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A multiscale analysis of deformation mechanisms near grain boundaries

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ABSTRACT

Understanding and harnessing the influence of grain boundaries on the mechanical properties of materials requires that we acquire data on the length scales of the grain boundary network. This has given rise to in situ imaging and spectroscopy techniques to measure grain orientations and strain distributions. It is difficult to apply these techniques to quantify the behavior of grain boundaries at elevated temperature for two reasons: (i) complexity of the experimental set-up and (ii) grain boundaries not only imparts strength and resistance to deformation, but also contribute creep deformation by grain boundary sliding mechanisms. An empirical model has been developed that correlates creep rates and grain boundary sliding; it is hypothesized that introducing grain boundary serrations reduces the grain boundary sliding mechanisms and thereby reduces creep rates. This presentation will discuss how mesoscale electron backscatter diffraction measurements of grain orientations have been coupled with 2D, in situ, full-field deformation measurements and ex situ, grid offset measurements to quantify the grain boundary strain accumulation and grain boundary sliding mechanisms. These measurements provide insight into the validity of the empirical model assumptions. Analysis of these coupled measurements was conducted on two nickel-based super alloys tested at constant stress and elevated temperature conditions (creep). The two materials had the same chemical composition and were processed to have similar microstructural architectures (grain size, twin fraction, particle size) but each material exhibited either microscopically planar or serrated high-angle grain boundaries. The analysis of the mesoscale data indicates that the introduction of microscopic serrations reduces the susceptibility of microstructure to experience grain boundary sliding but does not eliminate the activation of this mechanism. The coupled mesoscale measurements also enable a site-specific multiscale approach to quantifying structure–deformation mechanism relationships using transmission electron microscopy, and 3D microstructural quantification using serial sectioning and micro-Laue diffraction. These multiscale techniques have been applied to the super alloy with microscopically planar grain boundaries. They indicate that the tendency of grain boundaries to either accumulate deformation or transmit strain by grain boundary sliding is likely an inter-relationship between crystalline disorientation, active dislocation mechanisms, proximity of the local grain boundary network, and the nanoscale serrations of the grain boundaries.