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Characterization of Dynamic Damage of Copper Targets using X-ray Micro Tomography

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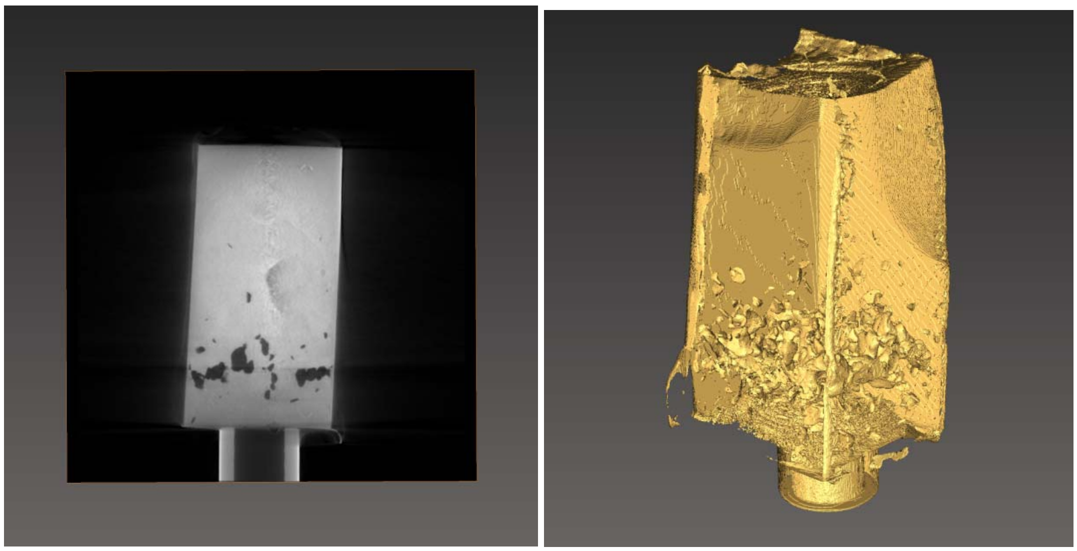
A study is currently underway to examine damage and failure characteristics of polycrystalline materials such as copper. Damage and failure for these materials is ductile in nature which means that there may be large deformation plasticity, shear localization, shear banding or void formation. Typical failure for copper under high hydrostatic tensile loading involves void formation. Void formation due to damage processes contains elements of initiation, growth, and coalescence which all lead to material failure. Nucleated voids will grow until they begin to overlap. In an attempt to better understand the incipient stages of these processes, we are using X-ray micro tomography, and classical metallographic and serial section techniques. X-ray micro tomography is being used as a first screen of the shocked samples to find voids, quantify their size and numbers, and determine volumes for further examination. The use of real 3D information will also be important for designing follow on experiments as well as providing statistically relevant damage data to advance current damage models. These models are used to predict material response under extreme conditions and with this data, we can validate predictions.

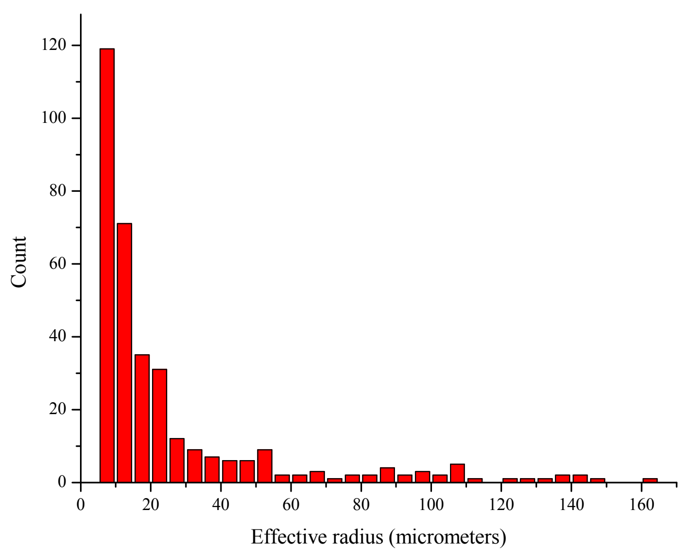
Micro x-ray computed tomography (MXCT) is often used to characterize materials for voids, fractures, or other damage. In these experiments, the Xradia MXCT which uses a Hamamatsu tungsten micro focus (5 µm) x-ray source to shine a cone beam of x-rays through the sample onto a scintillator was used. The scintillator converts the x-ray energy into visible light which is magnified by an Olympus microscope objective and imaged onto a CCD camera. The sample is rotated while radiographs are collected which are then reconstructed into a 3D rendering of the sample. Using this technique, data sets with sub-micron voxel sizes are possible. The data is reconstructed using the Xradia software, exported as a series of .tiff images and imported into Avizo Fire 6.1 for image analysis. Using a 64-bit HP computer running Windows 7 and using an Nvidia 5800 graphics card, 1 gigavoxel data sets can be easily manipulated.

Copper spall targets are cut into approximately 2x2 millimeter columns, cross sectional thickness is approximately 5-mm and imaged using the Xradia. Sample must be cut in order to allow better penetration of the X-rays at this magnification while maintaining high resolution. Shown below, a 2x2mm section of a 50mm in diameter copper target was impacted with a copper flyer plate that was 2.5-mm thick at 150 m/s. The shock direction is vertical with the plane of the page. The resulting shock wave created an incipient spall plane. This damage field within the Cu section was imaged. Using the Avizo software, the volume of the resultant voids are calculated from which an 'effective radius' is calculated. The 'effective radius' is simply the calculated void volume, which is assumed to be a sphere (it is not) and a radius is found. A comparison will be outlined in this talk of the changes in distribution of size and location of these voids as a result of changing crystal size and gas gun velocity as well as overlaying the 3D

CT data with metallography and EBSD to correlate the volumetric results to grain boundaries for a more complete characterization.



Left: Reconstructed image showing the cross section of a Cu target impacted at 150 m/s and the resultant spall. Spall voids seen 1/4 of the way up the sample. Right: Snapshot of the same reconstructed 3D image. The front face of the sample has been rendered transparent, the particles on the inside approximately 1/4 of the way up are the voids. The sample is approximately 1.4 mm wide.



Plot of effective void radius versus frequency calculated from 150 m/s shocked Cu.

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