HOT ISOSTATIC PRESSING OF U-10ZR ALLOY NUCLEAR FUEL BY COUPLED GRAIN BOUNDARY DIFFUSION AND POWER-LAW CREEP

A Thesis

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"Could it be that questions tell us more than answers ever do?"
- Michael Card, 1983

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ABSTRACT

McDeavitt, Sean M. Ph.D., Purdue University, December 1992. Hot Isostatic Pressing of U-10Zr Alloy Nuclear Fuel by Coupled Grain Boundary Diffusion and Power-Law Creep. Major Professor: Dr. A.A. Solomon.

Porous U-10Zr was produced using UH_3 and ZrH_2 powders and U and Zr metal powders. The powders were sintered under purified argon beyond pore closure to simulate fission gas bubbles. HIP experiments were performed at 700°C (γ phase) yielding an apparent driving force dependence of n=3.4±0.3 and an apparent activation energy of Q=187±10 kJ/mole. Experiments were attempted at 600°C (α' phase), but densification was not detectable. Post-HIP microstructures had modal pore sizes of 2.5±0.1 and 1.7±0.1 μm, pore spacings of 10±1 and 7±0.7 μm, and grain sizes of 34±4 and 114±12 μm for hydride- and metal-derived specimens, respectively. The hydride-derived specimens contained 25 vol.% of a ubiquitous Zr impurity phase stabilized by C, N, and O leaving ~5 wt.% Zr in solution, whereas the metal-derived specimens contained 5 vol.% of the Zr impurity phase leaving ~9 wt.% Zr in solution.

The coupled diffusion/creep cavitation model of Chen and Argon shows quantitative agreement with the measured HIP rates using n=5. The coupled model also predicts, for the first time, an asymmetry in HIP and swelling for identical driving forces due to differences in grain boundary stress. The difference in HIP behavior between metal- and hydride-derived material could be explained by differences in pore structure, whereas the differences in impurity particles and dissolved Zr content do not. A calculation of the

time-dependent HIP behavior was made which shows a varying time dependence that is consistent with the observed HIP rates.

The compressibility of U-10Zr is different from previously studied ceramics and metals and is significantly lower than U-5Fs, which appears to HIP by diffusive transport only. The differences could be due to higher grain boundary diffusivity and/or larger pore size-to-spacing ratios in U-5Fs causing diffusional growth to be rapid and dominant. The lack of detectable compressibility of U-10Zr in both the α' and α+δ phases may lead to problems with fuel/cladding mechanical interactions during normal and off-normal conditions, especially at high burnup when solid fission products occupy available porosity.