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A cross-platform comparison of dynamic material strength for tantalum

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Goal: Determine what controls Ta strength under a wide range of conditions

Approach

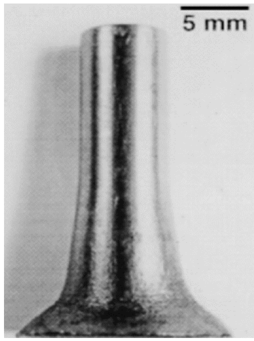
- Use a common source of Ta for all experiments
- Share Ta strength experiments (Z, NIF, Omega, and Taylor Cylinder)
- Conduct additional experiments to enhance data set.
- Model the experiments with different models and assumptions
- See what works and what doesn’t

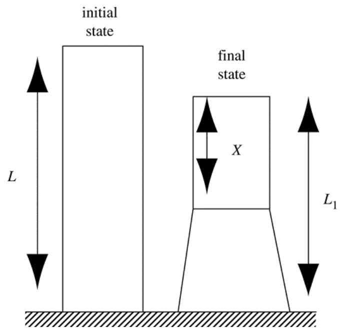
Other relevant SCCM talks

- B8.00004 :Brown and Hund, Bayesian model calibration of ramp compression experiments on Z
- D5.00002 : Lane, et. al, The plastic response of Tantalum in Quasi-Isentropic Compression Ramp and Release
- J4.00002 : Barton et al., Modeling the constitutive response of tantalum across experimental platforms
- O7.00001: Gray et. al, Structure / Property (Constitutive and Dynamic Strength / Damage) Characterization of Additively Manufactured (AM) Tantalum
- O7.00004: P. Powell, Studying dynamic flow stress of lead at high pressure and high strain rates on NIF
- T5.00003 M. Prime, Estimating and Interpreting an "Average'' Strength from Richtmyer-Meshkov Instability Experiments.
- T5.00005 : J. Mcnanaye, Measurements of Rayeigh-Taylor growth in solid and liquid copper in the Mbar regime
- T5.00006 : Rudd et al., Modeling of Laser-Driven High-Rate Deformation of BCC Tantalum and Lead
- T5.00004 : Park et al., Results of tantalum Rayleigh-Taylor strength experiments at high pressure and high strain rates on NIF and Omega

Platforms cover a large range of conditions and loading paths

Taylor Cylinder

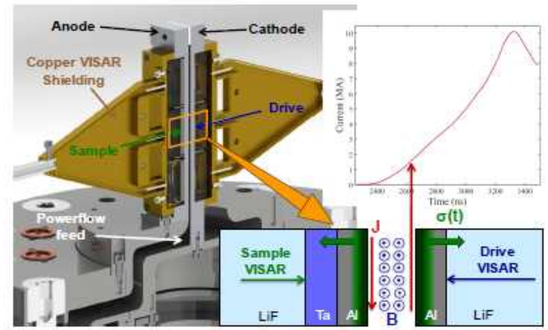




P ~.6GPaPa

$\dot{\varepsilon}$ ~10^{-3} -10^{3}

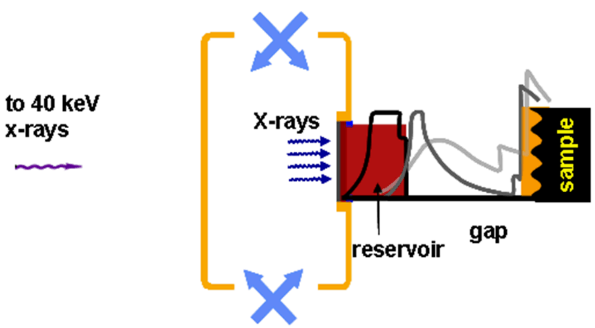
Z –Ramp Release



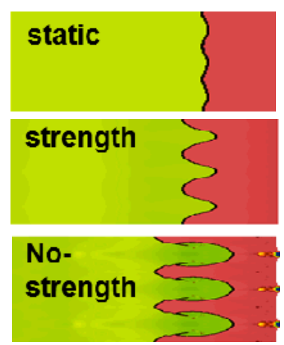
P ~50 – 380GPa

$\dot{\varepsilon}$ ~10^{5}

Rayleigh-Taylor instability strength experiments



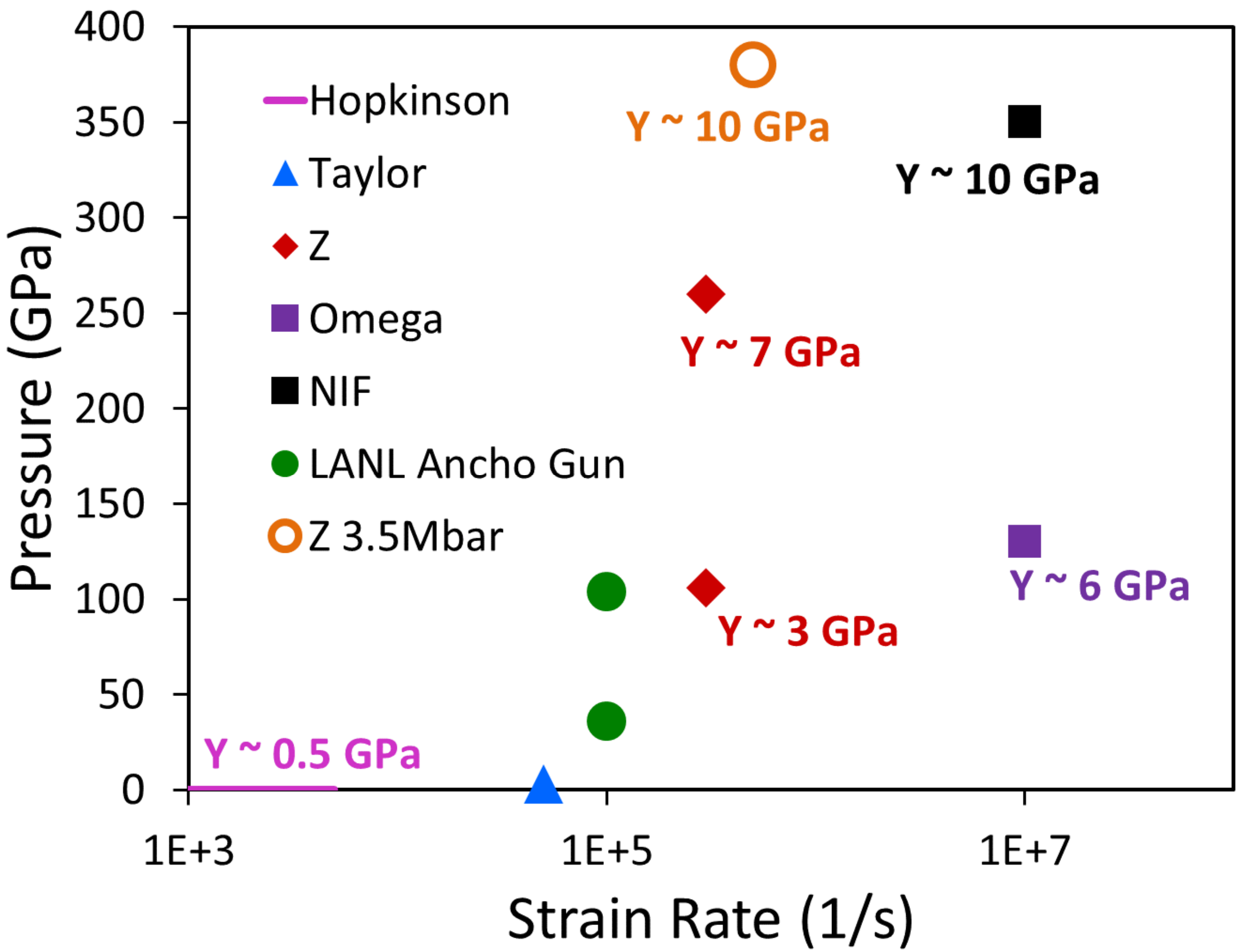
Omega
P ~50-100GPa
$\dot{\varepsilon}$ ~10^{7}



NIF

P ~350-500GPa
$\dot{\varepsilon}$ ~10^{7}-10^{8}

Platforms cover a large range of conditions

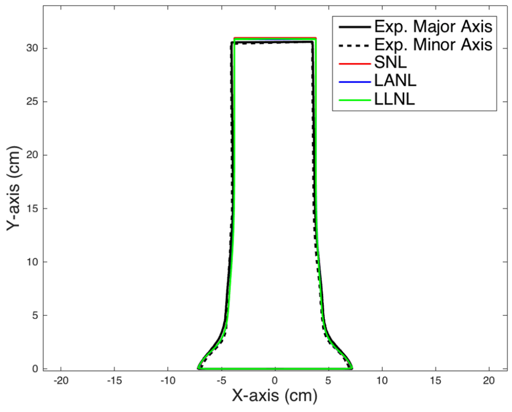


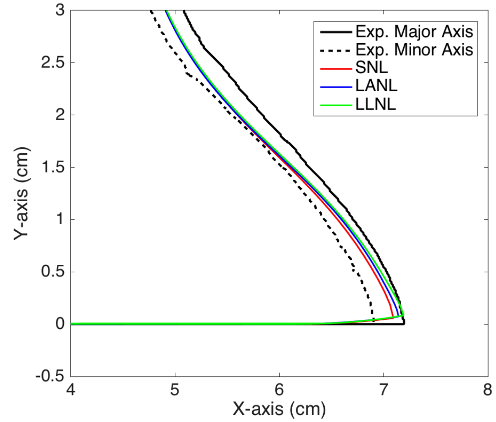
Different features/assumptions included in various models

- **SG** (Steinberg-Guinan, 1980) – A semi-empirical model : incorporates strain-rate and pressure dependence through the shear modulus
- **SGL** (Steinberg-Guinan-Lund, 1989) – Extension of SG model to incorporate low strain-rates and bcc materials
- **PTW** (Preston, Tonks, Wallace, 2003) – A phenomenological model: incorporates work hardening through a generalized Voce law at lower strain rates; above 10^9 1/s uses Wallace's theory of overdriven shocks to calculate flow stress rate dependence.
- **KP (**Kink-pair Lim, et al. 2016) – A model based on dislocation-based kink-pair theory describing temperature and strain rate dependent flow stresses in BCC metals. The kink-pair theory relates the stress required to move a screw dislocation over the Peierls potential to the temperature and applied strain rate.
- **LMS (**Livermore Multiscale Model, Barton et al., 2011,2013) – A physics-based model which integrates electronic structure calculations, molecular dynamics, dislocation dynamics, and polycrystal homogenization to inform functional forms and parameters for continuum-scale models for strength.

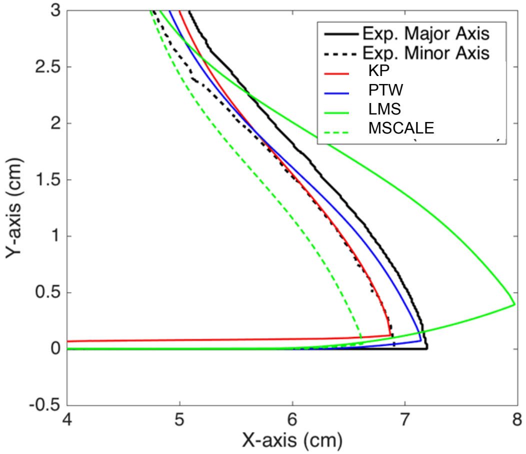
We compared codes/models on the Taylor Cylinder

- Got same results when all codes used the same models
  - PTW with same settings, rigid anvil, no friction, meshing to mitigate distortion, Sesame 93524 etc.
- PTW/KP bounded by data at the foot; LMS shows more deformation
- Anisotropy was not captured in these simulations





Different codes with the same models vs data: similar results



Different models vs data

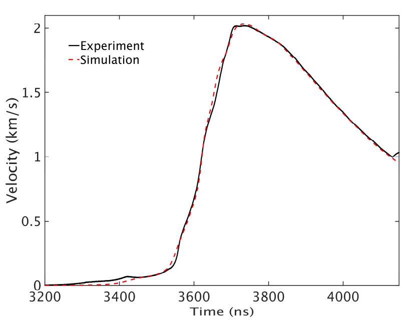
Preliminary look at high pressure experiments raises interesting questions

	Omega	Z	NIF	Z
Peak pressure (GPa)	~130	~100	~350	~380
Sample temperature	~1200 K	~610	~4500 K	~1500
Strain rate (1/s)	10^7	10^5	10^7	10^5
Data vs simulations	Matches LMS	Matches 1.25 PTW w QE LMS	Matches LMS or 2xSG	Matches 2xPTW w QE
Inferred flow stress	~6 GPa	~3 GPa	~10 GPa	~10GPa

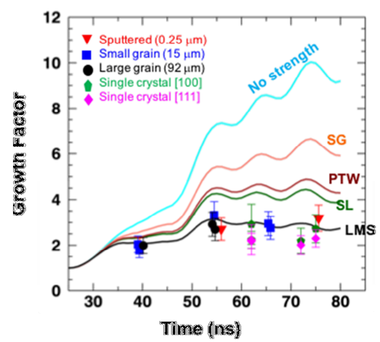
Preliminary look at high pressure experiments raises interesting questions

- Strength at 100 GPA :Omega twice as high as Z
  - Strain rate effect? Effect of pre-shock?
- Strength at 350GPa about the same at NIF and Z
  - No strain rate effect? Temperature effect? Loading history effect?
- Predictions of the phenomenological models are too weak for the high pressure experiments
- A quasi-elestic (analestic) release needed to model Z/Gun release experiments

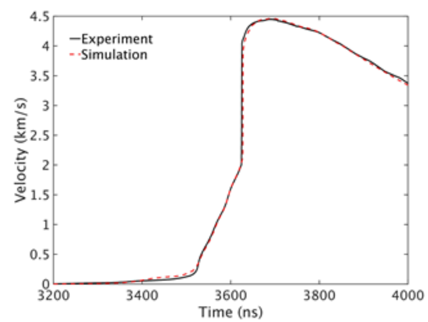
Z 100Gpa



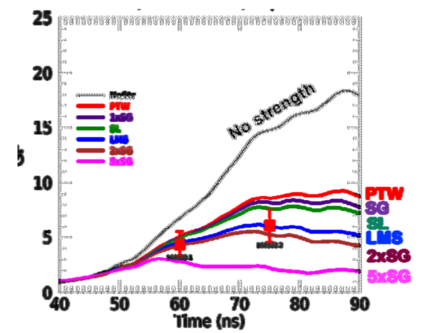
Ω 100Gpa



Z350 Gpa



NIF 350 Gpa

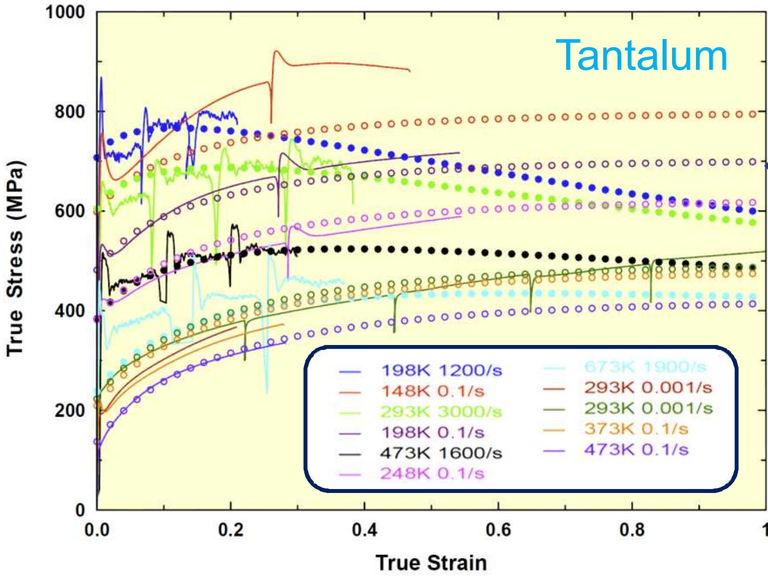


Caveat!! Different models, Different tweaks, Preliminary.

Conclusions

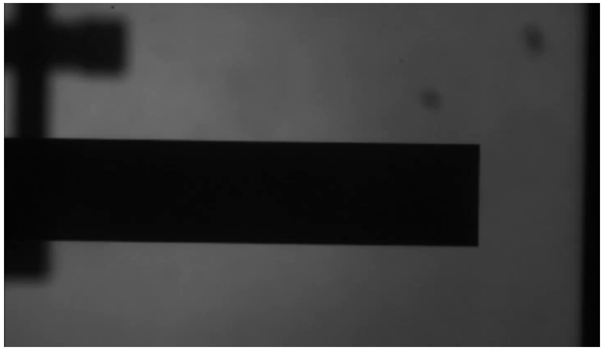
- Combining data sets and model analysis is giving valuable insights
- Sensitivity to the hydrocode can be controlled
- None of the models appear to do well on both low pressure/low strain rate and high pressure/high strain rate experiments
  - What processes change?
- Big question – Why is the strength on Z and laser/RT experiments different at 100GPa but similar at 350GPa?
- Next steps – systematic analysis and possibly additional experiments

Taylor Cylinder



Mechanical properties at temperatures and strain rates + advanced constitutive modeling.

T = 77 – 1273K
$\dot{\varepsilon}$ = 10^{-3} – 5×10^{3}/s

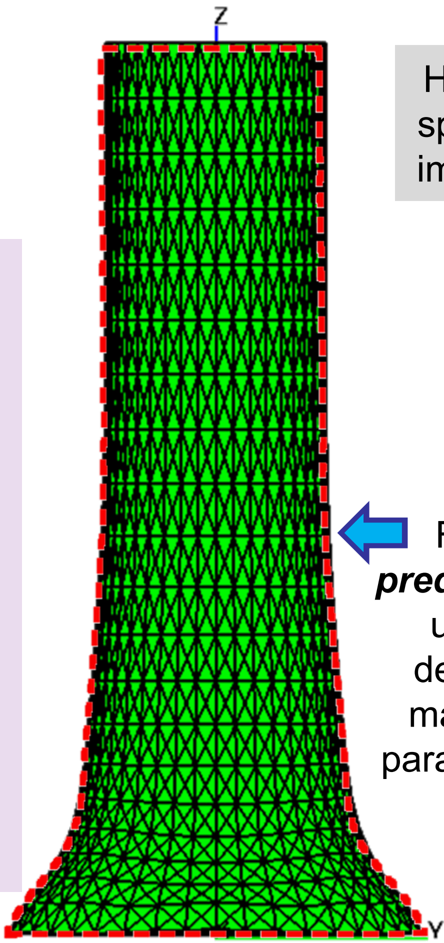


High-speed image

V_0 = 155 m/s   151 m/s   146 m/s

Taylor cylinder impact testing to validate strength models.

Started at 298K and increasd up to 800K from adiabatic heating at high strain rates (10^3–10^5/s) and to large plastic deformation (ε>1) at ambient pressure



FEM ***predictions*** using derived material parameters