Influence of Anode Creep on the Structural Reliability of Solid Oxide Fuel Cells

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Creep Reliability Overview

Structural integrity of the anode is critical to cell reliability especially in anode-supported SOFCs. Ni/YSZ cermet remains the popular choice for anode because of its superior electrical performance and stability under reducing atmosphere. One of the outstanding issues for long term reliability of SOFCs is creep of stack materials including the reduced Ni/YSZ porous structure. Creep deformation in the anode can lead to cell fracture or loss of contact thereby affecting reliability. Literature data on the creep of the Ni/YSZ anode at the SOFC operating range (700°C – 800°C) is scarce and is a focus of recent experimental studies. The influence of operational creep on reliability was studied with finite element simulations of a generic 3D SOFC design. The effect of thermal gradients, external loading and stack height on the creep deformations and subsequent reliability was also investigated with single and multi-cell stacks.

Technical Approach

1. Deduce creep model parameters for Ni/YSZ anode and other components at SOFC operating temperature range from experimental data or literature.
2. Develop single and multi-cell stack FEA models representing current planar SOFCs and implement creep for anode, glass seals, and interconnects.
3. Obtain temperatures for realistic operating conditions of multi-cell stacks from the electrochemistry models solved by in-house SOFC-MP-3D code.
4. Run simulations for long-term (currently 40,000 hours) creep and perform reliability evaluations.

Creep Model and Parameters

- Norton power law type implicit creep model shown in Equation (1) that correlates secondary creep strain rate to stress, temperature and material properties was implemented in the FEA.

$$\dot{\varepsilon}_{cr} = C_1 \sigma^{C_2} e^{-C_3/T} \qquad (1)$$

- The creep constant C_1 and stress exponent C_2 for the anode are obtained by scaling the high temperature test data from literature. The constant C_3 is the ratio of activation energy (Q) and the universal gas constant (R).
- The parameters for G-18 glass seals and 441-HP interconnects were based on experimental data generated under the SECA program and material data sheets. Figure 1 presents sample creep strain rate data for 10 MPa stress.

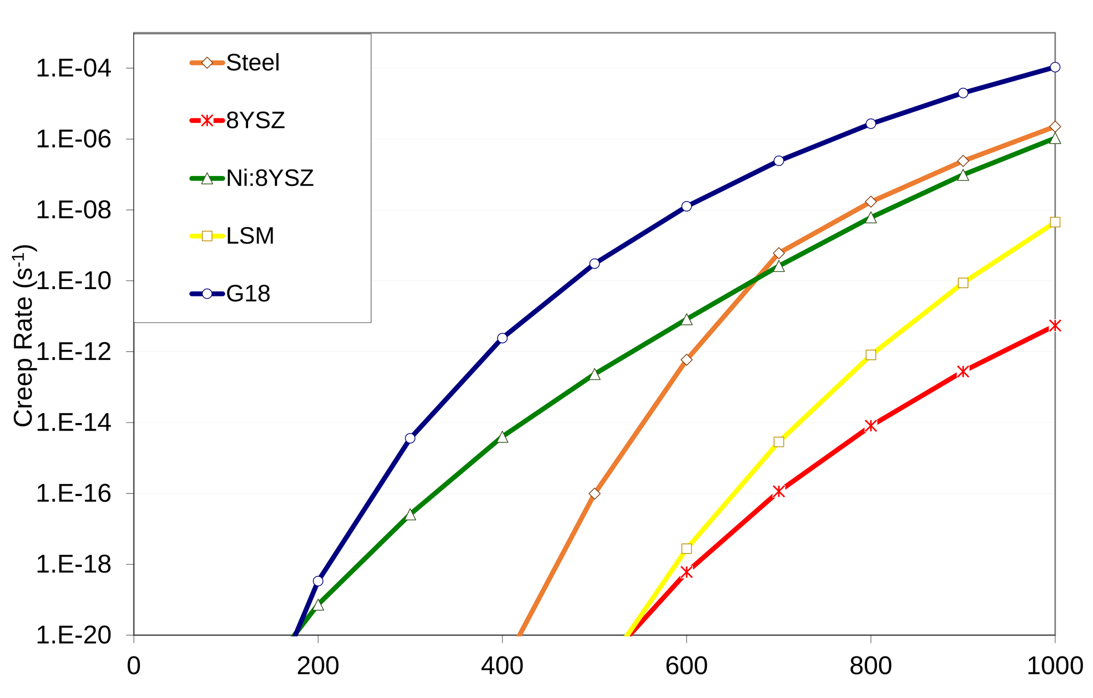

Figure 1: Sample Creep Strain Rates for SOFC Materials at 10 MPa Stress
(Note: Electrolyte and Cathode creep were not included in the current models)

FEA Model, Temperatures & Reliability

The structural analyses were carried out with the commercial FEA software ANSYS®. The stack modeling tool SOFC-MP-3D was used to simulate the electrochemistry and temperature distributions in stacks with planar (20 cm x 20 cm) cells in co-flow configurations as shown in Figure 2. The reliability was evaluated based on the statistical ceramic reliability theory.

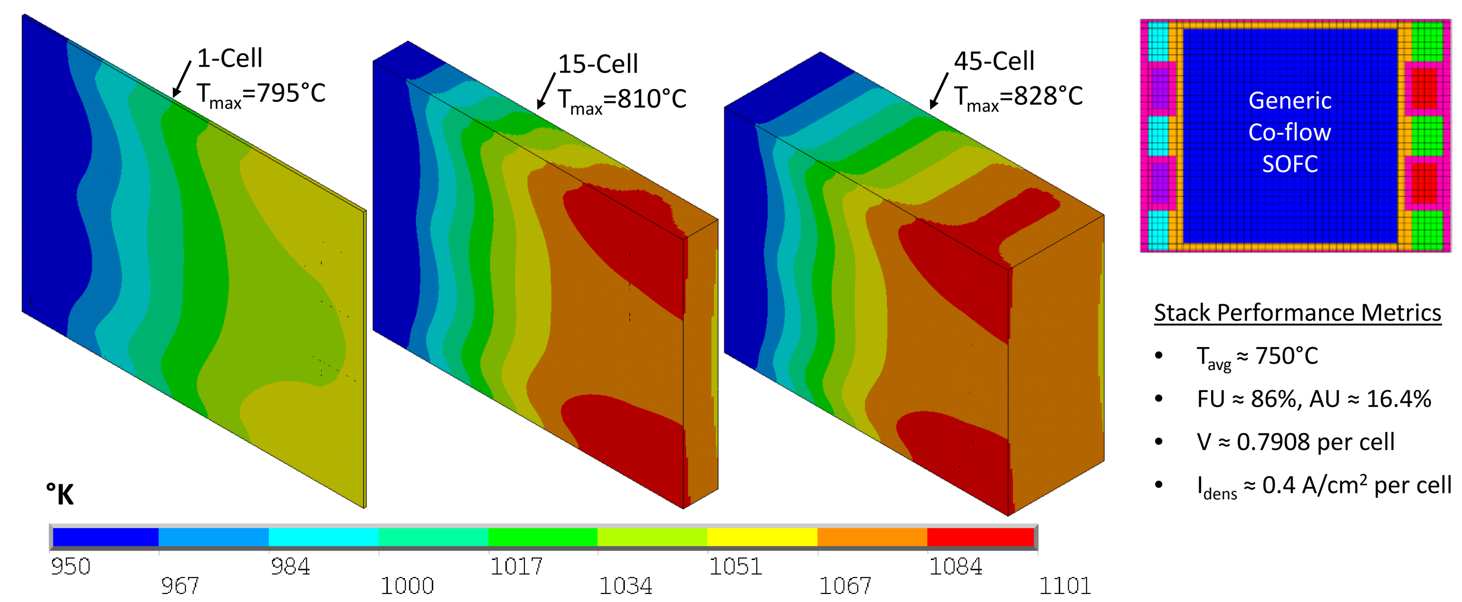

Figure 2: Temperature Gradients in 1, 15, 45 Cell Stacks with an Average Operating Temperature of 750°C

Reliability Results – 15 Cell Stack

Figure 3 presents cell-wise cathode and electrolyte failure probabilities (P_f) from the 15-cell stack before and after 40,000 hours of operation. The results show that long-term creep significantly increases the P_f of these layers, especially for cells near the end plates. Figure 4 presents the redistributed electrolyte stresses with reduced peaks but increased tensile areas.

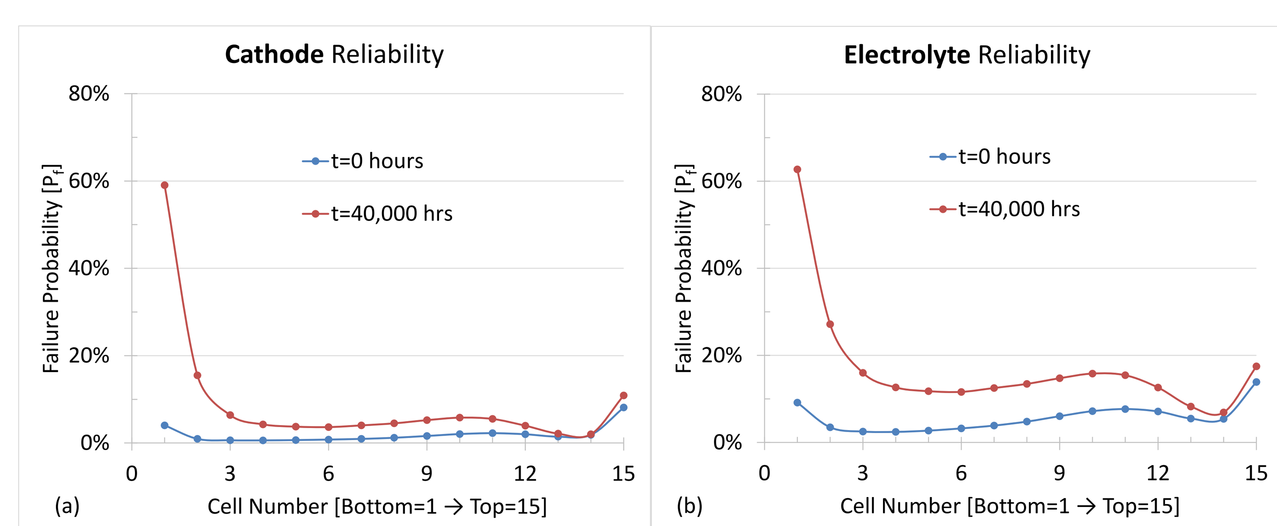

Figure 3: Cell-wise Failure Probability of Cathode (a) and Electrolyte (b)

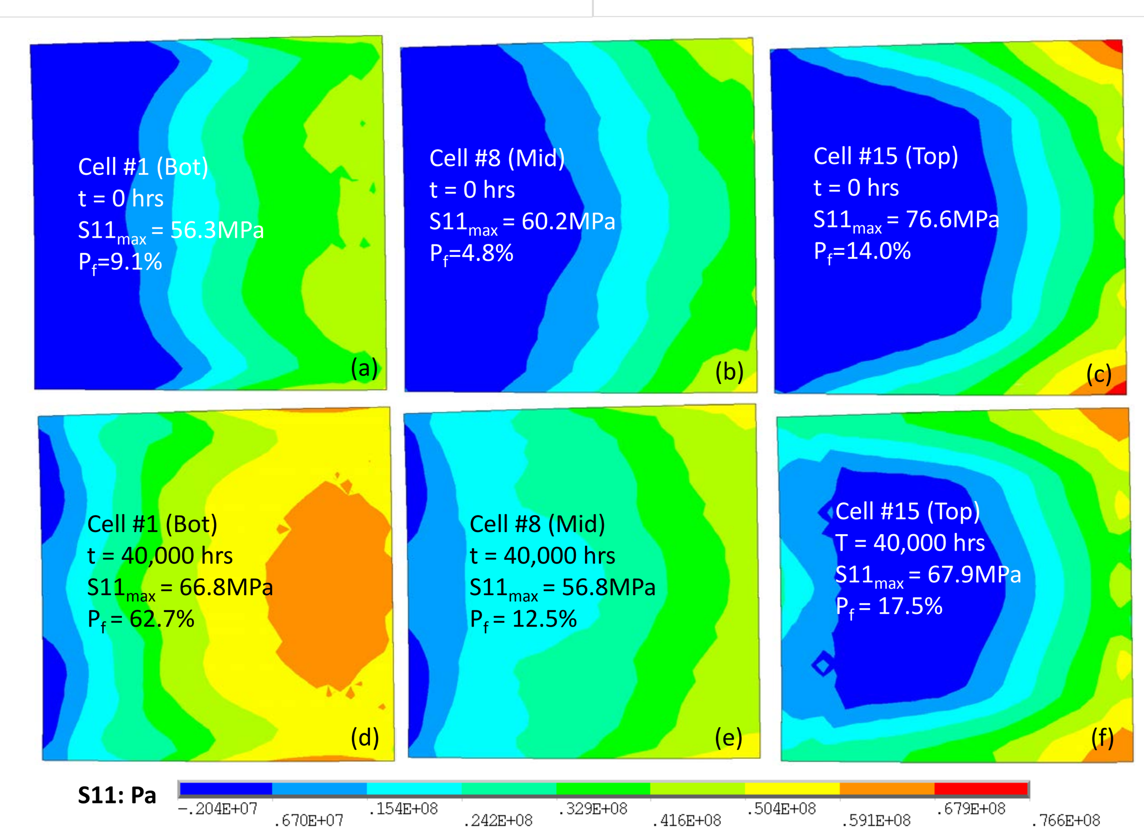

Figure 4: Principal Stress Contours from the Bottom (#1), Middle (#8) and Top (#15) cell Electrolytes Before (a, b, c) and After (d, e, f) 40,000 Hours of Operation

Reliability Results – 45 Cell Stack

Figure 5 presents cell-wise cathode and electrolyte failure probabilities (a, b) and corresponding peak principal stresses (c, d). Consistent with the 15-cell stack results, the operational creep increased failure probability despite reduced peak stresses in the cathode and electrolyte. The anodes are typically found safe (P_f ~ 0) before and after operation in all the stack models.

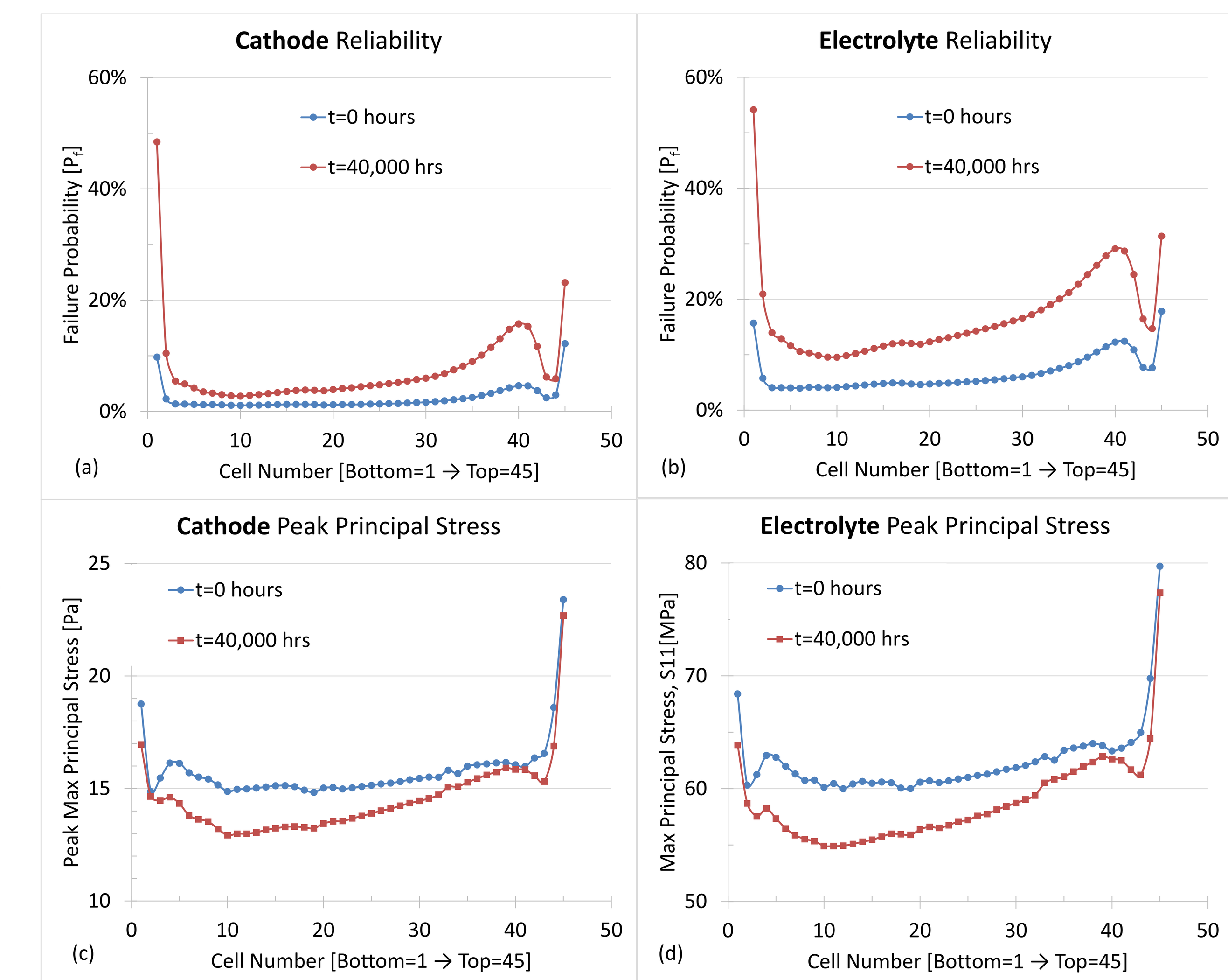

Figure 5: Cathode and Electrolyte Failure Probabilities (a, b) and Peak Principal Stresses (c, d) in 45-cell Stack

Influence of Compressive Load

Figure 6 presents the effect of compressive load on the end plates of a 15-cell stack for a negligible compressive preload (1 Pa) compared to 0.2 MPa specified in the earlier case (Figure 3). The results indicate that compressive load has a significant influence on the cell operational reliability especially under creep. The effect of creep is diminished without the external load.

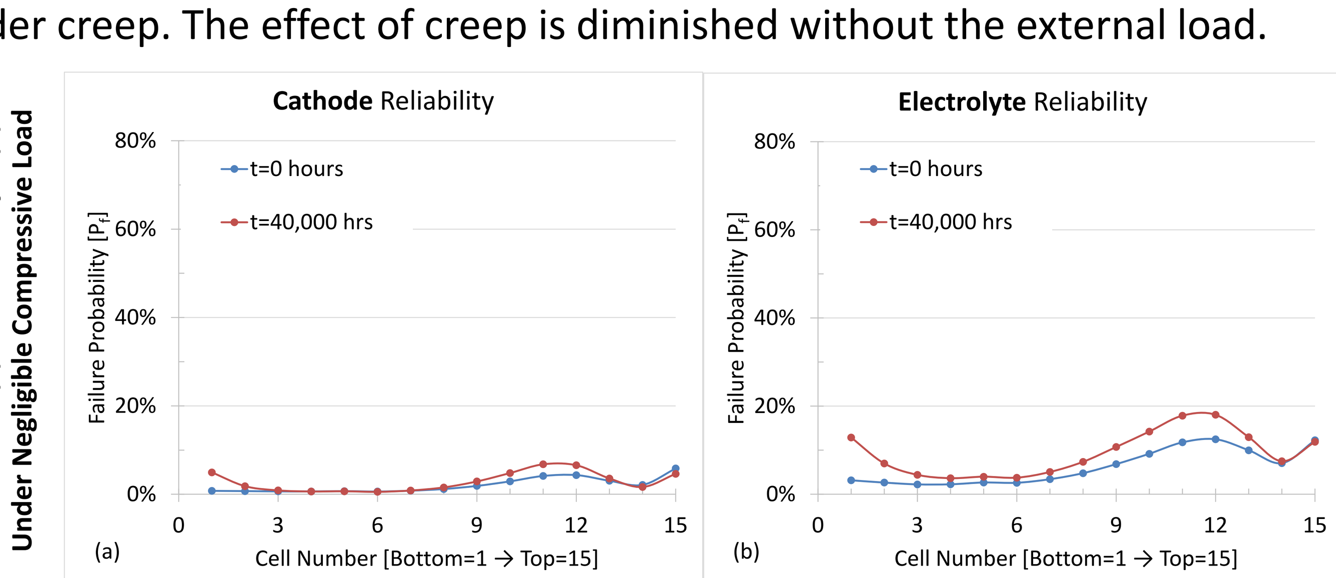

Figure 6: Cell-wise Failure Probability of Cathode (a) and Electrolyte (b) Under Negligible Compressive Load

Conclusions and Future Work

- Long-term creep may significantly reduce SOFC stack reliability.
- Anode creep relaxes tensile stresses in the anode and redistribute stresses in the electrolyte / cathode layers resulting in increased failure probabilities.
- External compressive load was found to adversely affect cell-level and overall stack reliability especially under creep.
- Future work will investigate the influence of flow configurations (counter-flow, cross-flow), cell design features (air/fuel ports), and boundary conditions (adiabatic, furnace) on the SOFC creep reliability.

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