
# Five achievements for Webinar

HEATSTACK

FCH
FUEL CELLS AND HYDROGEN JOINT UNDERTAKING

# Goals

The objective of HEATSTACK was to aid in the goal of making Fuel Cell micro Combined Heat and Power systems for home use more cost effective. This would aid in the goal of reduced $CO_2$ emissions, reduced $NO_2$ emissions, decentralised supply of electricity and improved efficiency.

There were two main approaches to achieving reduced costs

1 Improve the manufacturing processes to improve quality and reduce the time to manufacture.

2 Improve durability such that the SOFCmCHP system as a whole has a longer life.

# The change to AluCrom 318

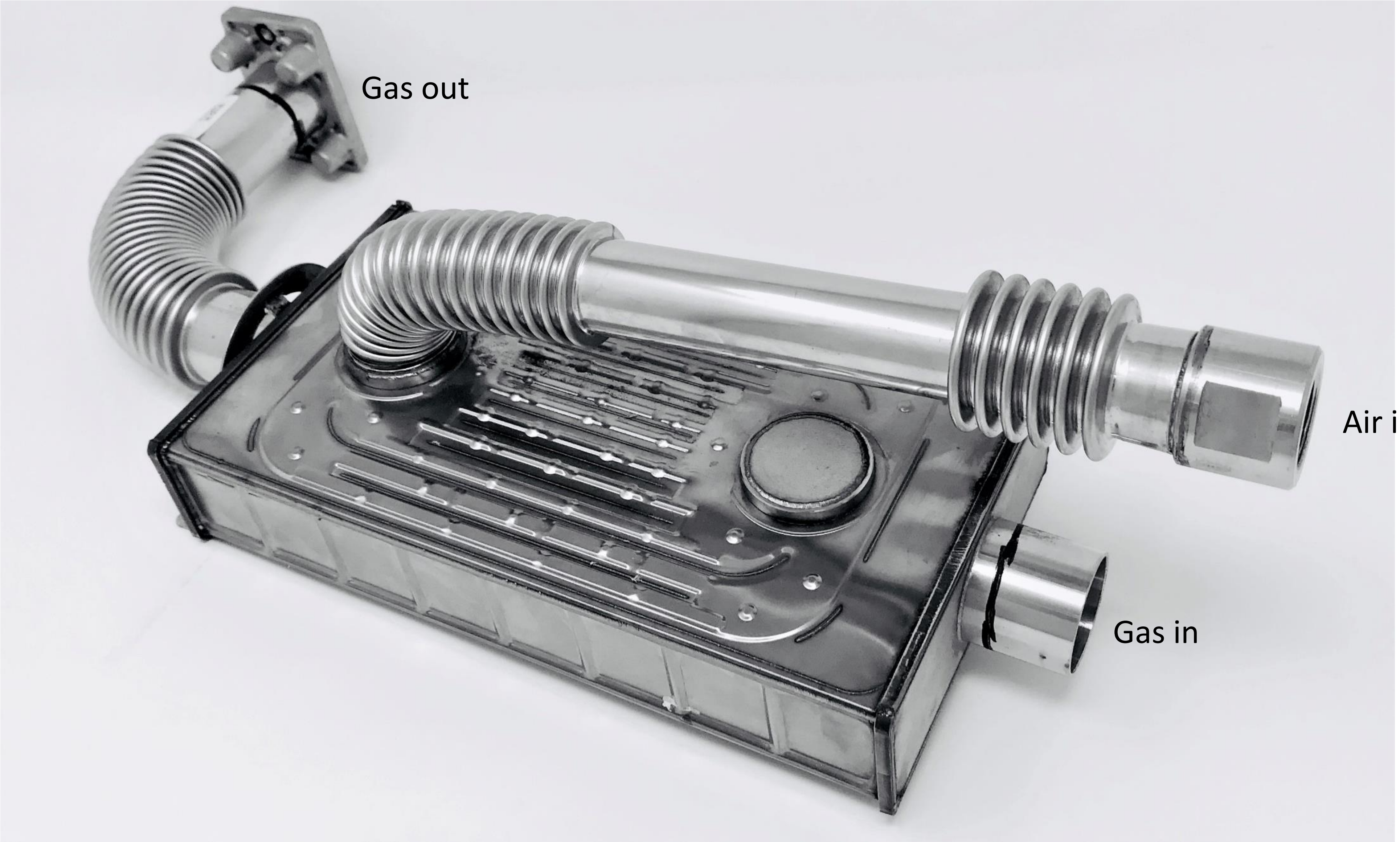
The Solid Oxide Fuel Cell at the heart of the mCHP requires a Cathode Air Pre-Heater. The CAPH as the name suggests pre-heats the air into the SOFC stack. This significantly improves efficiency and enables the SOFC to function at its working temperature.

The CAPHs supplied by Senior prior to HEATSTACK use Inconel 625 as the material for the heat exchange plates. 625 contains around 60%  nickel. It has very good high temperature strength which is suited the the working temperature of the CAPH with a gas inlet temperature of around 800C.
625 has two major disadvantages for use in a SOFC system. Nickel is very expensive and 625 material is typically about three times as expensive as a high temperature stainless steel. Also the corrosion resistance layer on the surface of 625 is a Chromium oxide. At high temperatures chromium evaporates from the surface. The chromium can thus contaminate both the fuel cell stack and the waste condensate.

A major part of HEATSTACK was investigating and managing the change from Inconel 625.

The material chosen to replace the 625 was AluChrom 318. It has less than 0.5% Nickel and 3.5% Aluminium. The very large reduction in Nickel has the potential to significantly reduce the cost / kg of the material. The aluminium content is designed to form an alumina oxide on the material surface thus significantly reducing Chromium evapouration.

# Image of CAPH



# 1 The change to AluCrom 318 – Cost saving



As stated on sheet 3 the low % of nickel in AluChrom 318 has the potential to significantly reduce the cost of the CAPH heat exchange plates.

AluChrom 318 is a new material without a significant market. Due to this it is not yet cost effective. As the market for CAPHs and other applications grows there will be a significant benefit reducing the cost of the CAPH and thus the overall SOFCmCHP system cost.

A further cost saving due to the change to AluChrom 318 is the reduced Chromium evaporation. With less Chromium evaporation there is less contamination of the stack which gives increased life and reduced overall costs.

Further, the waste gas from the SOFC, heating the CAPH air will also be contaminated with Chromium. This will be captured in the gas condensate. The chromium must be filtered out prior to discharge of the condensate. Reduced chromium in the condensate results in smaller or longer life filters which again is a cost saving.

# 2 The change to AluCrom 318 – Challenges of manufacture

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Inconel 625 has, at room temperature, an elongation of 51%. This means that the 625 sheet can be easily formed into the complex form required for the CAPH heat exchange plate.

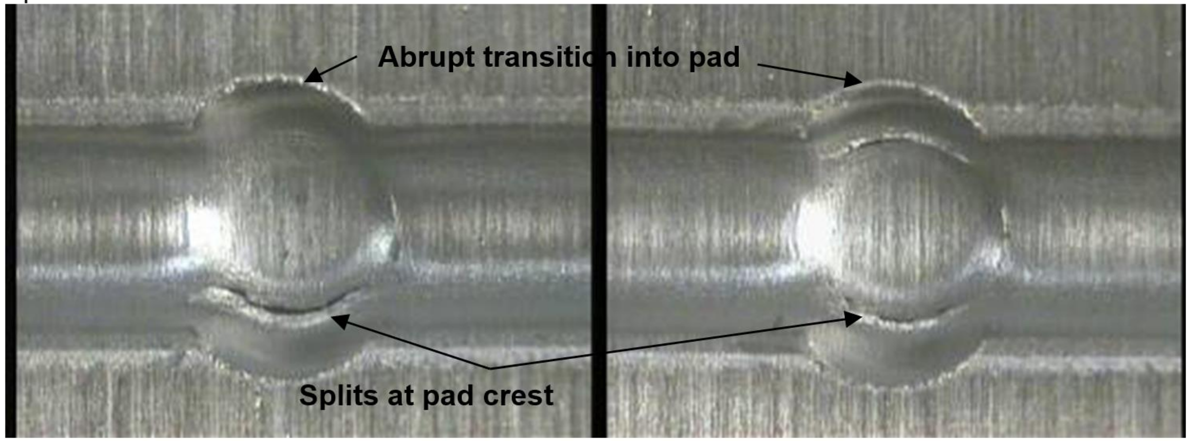
The elongation of Aluchrom 318 is only 22%. This relatively low elongation causes the material to thin excessively when being formed and can lead to splits in the heat exchange plate or an high stress area that could fail during use.

The form of the gas plate had to be very significantly modified to give a consistent and acceptable formed plate. Senior worked closely with their press tool manufacturer to reduce thinning and with CFD to ensure no significant change in performance. **This was successfully achieved during HEATSTACK**

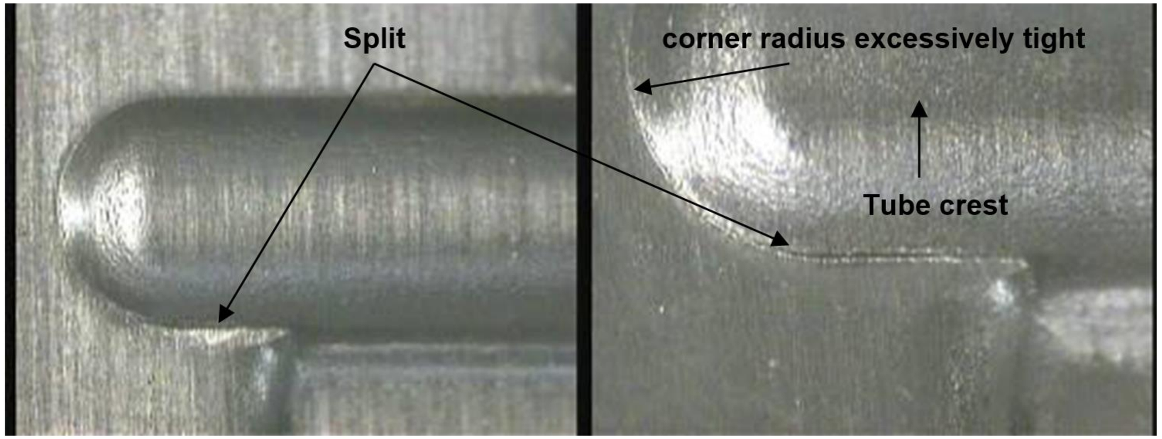
A further challenge was laser welding the Aluchrom. Inconel 625 can be nickel brazed, pre-heatstack any leaking CAPH core packs could have a dab of nickel braze placed over a leak and then vacuum brazed. Braze trials with Aluchrom 318 were unsuccessful. This then required a further improvement in laser weld consistency and quality for the AluChrom as there was no easy rework process. In addition to the need to improve the weld quality it was found that Aluchrom was more difficult to weld. Early work laser welding showed ‘blow holes’ and cracks around the welds. Changes were made to both the laser weld tool and more significantly the laser weld parameters. Once resolved the problems did not return. **This was successfully achieved during heatstack**

# Images of splits in plate after forming

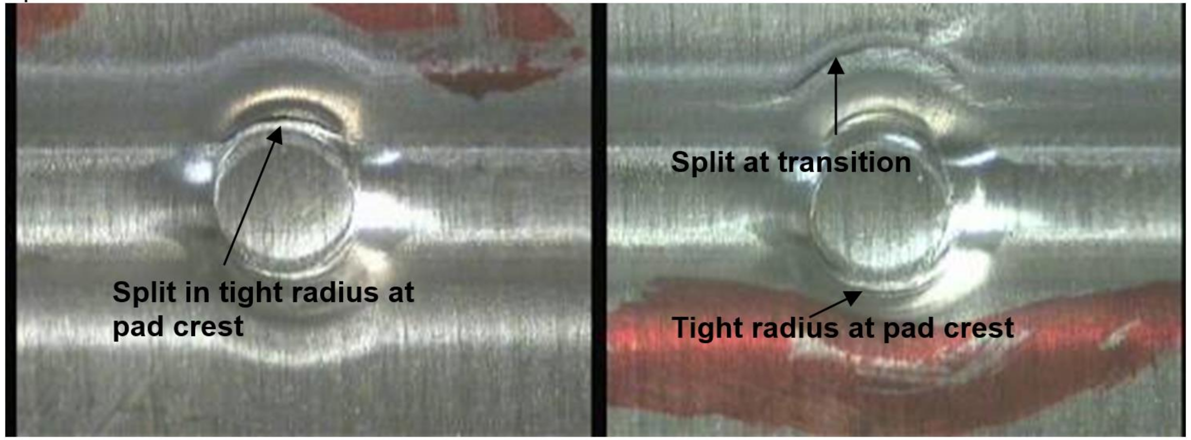
Spacers viewed from female side.




Gas tube ends female side

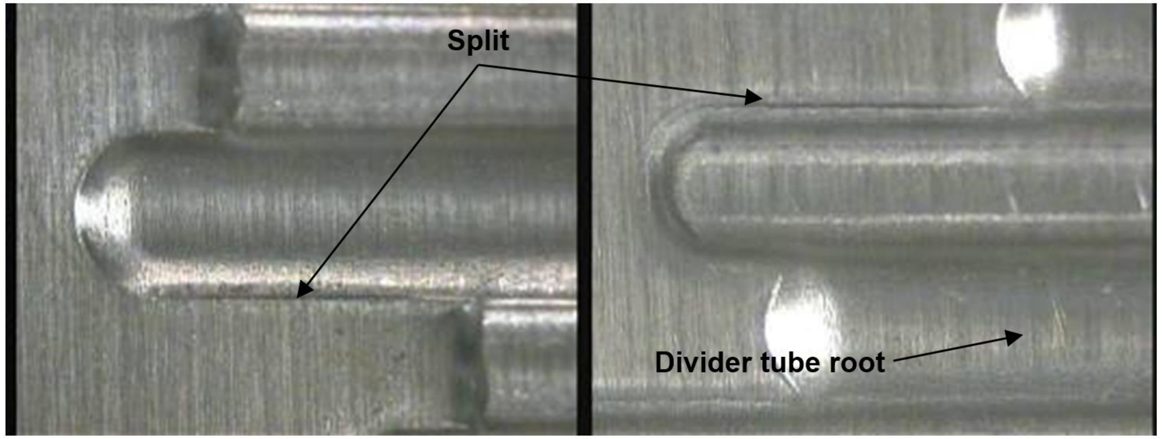



Spacers viewed from male side



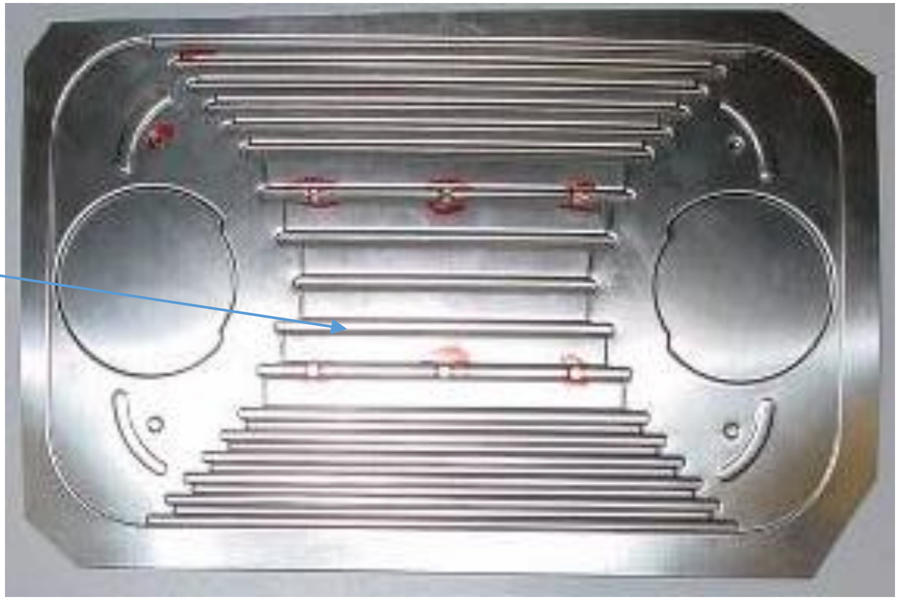

Gas tube ends female side

male side

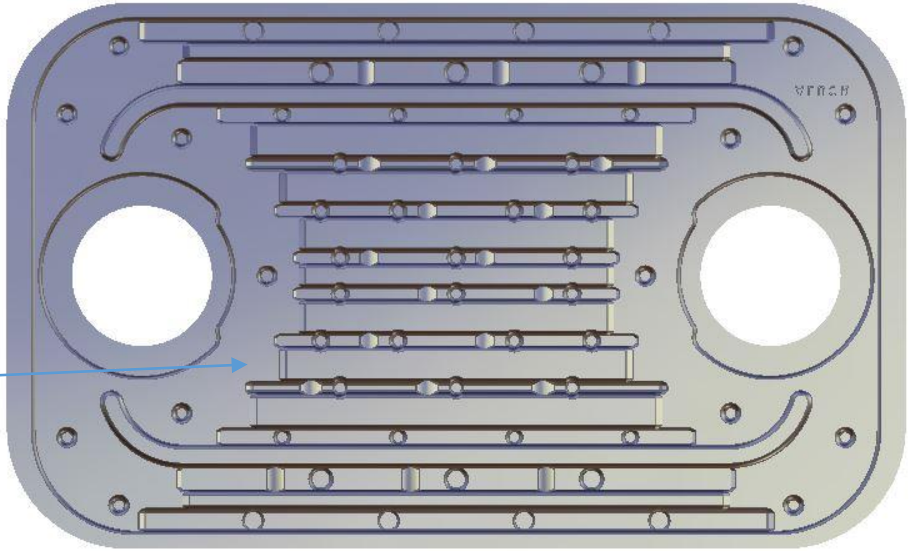


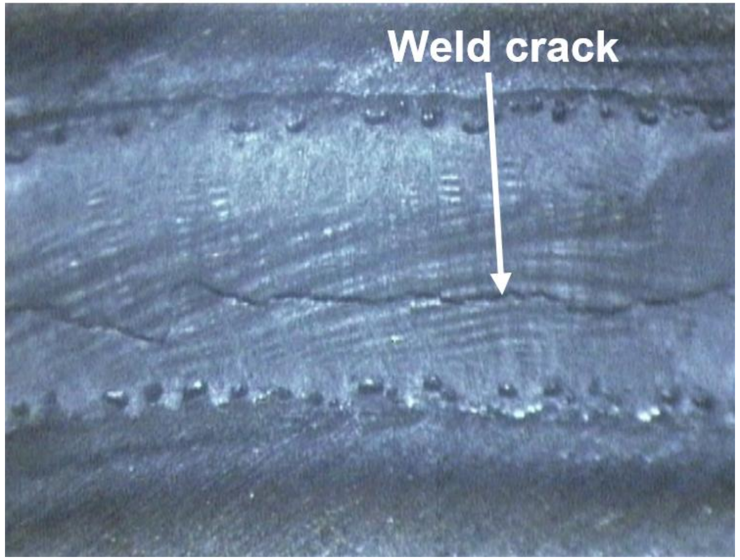
# Images of change in gas plate and weld problems

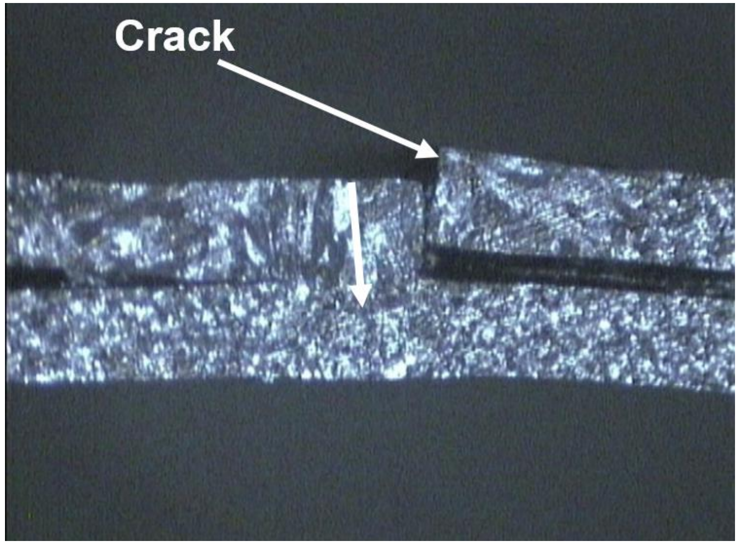
Pre HEATSTACK heat exchange plate



Heat exchange plate developed during HEATSTACK





# 3 The change to AluCrom 318 – Proving reduce Cr evaporation

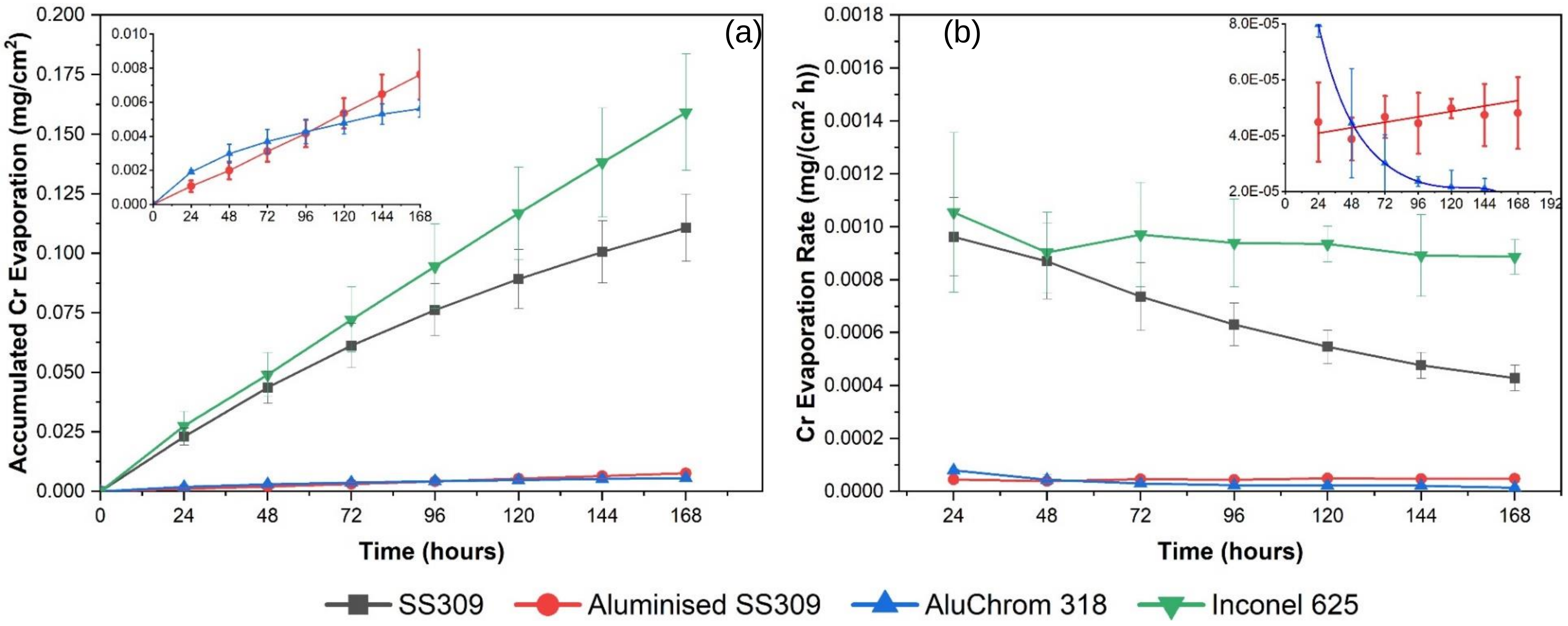



**Figure.** (a) Accumulated Cr evaporation and (b) Cr evaporation rates as a function of time for SS309, aluminised SS309 and AluChrom 318 exposed to 3 vol% $H_2O$ humidified air at 850 ˚C for 168 hours.

- Uncoated Inconel 625 and SS309 show very high level of Cr evaporation over the testing period.
- Aluminisation applied on SS309 could effectively reduced Cr evaporation but not in the long term since spallation of alumina scale was detected after 1000 hours high temperature exposure.
- AluChrom 318 with the formation of double-layered alumina scale shows the lowest amount of Cr evaporation among all the tested materials.

# 4 The change to AluCrom 318 – Pre-heat treating

Longer-term industrial operation of the AluChrom 318 heat exchanger plates under SOFC cathode environment showed a large amount of $Cr_2O_3$ formation around the exhaust outlet (cold zone) and a fast Al oxidation rate around the exhaust inlet (hot zone). For material optimisation, a pre-heat treatment was therefore proposed to allow sufficient formation of an alumina scale on the AluChrom 318 CAPH prior to the application in SOFC environments.

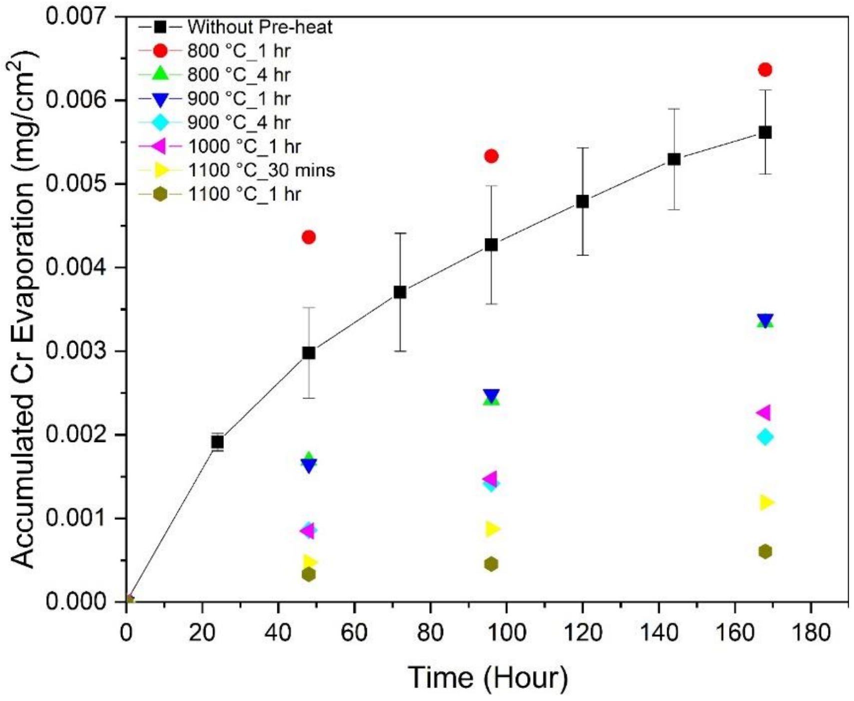



**Figure:** Accumulated Cr evaporation as function of time for the non-treated and pre-heated AluChrom 318 exposed at 850° C in 3 vol% humidified air for 168 hours.

The best corrosion resistance was observed for the samples pre-treated at 1100 ° C for 1 hour with a 98% reduction of oxidation rate and 90% reduction of Cr evaporation compared to the non-treated AluChrom 318 due to the formation of a compact and homogenous α-$Al_2O_3$ scale which can effectively prevent the Al and Cr from outward diffusion in the simulated SOFC environment.

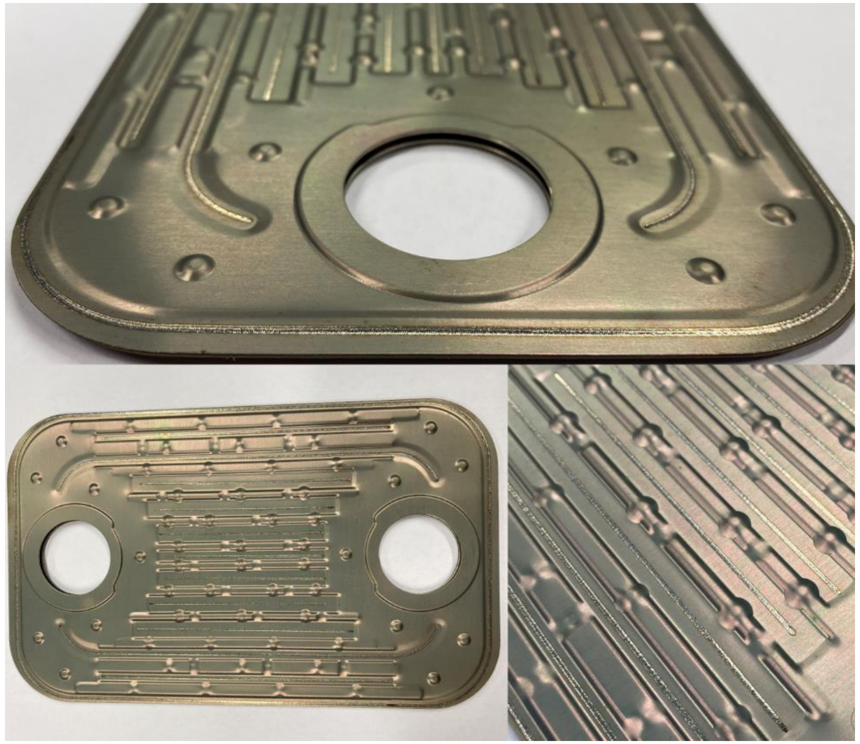


**Figure.** Photograph of two pre-treated AluChrom 318 plates welded into a single cell, showing the welding line.

# 5 Production ready processes for manufacturing CAPHs

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Prior to HEATSTACK all CAPHs were manufactured using prototype processes. It took 8.83 man hours to build one unit.

Within HEATSTACK capital and tooling was purchased, developed and proven.

There are, of course, multiple processes required to manufacture a CAPH. Each process was developed both within prototype and on the purchased low volume production equipment to improve quality and cycle time. The man hours to produce a CAPH were reduced to 2.86 hours. **This was successfully achieved during HEATSTACK**

At the end of HEATSTACK the capital and tooling was then transferred to Senior's Czech manufacturing plant  and installed ready for low volume production. **This was successfully achieved during HEATSTACK.**There is a lot of opportunity for the production engineers in Senior Czech to further improve the processes and reduce cycle times. As volumes increase further improvements can be made.

Senior are now ready to deliver the goal of lower cost components for SOFCmCHPs.

# Images of CAPH cell being set up in Senior Czech


# Achievements by Sunfire GmbH

**Outline:**
Development of an cost-efficient application route of glass sealant for the SOFC stack used in the micro-CHP-System

**Key achievements:**
- Cost and feasibility study: two-step stencil print is the favourable process with up to 10% cost savings of the SOFC stack
- Development of a suitable glass paste formulation
- Development of the stencil printing process
- Evaluation of the glass sealant with model tests, SOFC tests in the lab and tests in the micro-CHP System
- Design study and preparations for implementation of the new process into an automated production line