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

F. Greco[1], J. van Herle[1]

[1]FUELMAT Group, Institute of Mechanical Engineering, Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

Abstract

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, a thin and dense electrolyte, a compatibility layer and a porous cathode. 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 Figure 1, and concludes with the cooling down to room temperature. From the residual stresses in the layers, generated by the mismatch of thermal expansion coefficients, the failure probability of the cell can be evaluated, giving a quality-of-process index: defective cells must be withdrawn from the batch.

Use of COMSOL Multiphysics®: The geometry of the 3D model is a rectangular multilayer (4 layers), where two symmetries along x- and y- axis were adopted (i.e. simulating 1/4-cell). The Structural Mechanics Module was used. In Linear Elastic Material, Thermal Expansion node was added. Linear shape functions were chosen. The mesh is hexahedral (mapped mesh swept through the layer's thickness), refined at the layer's interfaces. Parametric Sweep was used in the study, with as parameters the electrolyte thickness combined with the compatibility layer thickness. In post-processing, the evaluation of the failure probability formula was performed using Global Evaluation.

Results: Results did not vary neither when using two different mesh size series, nor when using quadratic shape functions. In Figure 3 the stresses over an arbitrary through-the-thickness line are plotted. Due to the low thickness-to-sample size ratio, the tensile stress in the anode, relatively low, is balanced by a conspicuous compressive stress in the remaining layers, especially in the compatibility layer. The order of magnitude of these results is in agreement with the literature [1]. The residual stresses remain similar when changing the thickness of the compatibility layer and electrolyte. The failure probability of the cell is plotted in Figure 4 and was obtained considering only the anode, since negligible values were found in the other layers. The graphs refer to the final cooling down (fully fabricated cell), which is the most critical case; lower stresses and failure probabilities were found after the first cooling down, therefore they are considered in the failure probability evaluation.

Conclusion: The residual stresses after manufacturing of a complete ceramic solid oxide cell are

found to be tensile in the anode layer, and compressive in the electrolyte, compatibility layer and cathode. The failure probability was found to be significant only in the anode. With the layer thickness typically adopted, the failure probability of the cell ranges from 0.1% to 2 %. It decreases with the thickness decreasing of both the compatibility layer and the electrolyte.

Reference

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

Figures used in the abstract

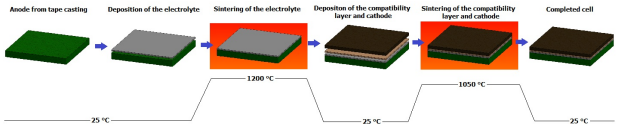

Figure 1: Schematic of the manufacturing of the cell.

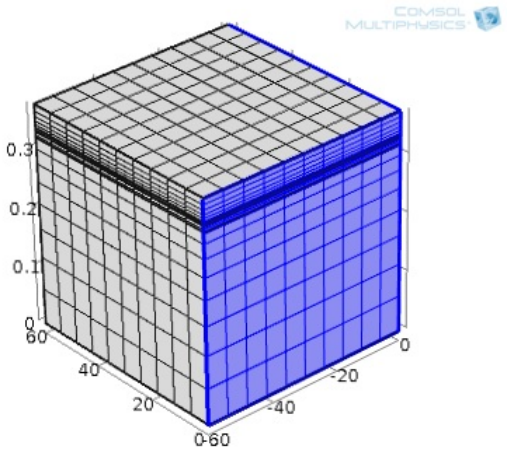

Figure 2: Geometry and mesh of a 1/4-cell. Symmetry condition on the selected faces. Dimension in millimetres.

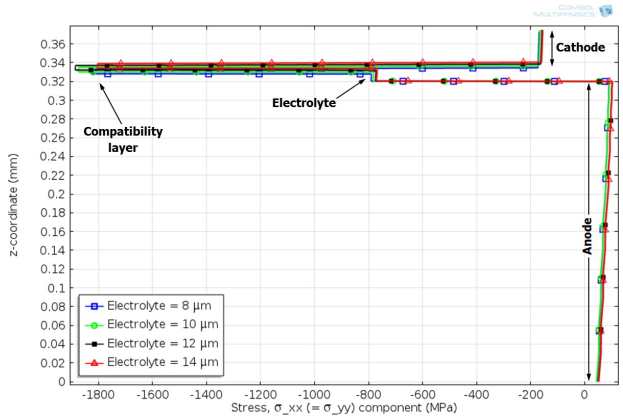

Figure 3: Through-the-thickness stress in the fully fabricated cell at room temperature (compatibility layer of 5 µm).

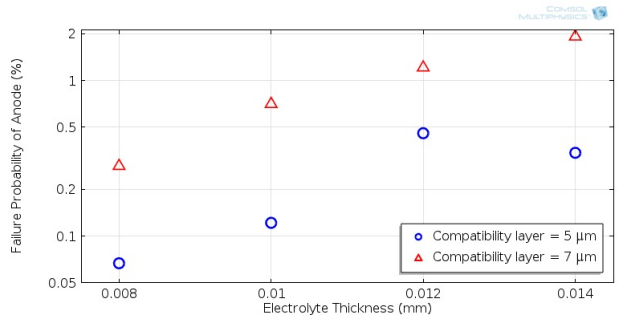

Figure 4: Failure probability of the anode layer (fully fabricated cell, room temperature).