



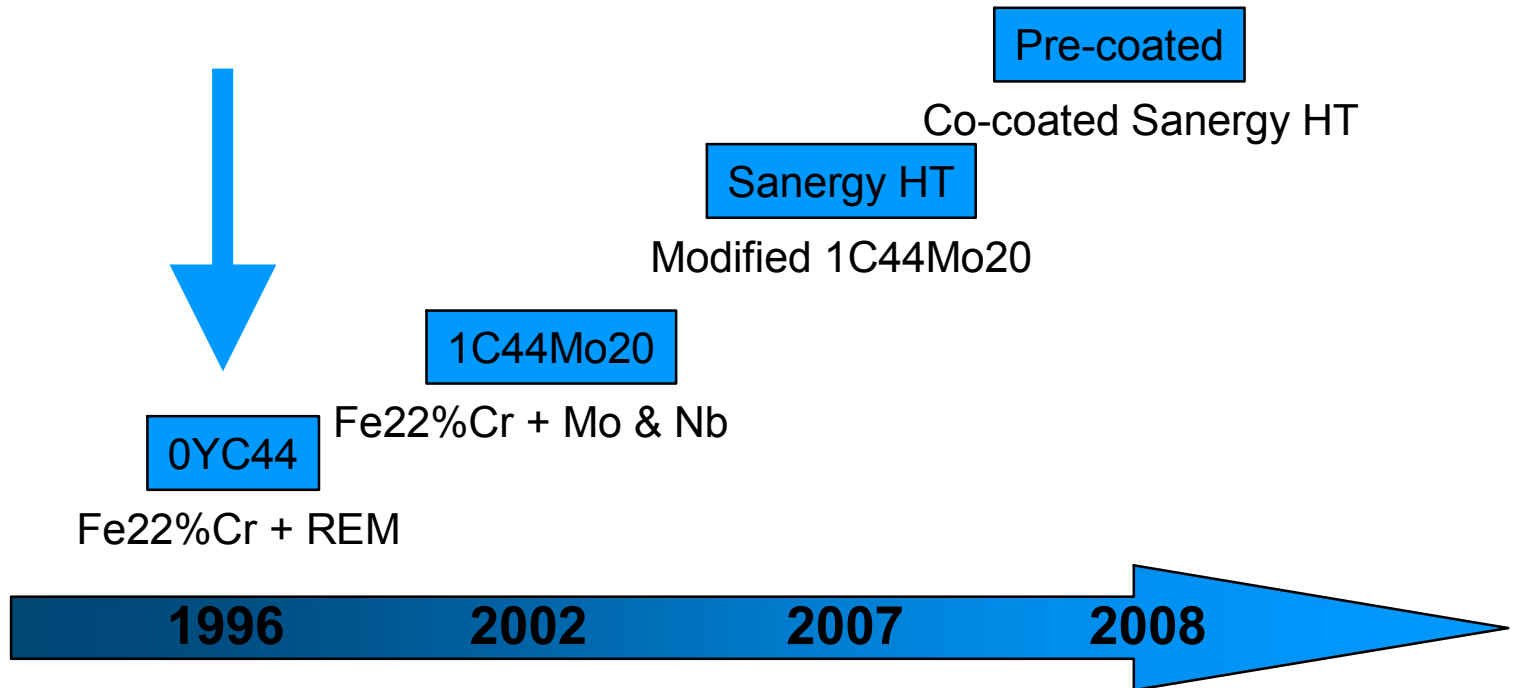
**Pre-Coated Sandvik Sanergy™ HT:
A New Advanced Interconnector Material in SOFCs**

**Mikael Schuisky
R&D Manager
Surface Technology**

Outline

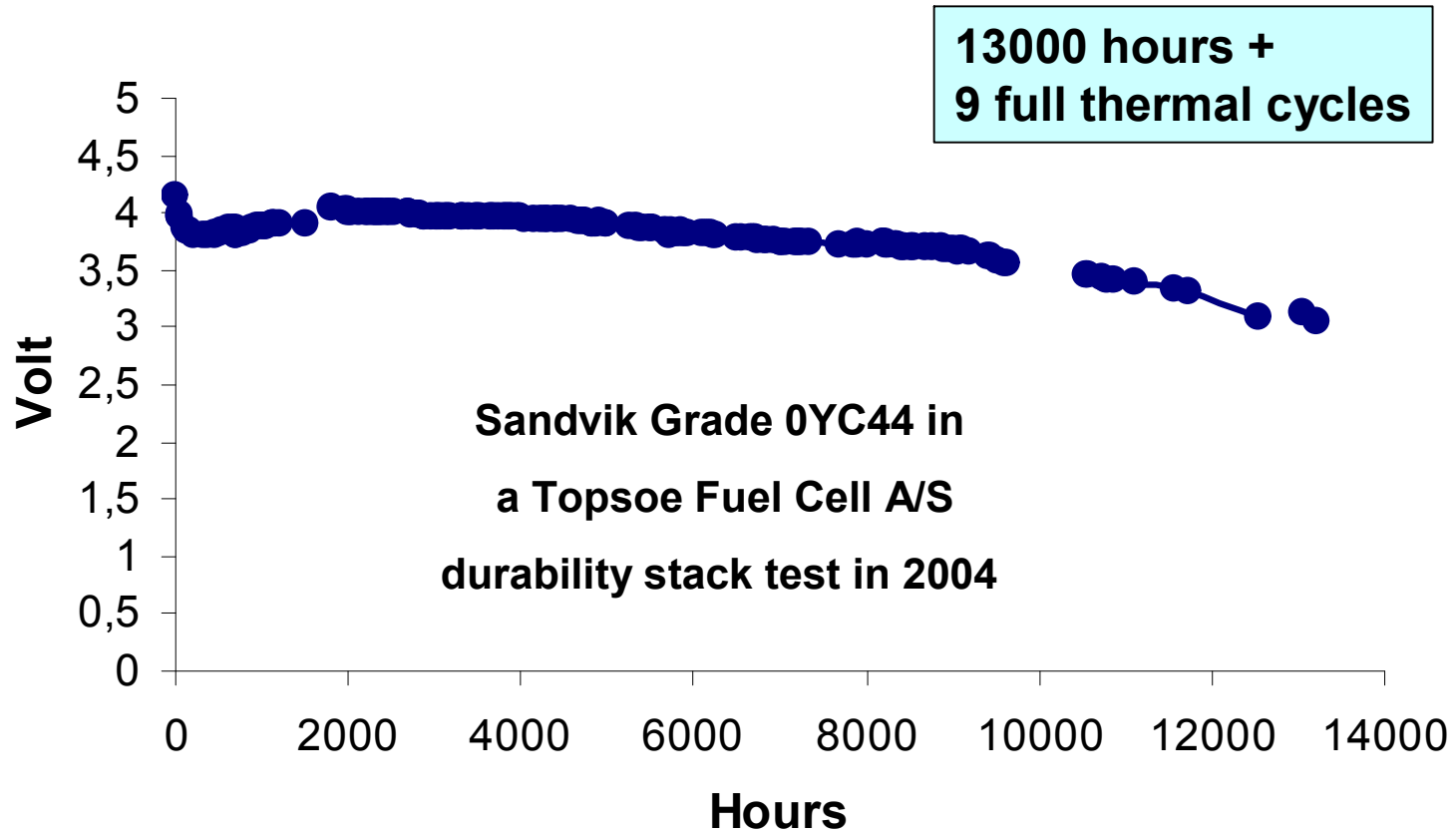
- **Background**
- **Sandvik Sanergy HT**
 - ✓ High temperature mechanical data
 - ✓ Electrical performance
- **Sandvik Surface Technology**
- **Pre-coated Sandvik Sanergy HT vs. uncoated**
 - ✓ Chromium evaporation studies
 - ✓ Electrical degradations studies
 - ✓ Stack test
- **Summary**
- **Acknowledgements**

Sandvik's alloy development for SOFC interconnect materials

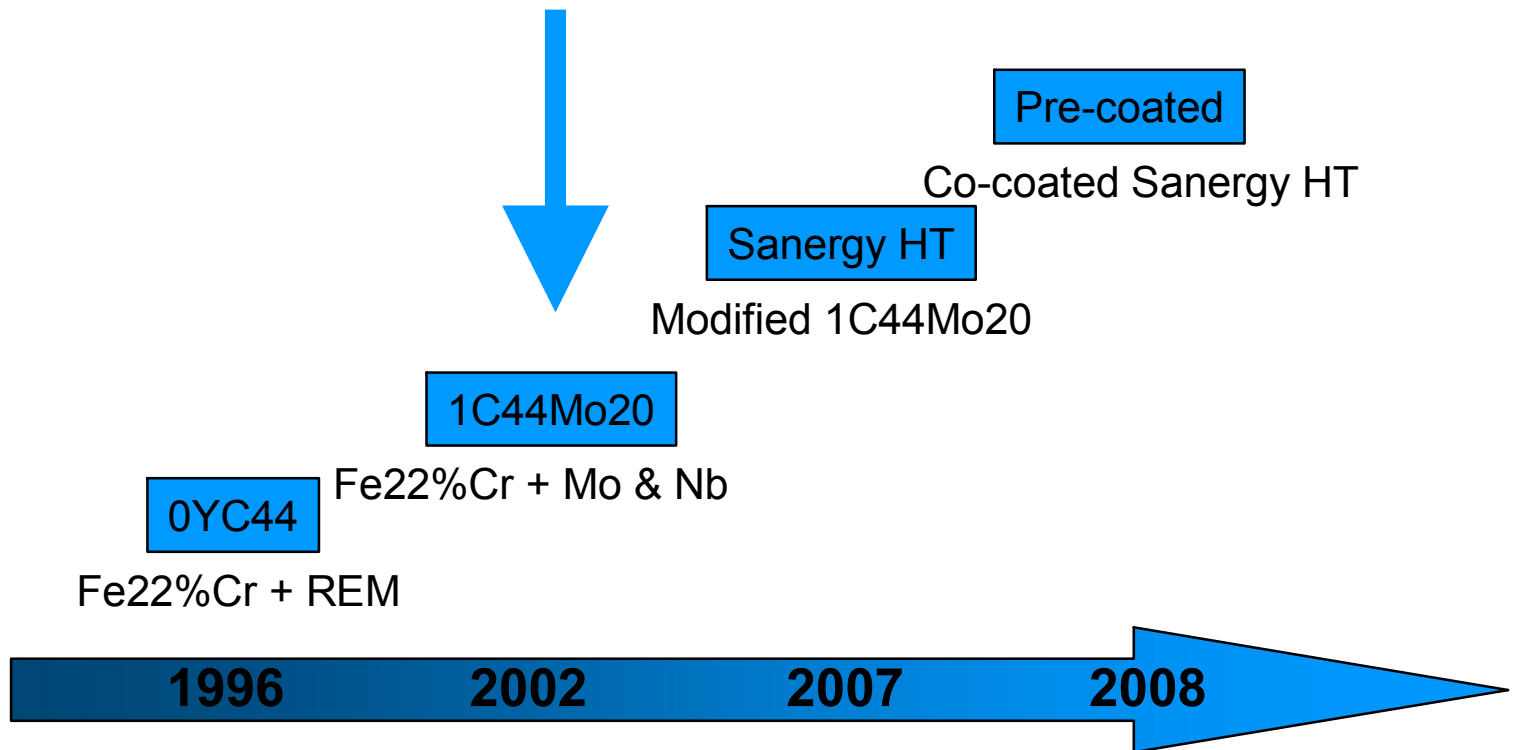


Stack Durability - 5 cell (12 x 12)

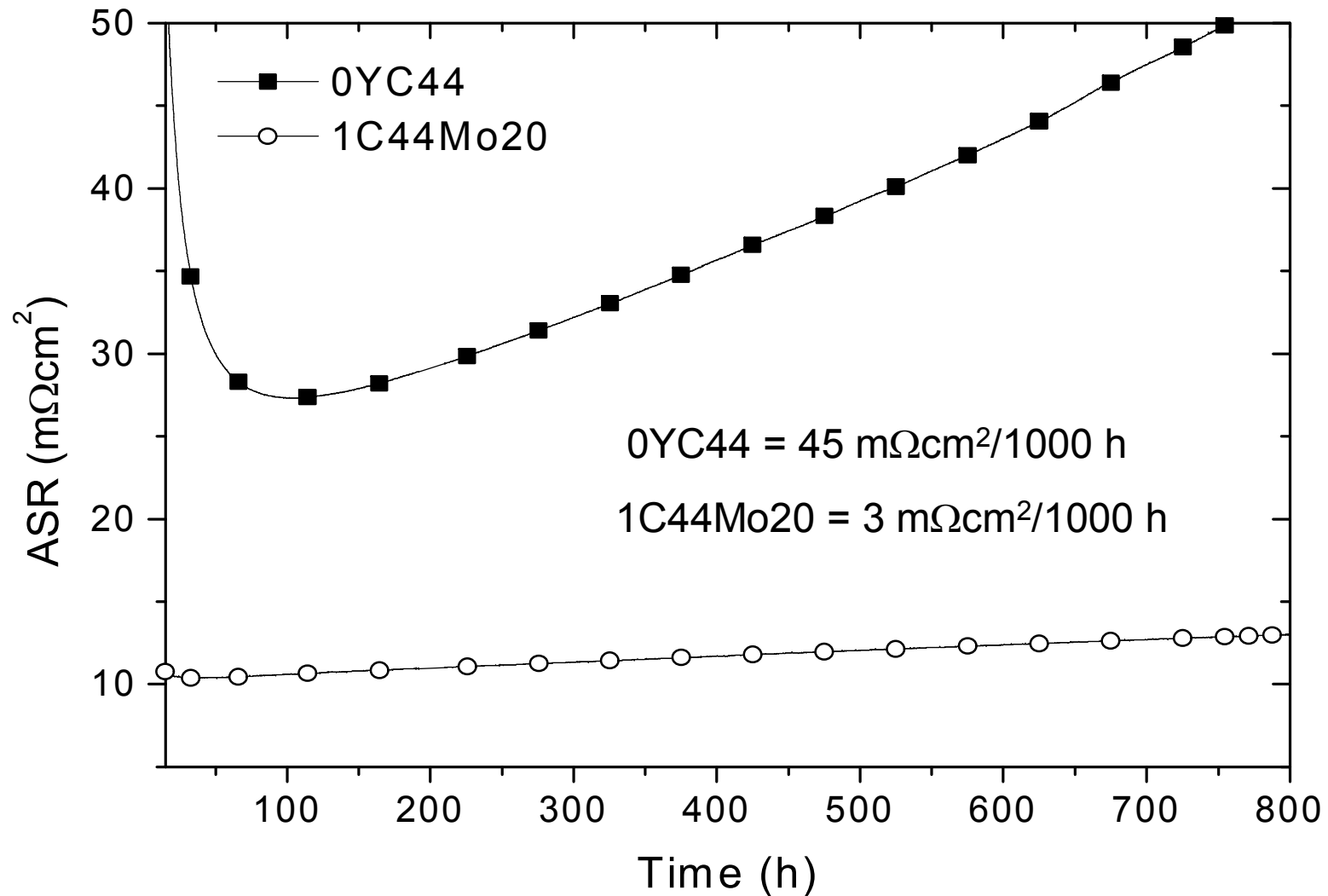
800 °C - 20 A



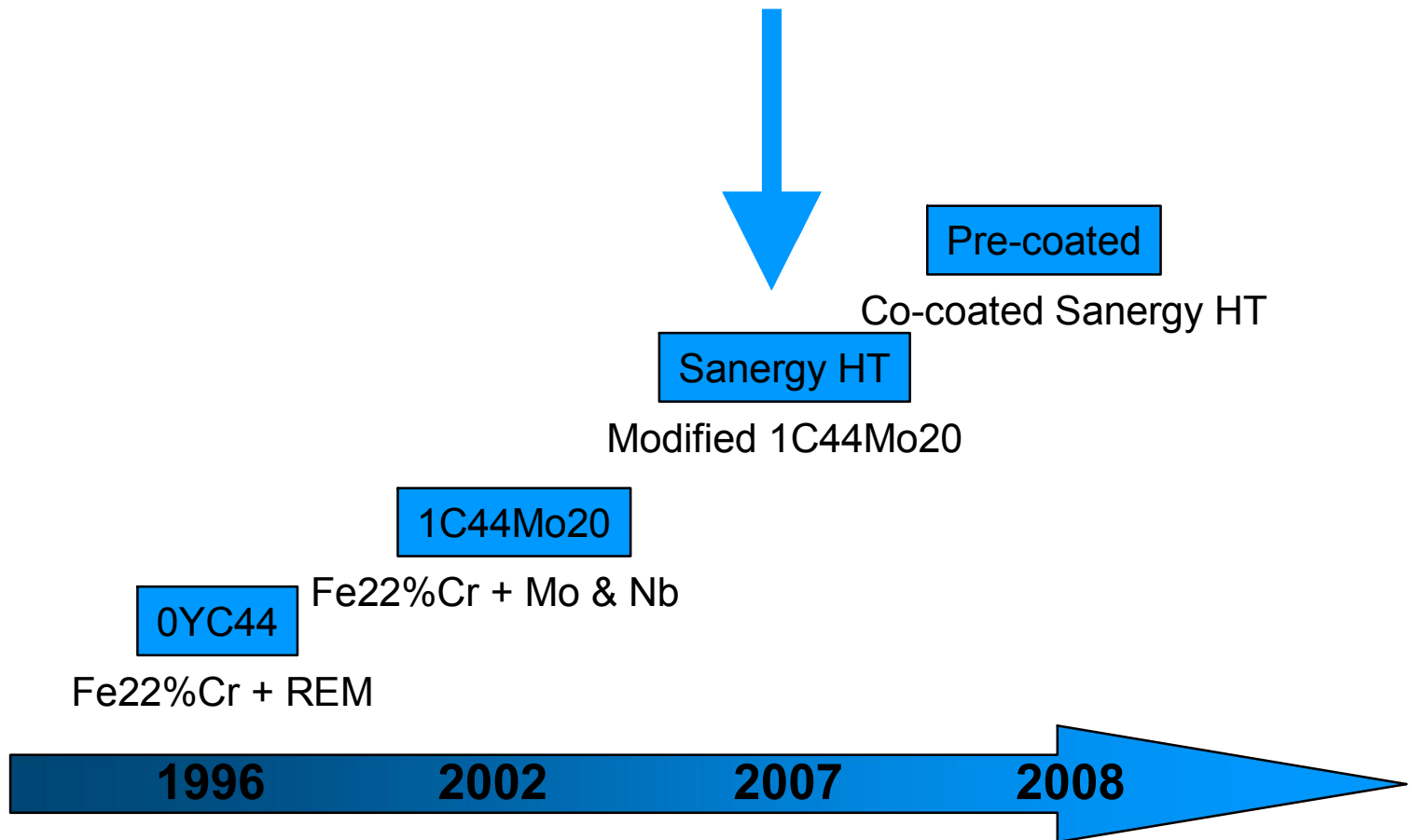
Sandvik's alloy development for SOFC interconnect materials



Area specific resistance tested at Risö in simulated SOFC environment



Sandvik's alloy development for SOFC interconnect materials

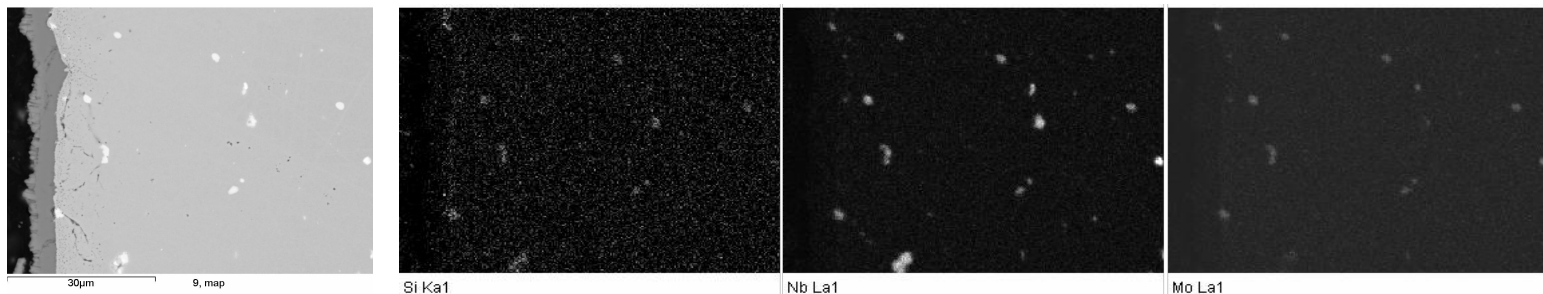


Sandvik Sanergy HT

- Is a ferritic chromium steel with the nominal composition

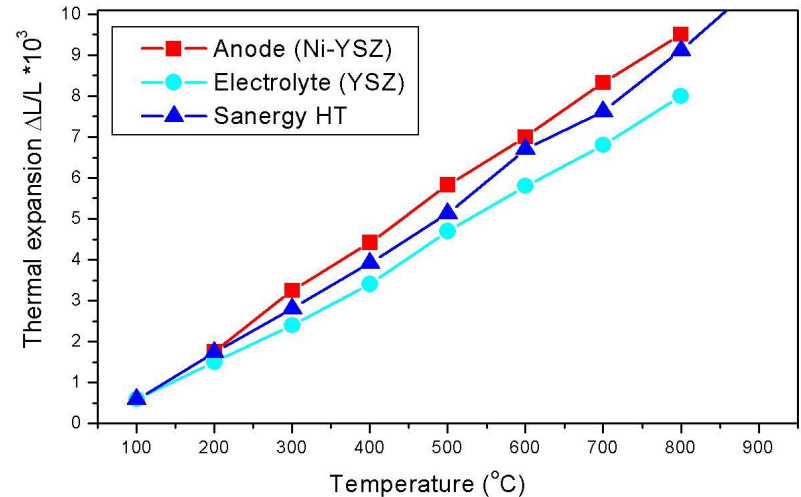
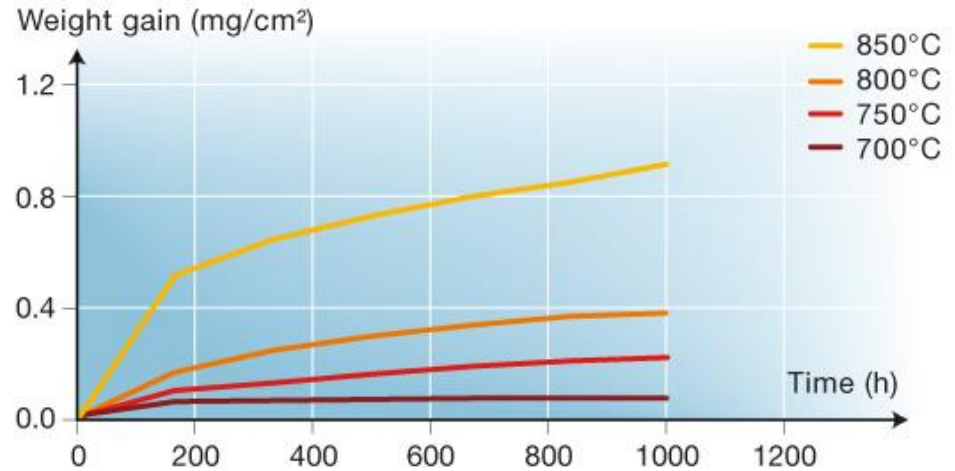
Cr	Mn	Si	Mo	Nb	Add.	Fe
22	≤ 0.5	≤ 0.30	1.0	0.75	Ti	Bal.

- The 22% Cr added is to give good corrosion resistance and the right thermal expansion.
- Mn forms spinel oxides at the surface.
- Mo and Nb is added to increase the high temperature strength and to trap the residual silicon in particles inside the matrix.
- Ti is added to improve the adherence of the oxide scale.
- Si is kept low to avoid the formation of silica under the chromia scale



Special features of Sandvik Sanergy HT

- Good high temperature corrosion resistance
- Well matched thermal expansion
- Improved high temperature strength
- Low electrical degradation
- Good processing and forming characteristics



High temperature mechanical data



3 times higher strength at SOFC operating temperature compared to conventional steels

SANERGY HT

Proof Strength at 800°C = 64 MPa

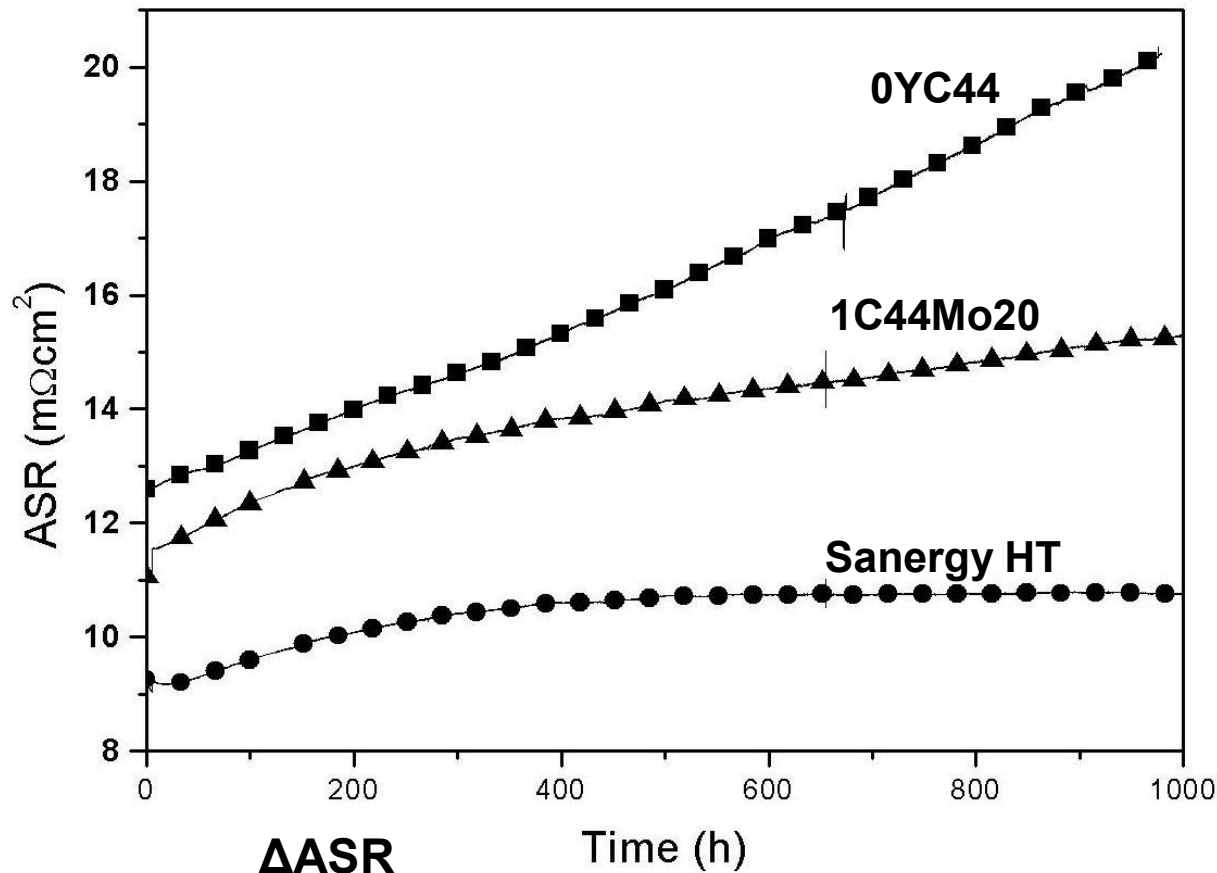
Tensile Stress at 800°C = 93 MPA

Commercial Fe22%Cr alloy

Proof Strength at 800°C = 28 MPa

Tensile Stress at 800°C = 28 MPA

Area specific resistance tested at Risö in simulated SOFC environment

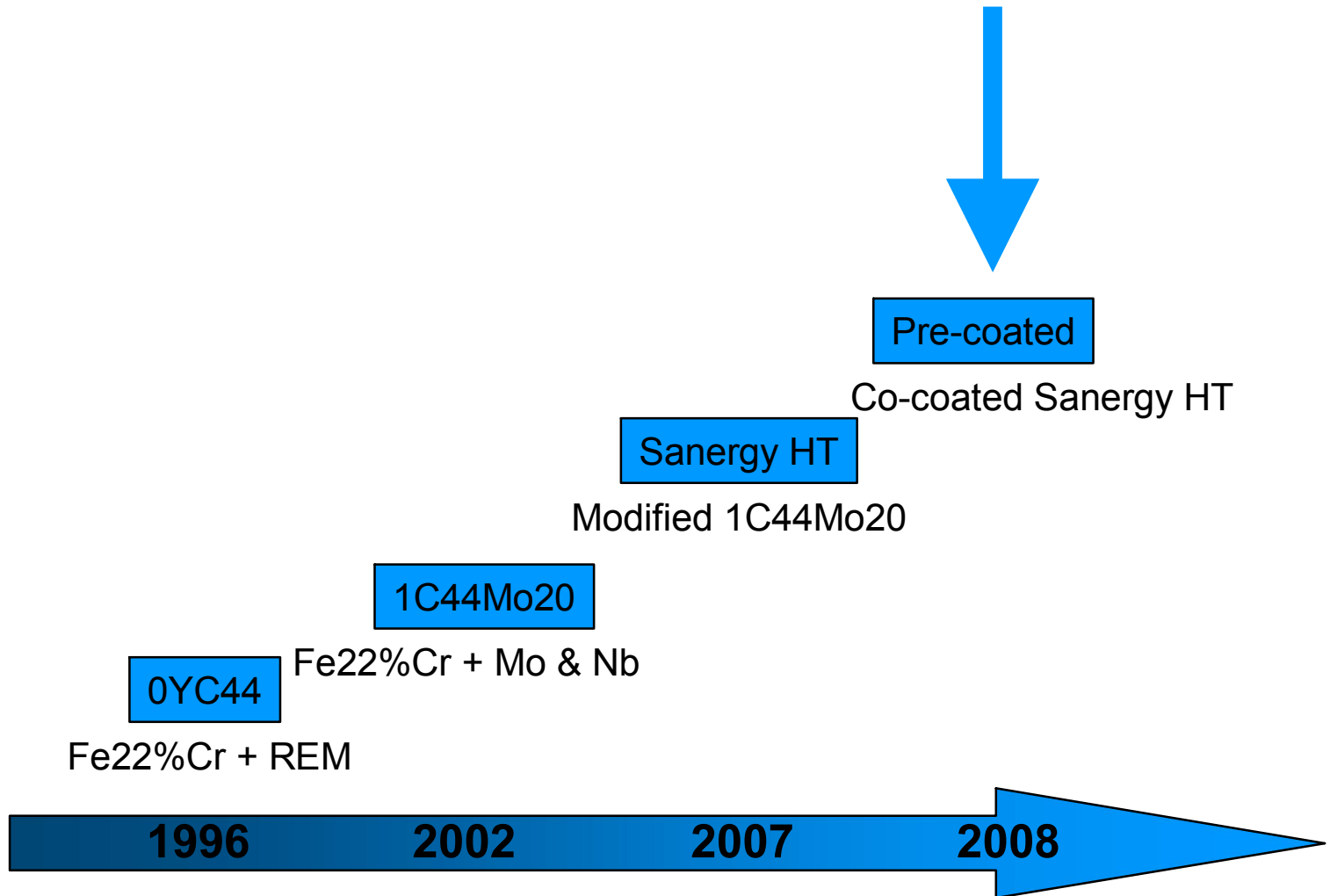


0YC44 ~ 7 mΩcm²/1000 h

1C44Mo20 ~ 3 mΩcm²/1000 h

Sanergy HT ~1 mΩcm²/1000h

Sandvik's alloy development for SOFC interconnect materials



The Surface Technology

is a part of Sandviks integrated production

**Electric-Arc-Melting –
AOD-refinement – Continuous Casting**

- Chemical composition
- Inclusion control

Hot rolling

- Strip shape

Cold rolling

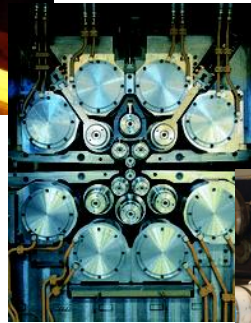
**Thickness tolerance – Flatness - Surface Standard
Mechanical strength**

Surface technology

- Physical properties
- Mechanical properties
- Corrosion properties
- Decorative appearance

Slitting

- Tolerances
- Straightness
- Burrs

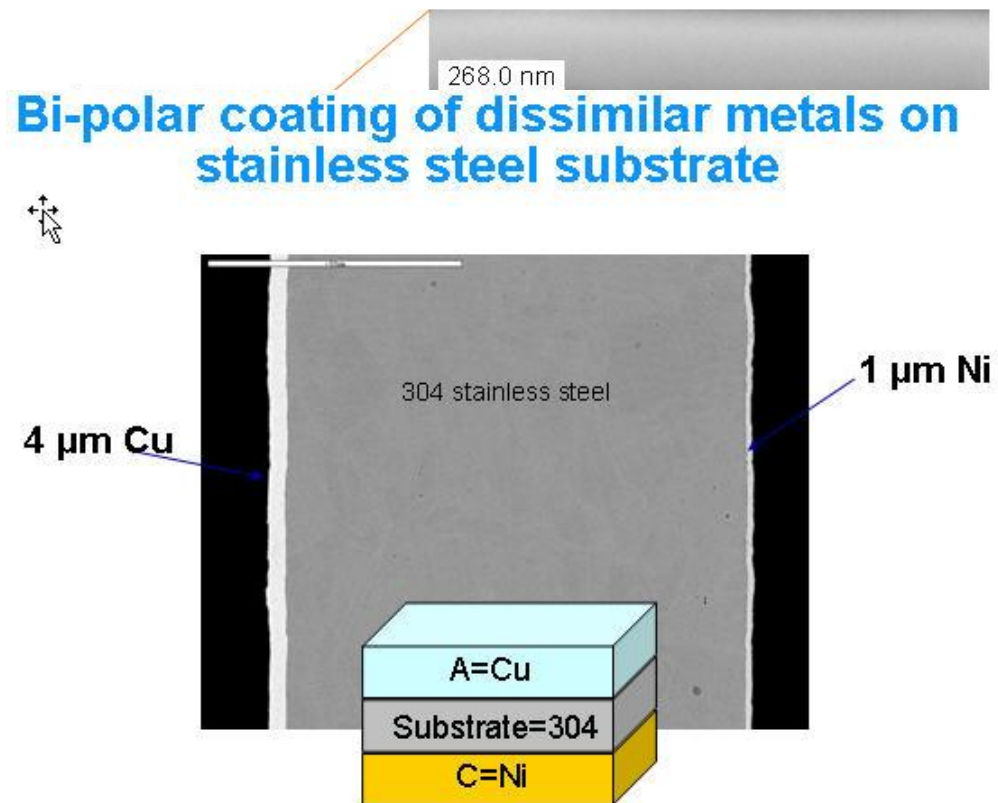




Surface Technology

For high demanding strip applications

- Large flexibility in production possibilities
- Single-sided coatings
 - ✓ Commonly used for spring contacts
 - ✓ Decorative layers
- Multi-layered structures
 - ✓ Improved adhesion and/or corrosion resistance by the underlying layer
- Bi-polar structures
 - ✓ Can be the same coating on both sides or different



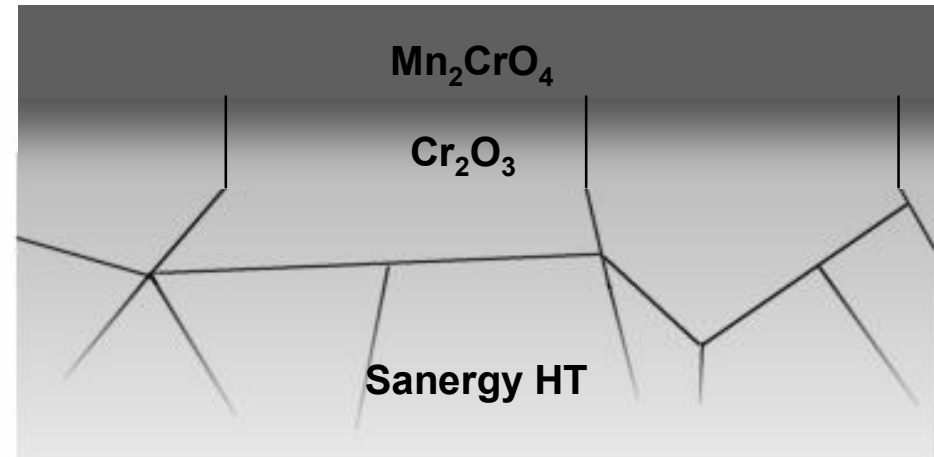
Why pre-coated Sandvik Sanergy HT

- **Cost savings**
 - ✓ The cost of batch coating plates
 - ✓ Handling costs (usually the stamping/shaping company is not the same as the coating company)
- **The main technical benefits with the Co coat are:**
 - ✓ Reduce or eliminate Cr-evaporation from the ferritic chromium steel surface.
 - ✓ Increase the surface conductivity of the oxide scale by promoting spinel $(\text{Co,Mn})_3\text{O}_4$ formation.
 - ✓ And by doing so lowering the degradation rate of the fuel cell

Difference in oxide formation on uncoated Sanergy HT and Pre-coated Sanergy HT

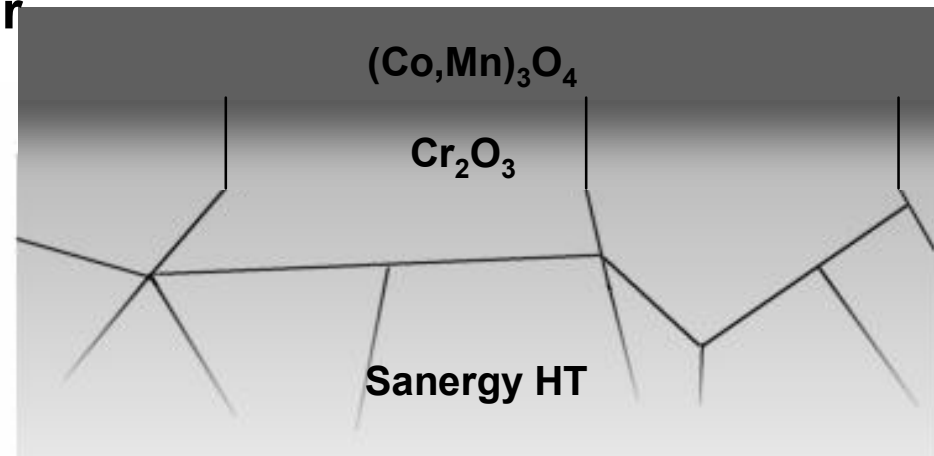
Uncoated Sanergy HT

Mn_2CrO_4 type of spinel as top layer



Pre-coated Sanergy HT

$(Co,Mn)_3O_4$ type of spinel as top layer



Conductivity of different Co-Mn spinels are* (at 800°C):

Co_3O_4 $\sigma = 6.0$ S/cm

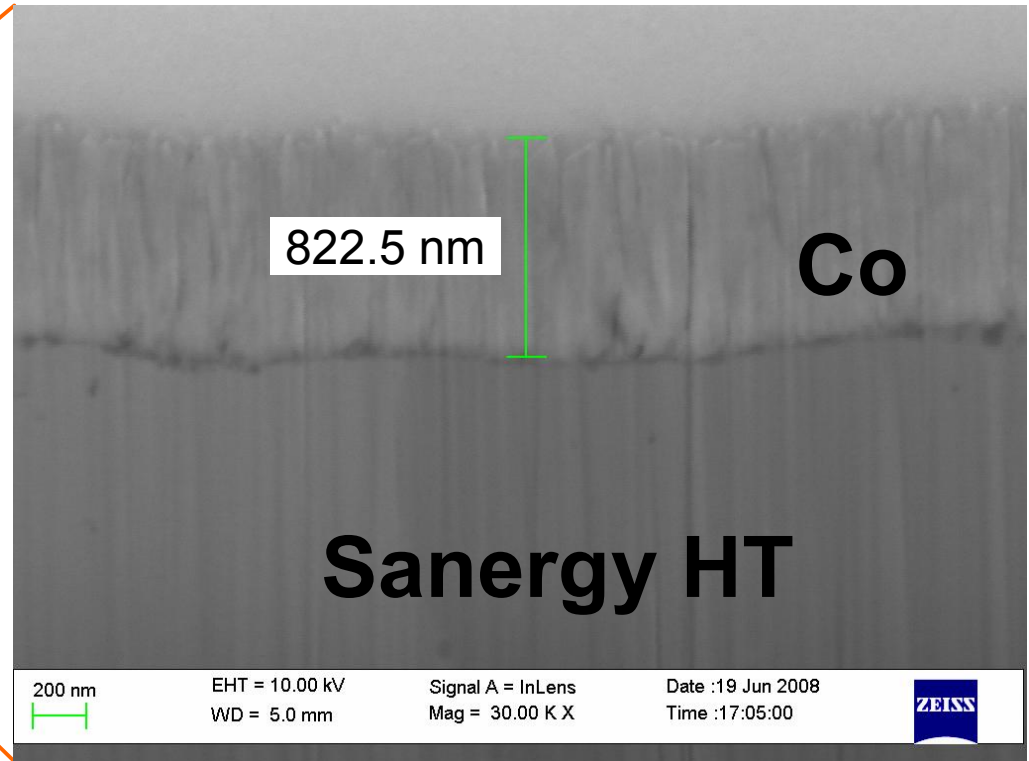
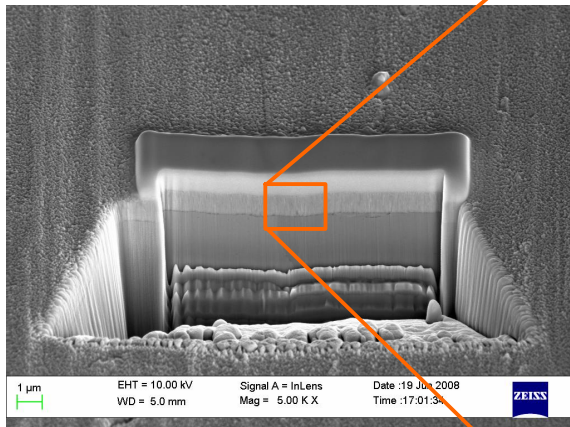
Co_2MnO_4 $\sigma = 60$ S/cm

$CoMn_2O_4$ $\sigma = 6.4$ S/cm

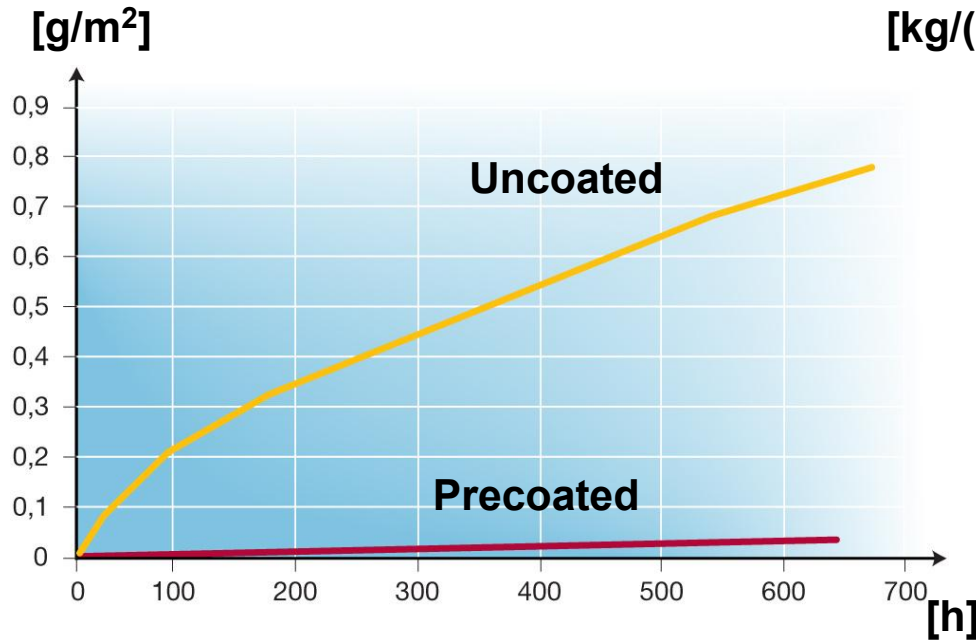
Mn_3O_4 $\sigma = 0.1$ S/cm

*A. Petric, H. Ling, J. Am. Ceram. Soc. 90 (2007) 1515.

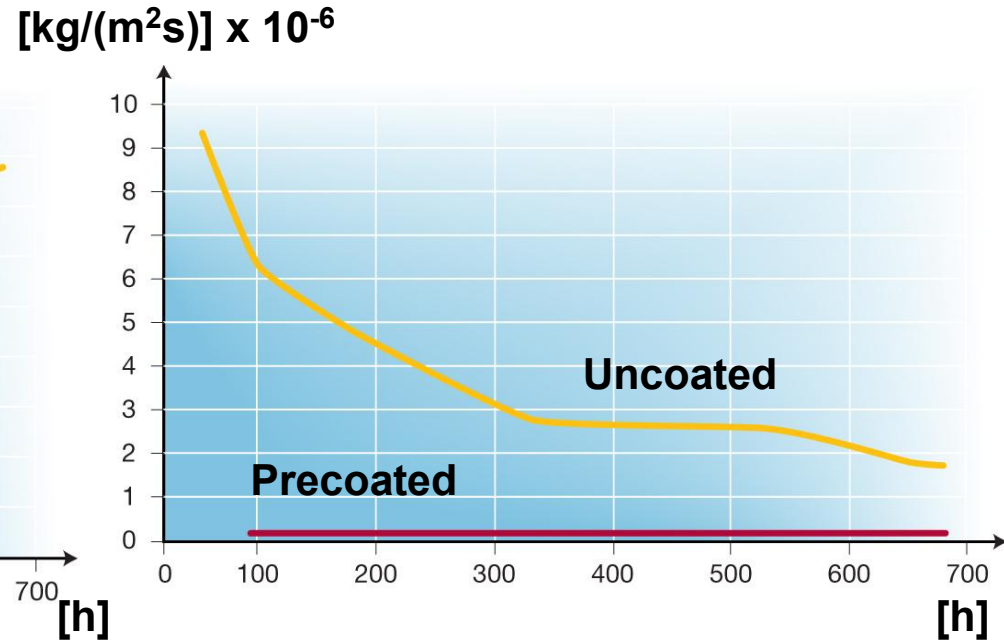
SEM Cross section of a Pre-coated Sandvik Sanergy HT



Chromium evaporation (850°C in 20% O₂ and 3% H₂O)



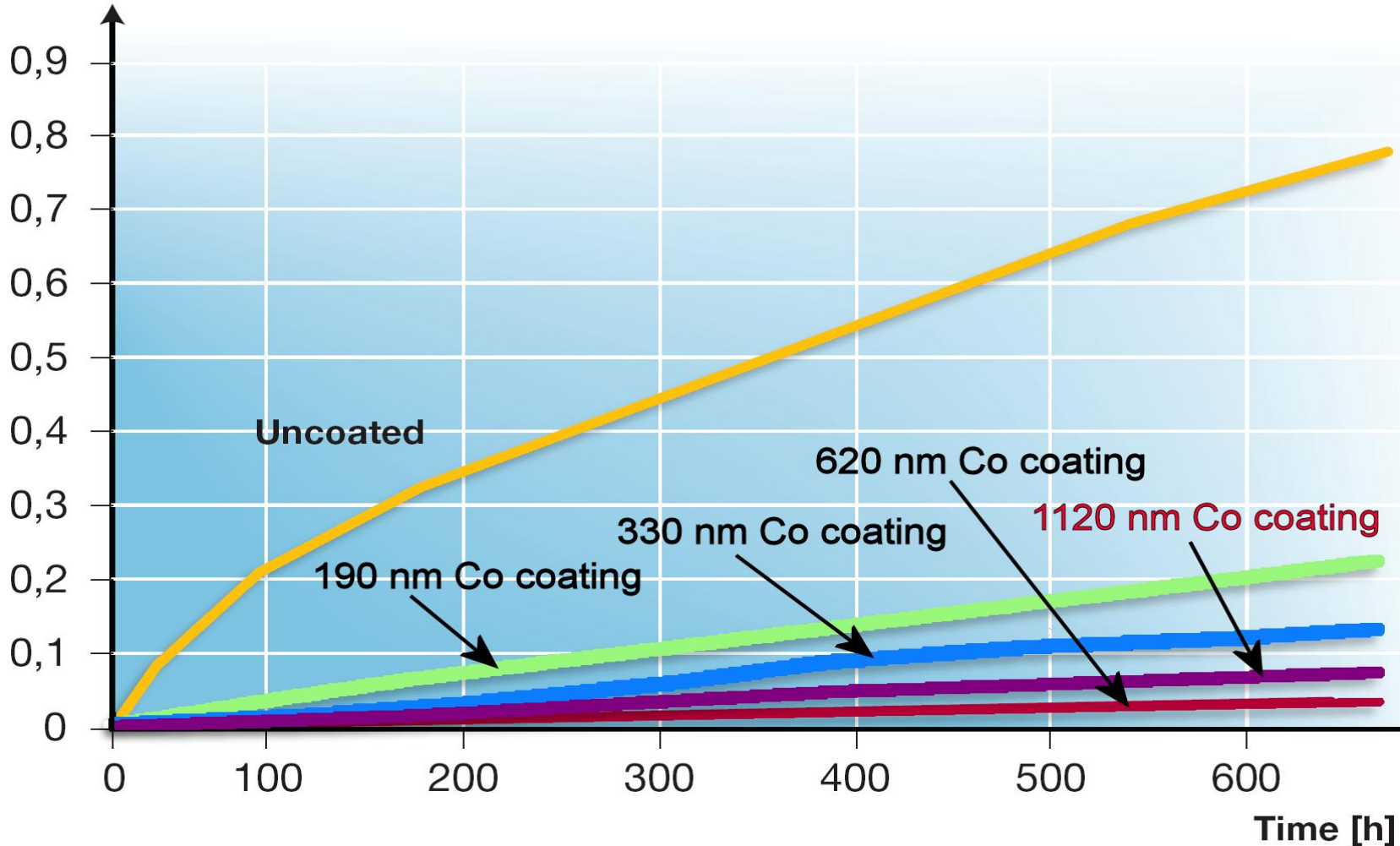
Accumulated



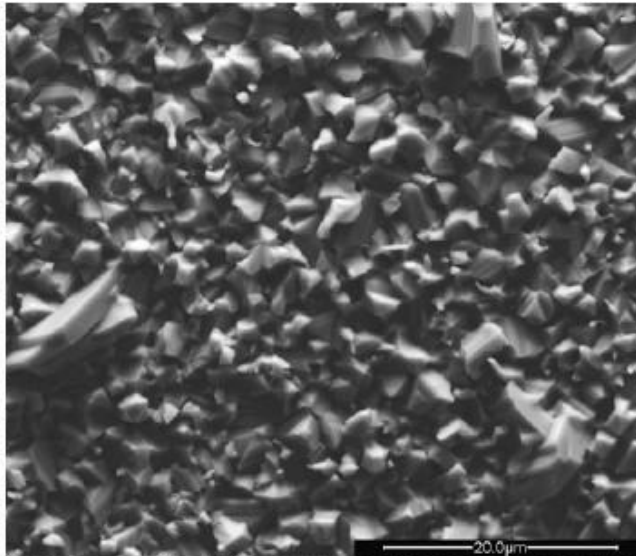
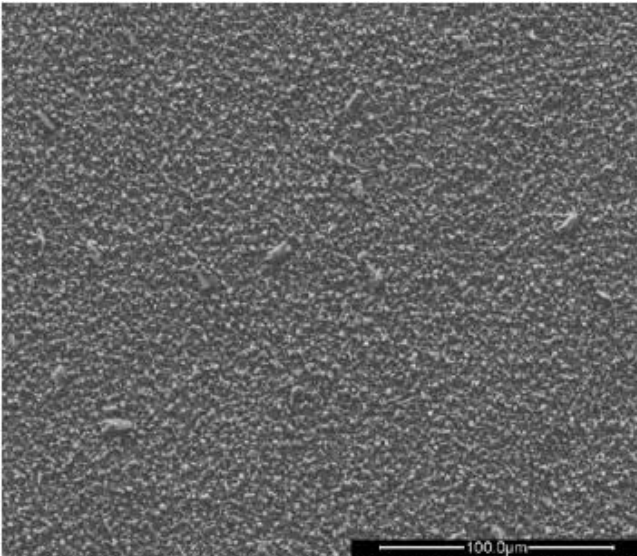
Rate of evaporation

Co thickness dependence

Accumulated Cr evaporation [g/m²]

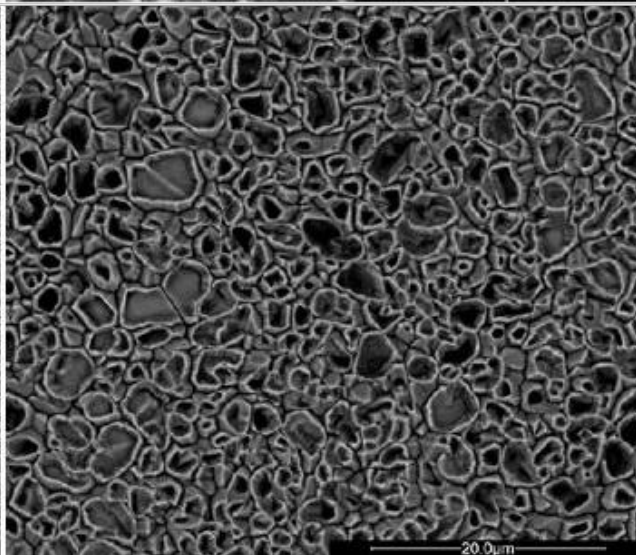
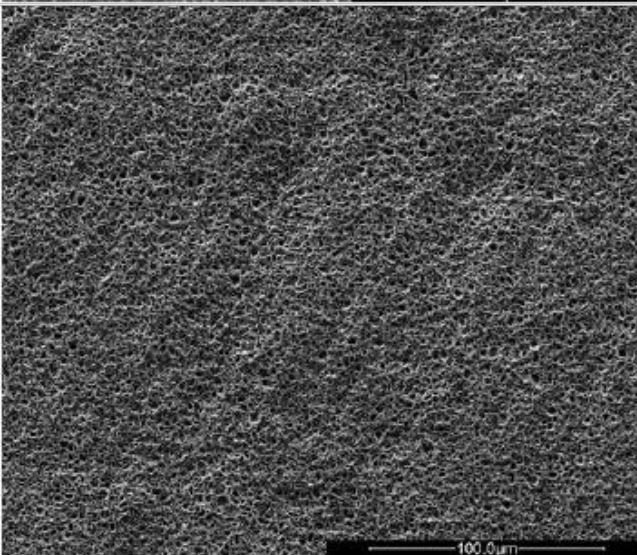


Surface morphology after exposure



620 nm

Spinel crystallites



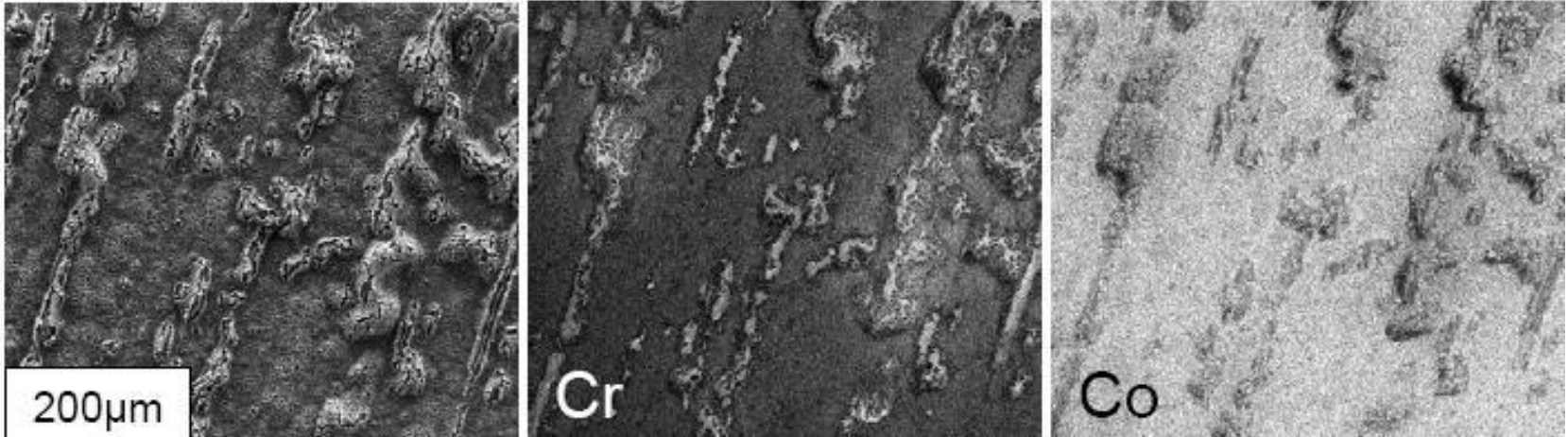
1120 nm

Hollow crystallites

Outgrowths

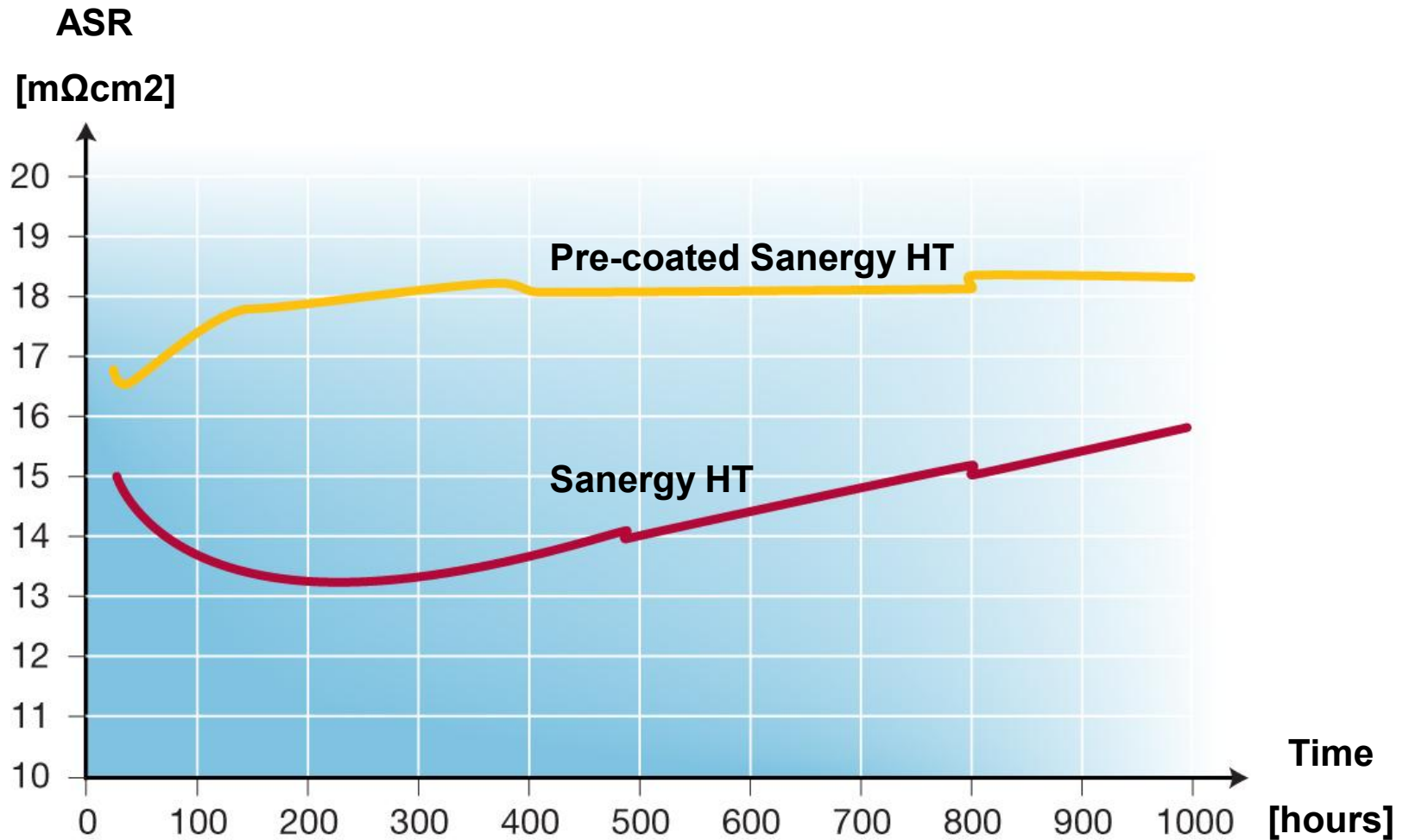
Cracks

EDS mapping after exposure of 1120 nm Co



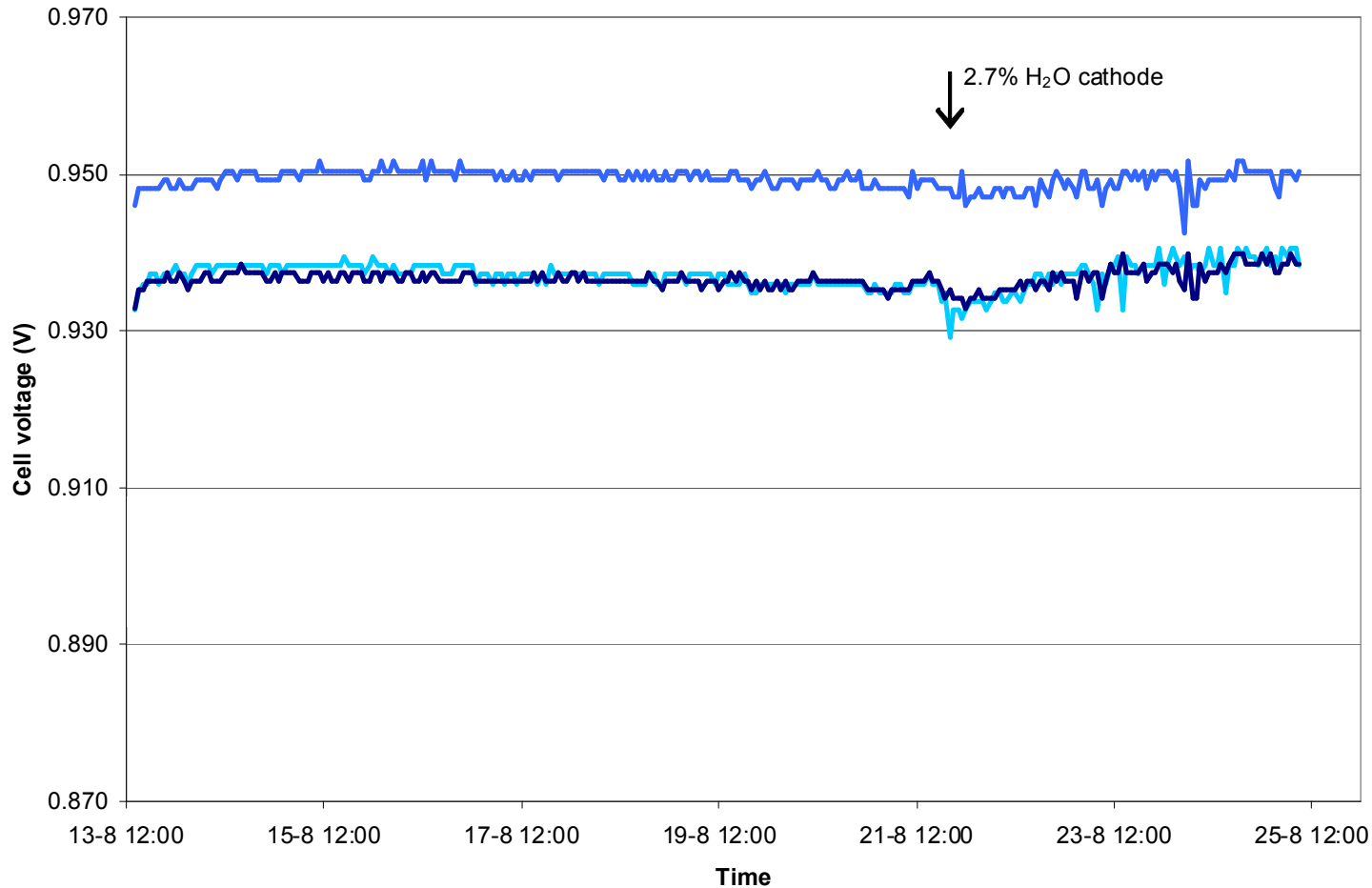
- **Outgrowths**
- **Cracks with Cr richer oxides**
- **Increase the Cr evaporation**
- **Optimal Co thickness less than 1000 nm**

Electrical degradation



Stack test at Topsoe Fuel Cell A/S with pre-coated Sanergy HT

H-33 in P2-076:
750 deg. C, 109 mA/cm²



Summary

- **Pre-coated Sanergy HT will save cost for the plate production**
- **Pre-coated Sanergy HT will reduce the Cr evaporation**
- **The Co thickness should be less than 1000 nm to have the best reduction of Cr evaporation**
- **Electrical degradation of Pre-coated Sandvik Sanergy HT is very low.**
- **Stack test of Pre-coated Sandvik Sanergy HT shows little or no degradation.**
- **Well match thermal expansion with the ceramic materials used in SOFCs, i.e. $12.3 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$ for the interval 30 - 900°C.**
- **Good high temperature corrosion resistance**
 - ✓ **Example: A weight gain of $< 0.40 \text{ mg/cm}^2/1000$ hours at 800°C.**
- **Three times as high Yield Strength at 800°C compared to Fe22%Cr alloys**

Acknowledgement

- The people at Sandvik
- Topsoe Fuel Cell A/S - stack test
- Chalmers University - Cr evaporation studies
- Risö- ASR measurements
- All Partners in the 7th EU Framework programme METSOFC



Thank you for your attention!

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