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Failure analysis of electrolyte-supported solid oxide fuel cells

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HIGHLIGHTS

- Failure analysis of SOFCs run under realistic operating conditions.
- Modelling of present stresses acting on the cell.
- Measurement of the residual stresses.
- Strength of the 3YSZ- and 6ScSZ-electrolytes.
- Failing mechanism of the cells has been elucidated.

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ABSTRACT

For solid oxide fuel cells (SOFCs) one key aspect is the structural integrity of the cell and hence its thermo mechanical long term behaviour. The present study investigates the failure mechanisms and the actual causes for fracture of electrolyte supported SOFCs which were run using the current μ-CHP system of Hexis AG, Winterthur – Switzerland under lab conditions or at customer sites for up to 40,000 h.

In a first step several operated stacks were demounted for post-mortem inspection, followed by a fractographic evaluation of the failed cells. The respective findings are then set into a larger picture including an analysis of the present stresses acting on the cell like thermal and residual stresses and the measurements regarding the temperature dependent electrolyte strength.

For all investigated stacks, the mechanical failure of individual cells can be attributed to locally acting bending loads, which rise due to an inhomogeneous and uneven contact between the metallic interconnect and the cell.

1. Introduction

1.1. Background

Solid Oxide Fuel Cell (SOFC)-based systems are promising candidates for the conversion of chemical energy stored in natural gas or hydrogen into electricity. Due to the direct electro-chemical process it is possible to reach electrical efficiencies of 70% and more. Therefore, a lot of effort has been undertaken to develop systems which provide these high efficiencies while using materials and processing routes which are commercially acceptable. After several decades of intensive fundamental and materials research some systems are on the market (for instance the *BlueGen* of *CFCL* and *Bloom's Energy Server* of *Bloom Energy*) or are close to their introduction (e.g. the Galileo 1000 N of Hexis). But despite the progress which is reflected in the availability of these devices nowadays, there is still room for improvement. Especially the long term issues have gotten more and more in the focus of the respective manufacturers. Some of the main problems which need to be improved are anode degradation, oxidation of the metallic

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interconnects, chromium poisoning of the cathode and the long-term thermo mechanical stability of the whole cell and that within the frame of real operation conditions, like multiple thermo and redox cycles, variation in the quality of gas composition and accidental exposure to sulphur [1–4].

In this study the fracture behaviour and the individual causes for cell fracture of electrolyte supported fuel cells under real operational conditions are investigated. The examined cells were provided by Hexis AG in Switzerland and run in the company's current SOFC-System, the GALILEO 1000 N.

One of the main tasks of the electrolyte is to physically separate the fuel from its oxidant, which it fails after its fracture. In any case the resulting intra cellular leakage will have a short- or long-term impact on the overall stack performance and could in the worst case lead to the instantaneous death of the respective fuel cell system [5].

Some experimental works have already been published regarding the mechanical stability of electrolyte supported cells [6–8] and the fracture behaviour outside a system at ambient conditions [9,10], but so far none to our knowledge where cell fracture has been considered and investigated within the environment of an actual operating system.

1.2. System and stack

The Galileo 1000 N employs a stack with a planar open radial design as sketched in Fig. 1. Since the stack is "open", cells are required to maintain their structural integrity upon multiple redox-cycling. Currently, only electrolyte supported cells are able to fulfil this demand while having the drawback of a higher ohmic resistance compared to anode supported cells. On the other hand the open design allows the stack mounting to be a relative simple process. The nominal operation temperature is 850 °C, measured at the bottom metallic interconnect MIC. The fuel is supplied after being partially catalytically oxidized through the centre hole of the stack onto the cell via the inner gas inlet channels of the anode side of the MIC (see Fig. 1). A fuel sealing plane at the opposite side prevents leakage onto the cathode. The air streams from the outside along four inlet channels towards the centre. It then flows back through the flowfield to the outer edge, where the non-utilised fuel is burned off and produces additional heat.

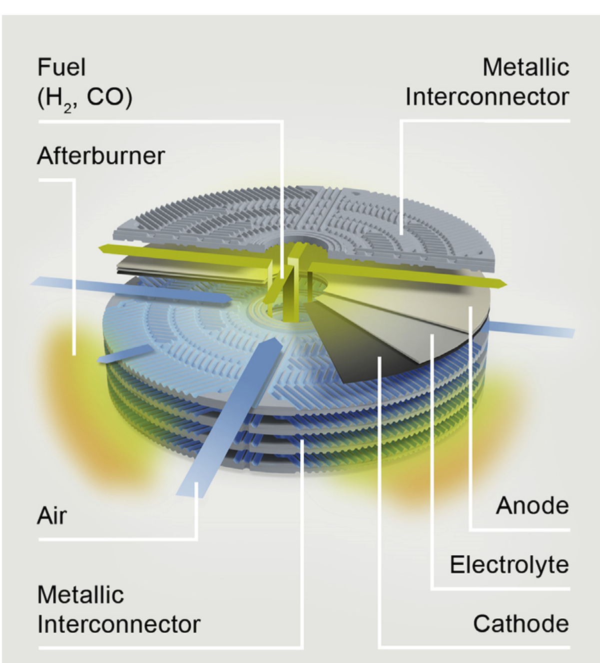

Fig. 1. Working principle of the stack of the Galileo 1000 N (courtesy of Hexis AG).

The MIC is a CrFe5 alloy manufactured and delivered by Plansee SE (Reutte, Austria) with a thermal expansion coefficient which matches that of the cell. The zirconia-electrolyte is purchased from Nippon Shokubai (Tokyo, Japan) and contained either 3 mol% of Y_2O_3 (3YSZ) or 6 mol% Sc_2O_3 (6ScSZ). These compositions were chosen due to their superior mechanical strength compared to the common electrolytes with 10 mol% Sc_2O_3 (10Sc1CeSZ) or 8 mol% Y_2O_3 (8YSZ) according to the supplier's data sheet. The discs are screen-printed with a $La_{0.75}Sr_{0.2}MnO_{3-\delta}$(LSM)-8YSZ-cathode and a Ni–$Ce_{0.4}Gd_{0.6}O_{2-\delta}$-anode developed by Hexis.

In order to understand the mechanisms which are responsible for cell fracture, stacks with a different operational history but the same design were chosen for post mortem inspection and fractography. Results from visual, light- and electron-microscopic analysis are then considered in a comprehensive context, laying the focus in particular on the mechanical behaviour of the electrolyte, as the element providing the cells integrity.

2. Failure analysis

2.1. Post mortem inspection and fractography

Three stacks with 3YSZ and six stacks with 6ScSZ electrolytes were taken for post mortem inspection. Each system was running either at Hexis or at customer sites under real operational conditions in the frame of the German CALLUX project [11]. The operation time ranges from 300 up to 40,000 h, the count of complete redox-cycles a stack had undergone from one to fourteen. After demounting, all examined stacks contained ruptured cells, while showing no severe or discontinuous loss in the overall performance during operation. This already indicates that the present stack design is relatively tolerant towards fracture and the resulting intra cellular leakage. This is due to the small pressure difference which is immanent to the open radial co-flow design. Nonetheless, a certain degree of leakage will happen reducing effectively the provided fuel. The quantitative assessment of the influence, which cell fracture has on the performance is the topic of a subsequent study.

The fracture pattern consists predominantly of radial cracks which can be accompanied by secondary fracture around the central hole, as seen in Fig. 3. Less often occurred cracks with a

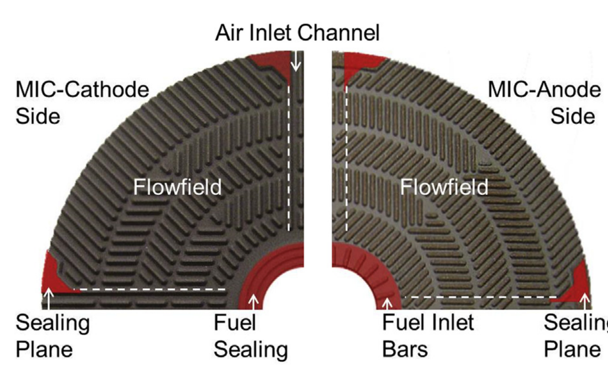

Fig. 2. Cathode side (left) and anode side (right) MIC structure with the positions of the air inlet channels and the flow-fields. The areas where frequent cell fracture is initiated are marked red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)