ELEVATED TEMPERATURE NANOINDENTATION AND IN-SITU SEM MECHANCIAL TESTING OF URANIUM FUELS

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Due to the Fukushima nuclear accident there has been a large effort by several countries to develop accident tolerant fuel forms for commercial light water reactors. A challenge with the current UO_2 fuel is its low thermal conductivity which leads to higher center line temperatures in the fuel. New nuclear fuel forms are looking to increase the thermal conductivity and other thermophysical proprieties while also maintaining adequate mechanical properties and uranium loading. The elastic modulus, fracture toughness, and creep properties of the fuel are important for modeling the pellet clad mechanical interactions during operation of a nuclear reactor. During the operation of a nuclear reactor the cladding material creeps down and fuel pellet swells which leads to physical contact between the two. The pellet clad mechanical interactions can lead to potential cladding failures and release of radioactive material. The advanced fuel forms that are under consideration for replacing UO_2 in commercial light water reactors is UN, U_3Si_2, composite UO_2 and UO_2 with additives. The composite UO_2 is looking to increase the thermal conductivity with different additions and the UO_2 with additives are intended to increase the grain size of the UO_2. The increase in grain size can reduce the release of fission gas products into the plenum of the cladding rod improving the operational lifetime of the fuel. While there is a large amount of work on the thermal properties of these accident tolerant fuel forms the literature is quite sparse on the mechanical properties necessary for modeling such interactions as the pellet clad mechanical interactions.

A technique that could measure the mechanical proprieties like hardness, elastic modulus, fracture toughness and creep properties of these new materials in their operating temperature range is elevated temperature nanoindentation. The periphery of fuel pellets in a light water reactor operates at 500 °C which is within the temperature range of current commercial high temperature nanoindentation systems. The main challenge with elevated temperature nanoindentation of these uranium base compounds is their sensitivity to oxygen. These uranium based compounds readily oxidize at the elevated temperatures (>500 °C) without environmental control in the nanoindenter chamber. For this study, a Hysitron Triboindenter has been modified to perform high temperature nanoindentation in an inert or reducing environment, minimizing oxidation in the specimens and facilitating the measurement of mechanical properties. The data collected will provide valuable datasets that feed directly into models for understanding the behavior of these advanced accident tolerant fuel forms in light water reactors.

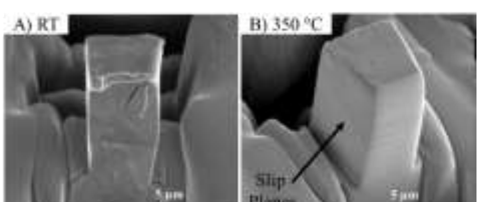

Figure 1: A) An in-situ SEM microcompression test of UO_2 at room temperature B) A microcompression test at 350 °C

In addition, in-situ scanning electron microscopy testing at the micron scale is being investigated as an addition way of measuring the mechanical properties of UO_2 and these advanced accident tolerant fuel forms. The development of these small scale mechanical testing techniques on fresh fuel would allow for applying them to spent nuclear fuel in the future. This would be of great interest in nuclear community since there is limited mechanical data of spent fuel in the literature due to the difficulty of testing the material because of its high levels of radioactivity. Microcompression testing in a single crystal of UO_2 at room and elevated temperature has been performed using the low vacuum mode of FEI Quanta 3D FEG SEM/FIB dual beam system at UC Berkeley. A Hysitron PI-88 system was used to perform the microcompression testing of the FIB manufactured specimens. During the testing a brittle to ductile transition in the deformation behavior was observed (as seen in Figure 1) and the Peierls stress for UO_2 was calculated that agreed well with the literature data. In addition, the microcompression specimens allow for the calculating the slip systems activated in the UO_2 at these temperatures. The successful results on the UO_2 allows progressing with in-situ SEM testing of the advanced accident tolerant fuel forms at elevated temperatures.