

Synergistic effects of UV radiation and corrosion on Zr alloys

Hongliang Zhang¹, Ranran Su², Adrien Couet³

¹ *Institute of Modern Physics, Fudan University*

² *University of Wisconsin-Madison, Madison, WI, USA*

hlz@fudan.edu.cn

Abstract Ultraviolet (UV) radiation and corrosion can be coupled in non-trivial ways and such coupling is of critical importance for the performance of materials in extreme environments. Understanding the corrosion mechanisms of Zr alloys in aqueous environments is important, as Zr alloys are the most commonly used cladding materials in pressurized and boiling water nuclear reactors. However, the confluence of these phenomena and their collective impact remains underexplored. This study bridges this knowledge gap by presenting a thorough investigation of Zr alloys exposed to corrosive high-temperature water under in-situ UV irradiation. We precisely quantify the oxide porosity in corroded Zircaloy-4 as function of exposure time and temperatures using our newly developed Machine-learning-based quantification method. The size, spatial distribution, morphology and interconnectivity of the pores are obtained and quantified through the 3D reconstruction. We found that initial UV exposure significantly accelerates corrosion and induces distinct changes in the microstructure of ZrO₂ oxides. Over time, we observed the formation of Fe₃O₄ particles on the ZrO₂ surface due to photo-dissolution of zirconia and photo-deposition of iron oxide magnetite. The emergence of Fe₃O₄ particles could enhance the corrosion resistance of the Zr alloy substrate. Furthermore, our results indicate that UV irradiation modulates the density and distribution of nanopores within the oxide layer by influencing oxygen speciation and the dynamics of oxide growth. These insights advance our understanding of the complex interplay between UV irradiation and high-temperature water corrosion.

Keywords Zr alloys; Corrosion; Nano-porosity; Machine-learning; 3D Reconstruction

Reference

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