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Monitoring Microstructural Evolution of Alloy 617 with Nonlinear Acoustics for Remaining Useful Life Prediction: Multi-Axial Creep-Fatigue and Creep-Ratcheting

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ABSTRACT

The proposed research will build upon a current investigation to develop a unified constitutive model intended for design-by-analysis of the intermediate heat exchanger (IHX) for a very high-temperature reactor (VHTR) design of Next Generation nuclear Plants (NGNPs). Model development requires a set of failure data from complex mechanical experiments to characterize the material behavior. Therefore uniaxial and multiaxial creep fatigue and creep ratcheting are being conducted on the nickel-based Alloy 617 at temperatures of 850 and 950°C. The time dependence of material behavior, and the interaction of time dependent behavior (e.g., creep) with ratcheting, which is an increase in the cyclic mean strain under load-controlled cycling, are major concerns for NGNP design.

The proposed research is aimed at characterizing the microstructure mechanisms activated in Alloy 617 by mechanical loading and dwell times at elevated temperatures. The acoustic-harmonic generation method will be researched for microstructural characterization. It is a nonlinear acoustics method with excellent potential for nondestructive evaluation and even online continuous monitoring once high-temperature sensors become available. It is unique because it has the ability to quantitatively characterize microstructural features well before macroscale defects (e.g., cracks) form. The nonlinear acoustics beta parameter will be correlated to microstructural evolution using a systematic approach to handle the complexity of multiaxial creep fatigue and creep-ratcheting deformation. Limited mechanical testing is proposed to supplement the current investigation and provide a full spectrum of data for thermal aging, tensile creep, uniaxial fatigue, uniaxial creep fatigue, uniaxial creep ratcheting, multiaxial creep fatigue, and multiaxial creep ratcheting. Thorough microscopy, including high-resolution transmission electron microscopy (HR-TEM), scanning transmission electron microscopy (STEM), energy dispersive spectroscopy (EDS), and scanning electron microscopy (SEM) is required and will be conducted to correlate the beta parameter with individual microstructure mechanisms.

The acoustic-harmonic generation method is well developed for longitudinal waves in large specimens. Higher harmonic generation in thin plates is becoming better understood and some success has been achieved. We propose to research applying the method to tubular mechanical test specimens, and eventually pipes for nondestructive evaluation. Tubular specimens, samples sectioned from these specimens, and pipes will all act as waveguides; thus, we will apply the acoustic-harmonic generation method to guided waves in shells. Coupling ultrasonic transducers to the shell sample will be achieved to generate a pure mode and receive low-amplitude harmonics.

The diverse project team, which includes a minority serving institution, enables the results of the microstructural evolution characterization to be employed for remaining useful life prediction. The unified constitutive model currently being developed for design purposes will be adapted for life prediction by correlating the beta parameter evolution obtained from nondestructive evaluation (or eventually online monitoring) to the model's internal state variables. Such a microstructure based constitutive model will enable improving the ASME-NH code for Alloy 617.