Enhanced Performance of U-Mo Nuclear Fuel via Surface Coating: Microstructure Analysis and Irradiation Behavior

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1. Introduction

To enhance the performance of U-Mo nuclear fuel, this study presents a novel approach involving surface coating of U-Mo particles to mitigate the adverse effects of reaction layer formation between U-Mo particle and the Al matrix. Previous attempts to add Si into the Al matrix showed limited success, resulting in rapid formation of the reaction layer and subsequent fuel plate integrity issues caused by Al consumption in matrix in some cases [1,2]. Microstructural analysis of as-fabricated U-Mo nuclear fuel further revealed incomplete diffusion of Si into U-Mo particles, leaving a significant portion of the surface of U-Mo particle exposed to the Al matrix. To address these challenges, a coating technique was developed wherein U-Mo powder was coated with Mo using Physical Vapor Deposition (PVD) process. Plate-type nuclear fuel was subsequently fabricated, utilizing the coated U-Mo powder dispersed within an aluminum matrix. For evaluation of performance of coated U-Mo particles, irradiation tests were performed up to 66.2 % U-235 burnup. Post-irradiation examination (PIE) encompassed micro-structural analysis of the fuel meat region and the interfacial region between fuel U-Mo powder and matrix, employing optical microscopy, scanning electron microscopy, and electron probe micro-analysis.

2. Methods and Results

In this section some of the techniques used to model the detector channel are described. The channel model includes a SiC detector, cable, preamplifier, amplifier, and discriminator models.

2.1 Fabrication of coated U-Mo powders

The U-Mo powder utilized was produced via centrifugal atomization, exhibiting a spherical morphology. A custom PVD system was developed to enable controlled coating of these spherical powders [Fig.1]. The coated powders, achieved through Mo deposition, were used for fabrication of plate-type nuclear fuel by using conventional meat-frame-covers assembly and hot rolling technique.

Fig. 1. Custom Physical Vapor Deposition (PVD) System Developed for Coating U-Mo Powder.

2.2 Microstructural characterization of as-fabricated mini-plate fuel

The microstructure of the Mo-coated U-Mo powder in the fuel meat of as-fabricated sample was examined using SEM (Scanning Electron Microscopy) and shown

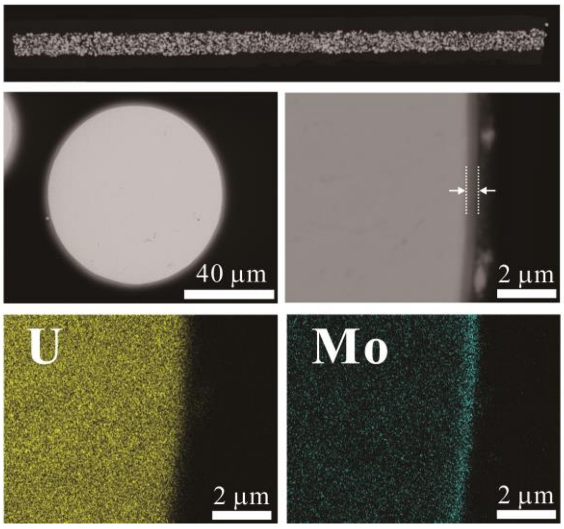

Fig. 2. Cross-Sectional Microstructure of Mo-Coated U-Mo Powder.

in Fig. 2. Continuous and constant coating layer on the surface of particle reveals successful coating.

2.3 Irradiation test

The average and maximum local heat flux, as well as burnup, were monitored and shown in Fig. 3. Mini-plate samples were irradiated up to 152.19 Effective Full Power Days (EFPD), displayed stable irradiation behavior, with an average burnup of 63.3 at. % U-235 and a local maximum burnup of 66.2 at. % U-235. As a post irradiation examination, non-destructive tests such as gamma scanning, fuel plate thickness and oxide film thickness measurement, and destructive tests for cross-sectional microstructure observation were performed.

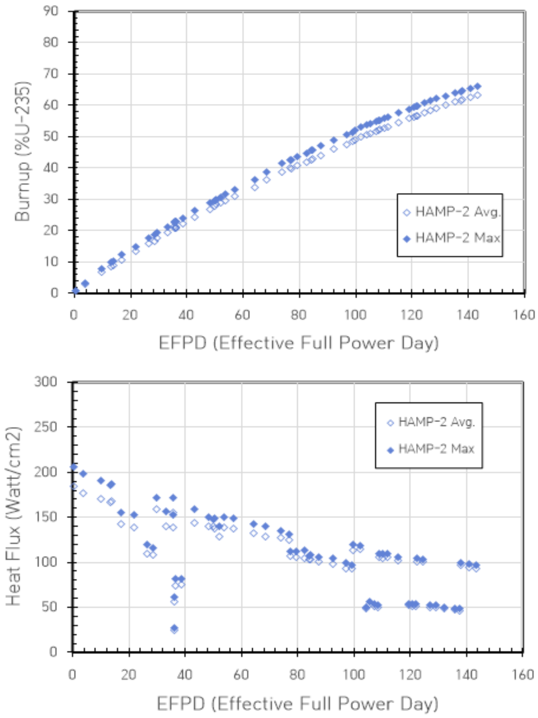

Fig. 3. Irradiation Test Results: Heat Burnup and Flux.

2.4 PIE for mini-plates

Figure 4 shows the cross-sectional microstructure of the fuel meat region of the Mo-coated U-Mo/Al dispersed plate fuel after irradiation. Notably, the fuel meat exhibited no abnormal swelling behavior up to the maximum burn-up (63 at. % U-235), and the formation of irradiation bubbles with a maximum diameter of 1 micrometer within U-Mo particles was suppressed. A thin and uniform reaction layer was also observed near the coating layer. It is considered that 1-micrometer thick coating layer retained its integrity throughout the irradiation test played a great role in improving performance of coated U-Mo particles.

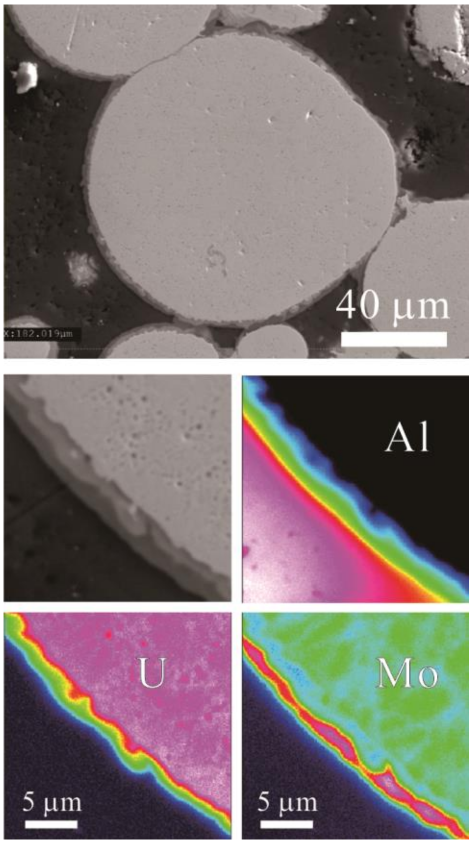

Fig. 4. Cross-Sectional Microstructure of Core Region in Mo-Coated U-Mo Distributed Plate Fuel.

3. Conclusions

In order to suppress the formation of a reaction layer between the centrifugal atomized U-Mo powder and the aluminum matrix, a coating layer was created on the surface of the nuclear fuel particle by the PVD process. Irradiation tests for mini-plate fuels having coated U-Mo fuel meat was performed up to 66.2 at. % U-235 burnup and PIE was also carried out after irradiation. Consequently, the study confirms the effectiveness of the coating layer in restraining reaction layer growth during irradiation. Overall, the application of a coating layer through PVD emerges as a promising strategy for suppressing reaction layer formation and enhancing U-Mo nuclear fuel performance.

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