Investigating Ta strength across multiple platforms, strain rates, and pressures

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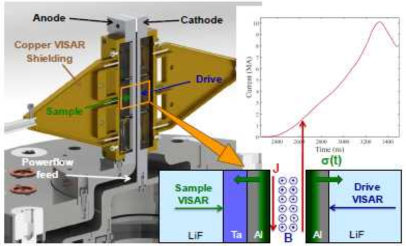

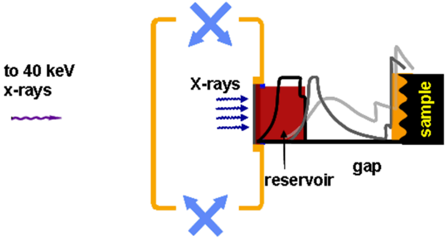

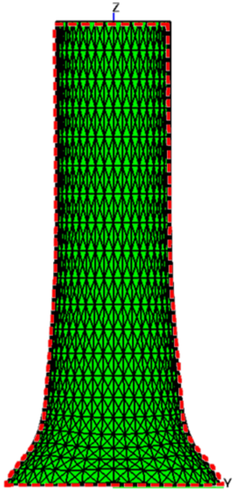

A collaboration to improve understanding of Ta strength

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Tantalum is a refractory [bcc] metal – defects and strength have a more complex behavior than in fcc

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

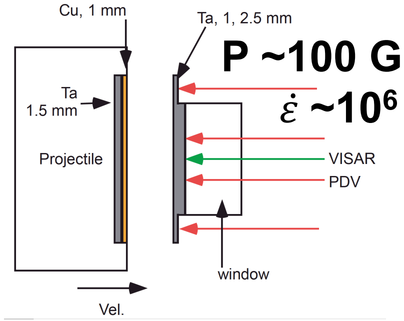
Tantalum's melting point of 3017 °C is exceeded among the metals only by tungsten, rhenium, and osmium

Tantalum was discovered in Sweden in 1802 by Anders Ekeberg

Why DPP?
HED Facilities Omega, NIF, and Z play a crucial role for high pressure work

The platforms together cover a large range of conditions and loading paths

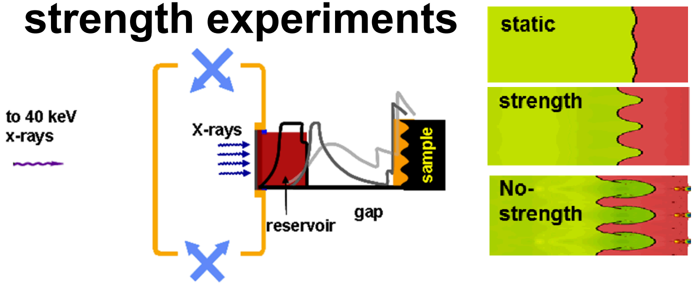
Gun impact/release



P ~100 GPa

$\dot{\varepsilon}$ ~10^6

Rayleigh-Taylor instability strength experiments



Omega

P ~50-100GPa

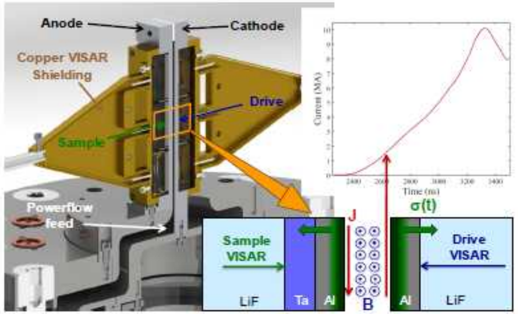
$\dot{\varepsilon}$ ~10^7

NIF

P ~350-500GPa

$\dot{\varepsilon}$ ~10^7-10^8

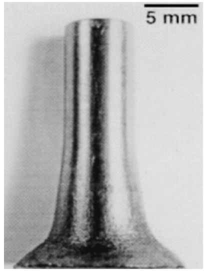
Z –Ramp Release



P ~50-380GPa

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

Taylor Cylinder



P ~0.6 GPa

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

The platforms together cover a large range of conditions and loading paths

Platform/ loading	Taylor Cylinder*	Gun (FS13) Shock-release	Gun (FS18) Shock-release	Z (2516)* Ramp Release	Omega* RT	Z (2488) Shock-Ramp Release	Z (3103)* Ramp Release	NIF* Ramp Release
Peak Pressure (GPa)	3	52	101	106	130	240	380	350
Sample Temperature (K)	305	700	1800	640	1200	900	1200	3800
strain rate (1/s)	$5x10^4$	$1x10^6$	$1x10^6$	$3x10^5$	$1x10^7$	$3x10^5$	$3x10^5$	$1x10^7$

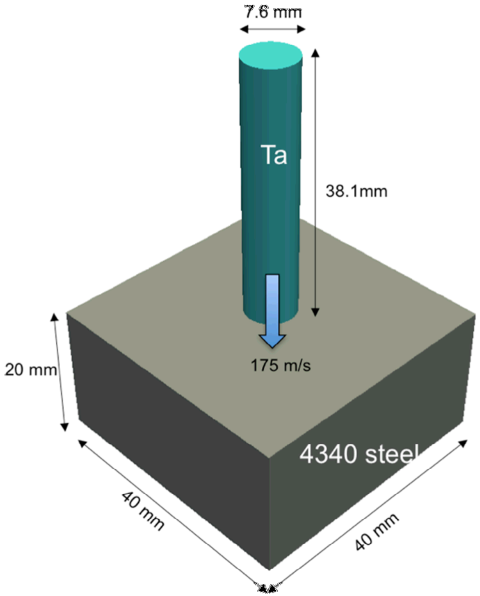
A Taylor cylinder experiment gives large plastic deformation at relatively high strain rate

V_0 = 155   151 m/s   146 m/s

Taylor cylinder impact testing to validate strength models.

Ambient 298K that heats adiabatically to 800K at high strain rates (10^3–10^5/s)

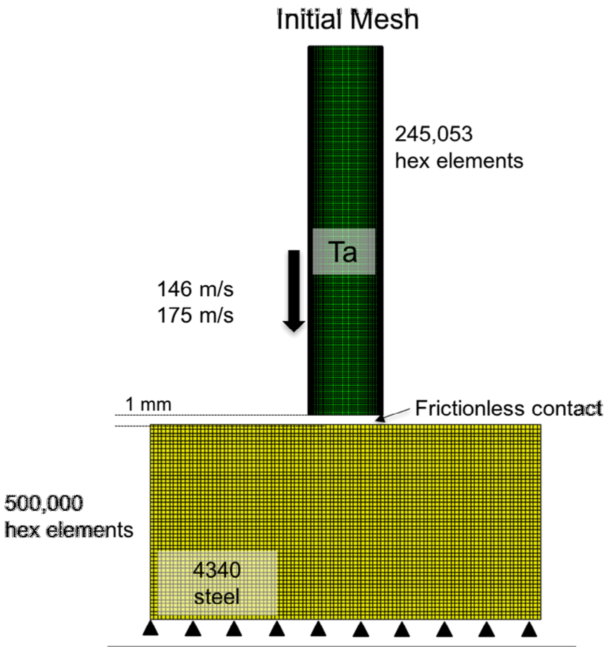
Large plastic deformation (ε>1) at ambient pressure



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

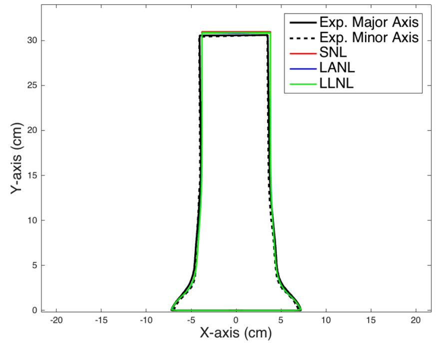
Several strength models for Ta with different foundations points to difficulty and interest

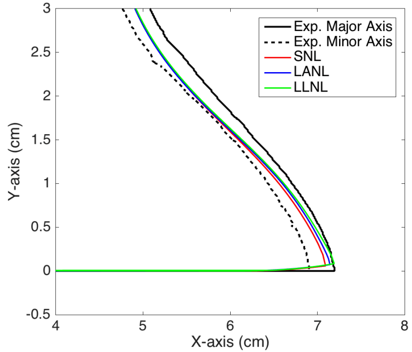
- **SG** (Steinberg-Guinan, 1980) – A semi-empirical model : incorporates strain-rate, and pressure dependence through the shear modulus
- **SGL** (Steinberg-Guinan-Lund, 1989) – Extension of SG model to incorporate low strain-rates and bcc materials
- **PTW** (Preston, Tonks, Wallace, 2003) – A phenomenological 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.



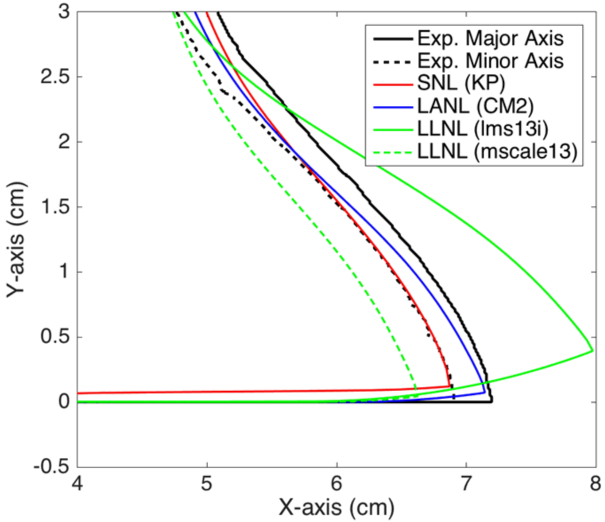
We chose the Taylor experiment to benchmark codes and simulation protocols

- We got the same results when all codes used the same models – *exactly the same models*
  - PTW, rigid anvil, no friction, meshing to mitigate distortion, Sesame 93524 EOS, etc. *No anisotropy*
- PTW/KP bounded by data at the foot; LMS shows more deformation





Different codes with the same models vs data: acceptable agreement (note we expect differences due to hydro scheme, artificial viscosity, etc.)



Different models vs data - differences between models are larger than between codes

A preliminary look at the high pressure experiments raises interesting questions

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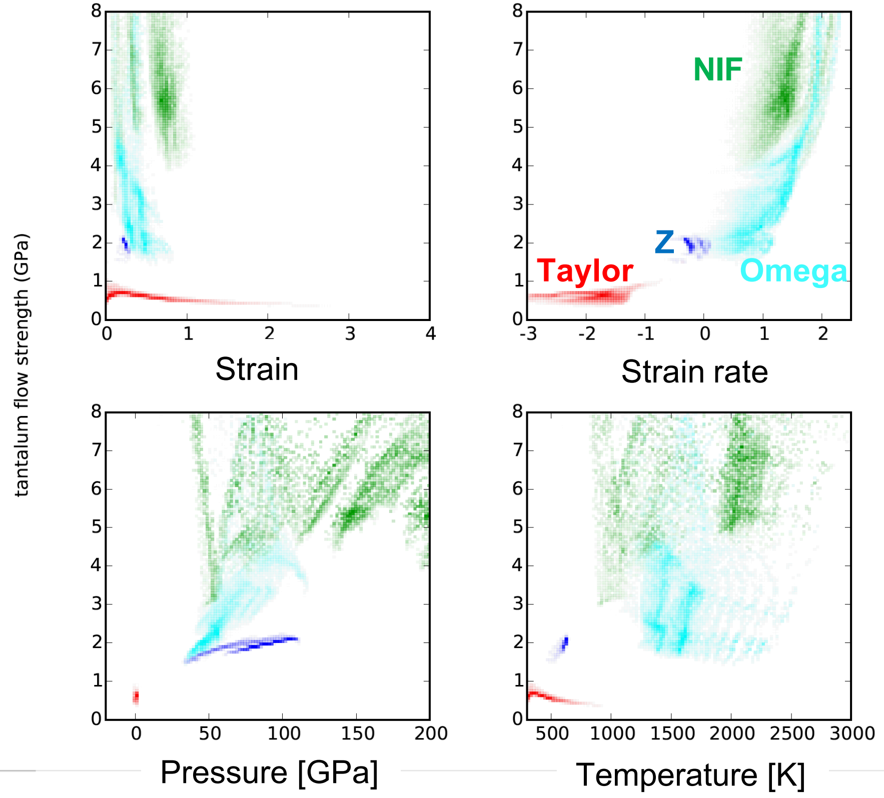
Inferred flow stress (GPa)	< 1	1.75	2.1	2.7	6	6.1	10.1	12
Data vs Simulations (matches)	PTW KP	PTW w QE	PTW w QE	1.25x PTW w QE KP	2x SG LMS	scaled PTW w QE	2x PTW	2x SG LMS

- Strength at 100 GPA: Omega twice as high as Z
  - Strain rate effect? Effect of pre-shock?
  - Inferred yield strength may not be most representative of the peak pressure and temperature.
- Strength at 350 GPa about the same 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

Loading paths are different for different platforms



- Flow strength during the experiments
  - strain; strain rate; pressure; temperature
- Z experiments small range of strain and strain-rate
- Omega/NIF experiments span a broader range of strain, strain-rate, pressure, and temperature

From this perspective, not surprising that it is challenging for any one model to capture the behavior over all of P, T, strain, and strain-rate

By looking at the behavior on different platforms we obtain a more complete picture of Ta

- Combining data sets and model analysis is yielding valuable insights
- Sensitivity to the hydro-code can be controlled – *took great care though*
- 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?
  - Is re-parametrization with high P/ε data enough?

- Next steps – additional analysis and experiments in overlapping regimes!