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Mechanisms-based Acceleration of Materials Qualifications for Creep-Fatigue Performance in Advanced Nuclear Systems

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ABSTRACT:

The goal of this research is to fully understand, quantify and model creep-fatigue 'damage' as a function of loading patterns, temperature and microstructural evolution. Using this experimental information over a large range of relevant stress levels and temperatures, we will provide a mechanisms-based creep-fatigue analysis approach which will properly qualify high temperature alloys for extended service in advanced nuclear systems where creep-fatigue is currently a major design limitation.

Since the approach to understanding and characterizing creep-fatigue interactions is based on microstructural evolution under complex loading conditions, it should also be possible to use this information for alloy design for enhanced creep-fatigue performance. This would be particularly significant for development and qualification of new or existing alloy for high temperature service in advanced nuclear systems.

The link between elevated temperature mechanical loading, the associated evolution of deformation microstructures (or ‘damage’ accumulation) and design practice will be provide by crystal plasticity models where finite element techniques are applied to interacting deformation of groups of crystals (grains) to describe bulk deformation response. This approach can be scaled to component level deformation analysis by expanding the local behavior over larger component volumes.

The results here will be a major advance beyond current creep-fatigue analysis methods which are primarily based on fatigue with hold-time methods. These methods require the use of much higher stresses that would be permitted in design, which then induce extremely high initial stress relaxation rates. For high temperature materials qualification, the use of extreme stress levels and stress relaxation rates may not provide useful materials information in an applications realm where materials deformation response are extremely sensitive to strain rates both in loading and relaxation (creep).