (supply)



Protective



Cr_2O_3 scale protecting from further corrosion

Condition to maintain a protective scale

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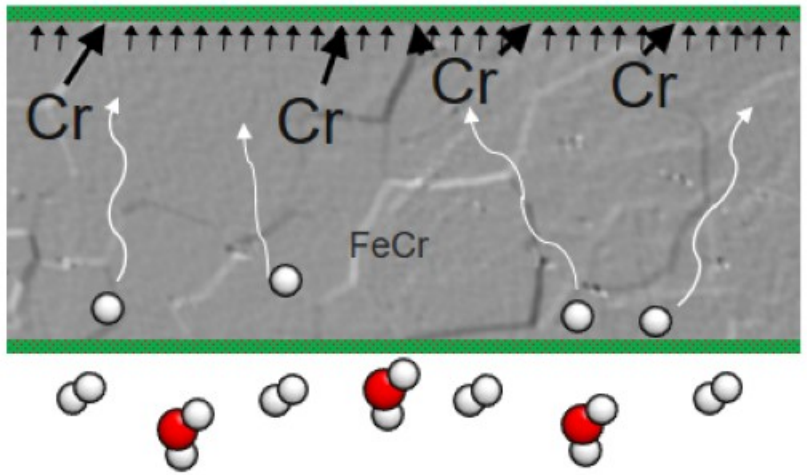
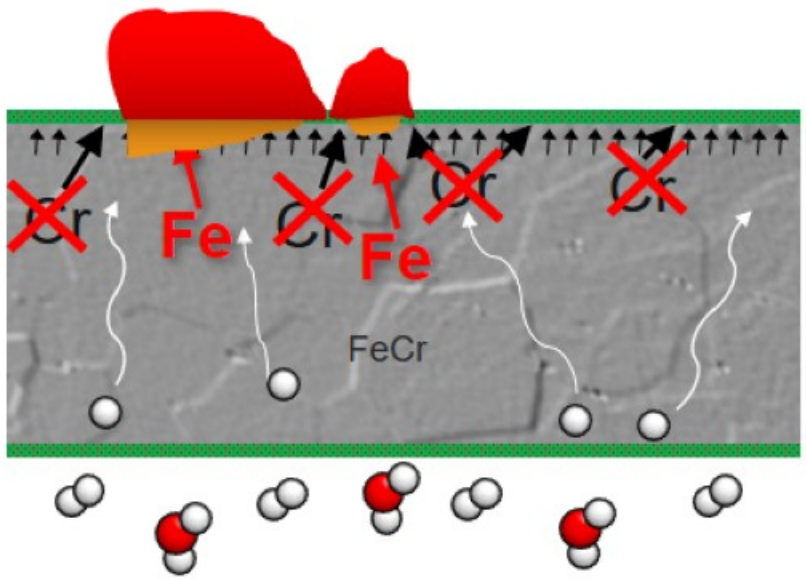
Single

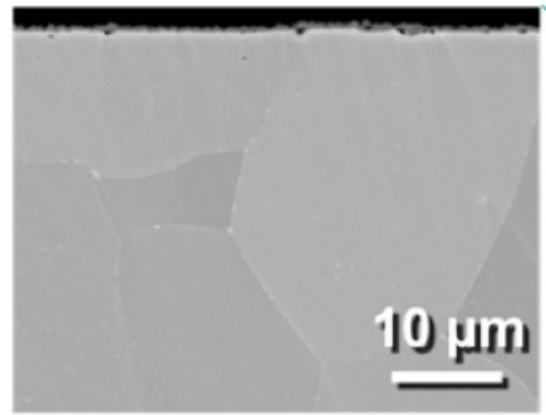


n_{Cr} (consumption) > n_{Cr} (supply)

Dual



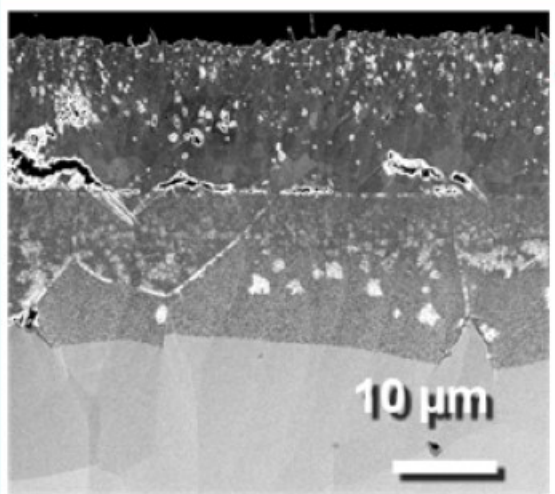
Protective



Single Atmosphere

Cr_2O_3 scale protecting from further corrosion

Non-protective



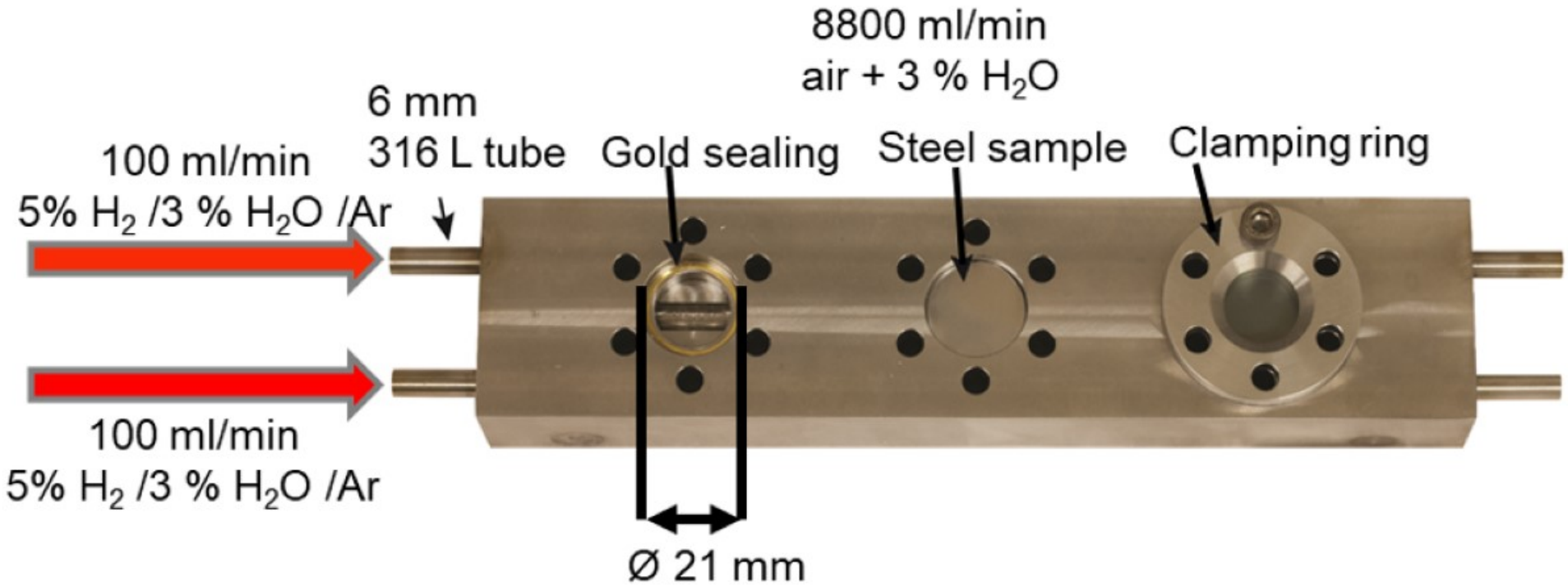
Dual Atmosphere

Thick layer of Fe_2O_3 reducing the performance of the SOFC

Summary

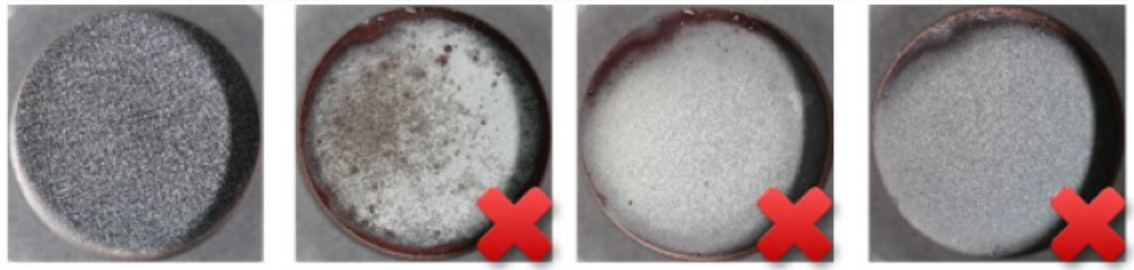
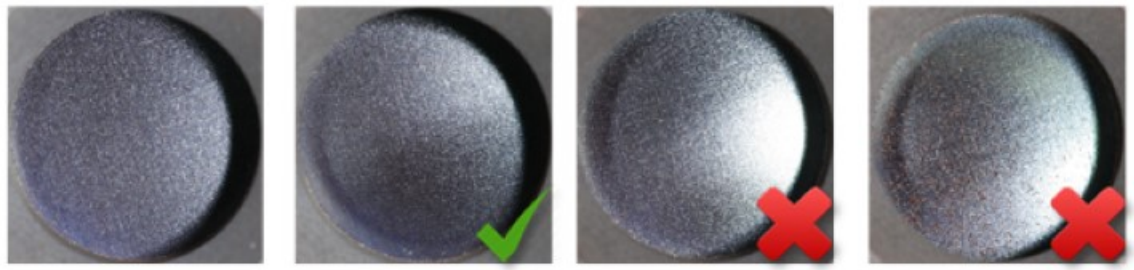
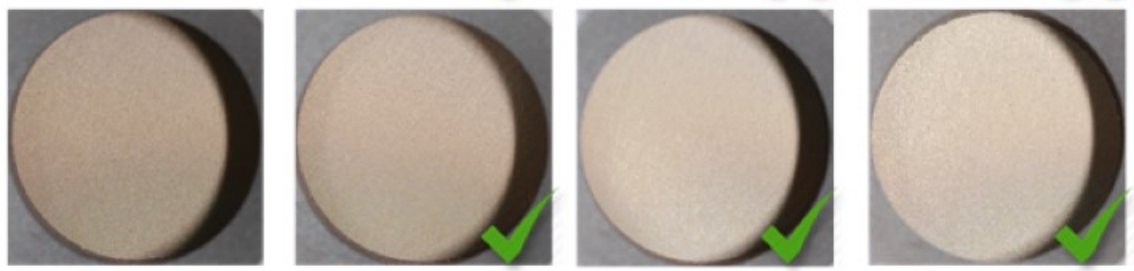
- Effect of pre-oxidation time
- Effect of pre-oxidation side
- The role of samples thickness
- Temperature dependence of the dual atmosphere effect
- Surface modifications effect

Experimental setup



- Dual conditions: Air-3%H_2O // Ar-5%H_2-3%H_2O
- Temperature: 600 °C
- Preoxidation parameter: 800 °C in air.

Effect of pre-oxidation time

$t_{pre\text{-}oxidation}$ \ $t_{exposure}$	0 h	24 h	500 h	1000 h
0 min				
45 min				
280 min				

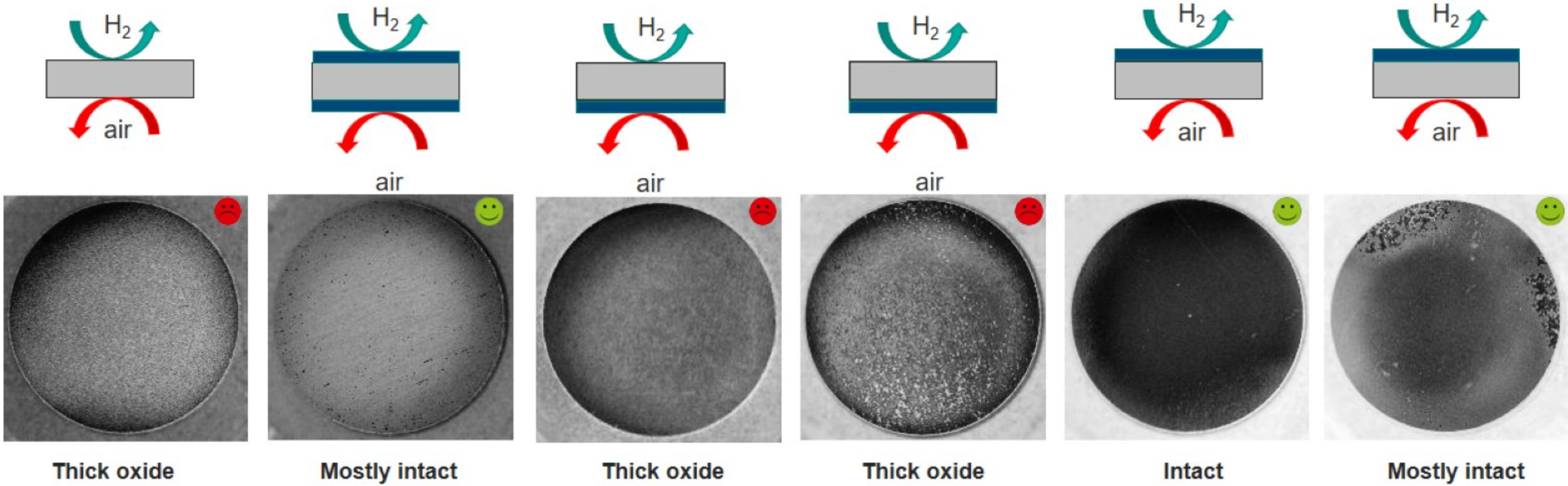
Exposure conditions: AISI 441, exposure temperature 600 °C, pre-oxidation temperature 800 °C in air.

Longer the pre-oxidation time, longer is the sample lifetime in dual conditions

Effect of pre-oxidation: which side?

Exposure conditions:

- Temperature : 600 °C
- Exposure time: 500 hours
- Pre-oxidation: 3 hours at 800 °C



Pre-oxidation reduces the ingress of hydrogen due to the oxide scale on the fuel facing side.

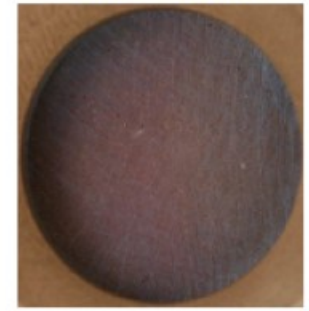
Thickness study

AISI 441 0.1 mm

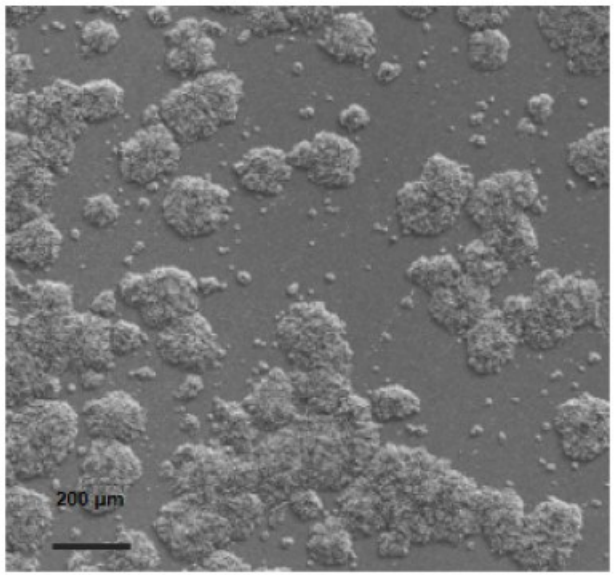
AISI 441 0.2 mm

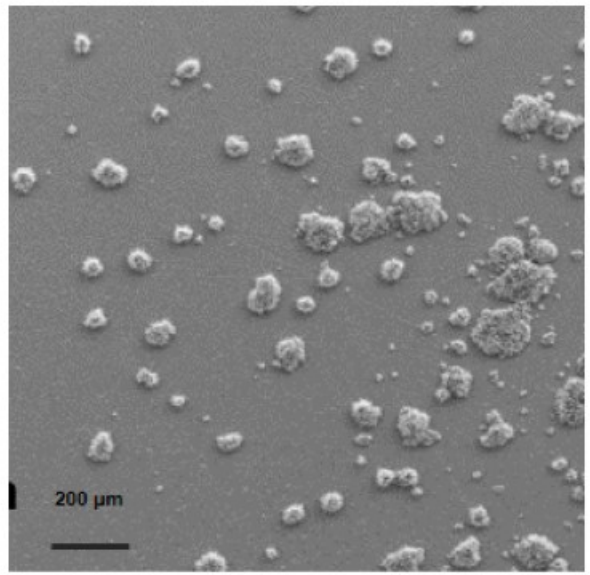
AISI 441 0.5 mm

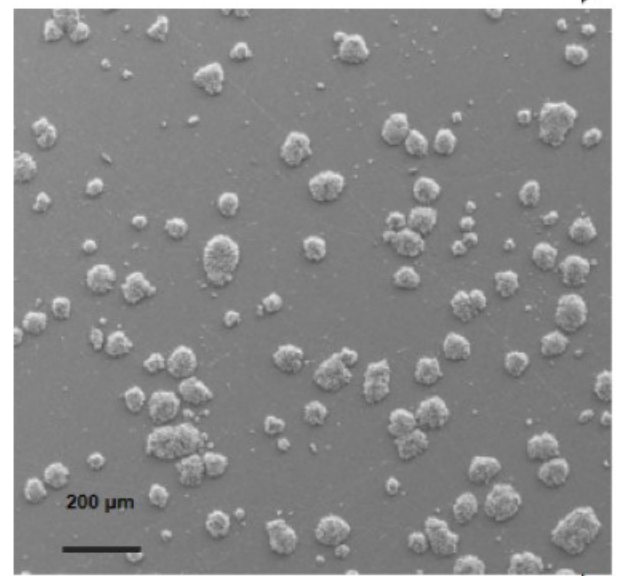
AISI 441 0.7 mm

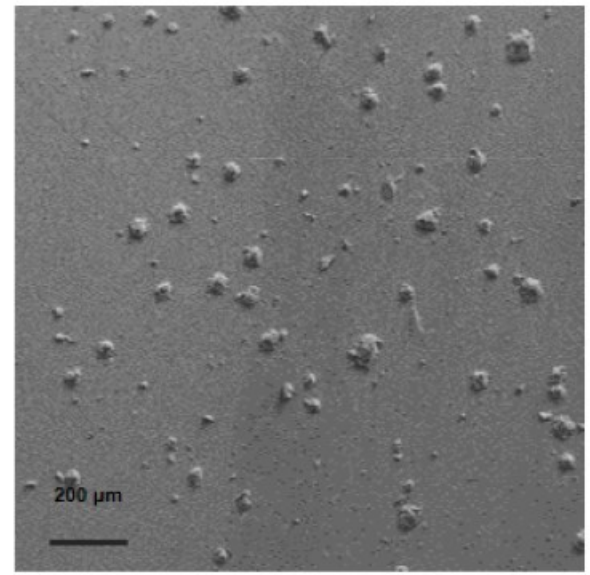


INCREASED THICKNESS









DECREASED CORROSION

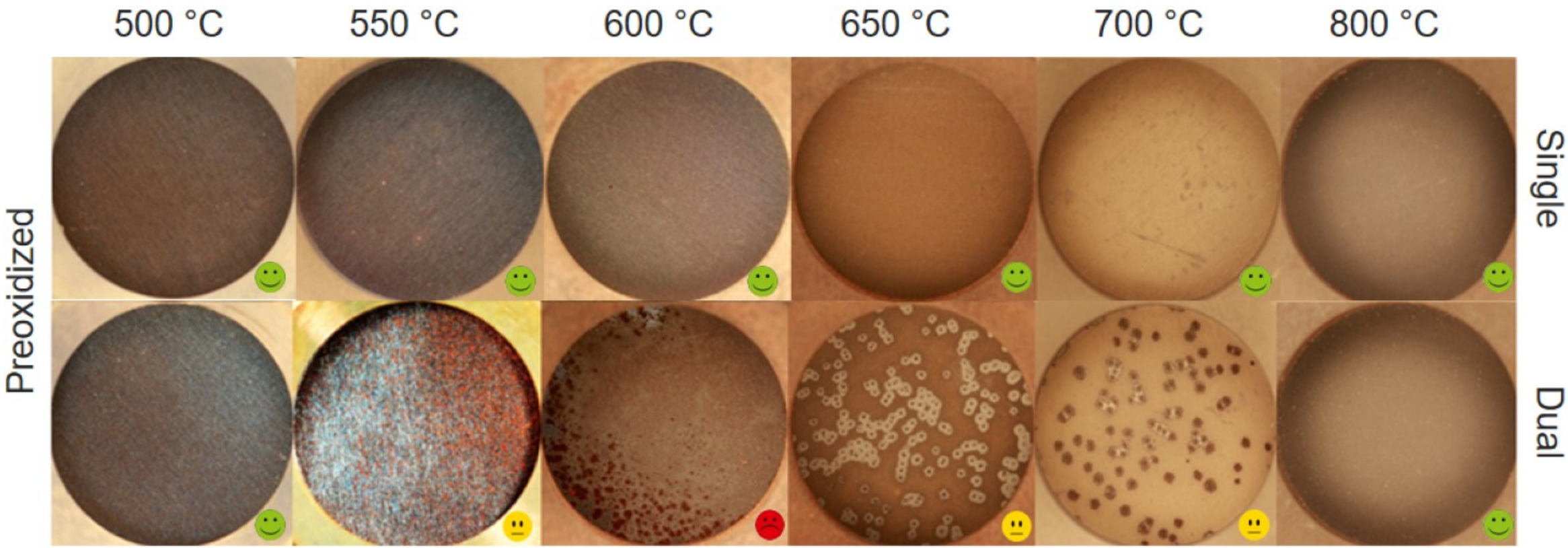
Exposure conditions: AISI 441, Temperature 600 °C, 20 minutes pre-oxidation at 800 °C, 2 weeks exposure

Sample thickness matters!!! Thinner samples perform worse under dual atmosphere conditions.

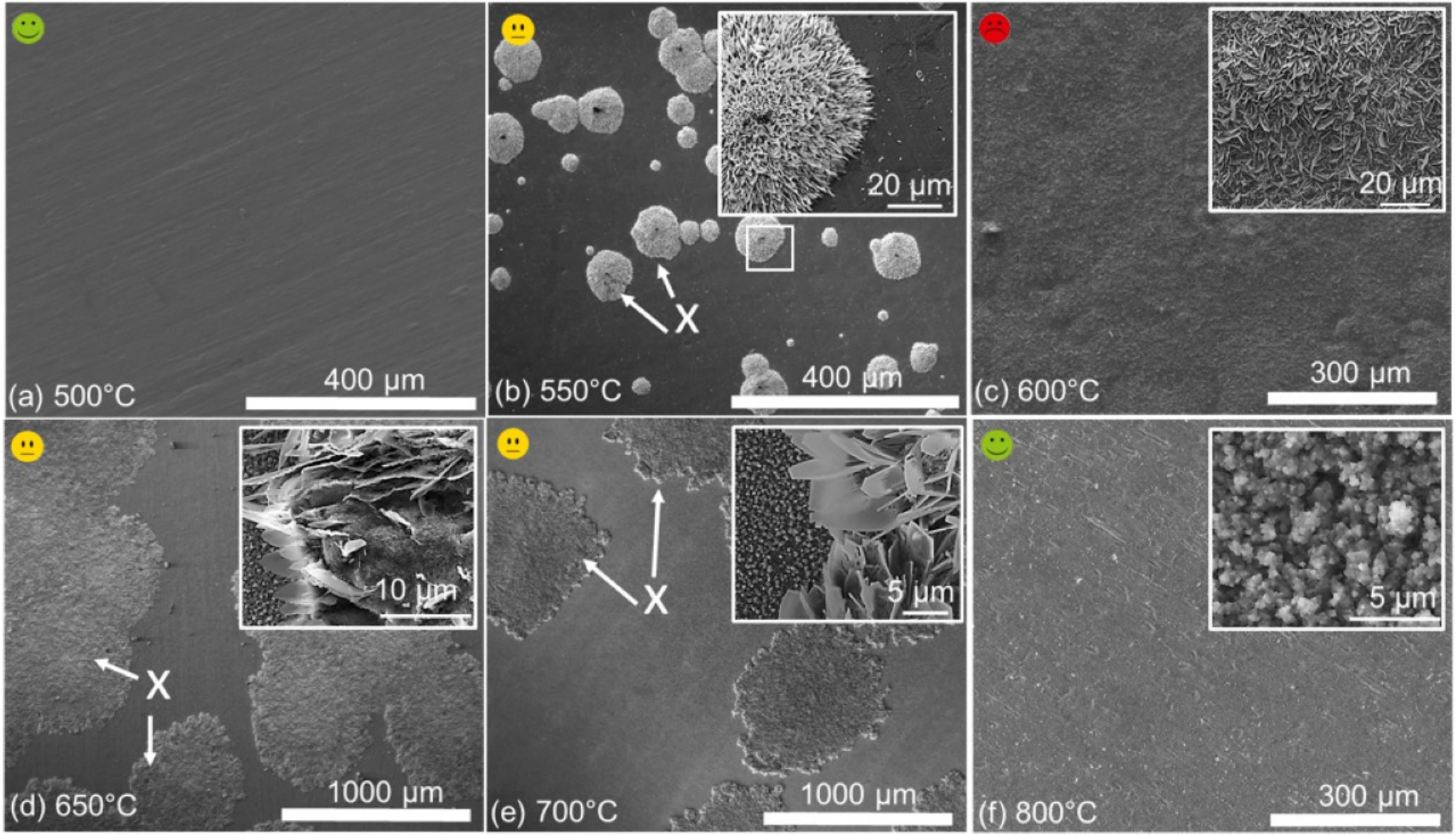
Effect of temperature

Exposure conditions:

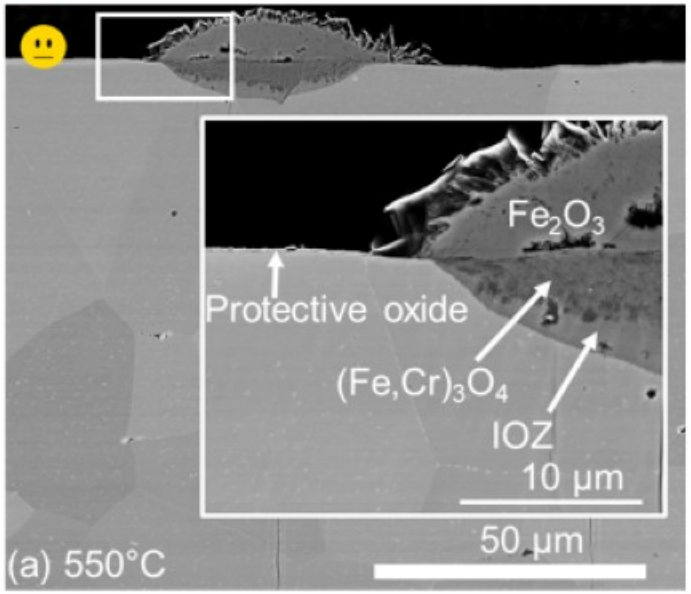
- Temperature : 500 °C, 550 °C, 600 °C, 650 °C, 700 °C, 800 °C
- Dual conditions: Air-3%H_2O // Ar-5%H_2-3%H_2O
- Pre-oxidation: 800 °C for 20 minutes
- Exposure time: 336 h

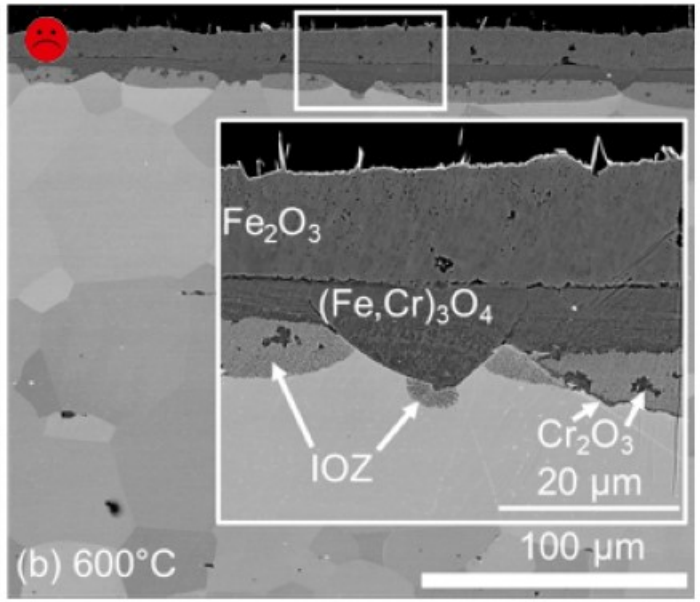


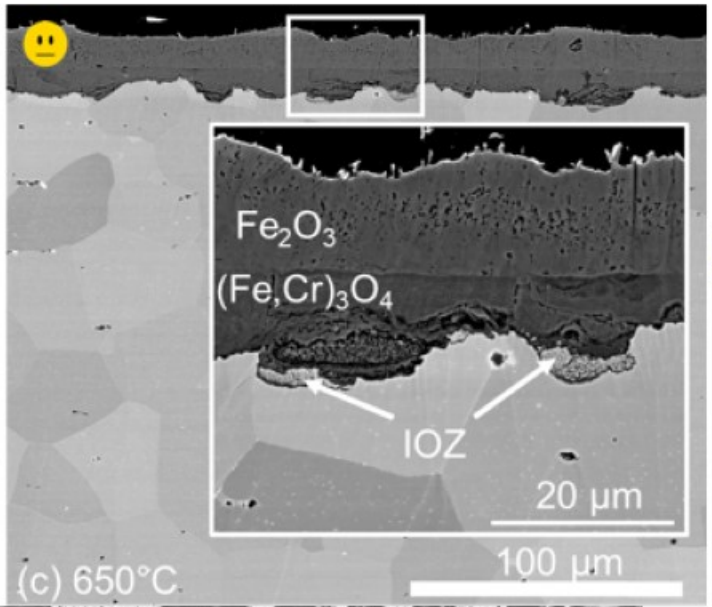
Pre-oxidized samples: SEM dual

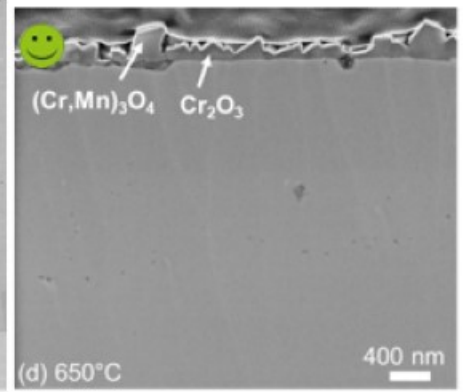


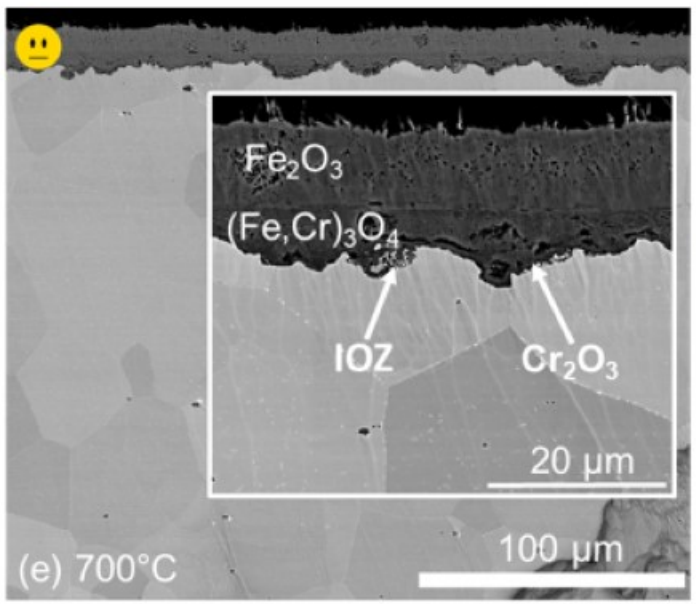
Pre-oxidized samples: SEM dual

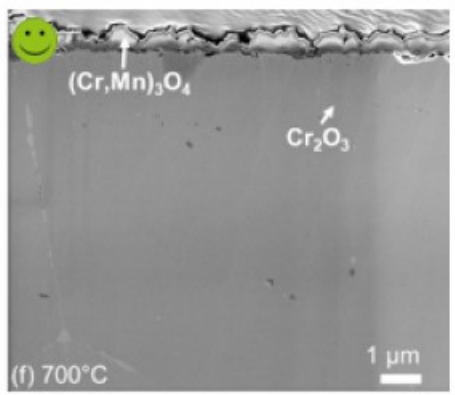


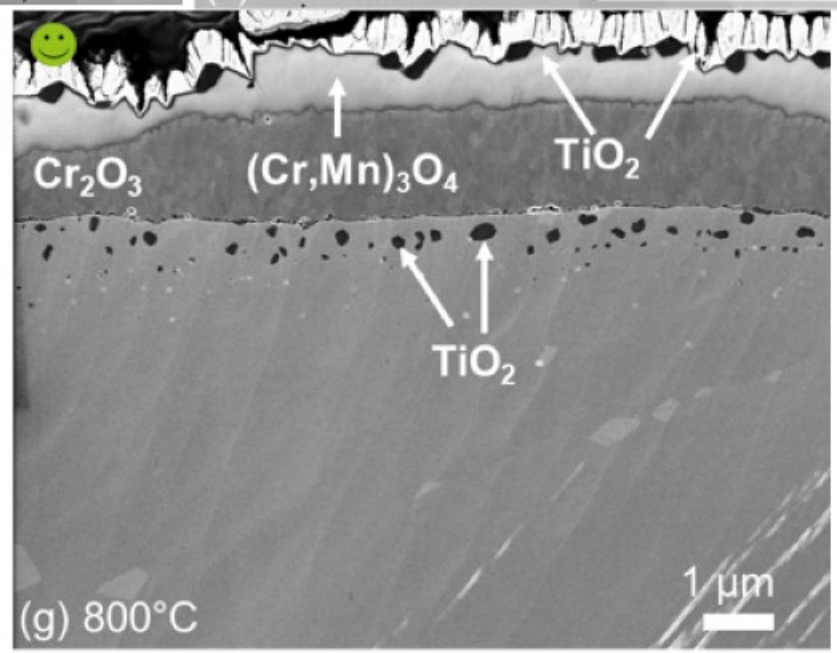




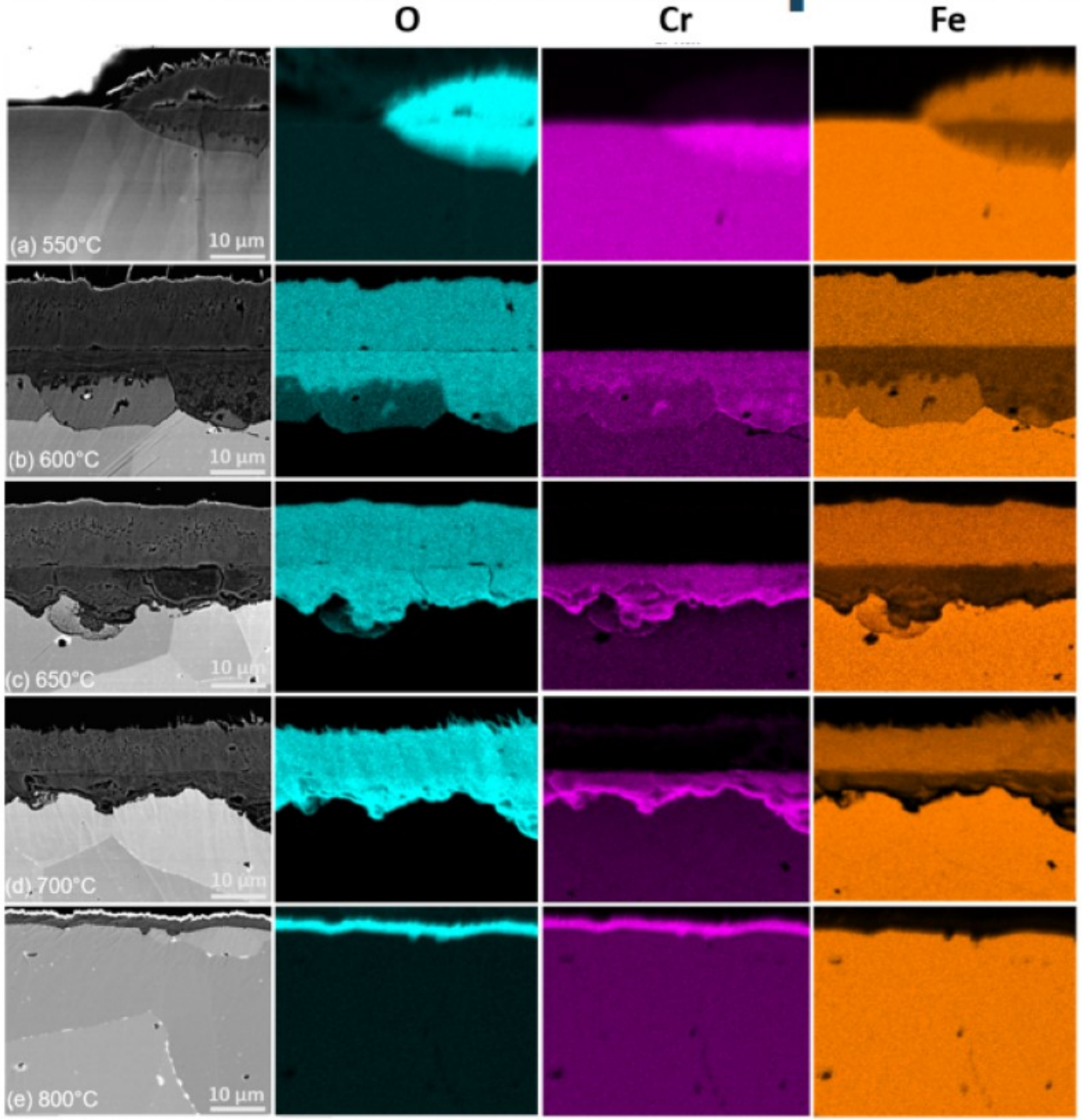






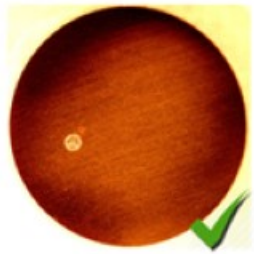


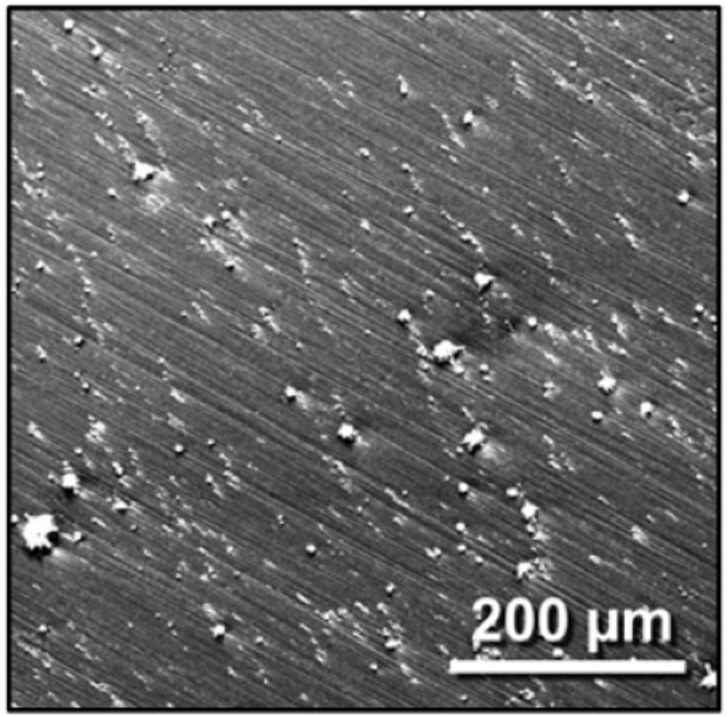
Pre-oxidized samples: SEM + EDX dual

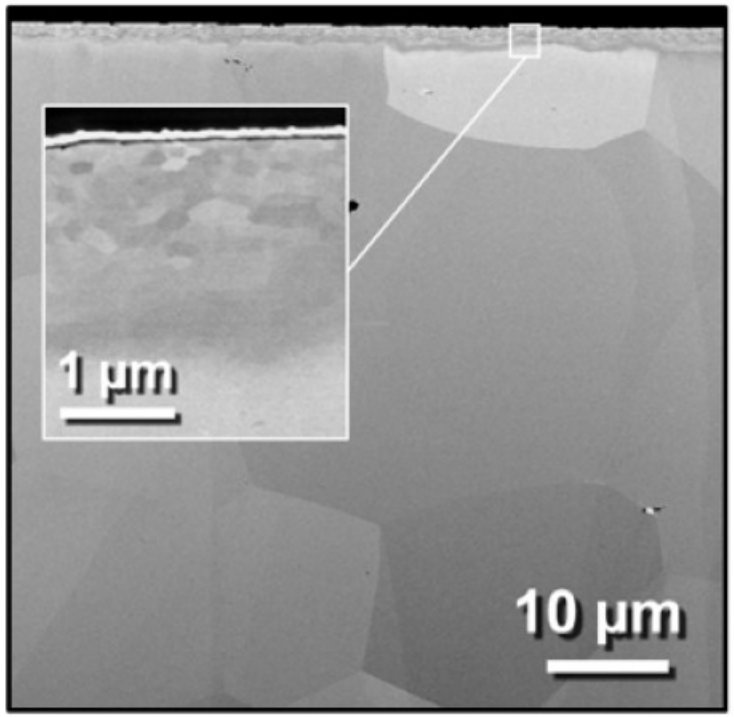


- Limited Fe_2O_3 nodules on the surface
- Maximum thickness of breakaway corrosion scale
- A continuous layer of Cr_2O_3 starts forming below the non protective oxide nodules
- Non-protective scale thickness decreased
- Fully protective Cr_2O_3 scale on top surface

Effect of surface modifications

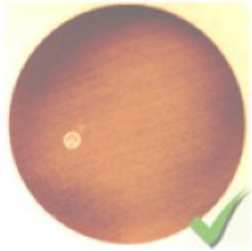
	336 h Exposure
Ground 1200P	
As-received	
Polished (¼ µm Diamond)	





Exposure conditions: AISI 441, non-preoxidized, dual atmosphere, 600 °C, 336 hours

Effect of surface modifications

	336 h Exposure
Ground 1200P	
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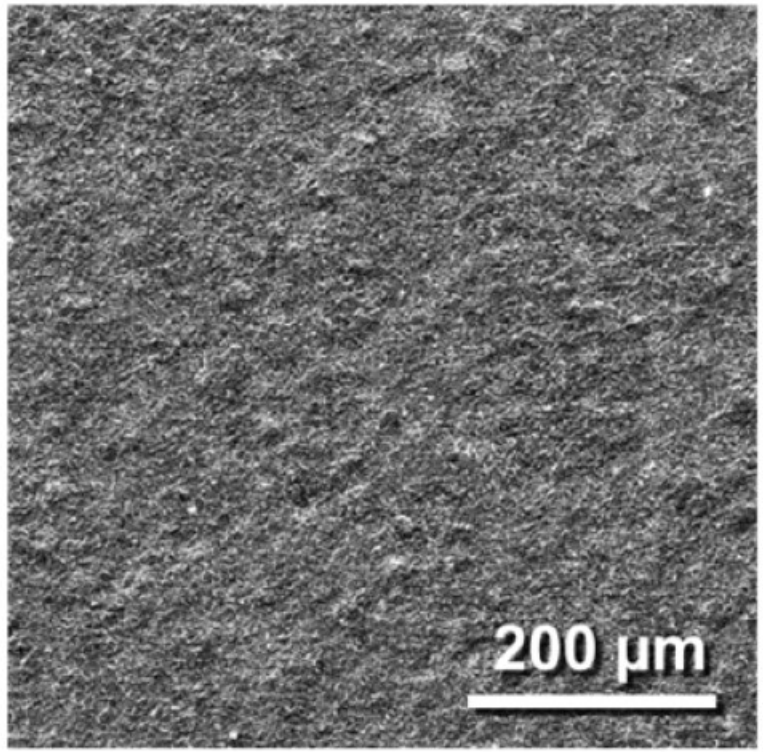

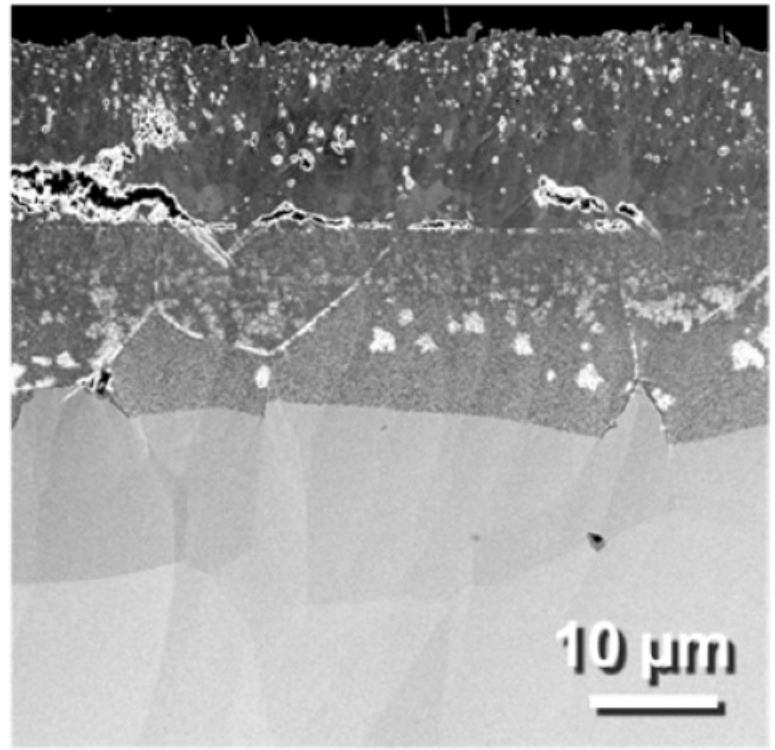

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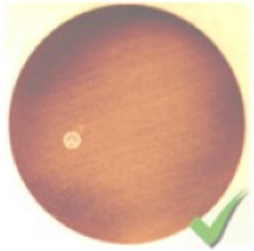
Ground 1200P	
As-received	
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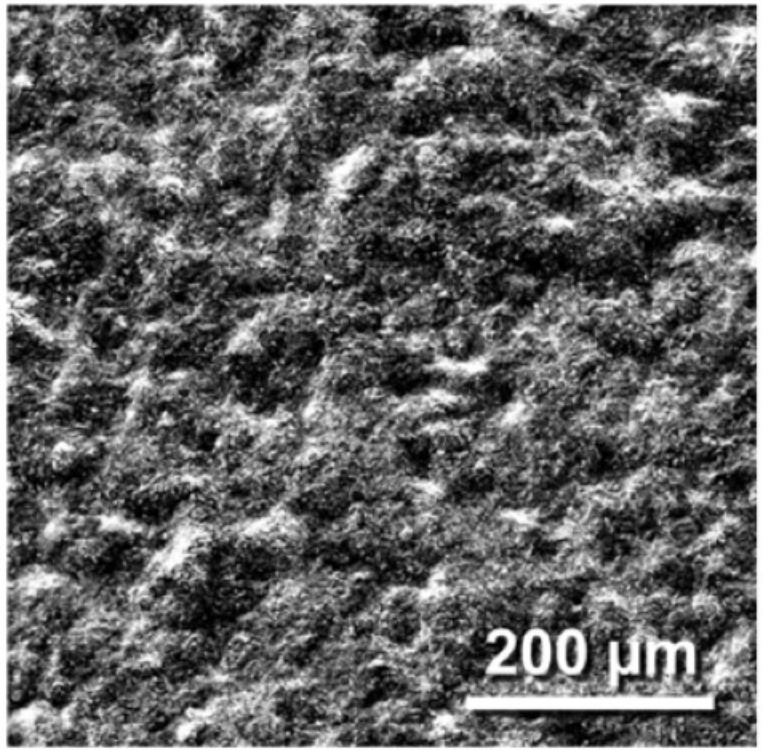
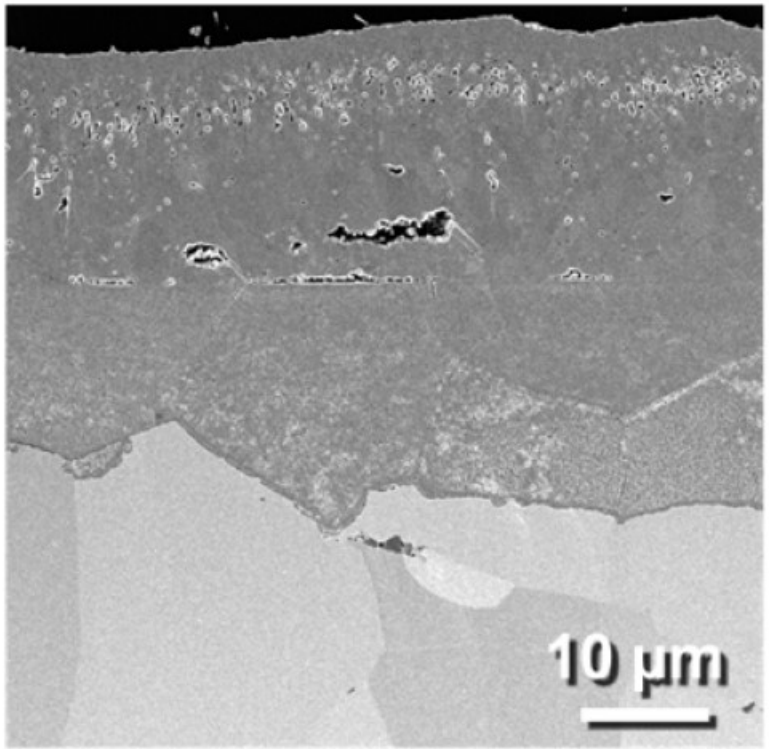
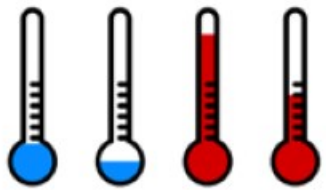




Exposure conditions: AISI 441, non-preoxidized, dual atmosphere, 600 °C, 336 hours

Final outcome:

Pre-oxidation is the most effective way of protecting the steel from dual atmosphere effect acting like a barrier, especially at fuel side



An inverse temperature effect is noticed above 600°C

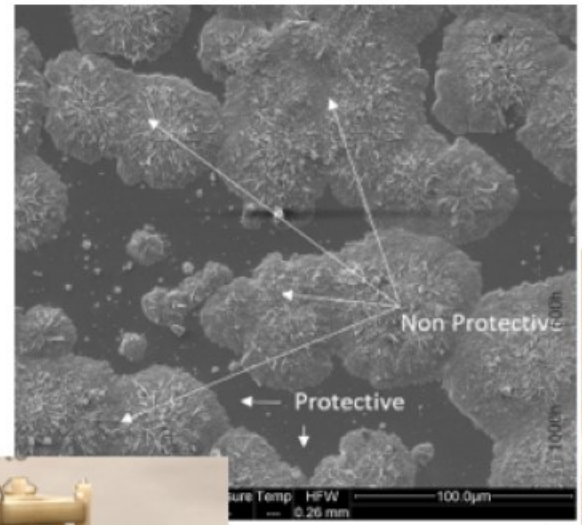
Thicker substrate helps reducing the dual atmosphere effect

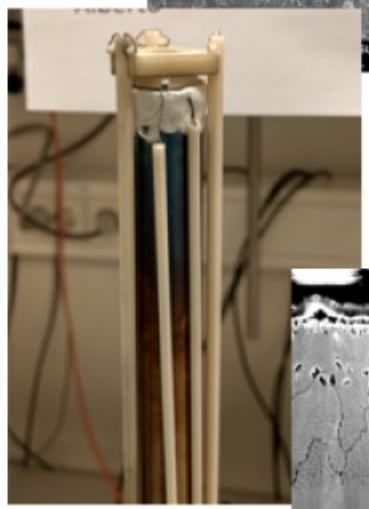
Including dislocations close to the metal surface helps Cr diffusion and protective scale formation

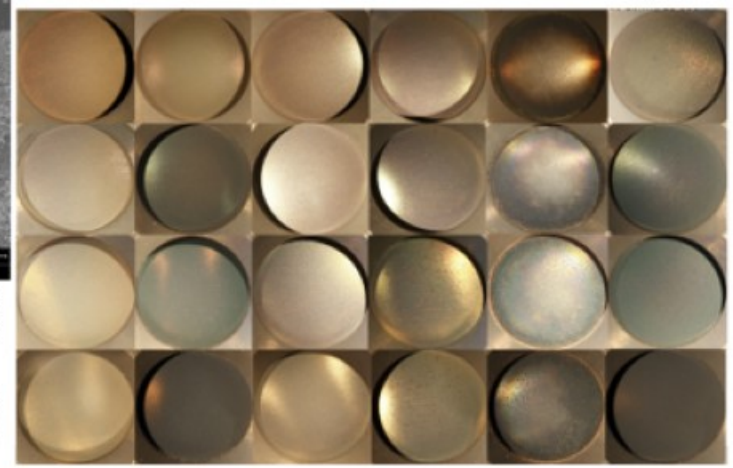
Ongoing studies

Dual atmosphere research fields

- Study on the initial stages of dual atmosphere corrosion
- Grain boundaries effect
- Mechanistic modeling of dual atmosphere effect
- Material comparison in dual atmosphere conditions
- Effect of applied current

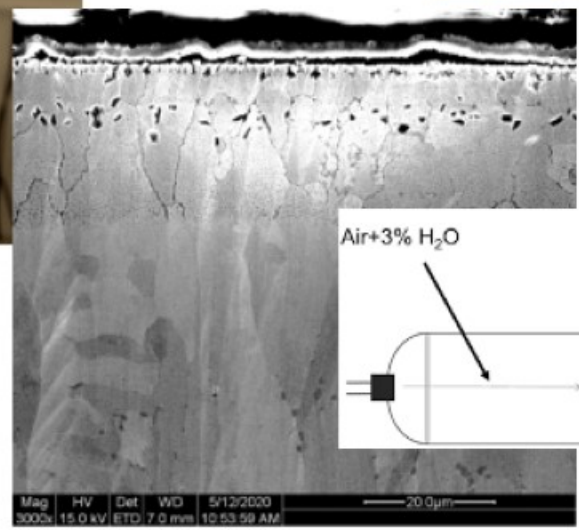


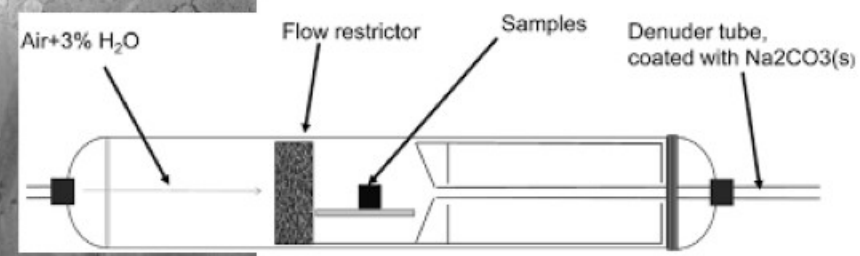




Single atmosphere research fields

- Coating development for IT-SOFC
- Chromium evaporation and oxidation studies
- ASR study on interconnects





.. And a lot more

Acknowledgments

The High Temperature Corrosion Centre

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