Investigation of a Novel NDE Method for Monitoring Thermomechanical Damage and Microstructure Evolution in Ferritic-Martensitic Steels for Generation IV Nuclear Energy Systems

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ABSTRACT

The main goal of the proposed project is the development of validated nondestructive evaluation (NDE) techniques for in situ monitoring of ferritic-martensitic steels like Grade 91 9Cr-1Mo, which are candidate materials for Generation IV nuclear energy structural components operating at temperatures up to ~650°C and for steam-generator tubing for sodium-cooled fast reactors. Full assessment of thermomechanical damage requires a clear separation between thermally activated microstructural evolution and creep damage caused by simultaneous mechanical stress. Creep damage can be classified as "negligible" creep without significant plastic strain and "ordinary" creep of the primary, secondary, and tertiary kind that is accompanied by significant plastic deformation and/or cavity nucleation and growth. Under negligible creep conditions of interest in this project, minimal or no plastic strain occurs, and the accumulation of creep damage does not significantly reduce the fatigue life of a structural component so that low-temperature design rules, such as the ASME Section III, Subsection NB, can be applied with confidence. The proposed research project will utilize a multifaceted approach in which the feasibility of electrical conductivity and thermo-electric monitoring methods is researched and coupled with detailed post-thermal/creep exposure characterization of microstructural changes and damage processes using state-of-the-art electron microscopy techniques, with the aim of establishing the most effective nondestructive materials evaluation technique for particular degradation modes in high-temperature alloys that are candidates for use in the Next Generation Nuclear Plant (NGNP) as well as providing the necessary mechanism-based underpinnings for relating the two. Only techniques suitable for practical application in situ will be considered. As the project evolves and results accumulate, we will also study the use of this technique for monitoring other GEN IV materials.

Through the results obtained from this integrated materials behavior and NDE study, new insight will be gained into the best nondestructive creep and microstructure monitoring methods for the particular mechanisms identified in these materials. The proposed project includes collaboration with a national laboratory partner and the results will also serve as a foundation to guide the efforts of scientists in the DOE laboratory, university, and industrial communities concerned with the technological challenges of monitoring creep and microstructural evolution in materials planned to be used in Generation IV Nuclear Energy Systems.