Multi-resolution in-situ testing and multiscale simulation for creep fatigue damage analysis of Alloy 617

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Program: RD&D: Creep Fatigue

ABSTRACT:

Project Objectives: The overall goal of this project is to develop novel testing and experimentally validated prediction methodologies for creep-dominated creep-fatigue response of structural materials for advanced reactor systems. The investigations will focus on the characterization and testing of Alloy 617, but the proposed testing and life-prediction methodologies are applicable to other structural materials as well. The research objectives of this proposal are: (1) Perform multi-resolution in-situ and ex-situ testing and imaging analysis for the fundamental creep-fatigue damage mechanism investigation; (2) Develop a new procedure for creep-fatigue testing at the coupon level and generate a database for model validation; (3) Formulate and implement models for simulation of creep-fatigue damage mechanisms and their interactions at the microstructure scale; and (4) Conduct microstructure simulations for creep-fatigue mechanism understanding and develop a microstructure-informed and experimentally validated phenomenological creep-fatigue life prediction model.

Proposed Methods and Potential Impacts: State-of-the-art experiments and numerical analyses are proposed for the characterization and investigation of creep-fatigue damage at various length scales. The proposed experimental study will use a multi-resolution in-situ and ex-situ testing and imaging-based method for the fundamental creep fatigue damage mechanism investigation. In-situ scanning electron microscopy testing will be used to observe the micro-level creep fatigue damage, such as inter- and trans-granular slip, crack and cavitation size and density, and the coalesce and interaction of different damage features. At the coupon level, new testing design and procedures will be developed to promote more creep damage within the material. Creep fatigue interaction map (CFIM) will be proposed to describe the creep-dominated, fatigue-dominated, and creep-fatigue transition failures of Alloy 617 at different temperatures and stress states. Physics-based numerical models will be developed to study the evolution of interacting creep-fatigue failure mechanisms. Creep and fatigue induced microstructure damage mechanisms will be modeled using crystal plasticity coupled with novel cohesive zone models for inter- and trans-granular failure evolution. State-of-the-art numerical algorithms for time marching will be devised to efficiently and accurately simulate deformation and damage accumulation response throughout the creep-fatigue life of the material. The numerical models will be validated using the results from the experimental studies. A simple phenomenological life-prediction model will be developed based on the experimental and numerical data, which will provide the design basis for Alloy 617. This research will not only lead to significant accomplishments at the basic research level for experimental and numerical investigation of creep-fatigue in high temperature alloys, but it will also thoroughly characterize the creep-dominated creep-fatigue failure in Alloy 617 – a primary candidate material for advanced reactor applications. A successful outcome of the proposed study will lead to a comprehensive mechanism understanding and mechanistic analysis of Alloy 617 in very high temperature reactor applications.

Budget and Individual Capabilities: The research, to be performed at Arizona State University (lead) and Vanderbilt University, requests $800,000 total for three years. The ASU team will be responsible for the overall project progress and experimental testing. The proposed budget for the ASU team is $450,000. The Vanderbilt team will be responsible for the numerical simulation and modeling. The proposed budget for the Vanderbilt team is $350,000.