CHARACTERIZATION TECHNIQUES AND METHODOLOGIES FOR ASSESSING SLIP TRANSFER ACROSS GRAIN BOUNDARIES

In order to continue pushing the boundaries of materials science and develop new components that employ cutting edge materials we must have a deep understanding of the atomic reactions at work when we form, forge, mold, and cut materials for engineering applications. Any design process requires steps where the material is plastically deformed to create a final part with a finished shape that can be utilized. Plastic deformation is characterized by permanent shape change in a material due to the motion of crystalline defects, i.e. dislocations, vacancies, twins, etc. Understanding and describing plastic deformation in materials is fundamentally challenging because as dislocations move through a material they interact with other lattice defects including other dislocations, substitutional and/or interstitial atoms, precipitates, and grain boundaries. These interactions during plastic deformation can have long-range and substantial impacts on the material’s bulk behavior and material properties. The goal of this doctoral work is to develop new techniques to study how dislocations interact with grain boundaries in polycrystalline microstructures and to further understand how the interaction of
dislocations with grain boundaries affects a materials deformation response. With this knowledge we hope to begin to understand and anticipate material failure due to stress concentrations at grain boundaries.

Deformation in polycrystalline and single crystal metals was investigated using novel analysis techniques to study dislocations structures near grain boundaries. The materials included: polycrystalline Ti-5Al-2.5Sn, polycrystalline commercially pure titanium, polycrystalline nickel, and single crystal NiAl. Multiple materials were used to develop myriad analysis methodologies and techniques that capitalized on the different properties of the individual materials. The structure and motion of dislocations near grain boundaries was studied using scanning electron microscopy (SEM) techniques including: electron backscattered diffraction (EBSD), selected area channeling (SAC), and electron channeling contrast imaging (ECCI). These SEM techniques provided real-world information about the material’s crystallography at discrete locations in the microstructure enabling data to be directly related to observed features and deformation responses using physically meaningful variables.

Experiments with Ti-5Al-2.5Sn, commercially pure titanium, and polycrystalline nickel developed new methods for characterizing slip transfer across grain boundaries using EBSD, ECCI, and SAC. These techniques were enhanced by focused ion beam (FIB) milling, which allowed the investigation of deformation and dislocation structures to extend into the 3rd dimension. Novel FIB milling methods were developed to study dislocation motion across phase boundaries in microcantilever beams of Ti-5Al-2.5Sn during microbeam bending experiments. These experiments provided new avenues to tie microstructural properties to measured deformation responses. ECCI was combined with FIB milling in a NiAl single crystal to develop a new technique termed 3D ECCI. This work demonstrated the proof of concept viability of
dislocation imagining at depth after surface material removal with a FIB. With 3D ECCI the study of dislocations in an SEM can be extended to whole material volumes and is no longer limited to the free surface of the material. These advances demonstrate new opportunities for studying how dislocations nucleate, interact, and traverse grain boundaries in crystalline structures, which can ultimately lead to a greater understanding of how microscopic features affect macroscopic properties.

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