High temperature corrosion of materials and components produced by additive manufacturing (AM)

HTC conference
5 November 2020

HTC project 2b

Project participants

- Chalmers
  - Mats Halvarsson
  - Mohammad Sattari
  - Krystyna Stiller
  - Irina Fedorova
  - Jan Froitzheim
  - Alberto Visibile
  - Özgür Gündüz
- Siemens Energy
  - Marie-Aude Porter
  - Yanli Fang
- Kanthal
  - Thomas Helander
  - Saud Saleem
- Sandvik Materials Technology
  - Mats Hättestrand
  - Fredrik Meurling

CHALMERS
UNIVERSITY OF TECHNOLOGY

Project goals

- Understand the differences and similarities between conventional and AM produced materials and the relation to the printing process
- Perform well-controlled laboratory oxidation testing in relevant environments
- Perform detailed microstructural investigations elucidating the microstructural changes in the material and the oxide scale formation
- Correlate the findings in order to describe the corrosion processes
- Build a fundamental understanding of the corrosion performance of AM produced materials, enabling fabrication of tailor-made materials for demanding high temperature applications

CHALMERS
UNIVERSITY OF TECHNOLOGY

Work plan 2020

- Project 1: FeCrAl alloys: Kanthal AM and Kanthal AF
  - Almost done, article to be submitted soon
- Project 2: Ni-base alloys: AM and conventional IN 625
  - Almost done, article draft exists
- Project 3: Ni-base alloys: AM and conventional IN 939
  - Almost done, article draft being produced
- Project 4: In-situ studies of the early stages of oxidation; AM and conventional materials
  - Final experiments ongoing
- Project 5: As-printed AM surfaces
  - To be started

Background

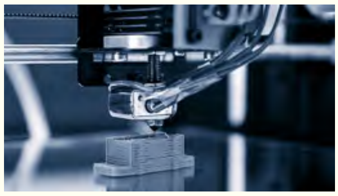
FeCrAl alloys:

- Heating elements for furnaces
- Construction materials in Concentrated Solar Power (CSP) system
- Catalyst support
- Cladding material in nuclear plants
- Etc…

Additive Manufacturing (AM)

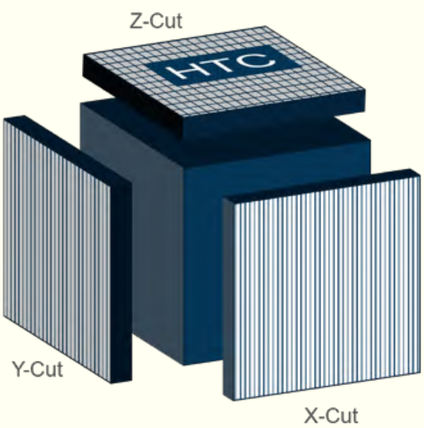
- Easier to produce complex shape without machining and welding

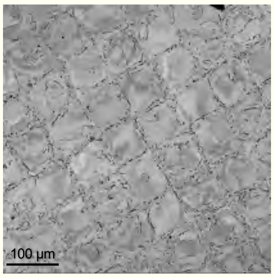
→ Unique microstructures which are highly anisotropic in the building direction



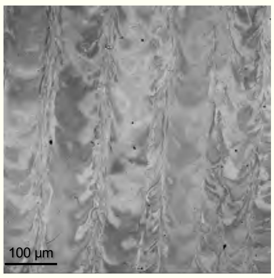
Aim of the work

- Evaluate the influence of anisotropy of the FeCrAl alloy on the oxidation behaviour
- Comparison with conventionally cast material

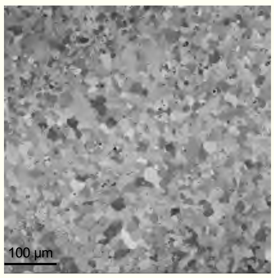




Z-cut AM100 material



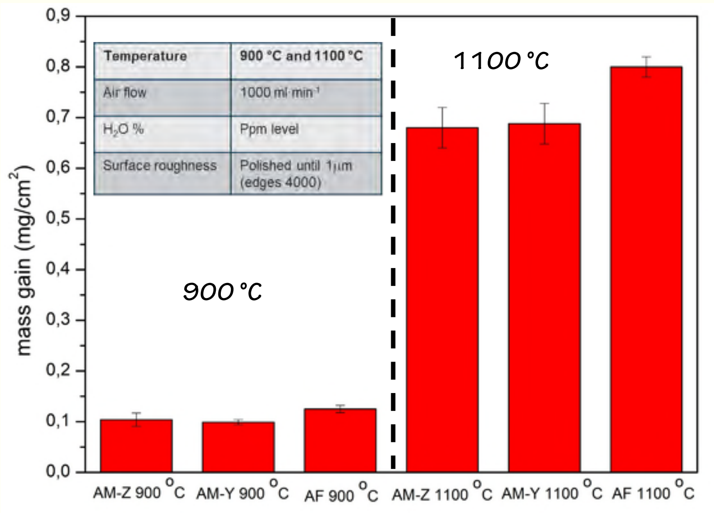
Y-cut AM100 material

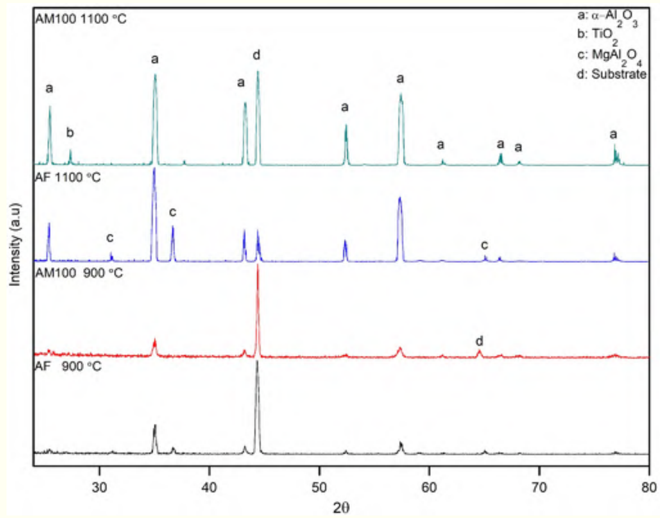


Conventional Kanthal AF

Element (wt.%)	Fe	Cr	Al	Si	C
Conventional	73	21	5.1	0.3	0.03
AM	72.4	21.6	5.31	0.34	0.02

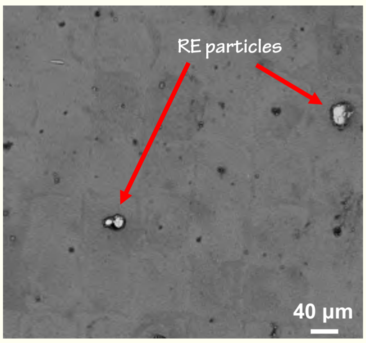
High temperature oxidation



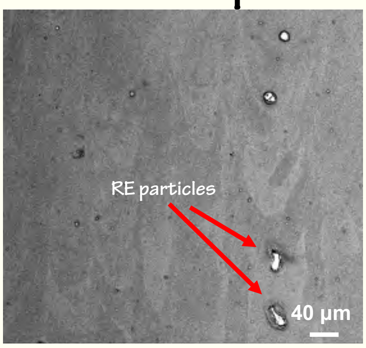


At 900 °C, there is no significant differences in the 2 cutting directions.
At 1100 °C conventional casted material is slightly higher due magnesium spinel formation.

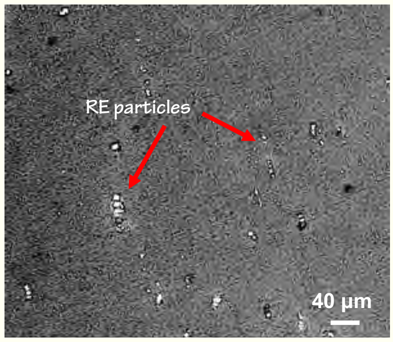
Microstructure after exposures at 900 °C



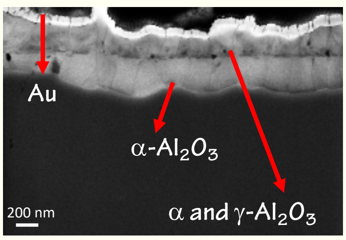
Z-cut AM100 material

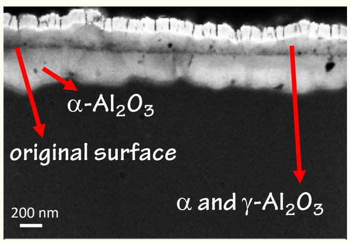


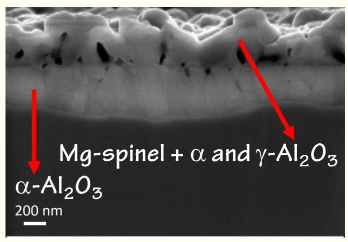
Y-cut AM100 material



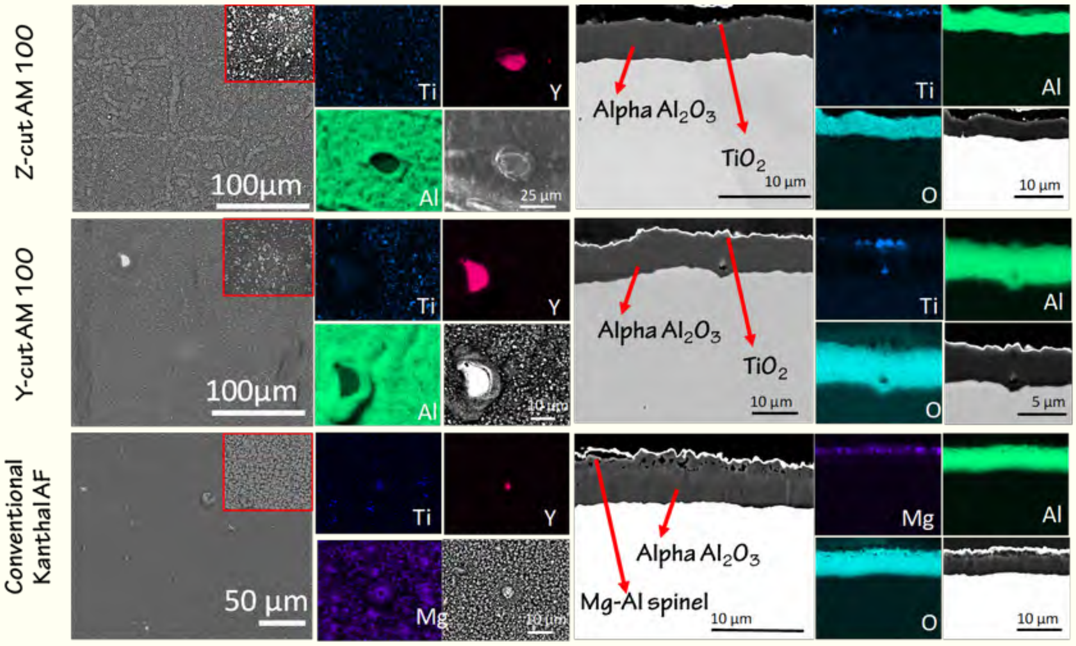
Conventional Kanthal AF



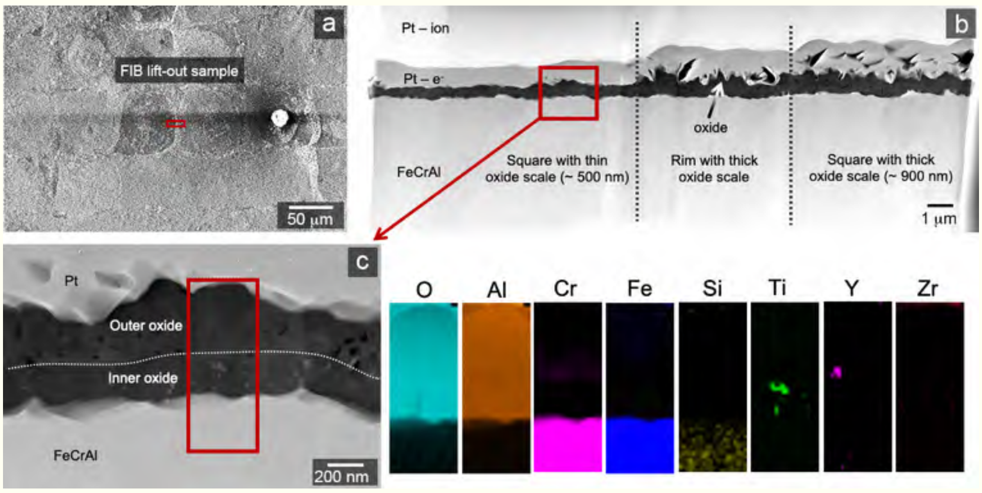




Microstructure after exposures at 1100 °C

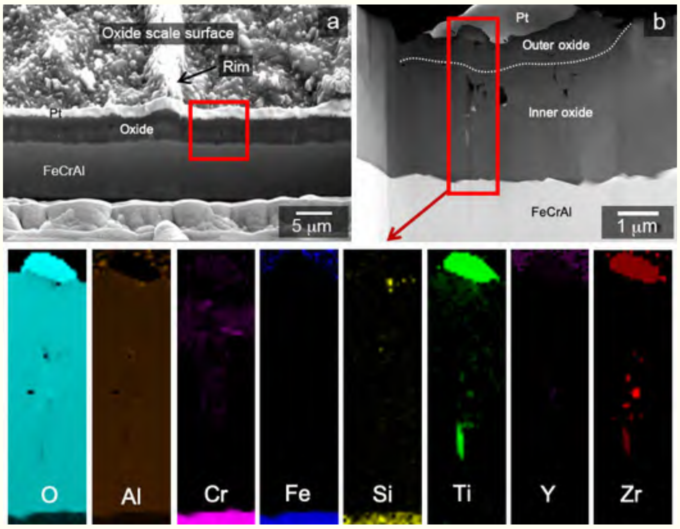


Advanced microscopy – exposure at 900 °C



- Some squares are more oxidized than others;
- The difference between thick and thin squares is 2 times;
- The thickness of inner and outer oxide layers is the same;

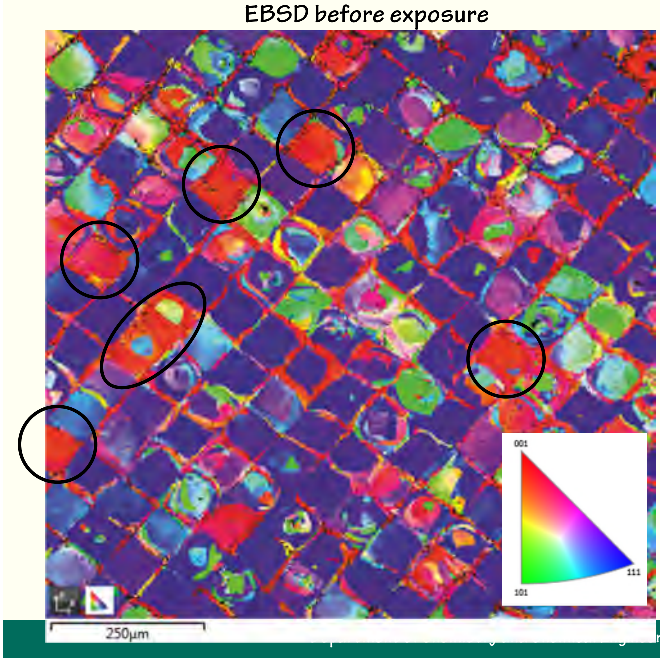
Advanced microscopy –exposure at 1100 °C



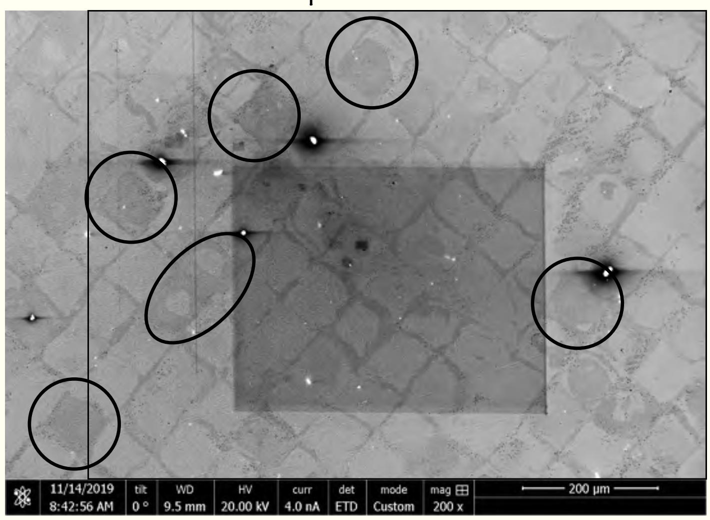
- All squares are oxidized similarly;
- Rims are oxidized more than squares;
- The thickness of inner oxide is much larger than one of outer oxide.

In-situ exposure at 900 °C for 1h

EBSD before exposure

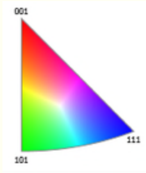


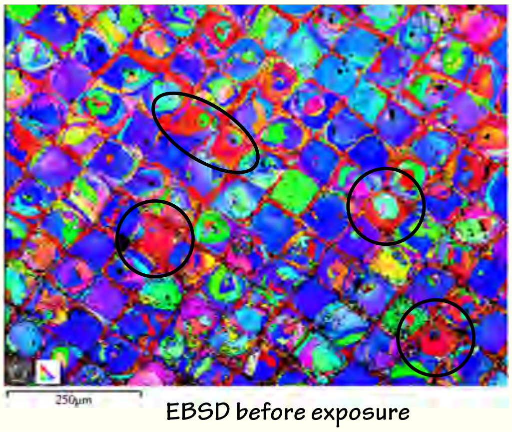
After exposure



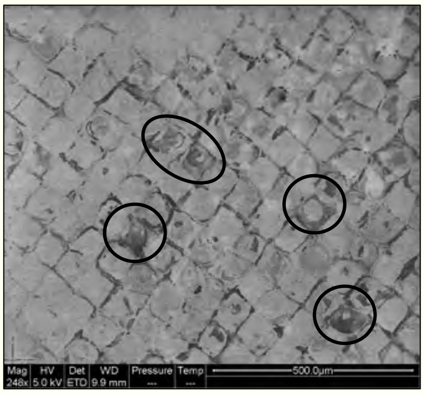
- Red squares and rims (001) correspond to thick oxide layer

Marker ex-situ exposure at 900 °C for 1 h





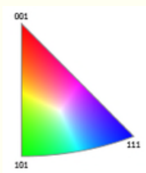
EBSD before exposure

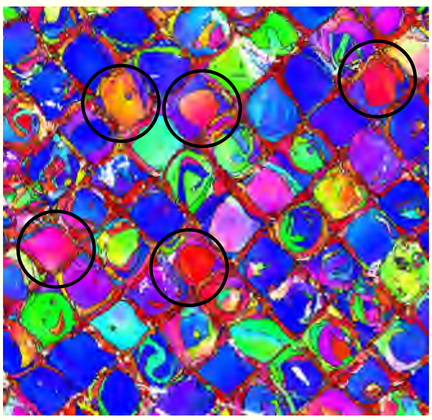


After exposure

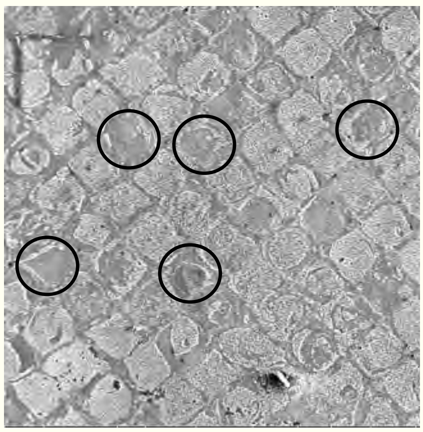
- Ex-situ experiment confirms the influence of grain orientation on the oxidation. Red squares and rims (001) correspond to thick oxide layer

Marker ex-situ exposure at 900 °C for 168 h





EBSD before exposure



After exposure

- Effect of of grain orientation on the oxidation remains after longer time of exposure

Summary

- The mass gain values did not show a substantial difference between Y and Z-cut, but the AM materials exhibited slightly lower mass gains compared to the conventionally produced material. It is suggested that this difference is due to a slight variation in the chemical composition of the used materials.
- The analysis of the oxide scales revealed a variation in oxide thickness after exposure at 900 °C, this contrast was absent at 1100 °C, due to the larger overall thickness of the oxide scale. In addition, there was a thickness difference between the narrow strips and squares. This is probably because of the fine-grained nature of the underlying metal in these regions, this difference was also apparent after exposure at 1100 °C.
- Grain orientation effect on the oxidation is found after exposure at 900 °C for 1 h, and it remains after longer exposure time.
- The AM processed FeCrAl material behaves overall very similar to the conventionally produced Kanthal AF. Although some local differences in oxidation rate are observed these seem to stem mostly from the initial phase of oxide formation and will probably not affect the overall oxidation kinetics and lifetime of a component over its service life.

Thank you!

AVANCEZ

1829

CHALMERS

UNIVERSITY OF TECHNOLOGY