High throughput assessment of creep behavior of advanced nuclear reactor structural alloys by nano/microindentation

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ABSTRACT:

The recent rapid development of Fe-based alloys for service in nuclear reactors has outpaced the ability for creep experiments to supply the needed guidance and validation of polycrystalline deformation models as part of the DOE-Nuclear Engineering Advanced Modeling and Simulation (NEAMS) program. Currently, these models lack experimental quantification of the activity of dislocation cross-slip vs. dislocation climb-based mechanisms needed to effectively apply the model over a wide range of microstructures and temperatures. Measurement of thermal and/or irradiation creep is typically a long term (years or more) endeavor requiring multiple load frames capable of handling relatively large samples. However, small-scale (nanometer to micrometer) testing is ideally suited to evaluating the mechanical response of either irradiated or unirradiated materials due to the small sample volumes (~ several μm^3) required. Through the use of elevated temperature strain rate jump tests, stress relaxation, or constant-load indentation creep testing, it can provide insight into the critical parameters (strain rate or stress exponent, activation volume, activation energy for diffusion) that describe the dominant creep mechanisms for a given set of creep conditions. **We propose a high-throughput, indentation based, cost-effective alternative for bulk thermal creep testing of 14YWT, HT-9, T91 tempered martensitic alloy, and FeCrAl alloys.** Our nano/microindentation-based datasets will be benchmarked to bulk-scale tensile creep data, gathered on identical heats of material. If successful, the techniques and datasets generated by this proposed work may be adapted for beamline use in NSUF facilities where in-situ nanomechanical testing can be conducted on samples undergoing ion beam irradiation. In this program, we will:

1. Further develop a method for evaluating thermal creep rates and mechanisms using material parameters (strain rate sensitivity, activation energies, activation volumes) that are attainable from high-throughput nanoindentation testing over a range of rates and temperatures.
2. Develop and validate a robust, microstructurally-informed model with large mechanical test datasets from (1) with the power to predict creep behavior for the range of complex microstructures found in the proposed materials systems.
3. Predict, using the model based in (2), secondary creep rates over a wide range of stress and temperature, as well as inform existing models capable of predicting tensile creep rupture. We will benchmark these predictions to experimental bulk creep data in the literature, and data generated in the proposed work.