Effects of Minor Element Additions in AA6061 on the Microstructural Evolution of the Interaction Region between U-Mo Alloys and AA6061 Claddings

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The U.S. Material Management and Minimization Reactor Conversion program is developing low-enriched molybdenum-stabilized uranium alloy fuels systems for use in research and test reactors. Monolithic and dispersion fuel plates have local regions where the U-Mo fuel can come into contact with the Al Alloy 6061 (AA6061) cladding. U-Mo alloys in contact with Al undergo diffusional interactions that result in the development of interdiffusion zones with complex fine-grained microstructures with multiple phases. In this study, the microstructural development of a diffusion couple consisting of U-10wt.%Mo vs. AA6061, annealed at 600°C for 24 hours was analyzed in detail by transmission electron microscopy with X-ray energy dispersive spectroscopy. The diffusion couple developed complex interaction regions where phase development was significantly influenced by the alloying additions of the AA6061. This study seeks to determine the effect of the minor element additions in the AA6061 and to identify any phases that may have developed as a result of these additions.

Project Description

U-Mo fuel plates encased in aluminum undergo chemical interactions that result in the development of a complex interaction region between the U-Mo fuel and the aluminum cladding. This study aimed to characterize the interaction region that develops between U-Mo alloys in contact with AA6061. Emphasis was given to the effects of the minor element additions in the AA6061 onto the interaction region between the U-Mo and the AA6061. Although more recent designs of U-Mo fuel plate systems place a Zr-diffusion barrier between the U-Mo and the AA6061, due to failure of the barrier or shearing of the ends of the fuel foils, the fuel plates can have regions where the U-Mo comes into contact

The often ignored minor element additions in aluminum alloys play a significant factor in the evolution of the interaction regions that develop between uranium alloys in contact with aluminum alloys.

with the aluminum. Thus, a clear understanding of the U-Mo/AA6061 interaction is required.

Prior characterization of diffusion couples of U-Mo in contact with AA6061 showed that the minor element additions in the AA6061 penetrate into the interaction region and affect its microstructural evolution. Comparison to the interaction regions that develop between U-Mo in contact with high-purity aluminum, the interaction regions between U-Mo and AA6061 develop more complex microstructures with phases that appear to contain mainly the elements from the AA6061 additions. These phases, if present, can significantly impact the fuel system performance during service. Thus, the phases must be conclusively identified so that any detrimental effects can be minimized or eliminated.

This study supports the qualification efforts of the fuel system under consideration. The data that this study generates will result in improvements in reliability and service life of the fuel systems. The acquired knowledge will also be generally available for any future system where U-alloys interact with aluminum alloys.

This work will contribute significant insight into the interactions of U-Mo with Al-alloys

— Emmanuel Perez, Materials Engineer, Idaho National Laboratory

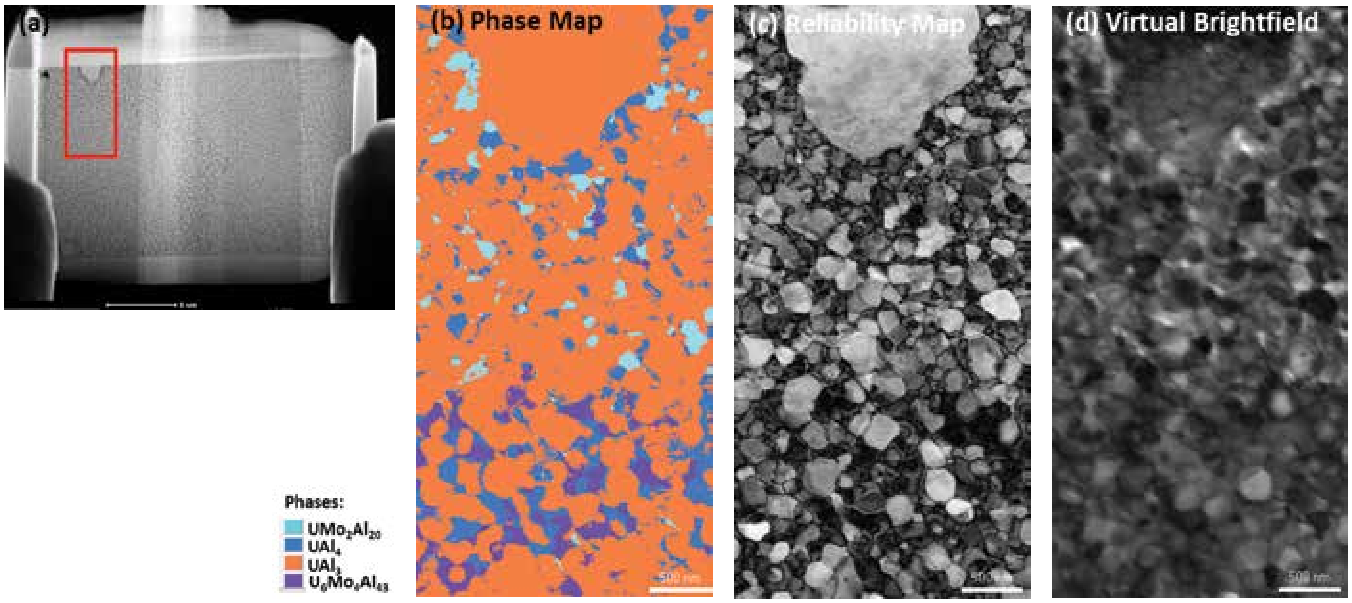

Figure 1. TEM characterization via the ASTAR system in a selected region of a TEM sample from the interaction region of a U-10Mo versus AA6061 diffusion couple annealed at 600°C for 24 hours. The micrographs show (a) the TEM sample, (b) a phase map identifying the UAl^3, UAl^4, $U^6Mo^4Al^{43}$, and UMo^2Al^{20} phases, (c) and (d) a reliability map and a virtual Brightfield micrographs detailing the microstructure of the selected region.

Accomplishments

Samples for characterization by scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were prepared via focused ion beam (FIB) at CAES. A total of nine TEM samples were successfully prepared and analyzed in detail. The samples captured sections of the interaction regions in a U-10Mo vs. AA6061 diffusion couple annealed at 600°C for 24 hours that represented the different microstructural features observed in the interaction region between the U-10Mo and the AA6061. SEM analysis was carried out in the FIB using its SEM capabilities. TEM analysis was carried by high-angle annular dark-field (HAADF) imaging, energy dispersive spectroscopy (EDS), selected area electron diffraction (SAED) on individual grains, and by precession diffraction analysis using the ASTAR system installed in the TEM. At of the end of FY 2015, analysis of the data was still in progress.

This work was facilitated by the CAES staff: Jatuporn Burns, Yaqiao Wu, Joanna Taylor, and Kristi Moser-McIntire.

Future Activities

The project aims to complete analysis of the collected data in FY 2016. This work is scheduled to be presented at the 2016 Minerals, Metals and Materials (TMS2016) annual conference. A publication of this study is planned, likely in the *Journal of Nuclear Materials*.

Publications and Presentations

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Distributed Partnership at a Glance	
NSUF and Partners	Facilities and Capabilities
Center for Advanced Energy Studies	Microscopy and Characterization Suite
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