NUCLEAR ENERGY UNIVERSITY PROGRAMS

Assessment of Embrittlement of VHTR Structural Alloys in Impure Helium Environments

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Abstract

The helium coolant in high-temperature reactors inevitably contains low levels of impurities during steady-state operation, primarily consisting of small amounts of H_2, H_2O, CH_4, CO, CO_2, and N_2 from a variety of sources in the reactor circuit. These impurities are problematic because they can cause significant long-term corrosion in the structural alloys used in the heat exchangers at elevated temperatures. Currently, the primary candidate materials for intermediate heat exchangers are Alloy 617, Haynes 230, Alloy 800H, and Hastelloy X. This project will evaluate the role of impurities in helium coolant on the stress-assisted grain boundary oxidation and creep crack growth in candidate alloys at elevated temperatures. The project team will:

- Evaluate stress-assisted grain boundary oxidation and creep crack initiation and crack growth in the temperature range of 500-850°C in a prototypical helium environment.
- Evaluate the effects of oxygen partial pressure on stress-assisted grain boundary oxidation and creep crack growth in impure helium at 500°C, 700°C, and 850°C respectively.
- Characterize the microstructure of candidate alloys after long-term exposure to an impure helium environment in order to understand the correlation between stress-assisted grain boundary oxidation, creep crack growth, material composition, and impurities in the helium coolant.
- Evaluate grain boundary engineering as a method to mitigate stress-assisted grain boundary oxidation and creep crack growth of candidate alloys in impure helium.

The maximum primary helium coolant temperature in the high-temperature reactor is expected to be 850-1,000°C.Corrosion may involve oxidation, carburization, or decarburization mechanisms depending on the temperature, oxygen partial pressure, carbon activity, and alloy composition. These corrosion reactions can substantially affect long-term mechanical properties such as crack-growth rate and fracture toughness, creep rupture, and fatigue. Although there are some studies on the effects of impurities in helium coolant on creep rupture and fatigue strength, very little is known about their effects on creep crack initiation and crack growth rate at elevated temperatures.