Measurements of strength at high pressure and strain rate using a high-power laser facility

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Experiments have been performed at the Orion laser facility to investigate the strength of polycrystalline metal samples as they are rapidly compressed to high pressure (10 – 80 GPa) with in-situ x-ray diffraction. Understanding the processes that control the behavior of materials at high strain rates is important in range of fields, but data relating to this is limited.

We infer the yield strength of the continuum from the strain anisotropy of the compressed samples, which is taken from the distortion of Debye-Scherrer rings. More detailed analysis of x-ray diffraction data can in principal reveal rich information that informs strength models at lattice scales, for example by isolating dominant plastic deformation mechanisms [1]. It is challenging to fully extract the rich information on lattice level dynamics contained in x-ray diffraction data of this type. Comparison with crystal plasticity finite element method (CPFEM) modelling has been used to help us to fully exploit our data.

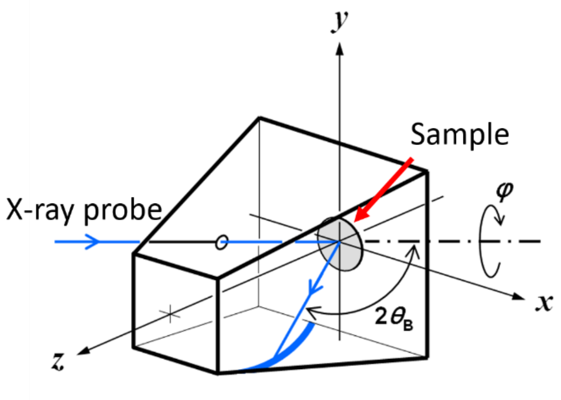

Figure 1: A diagram showing the layout of our x-ray probe, sample and image plates, which lie on the trapezium shaped sides of the box.

Our experimental platform is designed so that small, polycrystalline samples of 2 mm diameter, ~20 µm thickness can be compressed with a laser-pulse, and the compressed sample can at a set time later be interrogated with a quasi-monoenergetic x-ray probe produced by irradiation of a thin backlighter foil by a separate set of beams. The compression laser pulse can be shaped either to shock-compress the sample along the Hugoniot, or to ramp-compress it, keeping it cooler and closer to the isentrope than the Hugoniot.

Diffracted probe x-rays are recorded on image plates. Their layout is described in *Figure 1*. An example of image plate data recorded from a shock-compressed copper experiment is shown in *Figure 2*.

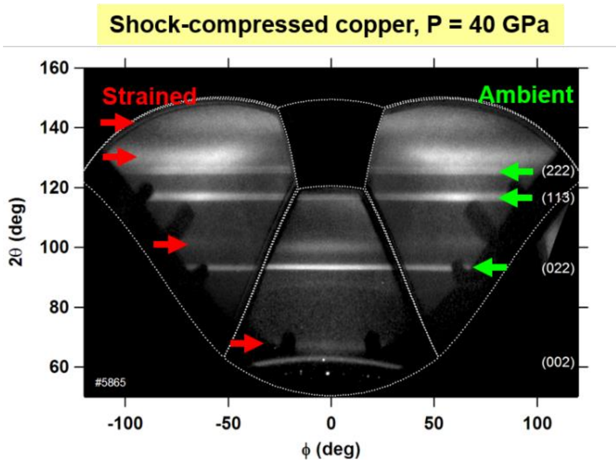

Figure 2: X-ray diffraction data recorded from shock-compressed copper, with three trapezium shaped image plates mapped onto a 2θ, ϕ plot. Both the narrow Debye-Scherrer rings from the ambient material, and the broader rings from the compressed material are recorded on the image plates.

Recent experiments have investigated shock and ramp compressed copper and tantalum. The ramp-compressed samples compressed in a uniform way that meant that we were able to measure a yield strength from the strain anisotropy. The shock-compressed samples strained less uniformly, with different crystallites having different elastic strain components. The difference in strain uniformity resulting from the two compression routes agrees with our CPFEM modelling.

Analysis of data from the shock compressed copper and tantalum revealed information relating to strength at high strain rates on smaller scales via comparison with our CPFEM modelling. For example, for shocked copper we found that slip system activity is more strongly biased towards those with the highest resolved shear stress than was expected. Data from the shock-compressed tantalum experiment bounded CPFEM modelling inputs relating to the strength of tantalum, which was initially overestimated in the model.

Another notable feature we saw both in the shock-compressed tantalum CPFEM models and experimental data was a broad strain gradient behind the shock front. The ramp-compressed data and models contained a much narrower spread in strain states.

[1] Werhenberg et al, *Nature*, 2017, **550**,