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Understanding Deformation and Failure Mechanisms via Multimodal and Multiscale Electron Diffraction Analysis

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Mechanical deformation and failure processes such as fatigue crack formation and ductile fracture are inherently multiscale processes, ranging from nanoscale crack nucleation mechanisms to collective dislocation interactions ranging across hundreds of microns. Understanding these processes requires multiscale characterization approaches that reflect the nature of the processes. A key factor in these multiscale approaches is the ability to quantify data in such a way that information can be passed between the length scales.

Advances in electron detector technology in both scanning and transmission electron microscopy, including the advent of direct-electron detectors, and increases in computational processing capacity have transformed electron microscopy-based characterization into a big-data analytics tool capable of multimodal image acquisition and high-resolution property mapping. This includes the ability to post-experiment select desired imaging conditions and map out the three-dimensional elastic strain tensor, crystal rotations, and dislocation density at length scales ranging from nanometers to centimeters [1]. Increases in electron detection efficiency available from direct-electron detectors also allows multimodal image acquisition to be coupled with *in situ* electron microscopy experiments such as heating, straining, and exposure to aggressive environments, giving us new insight into nano and mesoscale deformation processes [2].

In this talk, I will discuss the application of multiscale and multimodal electron microscopy techniques to understanding ductile fracture and fatigue damage, with examples taken from detecting individual dislocations from electron backscatter diffraction (EBSD) scans, strain localization and dislocation structures in additive manufactured IN718, and ductile fracture in Al alloys. Heat treatable Al alloys provide an especially interesting case study as they are composed of a range of secondary particles, including distributed intermetallic particles on the order of microns, dispersoids on the order of single microns, and sub-micron scale precipitates, as well as heterogeneities inherent to polycrystalline materials. In this study, notched Al 6061 dogbone samples were tested under tension in the scanning electron microscope (SEM) and EBSD scans were collected periodically at interrupted strain stages. The EBSD data were used to generate dislocation density maps, which could be spatially correlated to microstructural features of interest. Select sub-regions were investigated using high-resolution EBSD to investigate the evolving strain fields around triple junctions and intermetallic particles. Focused ion beam (FIB) machining was used to fabricate TEM samples from cracked intermetallic particles, revealing the local dislocation structure driving fracture processes.

Figure 1 shows the quantification of the dislocation fields in relation to grain boundaries, triple junctions, and intermetallic particles. As can be seen, all three features lead to dislocation accumulation, but the intermetallic particles have the largest influence on the surrounding defect fields. Figure 2 shows transmission electron microscopy (TEM) characterization of the defect fields surrounding a cracked intermetallic particle. Discussion will focus on mechanisms leading to defect accumulation in relation to microstructural heterogeneities and their relationship with ductile fracture of Al 6061 [3].

References:

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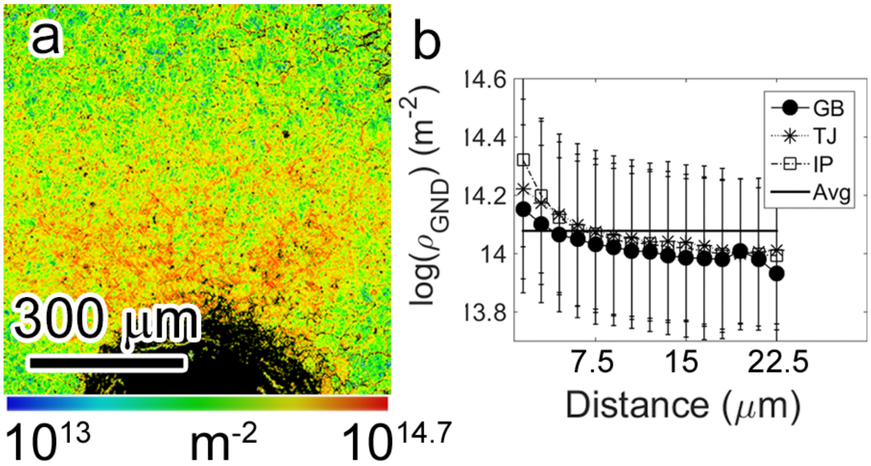

Figure 1. a) GND dislocation map in front of notch in strained AA6061. b) Quantification of GND accumulation as a function of distance from grain boundaries (GB), triple junctions (TJ) and intermetallic particles (IP).

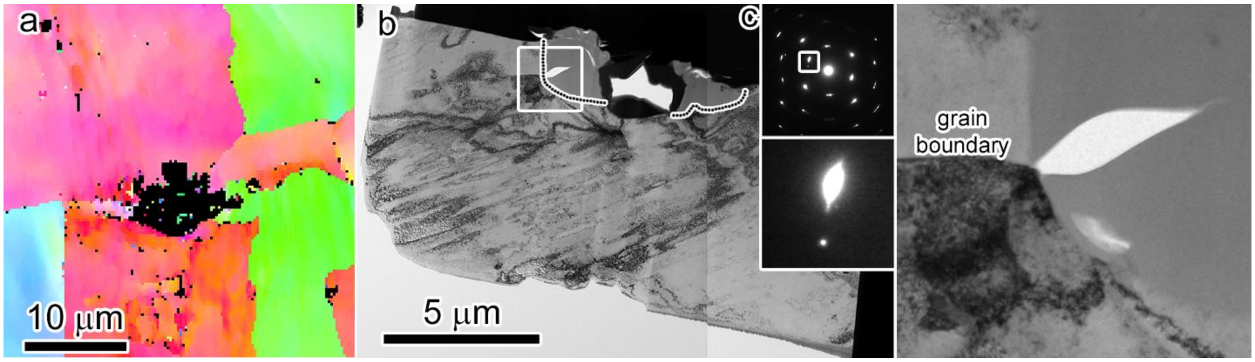

Figure 2. TEM analysis of cracked intermetallic particle. a) Orientation map around particle (particle appears as unindexed points in center). b) TEM image of dislocation structures around particle. Particle outlined by dotted line. c) Magnified image of boxed region in (b) showing crack forming in particle at GB/particle intersection.