Dynamic Strength Experiments at Lawrence Livermore National Laboratory

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Summary: We present a description of several experimental campaigns at LLNL designed to address dynamic strength under high pressure and high strain-rate loading conditions. We compare the results with the predictions of a new multiscale strength model.

At Lawrence Livermore National Laboratory (LLNL) we use a variety of platforms to conduct experiments designed to obtain data under dynamic loading conditions. The data are used to validate/invalidate models of constitutive properties used at LLNL. The different experimental platforms can achieve both shocked and ramp-loaded conditions and span strain rates from 10^3 to 10^8 s^{-1}. Typically the model validation begins with lower rate Split Hopkinson Pressure Bar data at rates of 10^3 s^{-1}, but at ambient pressures. Non-zero pressure and higher rate data are achieved using the gas guns at LLNL with pressures at 10s of GPa and rates near 10^5 s^{-1}. Collaborations with both Los Alamos National Laboratory's proton radiography (pRad) facility and VNIIEF allow data to be taken at 10 – 50 GPa and rates near 10^6 s^{-1}. Finally, a concerted effort at LLNL uses lasers, both the Laboratory for Laser Energetics' Omega facility (20 kJ) and LLNL's National Ignition Facility (2 MJ; NIF), to achieve pressures well in excess of 100 GPa and strain rates that vary dynamically from 10^6 to 10^8 s^{-1}. Each platform differs in the type of physics that can be probed, and in how strength is determined. For example, strength can be directly measured via ramp compression on a gas gun using large polycrystalline samples, while the laser experiments require inferring strength from the growth of instabilities on small samples that might be only a single grain in thickness.

The main focus of current experiments is to validate the new multiscale model (MSM), which has been developed at LLNL. This model begins at the smallest length scale using atomic potentials to derive elastic constants, EOS, and other information that are used to inform the next length scale on the molecular level. Using MD simulations dislocation mobilities are determined and passed on the next length scale where full dislocation dynamic interactions are determined. From the dislocation dynamics level simulations, continuum level models are determined and used in hydrodynamics codes to simulate experiments. Because of the expense and challenges of performing the *ab-initio* simulations the MSM works best at rates above ~10^4 s^{-1}, where most dynamic experiments reside. Pressure sensitivity is accounted for via a quadratic shear modulus form.

The major platform for dynamic experiments at LLNL is the Rayleigh-Taylor instability method. The method, first developed by Barnes et al. at LANL using a high explosives drive, begins with a metal foil that has a rippled pattern imposed on one surface. The surface is accelerated by some drive mechanism (either high explosives or a laser-shocked plasma) causing the ripple amplitude to grow. The growth is mitigated by the strength of the metal foil as compared with a classically growing liquid. Using models to simulate the growth, the overall strength of the material can be inferred, and more importantly, the model can be validated. Using the high explosives platforms at LANL and VNIIEF allows large-scale (1.5 mm thick x 2 cm diameter) samples to be studied at pressures up to 50 GPa and rates around 10^5 s^{-1}. Such platforms can study variations in grain size, material processing (e.g., wrought vs. rolled), phase transitions at low pressures, impurities, etc. An example of this technique as performed on the LANL pRad facility is shown in Figure 1. The most recent LLNL experiments at pRad were begun in June 2011 to study material response under a dynamic phase transition in iron. LLNL is also in the midst of conducting similar experiments at VNIIEF using flash x-ray on beryllium in collaboration with Victor Raevsky. An example of this technique is given in Figure 1 for tantalum, along with the derived and modeled growth curves.

The laser driven instability experiments are done on smaller targets (50 μm thick by 2 mm diameter) and much shorter timescales (10s of ns vs. a few μs), but at pressures in excess of 100 GPa. This platform can be used to study fundamental material properties under extreme conditions (strength, phase transitions, grain size effects at high rates, etc.). Recent efforts at LLNL 1) concluded a study of vanadium at 90 GPa at the Omega laser; 2) begun a new effort to study tantalum at 130 GPa at Omega; and 3) begun the drive development at 500 GPa at NIF for tantalum. The first tantalum instability strength measurements at 500 GPa will be completed in 2012. In 2012 LLNL will also begin studying phase transitions in iron at higher pressures and rates than were achieved at pRad. Figure 2 shows an example image of tantalum at 130 GPa taken at the Omega laser in 2010 along with growth modeled growth curves of several experiments. Note that the laser platform relies on face-on radiography and captures only one image per experiment in contrast with the high explosives platform that uses side-on imaging and can capture as many as 20 images in a single experiment.

In both the left and right sides of Figure 1, the new MSM fits the data well while the commonly used legacy models tend to over predict the growth (under predict the strength) at these pressures and rates.

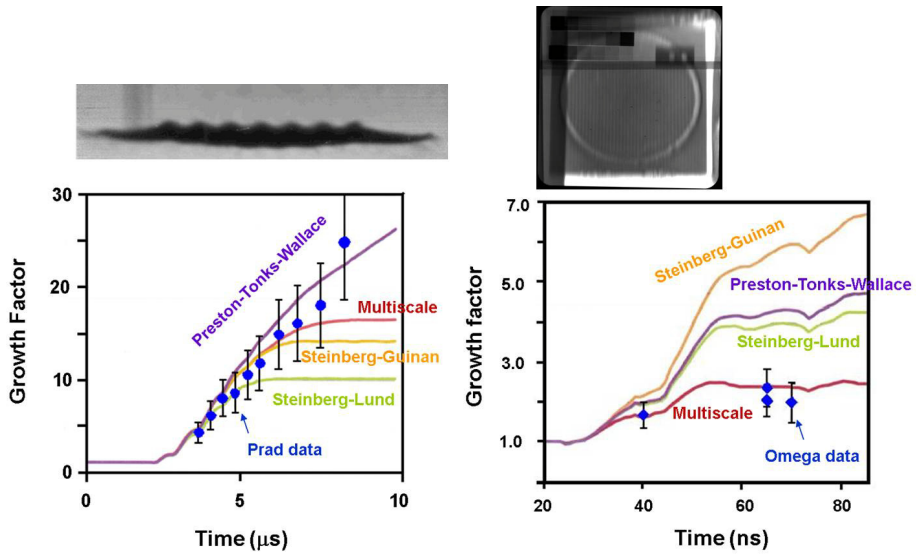

Figure 1 (Left) Example of HE driven RT strength experiment; and (Right) example of Laser driven RT strength experiment.

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