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Effects of irradiation on the interface between U-Mo and zirconium diffusion barrier

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HIGHLIGHTS

- Several irradiated fuel plates were characterized by microscopy that focused on the interface between U–Mo and Zr.
- The low-Mo sub-layer exhibits numerous sub-micron bubbles/porosity at low burnup.
- The UZr_2 sub-layer formed during fuel fabrication becomes increasingly discontinuous as burnup increases.
- The U–Mo/Zr interface in monolithic U–Mo fuels is relatively stable after irradiation to very high burnup.

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ABSTRACT

Irradiated fuel plates were characterized by microscopy that focused on the interface between U–Mo and Zr. Before irradiation, there were three major sub-layers identified in the U–Mo/Zr interface, namely, UZr_2, Mo_2Zr, and U with low Mo. The typical total thickness of this U–Mo/Zr interaction is 2–3 μm. The UZr_2 sub-layer formed during fuel plate fabrication remains stable after irradiation, without large bubbles/porosity accumulation. However, this sub-layer becomes increasingly discontinuous as burnup increases. The low-Mo sub-layer exhibits numerous sub-micron bubbles/porosity at low burnup. Larger, interconnected porosity in this sub-layer was observed in a medium-burnup fuel specimen. However, at higher burnup, regions with the extra-large bubbles/porosity (i.e., larger than 5 μm) were observed in the U-Mo fuel foil at least 5 μm away from the original location of this sub-layer. The mechanism for the formation of the extra-large bubbles/porosity is still unclear at this time. In general, the U–Mo/Zr interface in monolithic U–Mo fuels is relatively stable after irradiation. No large detrimental defects, such as large interfacial bubbles or cracks/delamination, were observed in the fuel plates characterized.

1. Introduction

During the development of high-density U–Mo dispersion fuel to convert research and test reactors from the use of highly enriched uranium (HEU) to low-enriched uranium (LEU), the interaction between the U–Mo fuel particles and the aluminum-alloy matrix during irradiation was found to impact fuel performance [1]. Similar interactions have also been observed during the development of monolithic U–Mo fuel. For early designs of U–Mo monolithic fuel plates with Al–6061 cladding, large fission-gas bubbles were observed in the interaction layer that formed between the U–Mo and the cladding. Fig. 1 shows an example of this behavior. Because a concentration of fission-gas bubbles along the interface can lead to delamination of fuel plates, limiting or eliminating interaction between the U–Mo fuel foil and the Al–6061 cladding is important for achieving acceptable irradiation behavior. For this reason, the selected U–Mo monolithic fuel design incorporates a zirconium (Zr) diffusion barrier layer between the U–Mo fuel foil and the aluminum-alloy cladding. Sixty-two HIP-bonded U–Mo monolithic mini-size fuel plates with a co-rolled Zr diffusion barrier layer have been irradiated in the ATR through the irradiation campaigns RERTR–9B, RERTR–10A, and RERTR–12. Large-size fuel plates, up to 40 inches in length, were also fabricated and irradiated in the ATR through the irradiation campaigns AFIP–3, AFIP-4, AFIP–6, AFIP–6MKII, and AFIP–7.

The selection of Zr as a diffusion barrier has been discussed

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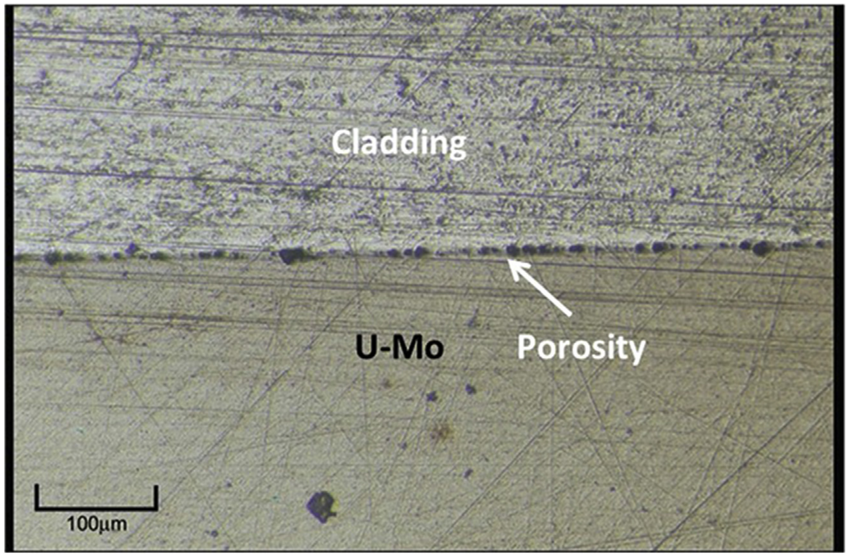

Fig. 1. An optical micrograph of the cross-section of an irradiated monolithic fuel plate from the RERTR–8 experiment shows porosity at the U–Mo/Al interface. Fuel plate #H1P010, average fission density: 5.8×10^{21} f/cm^3.

previously [2,3]. Utilizing diffusion couples, several investigations of the diffusion behavior between U–Mo and Zr have been documented in literature [4,5]. A more comprehensive study on the reaction between U–Mo and Zr can be found in Ref. [6]. In the laboratory-scale baseline fabrication process, the Zr diffusion barrier is applied to the U–Mo by a hot co-rolling process, followed by cold rolling Zr-coated foils to final thickness and then bonding the cladding using a hot isostatic press (HIP) [7]. This process is currently being scaled up by the commercial fabricator. The high-temperature co-rolling process establishes a thin (1–3 µm) but visible interaction layer between the U–Mo and the Zr. Fig. 2 and 3 show both the cross-section of a mini-size fuel foil after hot rolling at 650 °C and details of the U–Mo/Zr interface, respectively. The subsequent HIP-bonding process bonds the aluminum-alloy cladding to the Zr-coated U–Mo fuel foil. While the HIP, employing temperature and time restricted by Al-alloy properties, does not significantly contribute to further growth of interaction layer between the U–Mo and the Zr, it does establish a thin (1–2 µm) interaction layer between the Zr and the aluminum cladding. The main phases observed at the U–Mo/Zr interface have been reported previously, and include UZr_2, Mo_2Zr, and α-U [8–11].

During irradiation, the interaction layer between U–Mo and Zr continues to evolve. It is the purpose of this characterization study to document the behavior of this interaction layer when subjected

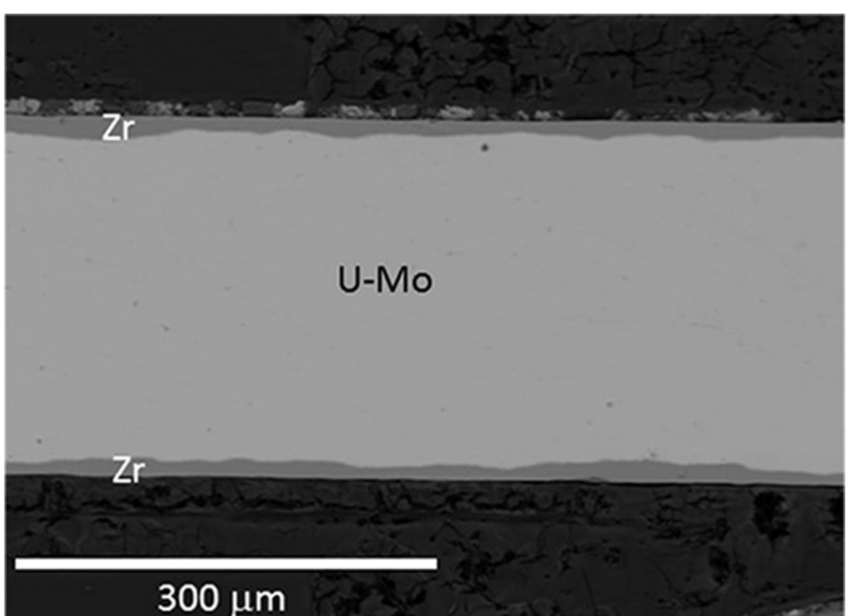

Fig. 2. An electron micrograph shows the cross-section of a hot-rolled fuel foil.

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