Dynamic material studies on pulsed power generators at Sandia

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Isentropic loading

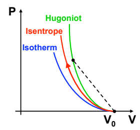
Shock experiment yields only a single final *P-V* point on Hugoniot, an isentropic experiment yields a continuum of points along the isentropic loading path.

- For simple waves, the flow in an inviscid fluid is isentropic (S=S_0=constant) and the conservation equations are given as,

$$d\sigma = \rho_0 C_L du_p \qquad dV = V_0 du_p / C_L \qquad dE = -\sigma(S_0)dV$$

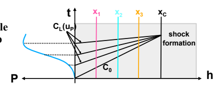
where C_L= dh/dt is the Lagrangian wave velocity which is approximately related to the U_S- u_p relation as,

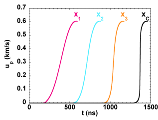
$$C_L \approx C_0 + 2su_p$$



Stress-strain loading paths can be determined continuously to peak pressure for most materials.

- The propagation of wave characteristics within a sample, and particle velocities at various Lagrangian positions demonstrate resulting ramp wave, and eventual shock wave formation at "critical" location x_C.

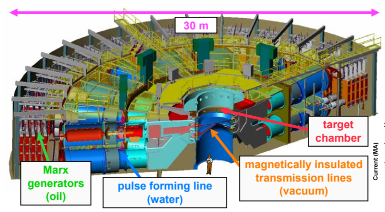


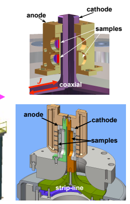


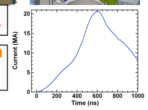
Z-accelerator

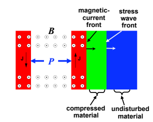
26 MA, 100-700 ns, 20-400 GPa, flyer plate > 40 km/s.

- Pulse shaping.
- Coaxial and strip-line configurations.







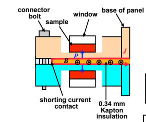


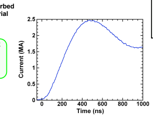
$$P \approx k_E \frac{B^2}{2\mu_0} = k_E \frac{\mu_0}{2}\left(\frac{I}{w}\right)^2$$

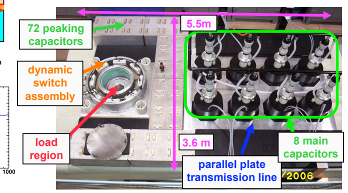
Veloce

2.5 MA, 440-530 ns, 5-17 GPa.

- No oil, water or vacuum insulation.
- More accessible to experimenters; economical to operate.



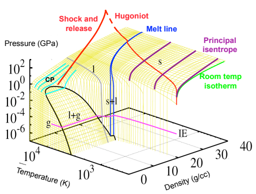




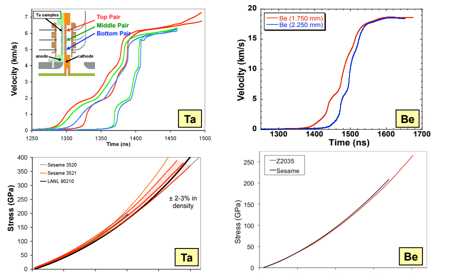
Equation-of-state

Isentropic Compression Experiments (ICE)

- Magnetic ramp compression on Z enables access to a large region of the equation of state surface

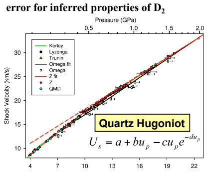


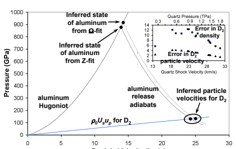
- Continuous compression of Ta (400 GPa) and Be (250 GPa) allow discrimination of tabular EOS



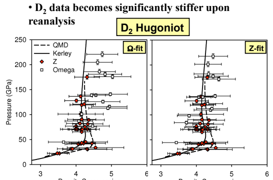
Magnetically launched flyer plates

- Difference in quartz standard from Z and Omega (Ω) experiments results in significant error for inferred properties of D_2

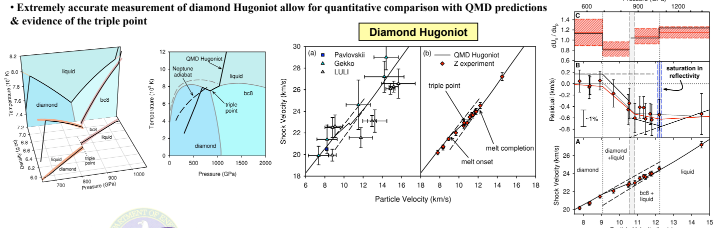




- D_2 data becomes significantly stiffer upon reanalysis



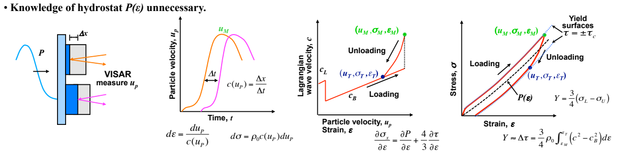
- Extremely accurate measurement of diamond Hugoniot allow for quantitative comparison with QMD predictions & evidence of the triple point



Strength of materials

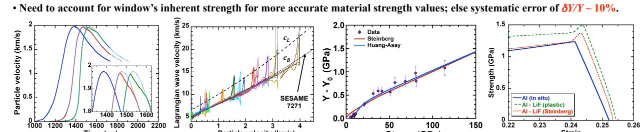
Material strength determined from the difference between loading and unloading curves.

- Use measured velocity profiles to obtain Lagrangian wave velocities and stress-strain of samples during ramp loading and unloading.
- Knowledge of hydrostat $P(\varepsilon)$ unnecessary.



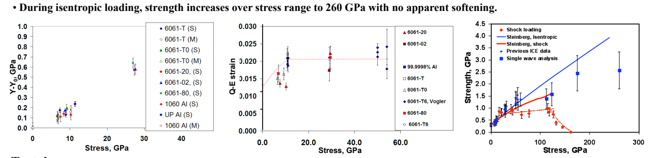
LiF windows

- Strength of LiF under isentropic loading (5-114 GPa) increases and compare well with Steinberg and Huang-Asay strength models.
- Need to account for window's inherent strength for more accurate material strength values; else systematic error of $\delta Y/Y \sim 10\%$.



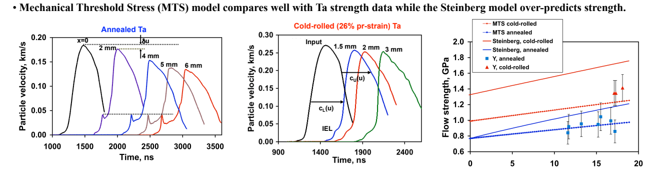
Aluminum alloys

- Strength of Al increased mainly due to pressure hardening; change in strength insensitive to initial yield values.
- Under shock loading, softening of strength observed below melt states (40-115 GPa) & rapidly decreases over stresses of 120-160 GPa.
- During isentropic loading, strength increases over stress range to 260 GPa with no apparent softening.



Tantalum

- Wave profiles obtained on Ta show significant effects of initial processing: annealed Ta elastic precursor disperses and amplitude decreases with distance while cold-rolled Ta elastic precursor maintains constant amplitude.
- Mechanical Threshold Stress (MTS) model compares well with Ta strength data while the Steinberg model over-predicts strength.



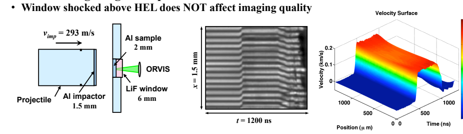
Spatially resolved yielding of windows

Measurement of spatially resolved velocity histories with line-imaging ORVIS

- 7.3 × magnification, ~90 μm/fringe, 750 mm focal length collection lens

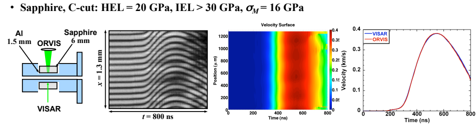
Shock loading: single compressed state

- Window shocked above HEL does NOT affect imaging quality

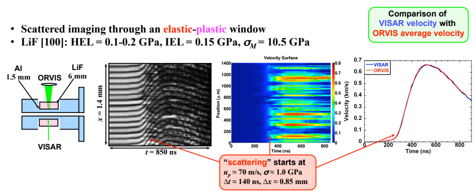


Ramp loading : range of compressed states

- Clean imaging through an elastic window
- Sapphire, C-cut: HEL = 20 GPa, IEL > 30 GPa, σ_M = 16 GPa

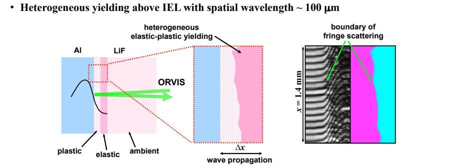


- Scattered imaging through an elastic-plastic window
- LiF [100]: HEL = 0.1-0.2 GPa, IEL = 0.15 GPa, σ_M = 10.5 GPa



Fringe degradation likely due to light refracting erratically through non-uniform elastic-plastic wave structure of ramp loading

- Heterogeneous yielding above IEL with spatial wavelength ~ 100 μm



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