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Dynamic Operation Strategies for High-Temperature Solid Oxide Electrolysis Cells

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Abstract

Solid oxide electrolysis cells (SOECs) are increasingly expected to operate under non-steady conditions rather than fixed steady-state loads. To enable future large-scale deployment, it is essential to understand how different forms of dynamic operation impact cell reliability. In this work, we establish a systematic evaluation framework to examine the durability of anode-supported SOECs under four representative dynamic stress modes: steam cycling (3–75% H_2O in H_2), reversible operation cycling between SOEC and SOFC modes, thermal cycling at both OCV (150–750 °C) and under load (600–800 °C at 1.3 V), and full vs. partial redox cycling (50% $H_2 \leftrightarrow$ 50% N_2). Results indicate that steam cycling, mode switching, and thermal cycling at OCV do not induce noticeable accelerated degradation, while thermal cycling under load remains largely tolerable within the tested temperature window. In contrast, full redox cycling leads to structural failure, whereas partial redox cycling produces manageable degradation without catastrophic damage. After operation, cells are characterized in detail to reveal structural and compositional evolution, using SEM/EDS, computed tomography, and beamline XRD. These findings demonstrate that multiple types of dynamic experiments—not only redox fluctuations—are necessary to fully evaluate SOEC robustness. The developed methodology provides a foundation for defining operating boundaries, guiding future accelerated protocols, and ensuring reliable SOEC performance under real, variable-demand conditions.