Fundamental Understanding of Creep-Fatigue Interactions in 9Cr-1MoV Steel Welds

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ABSTRACT:

The severe environments of stress and elevated temperature in advanced reactors result in loading conditions that stimulate strong creep-fatigue interactions in structural materials such as 9Cr-1MoV steel. The published studies of creep-fatigue behavior are typically based on "bulk" stress-strain data recorded during testing and "post-mortem" microstructure characterization. Such data does not directly provide any knowledge of *local* phase, microstructure, stress and strain conditions under which the crack propagates driven by the interactions of creep and fatigue. Moreover, the weld joint is oftentimes the weakest link in the structural component due to the welding-induced microstructure and residual stress gradients. The knowledge of creep-fatigue interactions for 9Cr-1MoV steel welds is much limited. Improving the mechanistic understanding of the creep-fatigue damage of 9Cr-1MoV steel and welds with highly inhomogeneous microstructure is crucial for the safety and design of key structural components in advanced, high-temperature reactors.

The overarching goal of the proposed project is to advance the state of knowledge and fundamental understanding of creep-fatigue interactions in 9Cr-1MoV steels and their welds, especially under loading conditions where creep is the dominant damage mechanism. The specific objectives including:

- Developing a novel approach that holistically integrates (1) cost-effective, long-term creep-fatigue tests, (2) advanced material characterizations, and (3) multi-scale finite element modeling.
- Applying the integrated approach to probe the local conditions for creep-fatigue damage evolution in the 9Cr-1MoV base steels and welds with highly inhomogeneous microstructure.
- Establishing an improved prediction of creep-fatigue life for 9Cr-1MoV steels and their welds.

Addressing limitations of currently available supporting experimental data, the outcomes of the proposed project include the much needed quantitative experimental data for creep-fatigue behavior of 9Cr-1MoV steels and welds, especially for the creep damage dominated region. Another major outcome is the multi-scale finite element models and material constitutive equations to be developed as a physics-based computational foundation for improving the life predictions of advanced reactor structures. If successful, the project is expected to have significant impacts on understanding the performance of metallic alloys for the long service times and high operating temperatures associated with advanced reactor system development.

Finally, the dollar value of the effort to be performed by each participant over the three-year period of performance is summarized as the following: [1] Ohio State University, Project Lead, $587.4K; [2] Oak Ridge National Laboratory, Collaborator, $130K; [3] University of Tennessee - Knoxville, Collaborator, $51K; [4] Electrical Power Research Institute, Industry Advisor, $29.6K; [5] ITW Welding Group, Industry Advisor, $0K (in-kind cost-share); [6] Chemnitz University of Technology, Germany, Collaborator, $0K (in-kind cost-share).