Mechanical Engineering Doctoral Defense

Three Dimensional Characterization of Microstructural Effects on Spall Damage in Shocked Polycrystalline Copper

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abstract

Shock loading is a complex phenomenon for which spall damage is the predominant failure mode. Studying incipient stages of spall damage is of paramount importance to accurately determine initiation sites in the material microstructure where damage will nucleate and grow and is the focus of this research. Shock loading experiments were conducted via flyer-plate impact tests for pressures of 2-6 GPa and strain rates of 10^5/s on copper polycrystals of varying thermomechanical processing conditions. Serial cross sectioning of recovered target disks was performed along with electron microscopy, electron backscattering diffraction (EBSD), focused ion beam (FIB) milling, and 3-D X-ray tomogrpahy (XRT) to gain 2-D and 3-D information on the spall plane and surrounding microstructure. 2-D statistics on grain boundaries (GB) containing damage were performed and GBs of misorientations 25° and 50° were found to have the highest probability to contain damage in as-received (AR), heat treated (HT), and fully recrystallized (FR) microstructures, while {111} Σ3 GBs were globally strong. The AR microstructure's probability peak was the most pronounced indicating GB strength its dominant factor for damage nucleation. 3-D XRT data was used to digitally render the spall planes of the AR, HT, and FR microstructures. From shape fitting the voids to ellipsoids, it was found that AR microstructure contained greater than 55% intergranular damage, whereas the HT and FR microstructures contained predominant transgranular and coalesced damage modes, respectively. 3-D reconstructions of large volume damage sites in shocked Cu multicrystals showed preference for damage nucleation at GBs between adjacent grains of a high Taylor factor mismatches as well as void growth for an angle between the shock direction and the GB physical normal of ~30°-45°. 3-D FIB sectioning of individual voids led to the discovery of uniform plastic zones ~25-50% the size of the void diameter and plastic deformation directions were characterized via local average misorientation maps. Fabrication of square waves using photolithography and chemical etching was developed to study the nature of plasticity at GBs away from the spall plane. Grains oriented close to <0 1 1> had half the residual amplitudes than grains oriented close to <0 0 1>.

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