8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

Dynamics of the Onset of Damage in Copper under Shock Loading

***Aaron Koskelo[1], Scott Greenfield[2] and Dennis Paisley[3]**

[1] Los Alamos National Laboratory
Postal Address
koskelo@lanl.gov

[2] Los Alamos National Laboratory
Postal Address
greenfield@lanl.gov

[3] Los Alamos National Laboratory
Postal Address
paisley@lanl.gov

Key Words: *Shock loading, copper, spall.*

ABSTRACT

Current efforts in the dynamic loading community clearly indicate an increasing awareness of the importance of microstructural heterogeneity on nucleation and propagation of damage[1], and work to establish correlations between microstructural features and damage nucleation is being carried out. However, current “top-down” approaches based on experiments with bulk polycrystalline samples coupled with the standard shock diagnostics and post-shock characterization make it difficult to establish physically-based links between microstructure and damage. The effect of voids and inclusions on the nucleation of damage during dynamic unloading is widely recognized[2], but poorly-understood. Much of the difficulty has been in preparing samples where the sensitivity to a given microstructural aspect can be studied systematically. Achieving this systematic understanding requires a “bottom-up” approach that combines microstructural design, appropriate pre- and post-loading characterization, and advanced in-situ diagnostics, as well as detailed atomistic and continuum modeling.

Polycrystalline plasticity models are often used to simulate dynamic deformation of metals. Many of these models are based on the Taylor approximation, whereby the strain in each grain is assumed to be equal to the applied macroscopic strain. Taylor-based models cannot account for localized deformation modes that can lead to material failure. Hence, predictions of failure in polycrystalline materials require the consideration of trans- and inter-granular failure mechanisms. In particular, grain boundaries may act as barriers to the propagation of failure modes that originate inside the grains or as sites of failure initiation. These failure modes can also be affected by the heterogeneous strains at and around grain boundaries due to material anisotropy

Experimental studies have shown that the initiation and propagation of intergranular and transgranular failure modes in face-centered cubic (fcc) bicrystals and polycrystals are directly related to the boundary misorientation. For high-angle misorientations, dislocation pile-up and high stress concentration can lead to intergranular fracture. The investigation of these local deformation modes in polycrystals is experimentally complicated due to the unavoidable sample-to-sample variations. The use of single crystals, bicrystals and multicrystals as models of individual grains, grain boundaries

and grain boundary connectivity (triple points, etc.) is the appropriate first step to understand the dynamic deformation modes associated to microstructural features. This is particularly true for shock loading, since relatively few experiments with bi- and multi-crystals have been carried out.

Our work applies an integrated combination of material synthesis by design, shock/recovery experiments, post-shot metallography, theory, and simulation. Our goal is to correlate the observed localized displacements and velocities during dynamic loading with the microstructure, damage location and damage character on recovered samples. Samples are characterized as fully as possible before they are shock loaded with laser-driven flyers. We have developed a sensitive transient imaging displacement interferometer3 (TIDI), coupled with point and line VISARs, which together view the localized dynamic, microscopic displacement and velocity history at the optically accessible break-out surface. The dynamic information is very accurately correlated with pre-shot grain orientation maps and post-shot metallographic analysis. Absolute timing methods allows us to use point VISAR, the standard technique, to correlate the dynamics seen in the interferometeric data with the position in time in the shock compression and release profile.

Some of our results on copper specimens at the time this abstract was written include:

1) A clear transition in void nucleation location occurs when specimens transition from quasi-columnar to multicrystalline. In the quasi-columnar case the damage is largely transgranular, in the multicrystalline case void nucleation occurs primarily along grain boundaries.

2) Post-shot metallographic data shows the location of void formation in many of our specimens. In one specimen, incipient spall appears where one would expect from the typical 1-dimensional computations but then follows along an individual grain boundary well away from the spall plane indicating a "weak" grain boundary. This implies that spall strength can vary substantially from point to point for incipient spall conditions.

3) Dynamic microscopy measurements show multiple length scale phenomena including

- Hundreds of nanometers high elastic distortions along grain boundaries due to anisotropy in wave propagation speed between adjoining grains. These distortions evolve over at least the first hundreds of nanoseconds after the arrival of the shock front at the surface. The result clearly shows that to completely model shock propagation in polycrystalline material, the details of the material microstructure must be accurately known.

- 0.5 to 1.0 micron distortions that appear at the first arrival of the plastic wave at the breakout surface of the material, some distortions appear correlated with damage induced near the surface during the shot. Damage assessment was based on post-shot metallography

- Deformations on the order of tens of microns wide and probably tens of nanometers in height that evolve laterally and out-of-plane through several cycles of compression and release in a single spall shot.