

Chemical Interactions Between Metallic SFR Fuel and Advanced Claddings

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by

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INTRODUCTION

Advanced cladding materials are being considered for high-temperature applications in Generation IV reactors (e.g. T91, ODS steels). These materials provide better mechanical properties (e.g., creep strength) at these higher temperatures than the more commonly employed cladding steels (e.g., HT-9). However, consideration must also be given to other high-temperature phenomenon besides just the mechanical properties of the cladding when using fuels at high temperatures. In particular, the compatibility of the fuel and cladding must be considered. In Sodium Fast Reactors (SFRs) that employ metallic fuel, interactions of fuel and cladding (FCI) during irradiation of a fuel element can result in the formation of strength-reducing zones or possibly the formation of low melting phases [1]. This paper reports the results of diffusion experiments that were conducted with metallic fuel and advanced cladding materials at the relatively high temperature of 700°C.

DESCRIPTION OF THE ACTUAL WORK

Diffusion couple techniques were employed to evaluate FCI for fuels exposed to relatively high temperatures. Initially, a prototypic fuel alloy was cast to imitate high-burnup fuel. It comprised U, Pu, Zr, Nd, Mo, and Ru and was labeled Fuel Alloy 1. The final composition of this alloy was (in wt%): 65U-19Pu-9Zr-2Nd-2.5Mo-2.5Ru. The U, Pu, and Zr are typical constituents in a ternary, metallic fuel. The Nd was added to account for the lanthanide fission products that build up in a high-burnup fuel. These fission products are elevated in concentration of the fuel/cladding interface and play a big role in FCI [1]. The Mo and Ru were added to represent the noble metal fission products that build up in irradiated fuel and participate in FCI. Along with the cast alloy, a 71U-19Pu-10Zr fuel (Alloy 2) that was available was selected to represent the standard metallic fuel irradiated in an SFR. For the cladding materials, a HCM12A alloy, Alloy 800H, and an oxide dispersion strengthened (ODS) steel² were

selected as advanced claddings to be used in the diffusion couples.

Diffusion couple stacks were assembled and annealed at a relatively high temperature for various times. The stacks alternated fuel and cladding materials. The annealed stacks were then sliced longitudinally, mounted, polished, and examined using a scanning electron microscope (SEM) equipped with energy and wavelength dispersive spectrometers to determine the morphology of the formed diffusion structures, phase compositions and the overall interdiffusion behavior of the fuel and cladding constituents.

RESULTS

In Figure 1, diffusion structures that developed for diffusion couples between ODS and HCM12A cladding materials and fuel Alloy 1 are presented. These structures are relatively large. For the ODS/fuel Alloy 1 couple the presence of large voids suggests that potentially some of the phases melted at this temperature. The presence of cracks in the diffusion structures suggests that some of the formed phases are brittle. Figure 2 shows the structure that formed in the ODS/fuel Alloy 2 couple. The 71U-19Pu-10Zr fuel developed a Zr-rich layer at the fuel/cladding interface that seemed to impede the FCI.

For diffusion couples between metallic alloy fuels and advanced cladding steels that are annealed at 700°C, appreciable interdiffusion can occur between the fuel and cladding alloys. For specific compositions within the interdiffusion zones that form, large voids were observed. This likely indicates melting has occurred, increasing interdiffusion rates in the process. However, the presence of a Zr-rich layer on the surface of the fuel can significantly impede interdiffusion.

Therefore, based on the observations described above, the chemical interactions between the fuel and cladding in a fuel element need to be considered when developing

² The ODS cladding was an experimental alloy with a composition of: 10.78Cr-7.72Mo-0.46Ti-

0.10Y₂O₃-0.062O-0.053C-0.02Si-0.015Mn-0.009N-0.001S-bal Fe.

advanced claddings for application in Generation IV reactors.

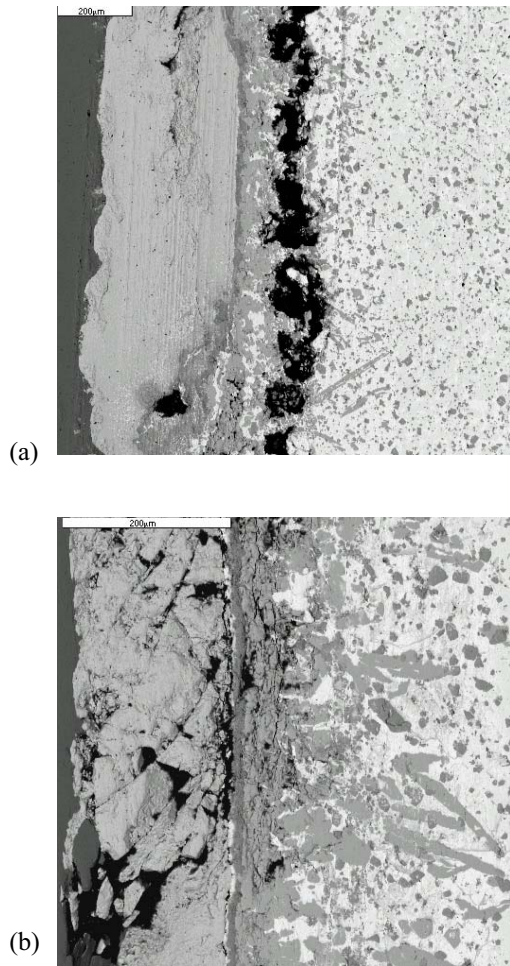


Fig. 1. SEM micrographs showing the diffusion structures that developed for the couples between a fuel alloy doped with fission products and (a) the ODS alloy and (b) the HCM12A alloy when they were annealed at 700°C for 25 hours. The fuel is to the right and the cladding is to the left. The scale bars are 200 μm.

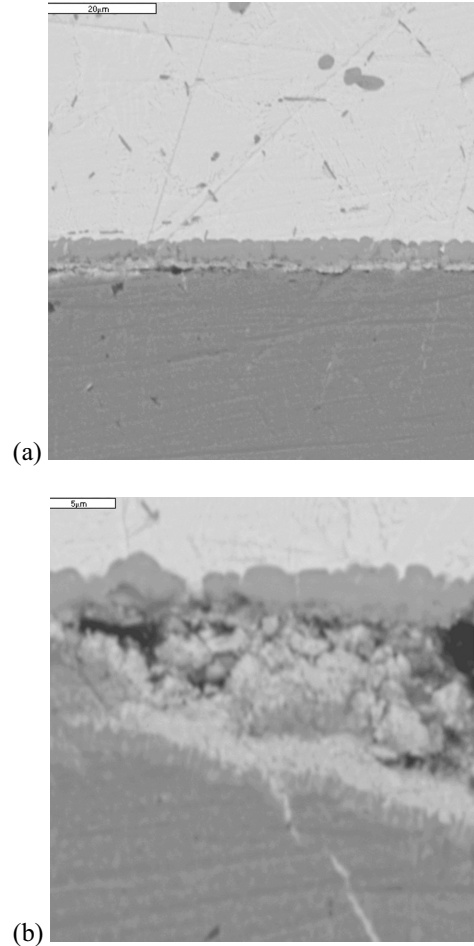


Fig. 2. SEM micrographs showing the diffusion structures that developed for the couple between U-19Pu-10Zr fuel and an ODS alloy that was annealed at 700°C for 25 hours. The fuel is at the top and the cladding is at the bottom. (a) is where a Zr-rich layer (medium contrast) that forms remains intact, and (b) is where it has broken down. The scale bars are 20 μm and 5 μm, respectively.

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