Multiscale high-throughput experiment/modeling approach to understanding creep behavior in Additively Manufactured reactor steels

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ABSTRACT:

The recent rapid development of AM steels for service in nuclear reactors has outpaced the ability for experiments to supply the needed guidance and validation of polycrystalline deformation models as part of the DOE-NEAMS program. Currently, these models lack the spatially-resolved experimental quantification of dislocation cross-slip vs. dislocation climb-based mechanisms needed to address realistic operating temperatures for heterogeneous AM microstructures. **Our recent work demonstrates that a combination of high-throughput, high-temperature indentation Strain Rate Jump Tests (SRJT) and a few bulk dead-load creep tests is sufficient to determine creep lifetime in Gr 91 alloy. This discovery has the potential for order-of-magnitude improvements in the time necessary to determine creep time to rupture and subsequent alloy design and qualification.** Using our combined model/experiment approach, only 36 hours of tension testing, and ~8 hours of indentation testing provides the data needed to calculate creep lifetime predictions based on the well-established Larson-Miller Parameter (LMP). This stands in stark contrast to the dozens of bulk samples currently needed for a state-of-the-art creep data set. Moreover, a combination of bulk, meso-scale, and micrometer-scale testing is ideally suited to evaluating the mechanical response across the critical length scales of an AM part and guiding NEAMS models to handle increasingly heterogeneous structures. For all three length scale tests, elevated temperature strain rate jump tests or stress relaxation testing can provide insight into the critical parameters (strain rate or stress exponent, activation volume, activation energy for diffusion) that describe the site-specific, or aggregate dominant creep mechanisms for a given set of creep conditions. **We propose to develop a high-throughput predictive toolkit to determine creep performance and lifetime for AM microstructures built upon a microstructurally-informed mesoscale model, high-throughput indentation testing, and bulk tension testing. Our multiscale approach will be tuned to address the microstructural heterogeneity prevalent in AM materials through elevated temperature mechanical mapping of AM 316H Stainless Steel (316H SS), Grade 91 (Gr 91) and Titanium-Zirconium-Molybdenum (TZM) alloys.** These data sets will guide and validate microstructurally-informed NEAMS models capable of predicting mechanical response ranging from ambient quasistatic to creep deformation conditions and will closely complement advancements in the DOE-NE Advanced Materials and Manufacturing Technology (AMMT) portfolio.