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Title: Surface Shear Strains Induced by Quasi-steady Sweeping Detonation Waves

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(Shock Compression and Condensed Matter)

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Surface Shear Strains Induced by Quasi-steady Sweeping Detonation Waves

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Abstract

Measurement of both components of the free surface velocity generated in experiments using flat plates driven by a sweeping wave allows estimation of the surface strains. Measurement of both components of velocity is accomplished by using crossed PDV probes to view the same point from two independent directions. The estimation strain requires some analysis of the shock interaction with the free surface to obtain expressions for the plastic shear strain in terms of the measured velocities. An example of an application of the analysis to a flat plate of tantalum driven by a deta-sheet configuration is provided.

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General approach

- Measure normal and tangential velocities
  - Crossed PDV probes
    - One probe normal, one at an arbitrary angle
  - Convert to normal and tangential velocities (u,v)
- Select strain approximation
  - Steady wave assumption
  - Plastic rigid
  - 2 Dimensional
- Estimate velocity variation with depth
  - Shock velocity, rarefaction velocity addition
- Application to example data sets

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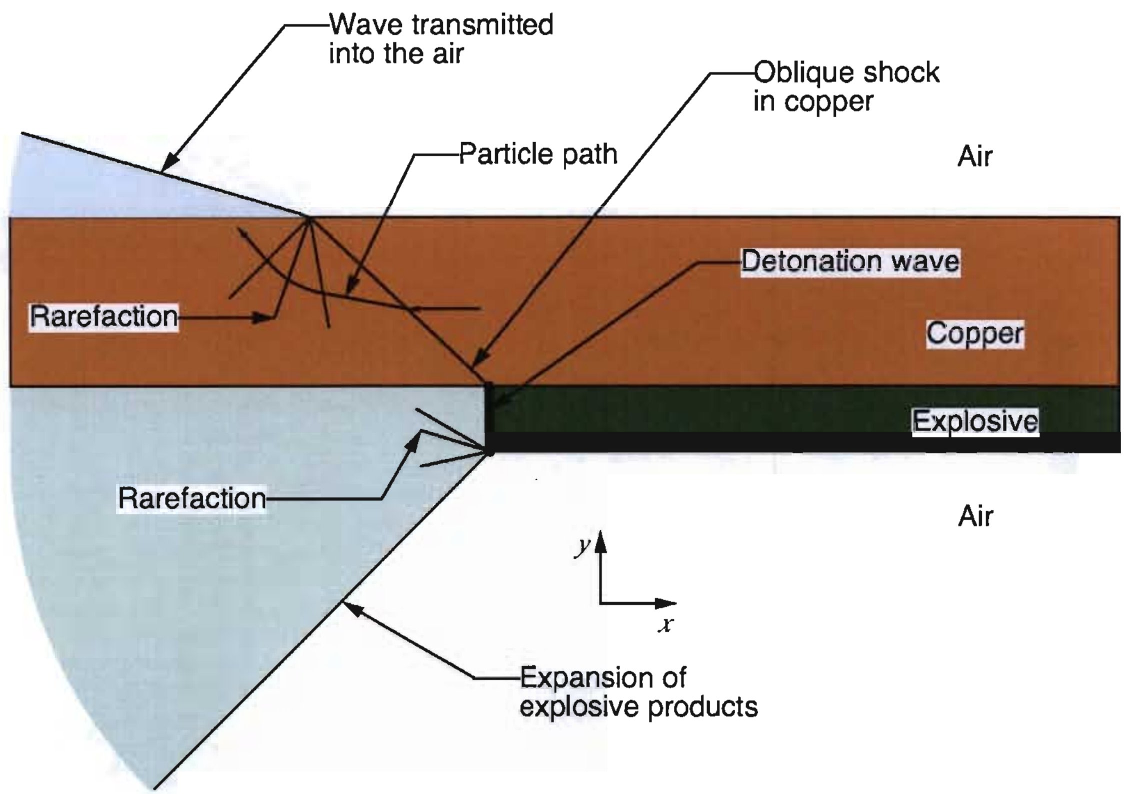
Sweeping wave experiments are quasi-steady

- Observer rides on the shock/free surface intersection
  - Metal ahead is un-deformed
  - Metal behind is deformed but does not change shape

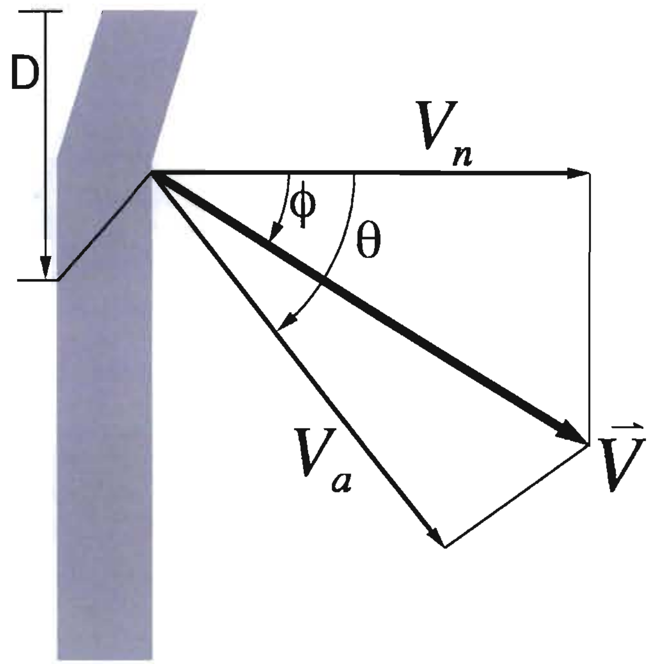
- Line wave initiation
  - 2 D motion (center)

- Rarefactions
  - Introduces scales
  - Limits region



Two PDV probes to measure 2 D vector

- One probe aligned normal to the plate
- One probe at some obliquity
- From the geometry:



$$V_a = V\cos(\theta - \phi)$$
$$V_n = V\cos(\phi)$$
$$V_a/V_n = \cos(\theta - \phi)/\cos(\phi)$$
$$\phi = \tan^{-1}\left[(V_a/V_n - \cos(\theta))/\sin(\theta)\right]$$

Strain

- **Rigid-plastic**
  - **Elastic strains are taken as zero**
- **Write in terms of increments**

$$d\varepsilon_{xx} = \frac{\partial(d\delta_x)}{\partial x}$$

$$2d\varepsilon_{xy} = \frac{\partial(d\delta_y)}{\partial x} + \frac{\partial(d\delta_x)}{\partial y}$$

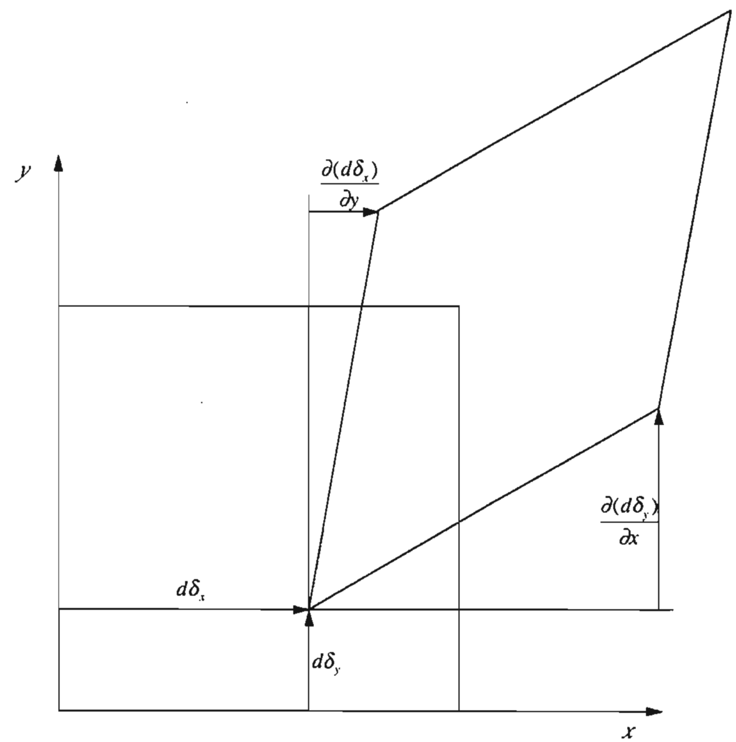
$$2d\theta_z = \frac{\partial(d\delta_y)}{\partial x} - \frac{\partial(d\delta_x)}{\partial y}$$

- **Velocities**

$$\dot{\varepsilon}_{xx} = \frac{\partial u}{\partial x}$$

$$2\dot{\varepsilon}_{xy} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}$$

$$2\omega_z = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$



Steady wave approximation

- To the observer riding the intersection
  - Steady surface profile is observed y(x) where

$$x = Dt$$

- The strains become

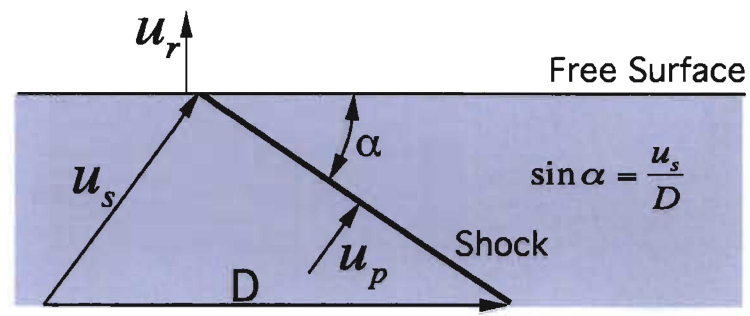
$$\frac{d\varepsilon_{xx}^{p}}{dt} = \frac{1}{2D}\left|\frac{\partial u}{\partial t}\right| \text{ or } \qquad \frac{d\varepsilon_{xy}^{p}}{dt} = \frac{1}{2}\left|\frac{1}{D}\frac{\partial v}{\partial t} + \frac{\partial u}{\partial y}\right| \text{ or}$$

$$\varepsilon_{xx}^{p} = \frac{1}{2D}\int\left|\frac{\partial u}{\partial t}\right| dt \qquad \varepsilon_{xy}^{p} = \frac{1}{2}\int\left|\frac{1}{D}\frac{\partial v}{\partial t} + \frac{\partial u}{\partial y}\right| dt$$

- Note that the velocity gradient $\partial u/\partial y$ needs approximation

The tangential velocity originates from the oblique shock

- Shock induces mass velocity perpendicular to the shock locus



- Rarefaction induces mass velocity ~perpendicular to the free surface
- Add velocity vectors

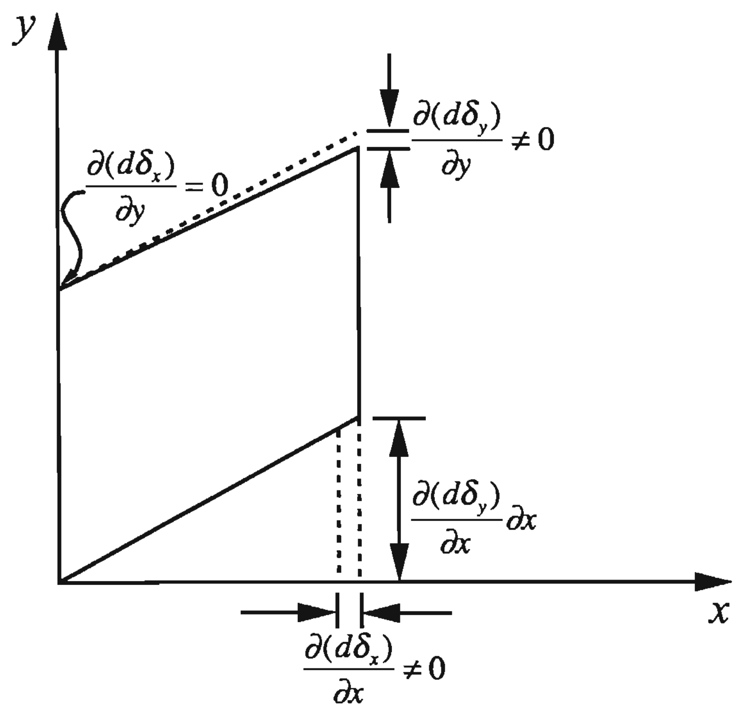
$$\vec{u}_{fs} = u_p \sin\alpha \vec{i} + (u_r + u_p \cos\alpha)\vec{j}$$

- Note that u is constant with depth

$$\frac{\partial u}{\partial y} \approx 0$$

Compression + Shear

- **Shock approximation provides a simple strain model**
- **Calculate strains directly from velocity components**

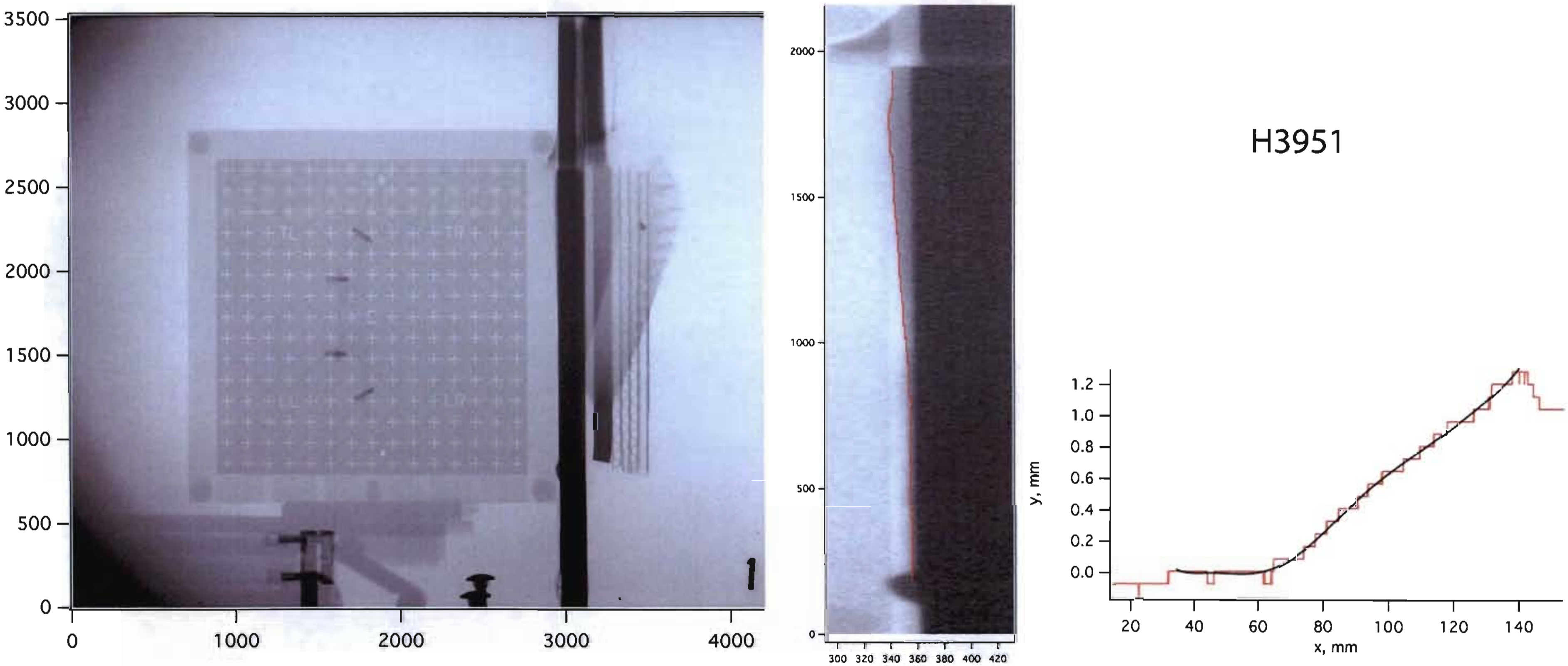


$$\varepsilon_{xx}^{p} = \frac{1}{2D}\int\left|\frac{\partial u}{\partial t}\right|dt \text{ and}$$

$$\varepsilon_{xy}^{p} = \frac{1}{2D}\int\left|\frac{\partial v}{\partial t}\right|dt$$

A Ta plate example

- Driven by deta sheet through a foam gap



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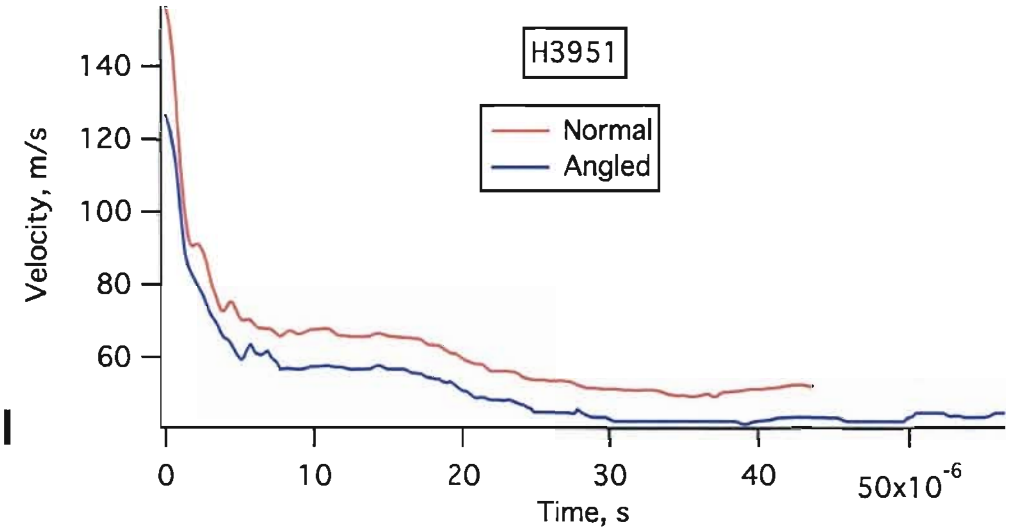
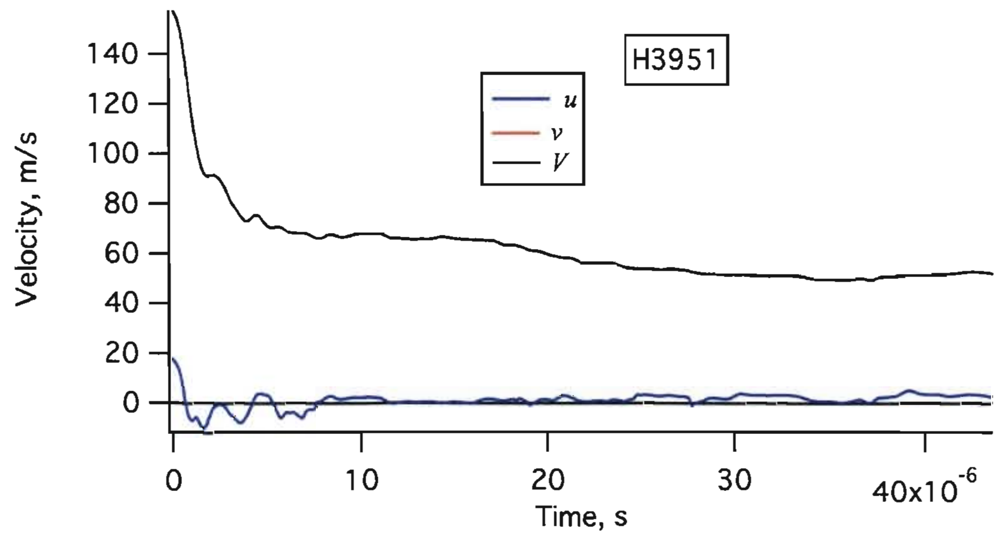
Probes at zero and 30 deg. obliquity

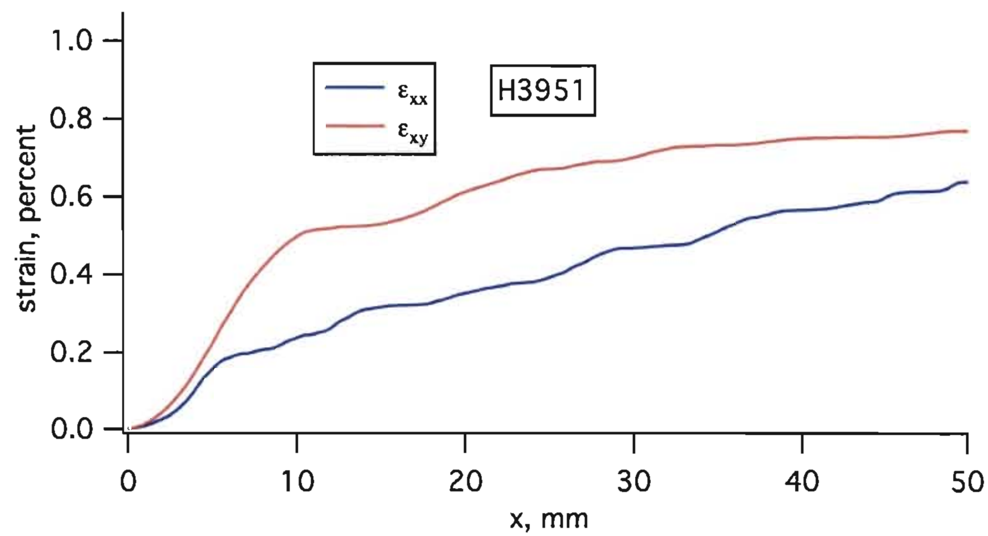
- **Individual measurements show difference**
- **Resolved components show**
  - **Small tangential component**
  - **Total velocity is nearly equal to the normal component**





Estimated strains

- **Shear strains larger than normal strain**



- **In this example, assumption of dominance of plastic strains should be checked**
  - **Low strains caused by "soft push" drive**