Mechanical Engineering Doctoral Defense

Creep-Fatigue Damage Investigation and Modeling of Alloy 617 at High Temperatures

School for Engineering of Matter, Transport and Energy

Fraaz Tahir

Advisor: Yongming Liu

abstract

The Very High Temperature Reactor (VHTR) is one of six conceptual designs proposed for Generation IV nuclear reactors. Alloy 617, a solid solution strengthened Ni-base superalloy, is currently the primary candidate material for the tubing of the Intermediate Heat Exchanger (IHX) in the VHTR design. Steady-state operation of the nuclear power plant at elevated temperatures leads to creep deformation, whereas loading transients including startup and shutdown generate fatigue. A detailed understanding of the creep-fatigue interaction in Alloy 617 is necessary before it can be considered as a material for nuclear construction in ASME Boiler and Pressure Vessel Code. Traditional strain-controlled tests, which produce stress relaxation during the hold period, show a saturation in cycle life with increasing hold periods due to the rapid stress-relaxation of Alloy 617 at high temperatures. Therefore, applying longer hold time in these tests cannot generate creep-dominated failure. In this study, uniaxial isothermal creep-fatigue tests with non-traditional loading waveforms were performed at 850 and 950°C, with an objective of generating test data in the creep-dominant regime. The new loading waveforms replaced the strain-controlled hold periods of traditional tests with force-controlled hold periods, which cause creep deformation. The experimental data provided evidence for the inadequacy of the widely-used time fraction rule for estimating creep damage under creep-fatigue conditions. Micro-scale damage features in failed test specimens, such as fatigue cracks and creep voids, were analyzed to find a correlation between creep and fatigue damage. The results from this image-based damage analysis were used to develop a phenomenological life-prediction methodology called the effective time fraction approach. Finally, the constitutive creep-fatigue response of the material at 950°C was modeled using a unified viscoplastic model with a damage variable. The simulation results were used to validate an energy-based life-prediction model, as an improved version of the effective time fraction rule.

April 10, 2017; 12:00PM; ERC 490