<table>
<thead>
<tr>
<th>Title:</th>
<th>Use of Richtmyer-Meshkov Instability to Infer Yield Stress at High-Energy-Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intended for:</td>
<td>Ejecta Workshop</td>
</tr>
</tbody>
</table>
Abstract

We use a model for the Richtmyer-Meshkov instability to infer a material's yield stress under shock loading.
Use of Richmyer-Meshkov Instability to Infer Yield Stress at High-Energy-Density

Guy Dimonte,
G. Terrones, F.J. Cherne, T.C. Germann, V. Dupont,

Outline & Summary

DEVELOPED model for RMI in materials with strength using simulations with PAGOSA hydrodynamics code in 2D
Atwood # = -1, Copper (Cu) density & Up-Us relation
Perfectly-plastic constitutive realtion with adjustable Yield

Saturation amplitudes depend on RMI growth rate & Yield
Ejecta produced when spike growth becomes unbounded (not melt)

TESTED model with MD simulations of crystalline Cu with SPaSM in 2D
RMI simulations calculate growth rates
Stress-strain simulations calculate Yield directly

USED model to infer Cu Yield under shock loading in pRad experiments
Measured spike growth using velocimetry with 36 GPa shock (no melt)
Varied 2D initial perturbations
Inferred Yield ∼ 0.47 GPa is consistent with previous measurements
G. Terrones performed variety of 2D RMI simulations using PAGOSA with Copper assuming a perfect-elastic-plastic with adjustable YIELD

\[
k_{h_{y}} = \frac{\rho_{s}}{Y} \left[ \frac{V_{0}}{c_{s}} \right]^{2}
\]

PAGOSA results with different Yields, initial perturbations & shock strengths can be consolidated in terms of RMI yield parameter \( k_{h_{y}} \)

Spikes saturate for \( k_{h_{y}} \leq 11 \)

\[
k_{h_{y}} = 0.08 + 0.24 k_{h_{y}}
\]

Measure spike growth rate

\[
V_{e} - V_{m} = A' \left[ \frac{k_{h_{y}} V_{0}^{2}}{2} \right]
\]

& saturation amplitude to infer yield

\[
Y_{RM} \approx 0.24 \frac{\rho_{s}}{k_{h_{y}}} \left[ \frac{V_{0}^{2}}{Y} \right]^{2}
\]

Spikes grow unboundedly for \( k_{h_{y}} > 11 \) to produce ejecta in solid state (no melt)

Peak velocity \( \propto V_{MB} \)

Bubbles saturate even in fluid state & regulate the amount of ejecta
SPaSM code was used to perform molecular dynamics (MD) of RMI in Cu crystal for different shock strengths & initial conditions to infer Yield

Launch 83 GPa shock in Cu

\[ U_p = 1.5 \text{ km/s} \]
\[ W_i = 6 \text{ km/s} \]
\[ T = 1003 \text{ K} < T_{\text{melt}} = 1350 \text{ K} \]

Perturbations with \( kh_o = 1 \)

\[ \tau = -0.38 \]
\[ \tau = 1 \]
\[ \tau = 3 \]
\[ \tau = 6 \]

Spikes grow via RMI to saturation

\[ V_{lp}^0 \sim 0.6 \text{ km/s} < V_{sp} \]

Inferred Yield \( Y_{\text{RM}} \sim 1.1 \pm 0.3 \text{ GPa} \)

Dimonte et al

SPaSM (MD) code was used to calculate STRESS-STRAIN relation for Cu crystal @ same temperatures & strain-rates as MD-RMI simulations

Measure resistance force (Stress) as Cu crystal is distorted (shear strain)

Stress-Strain relation is complex due to viscous & plastic work, but average Stress over Strain of RMI is consistent with \( Y_{\text{RM}} \)

Dimonte et al
RMI experiments on pRad with unmelted Cu & different initial perturbations inferred $Y_{RM} \sim 0.47 \pm 0.1$ GPa consistent with previous results.

Wavelength $\lambda = 0.55$ mm

HE driven shock in Cu (36 GPa)

$W_i = 5$ km/s

$T < 600$ K

Velocimetry probes obtain interface speed $U = 1.46$ km/s and

Spike growth rate $V_{Sp}$

Integral of $V_{Sp}$ gives saturation amplitude

$Y_{RM}$ inferred from RMI model is consistent with PTW & previous measurements

Large perturbations $kh_i > 10$ exhibit ejecta transition below melt

**Outline & Summary**

**DEVELOPED model** for RMI in materials with strength using simulations with PAGOSA hydrodynamics code in 2D

Atwood $\# = -1$, Copper (Cu) density & Up-Us relation

Perfectly-plastic constitutive relation with adjustable Yield

Saturation amplitudes depend on RMI growth rate & Yield

Ejecta produced when spike growth becomes unbounded (not melt)

**TESTED model** with MD simulations of crystalline Cu with SPaSM in 2D

RMI simulations calculate growth rates

Stress-strain simulations calculate Yield directly

**USED model** to infer Cu Yield under shock loading in pRad experiments

Measured spike growth using velocimetry with 36 GPa shock (no melt)

Varied 2D initial perturbations

Inferred Yield $\sim 0.47$ GPa is consistent with previous measurements