Simulation and Validation of Thermo-mechanical Stresses in Planar SOFCs

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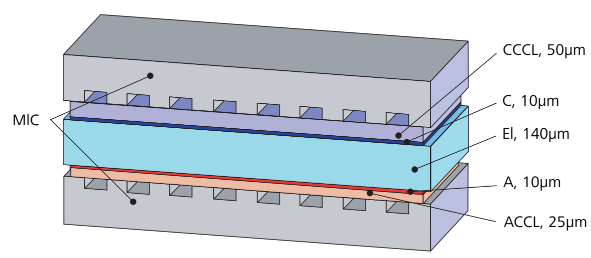
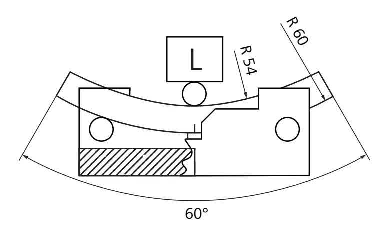
Introduction

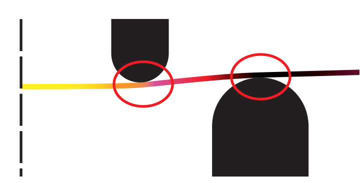
For their successful commercialization, stationary solid oxide fuel cell (SOFC) systems should achieve a lifetime of at least 40'000 h. Hexis Ltd., Switzerland, develops such a combined heat and power system (CHP) in the 1 kWel-range tailored for use in a single-family house. The Hexis Galileo system runs from CPO-reformed natural gas and is based on planar, electrolyte-supported SOFC technology with a stack temperature of about 900°C. So far, with the Galileo system, lifetimes of more than 14'000 h and a steady-state power degradation of 1–2% per 1000 h have been demonstrated. However, further R&D is required, mainly to improve both lifetime and reliability of the SOFC stack. The total degradation of the stack is the sum of different aging processes that are in general associated with both structural and material transformations. Problems include fuel leakages that cause temperature hot spots, the build-up of oxide layers on interconnects, chromium poisoning of cathodes and nickel coarsening in anodes. Another potential malfunction is the breakdown of the cells due to extensive mechanical stresses and/or insufficient robustness of the materials used. Transient operation modes (e.g. thermo-cycles, redox cycles) are especially critical for this type of failure. Therefore, to improve the mechanical robustness and to lower the mechanical stresses on the stack level, a detailed understanding of the potential thermo-mechanical failure mechanisms is important.

Mechanical Properties

To study possible failure modes of the Hexis Galileo SOFC stack, various stack components such as Ni/YSZ anodes, LSM cathodes, TZ-3YS electrolytes and Cr5FeY-based metallic interconnectors (MIC) have been characterised with respect to their thermo-mechanical properties. Specifically, coefficients of thermal expansion, Young's moduli, bending strengths, Poisson's ratios and fracture toughnesses have been measured.





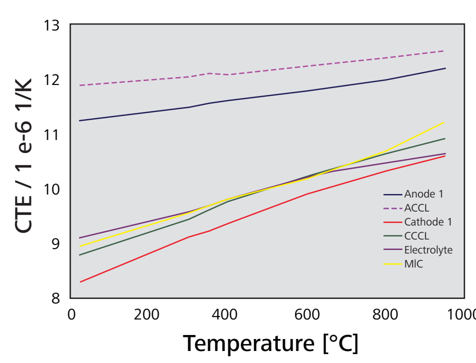


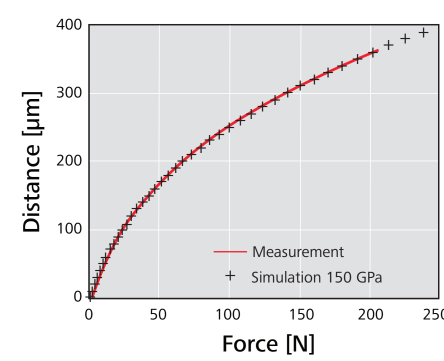
Diameter / Radius: Inner Ring: 12.5/1.5 mm; Outer Ring: 25.0 / 2.5 mm

Test matrix

Measurement	Sample / size [mm]	Samples and remarks
CTE [a)]	Pellet / 5 x 5 x 25	El, A, ACCL, C, CCCL
CTE [a)]	Bar / 3 x 4 x 50	MIC
Young's modulus [b)]	Disc / ø 36	El, El+A, El+A+ ACCL, El+C, El+C+CCCL, complete cell [c)]
Young's modulus	Bar / 3 x 4 x 50	MIC, skin not removed
Strength [d)]	Half-moon	El, complete cell [*,c)]
Frac. toughness [d)]	Notched half-moon	El, complete cell [c)]
Poisson ratio [e)]	Bar / 50 x 15 x 1	MIC, skin removed
Warpage	Disc / full cell size	complete cell [c)]

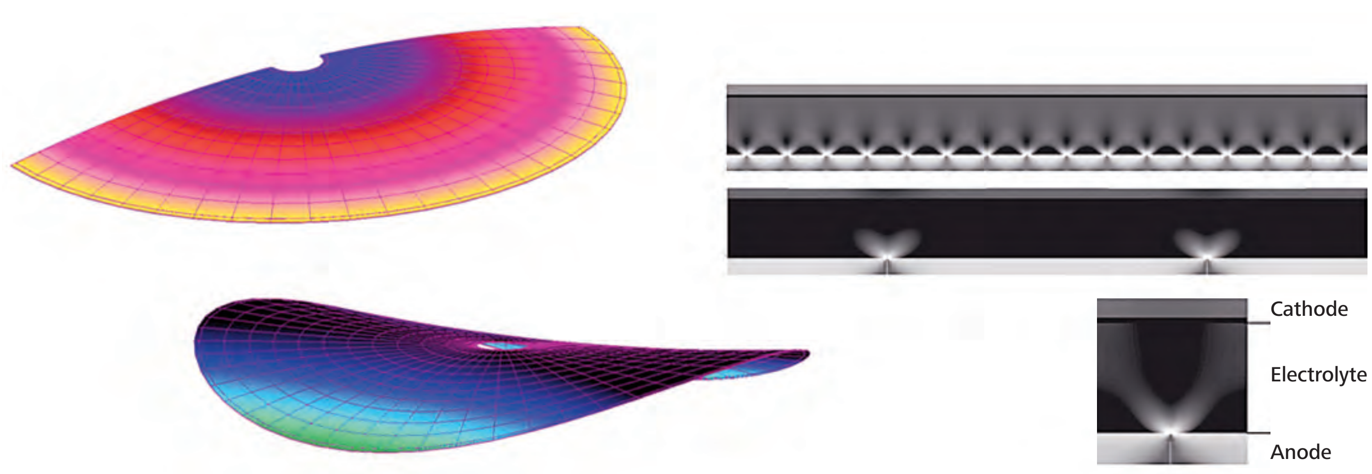
[a)] RT → 1'000°C; [b)] RT, 850°C, 950°C; [c)] A+ ACCL 2+El+C+CCCL; [d)] RT, 950°C; [e)] RT
[*)] as fabricated & after operation





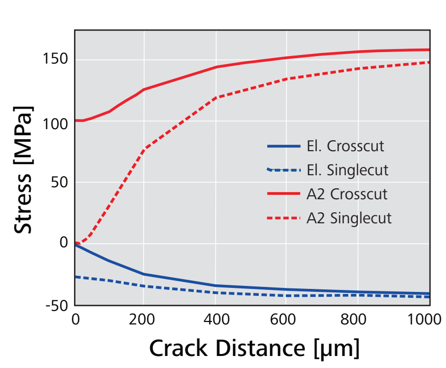
Modelling

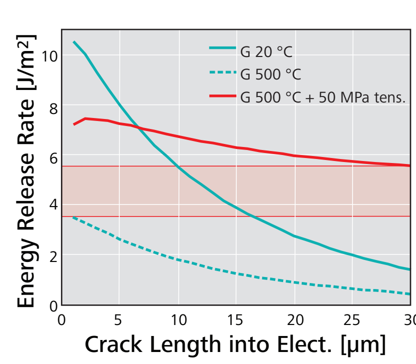
The temperature-dependent warpage of complete cells was investigated by video analysis. Finite element (FE) models were used to analyze various thermo-mechanical phenomena on different length-scales. The simulations explain the "saddle-like" deformations of cells often observed at room temperature.

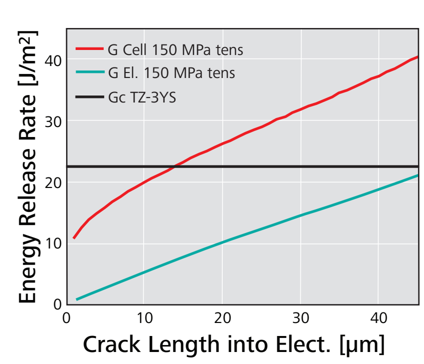


Conclusion

FE modeling showed that cracks that first develop within the anode induce local tensile stresses within the electrolyte and hence represent a weakening mechanism for the cells. It was shown that the induced electrolyte stresses depend on the frequency of the anode cracks. The electrolyte stresses decrease as the distances between the anode cracks become smaller.







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For further details:
J. Kuebler, et.al, Fuel Cells, 2010, 1066–1073