Residual Stresses and Failure Probability of Solid Oxide Fuel Cells Due to the Sintering Process

Fabio Greco, Arata Nakajo, Jan Van herle
FUELMAT Group, Institute of Mechanical Engineering, Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland.

Introduction: A solid oxide fuel cell (SOFC) is an electrochemical device which converts the chemical energy of a fuel directly into electricity. It is composed of four layers of different ceramic materials: a porous anode (320 μm thick), a thin and dense electrolyte (10 μm thick), a compatibility layer (5 μm thick) and a porous cathode (40 μm thick). The anode layer is produced by tape-casting, the remaining layers are deposited by screen-printing. The layers are sintered together at high temperatures. The manufacturing is shown in Fig. 1.

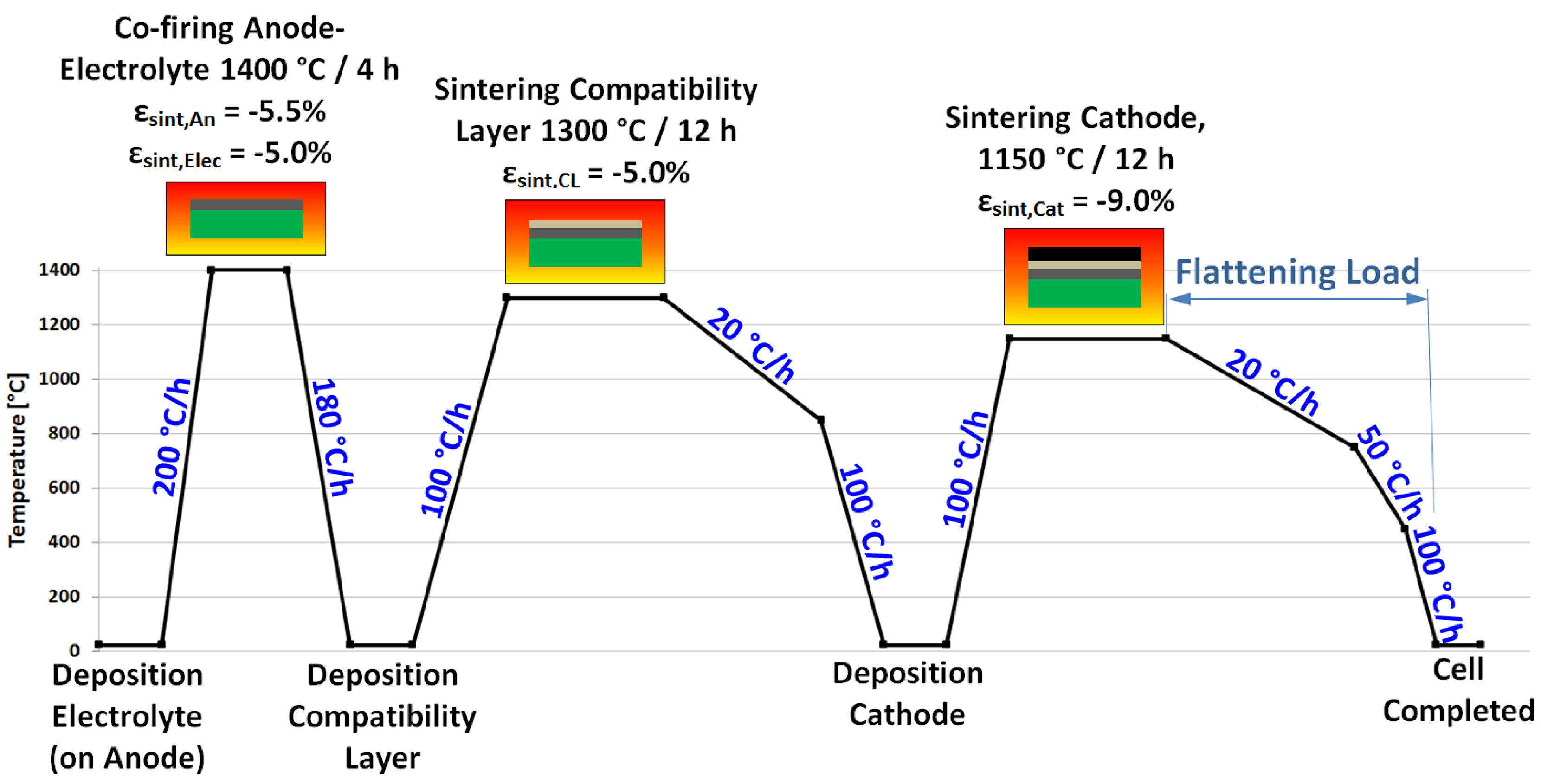

Figure 1. Schematic of the manufacturing of the cell and process data.

During heating up and cooling down, stresses are generated in the layers due to the different thermal expansion coefficients. These stresses generate the bending of the cell.
Since the cells are then piled-up to form a stack, a reduced final bending of the cell is desired to obtain an even contact (important for electrical conductivity and gas tightness) as well as to avoid additional stresses during assembly.

Computational Methods: The model implemented in COMSOL Multiphysics® is an ¼ of the cell in 3D representation (Fig. 2).

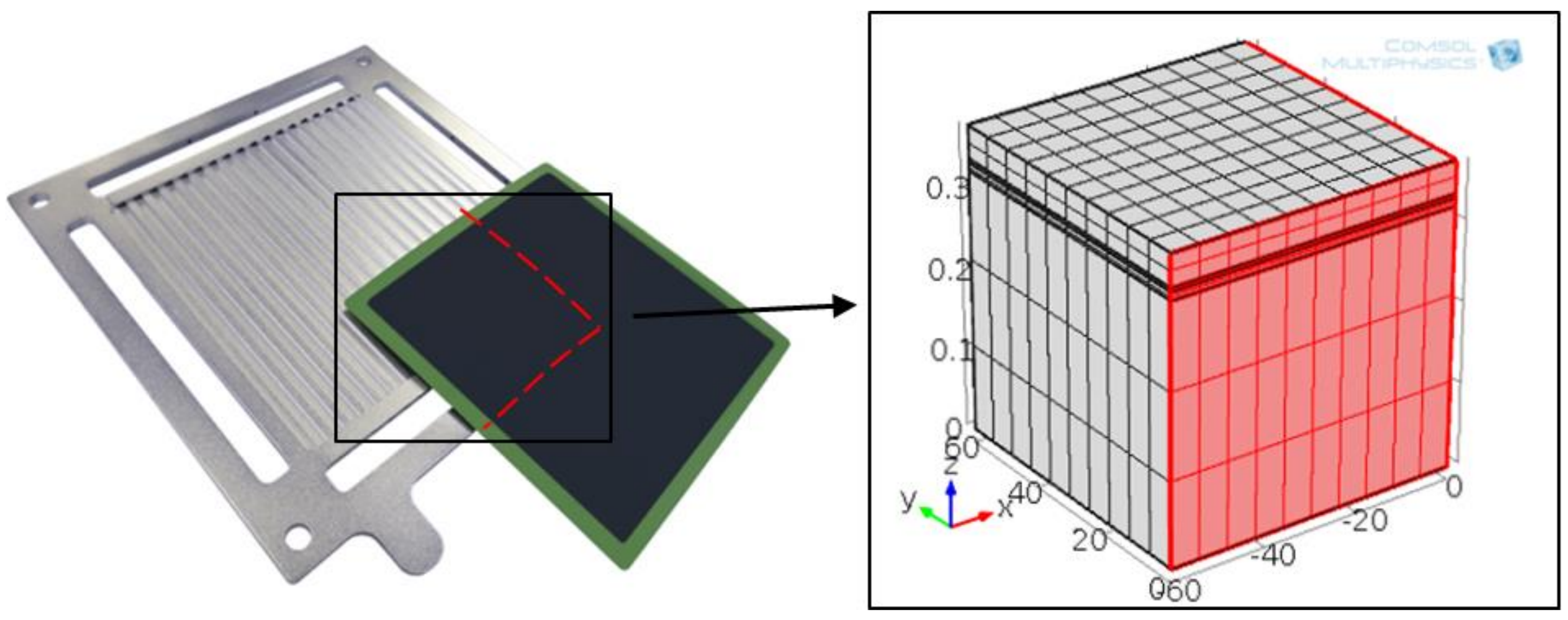

Figure 2. Representation of ¼ of the cell, mesh and symmetry on red faces (dimensions in millimeters).

The cell geometry has been meshed by hexahedral elements. Second order shape functions have been used. The simulation has been carried out using *Solid Mechanics* physics, involving *Thermal Expansion* and *Creep* nodes in *Linear Elastic Material* model.

Layer	Material	E [GPa]	ν [-]	α [×10^{-6} °C^{-1}]
Anode	NiO-8YSZ (56 wt.% NiO)	79	0.29	11.90
Electrolyte	8YSZ (8 mol.% Y_2O_3 fully stabilized ZrO_2)	210	0.31	10.90
Comp. Layer	20YDC ($Ce_{0.8}Y_{0.1}Sr_{0.1}O_{2-\delta}$)	210	0.31	12.10
Cathode	LSCF ($La_{0.5}Sr_{0.5}Fe_{0.5}Co_{0.5}O_{3-\delta}$)	30	0.33	15.34

Table 1. Mechanical properties of the SOFC materials.

Sintering strains were simulated by means of *Initial Stress and Strain*. Sintering strains, thermal loads and flattening pressure were applied via step functions. The study was performed using *Time Dependent* steps.

Results: The cooling down from the cathode sintering step without the application of any flattening pressure entails a considerable curvature of the cell (Fig. 3, green line). On the other hand, the concomitant presence of creep and counter-bending pressure can flatten the cell, as plotted in Fig. 3 (blue line). The pressure producing the flattening of the cell was found to be around 2000 Pa, applied on the anode.

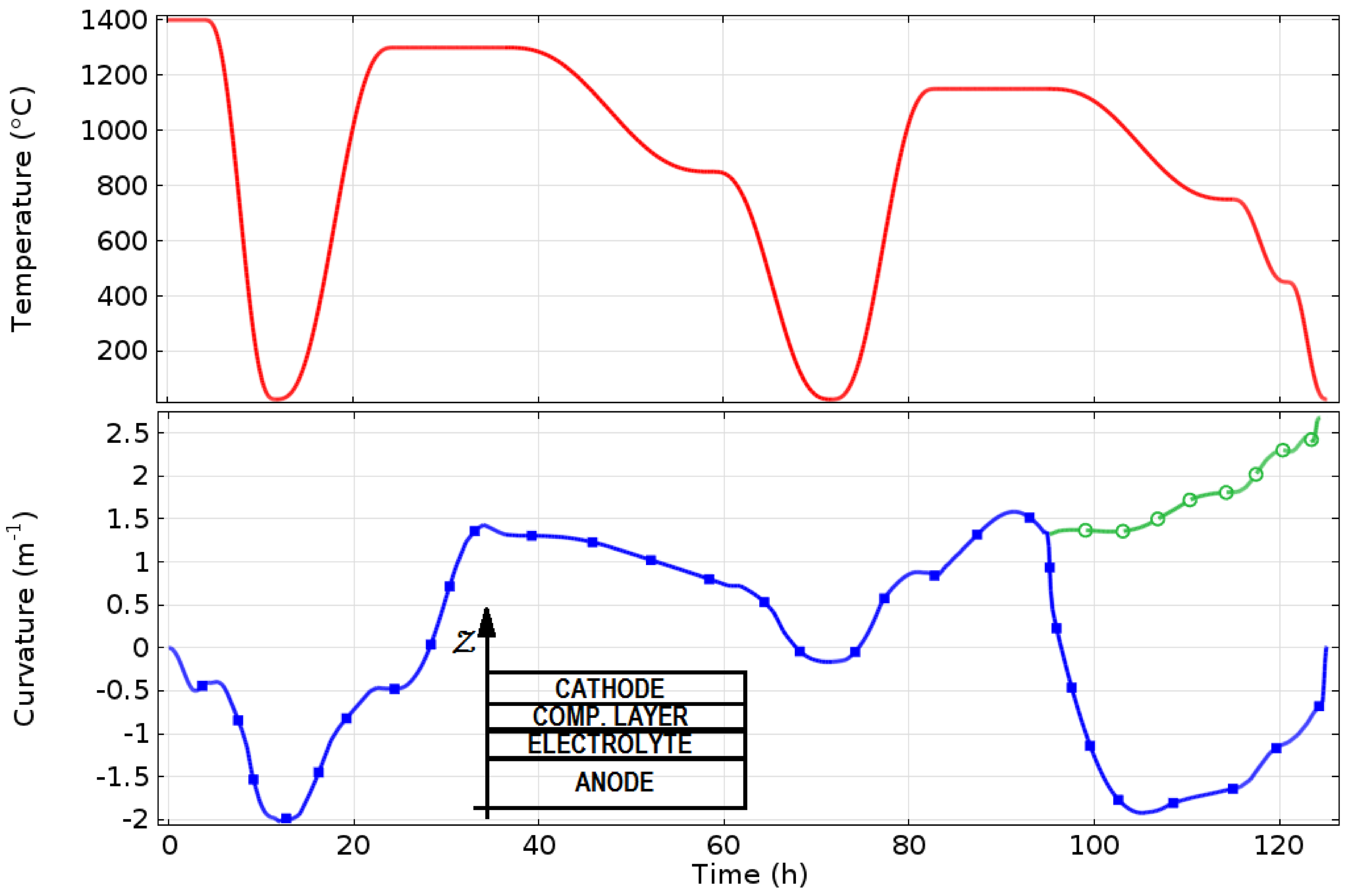

Figure 3. Implemented temperature profile (upper graph) and resulting curvature of the cell (lower graph). Green line: curvature without flattening pressure.

The through-the-thickness stress in the cell at the end of the cooling down from the cathode sintering ("Cell Completed" step) is plotted in Fig. 4. Both the electrolyte and the compatibility layer are in compressive stress, whereas the cathode is in tensile stress. For the electrolyte, high compressive stress has been found, as reported in Ref. [1]. The anode is in tensile stress at the free face, and in compressive stress near the interface. Similar values were found if the flattening pressure is not applied.

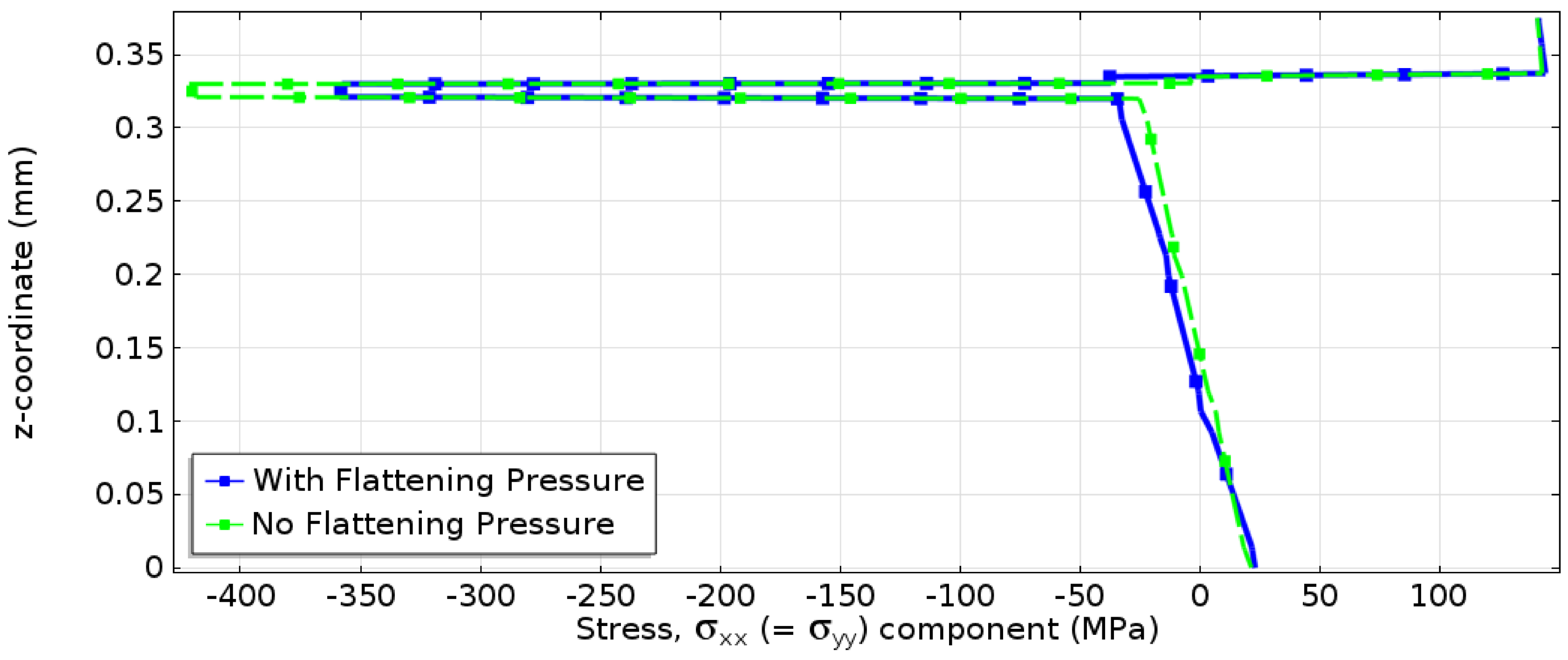

Figure 4. Through-the-thickness stress in the fully fabricated cell at room temperature.

The failure probability of the anode has been calculated using a strength σ_0 equal to 79 MPa, a volume reference V_0 of 4.812 mm^3 and Weibull modulus m equal to 7 (assumed values). Considering the stress state in the completed cell after the flattening procedure (Fig. 4), the failure probability of the anode is around 3%.

Conclusions: For the given temperature profile, sintering data and material properties, the pressure to make the cell flat has been found. It was noticed a high curvature of the cell if the flattening pressure does not apply. Both the electrolyte and the compatibility layer are in a beneficial compressive stress state. A failure probability of 3% of the anode has been calculated under this stress state.

References:

1. J. Malzbender et al., Curvature of Planar Solid Oxide Fuel Cells during Sealing and Cooling of Stacks, *Fuel Cells*, 06, 123-129 (2006).