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Computational and Experimental Investigation of the Shock Compression Response of Cold-Rolled Ni/Al Multilayers

Paul Specht[1], Naresh Thadhani[1], and Timothy Weihs[2]

1) School of Material Science and Engineering, Georgia Institute of Technology, Atlanta GA
2) Department of materials Science and Engineering, The Johns Hopkins University, Baltimore MD

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Overview

- Motivation and Objectives
- Microstructural Characterization of Ni/Al Multilayers
- Uniaxial Strain Experimental Analysis
- Computational Analysis
- Conclusions

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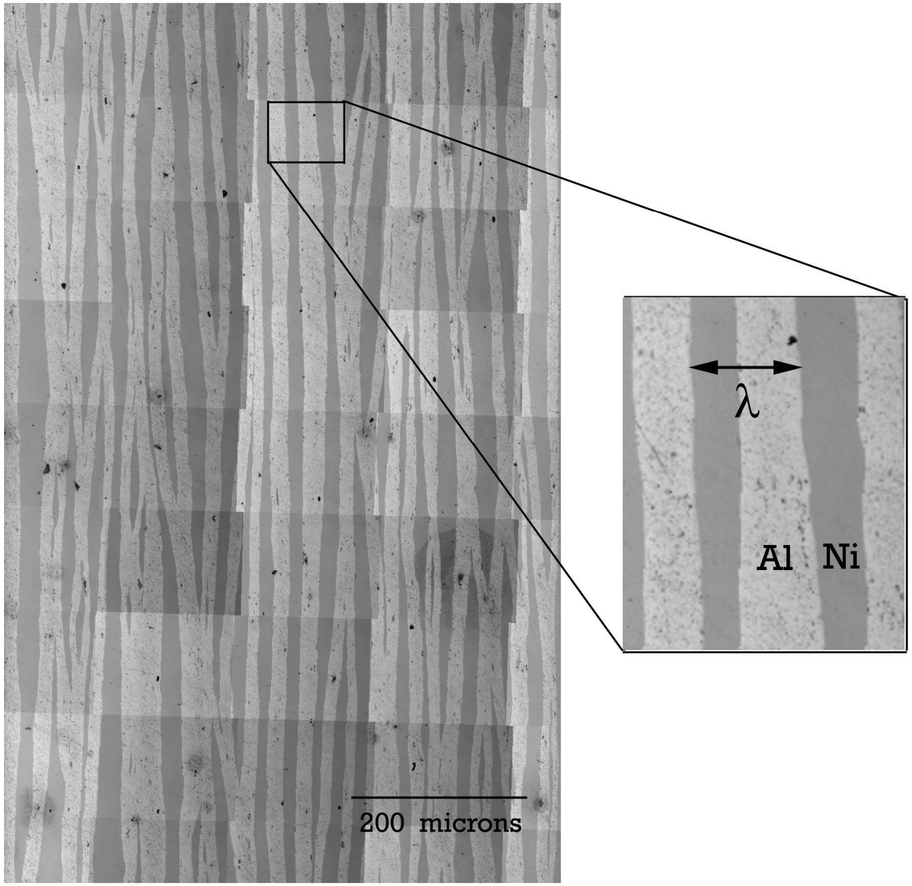
Motivation and Objectives

- Multilayers have a variety of beneficial properties for use as multi-functional structural energetic materials (MSEMs)
  - Fully dense, highly reactive, intimate contact between constituents
- How does the underlying microstructure effect the mechanical initiation of reaction during shock compression?
  - In particular, does this microstructural dependence vary from thermal initiation
- How various microstructural features effect the propagation of a shock wave?
  - Effect interfaces have on the amount irreversible energy deposition into the microstructure

Multilayer Ni/Al Composites

- Fabricated at Johns Hopkins University by Dr. Timothy Weihs [1]
- Made with Ni-201 and Al-5052-H19 foils
  - Laminate shown has:
    - 3 rolling cycles
    - 28 μm bilayer spacing, λ
    - Stoichiometry – NiAl
    - Total thickness ~600 μm



Longitudinal Cross-Section

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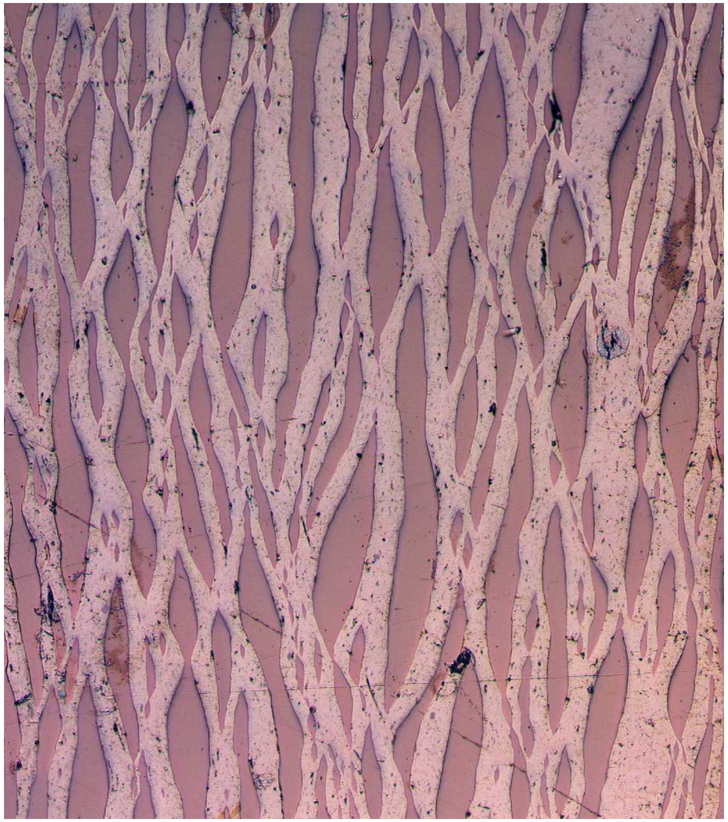
[1] U.S. Patent Application No. 20110027547

Microstructural Variation

- Despite the periodicity of the microstructure these are still very heterogeneous systems
  - These materials can only be loosely approximated as uniformly layered composites
- Microstructures differ for the longitudinal, transverse, and short-transverse cross-sections



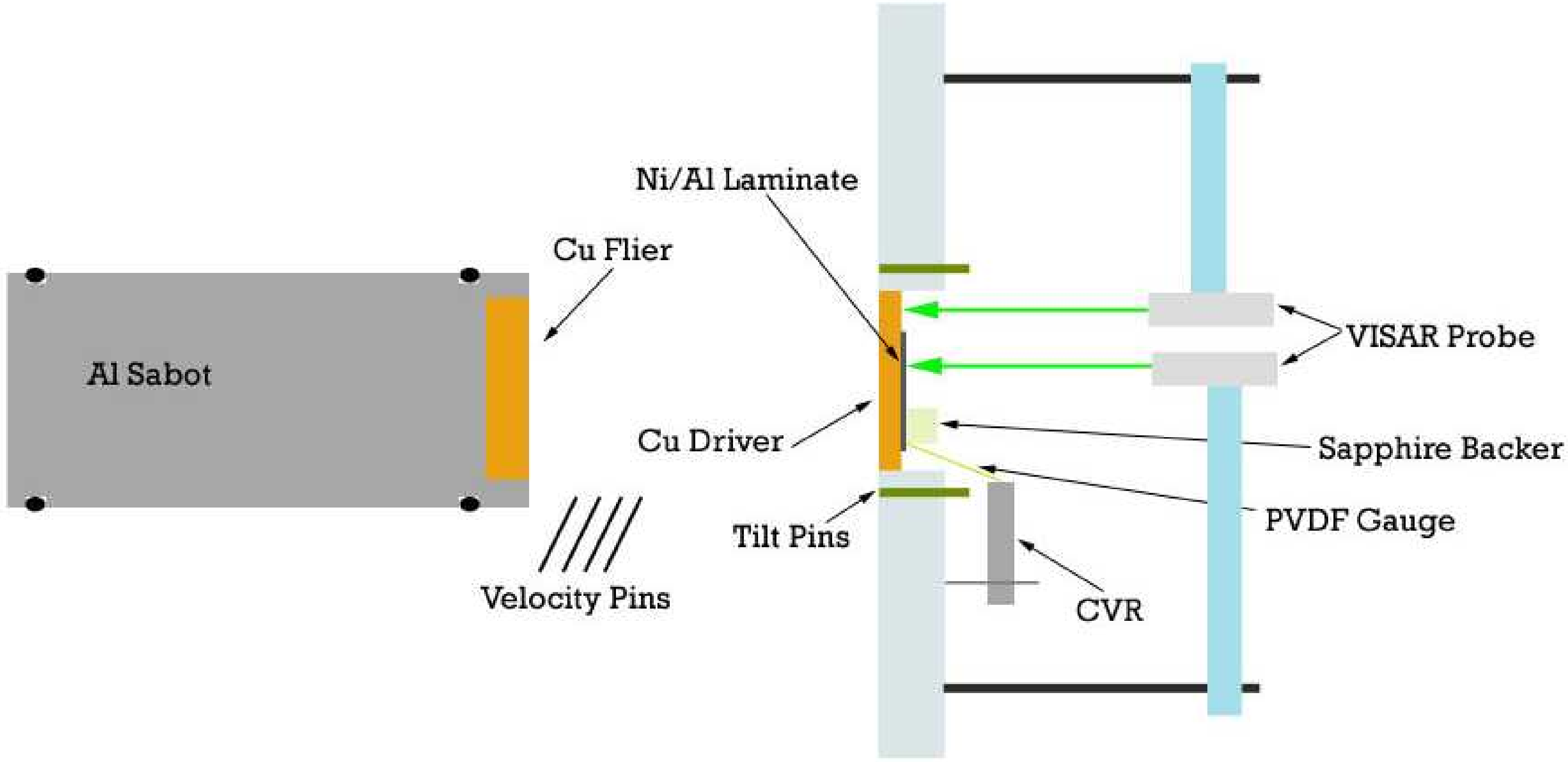
Transverse cross-section

Uniaxial Strain Experiments

- Performed uniaxial strain experiments on the perpendicular configuration
  - 80 mm single stage light gas gun
  - Use various time-resolved diagnostics (PDV, VISAR, and PVDF stress gauges) for determination of Hugoniot points
  - Attempted measurement of two quantities (Us and Up), but often need to use impedance matching
- Measurements are complicated by the thin, irregular nature of the samples
  - Wave transit times are ~ 200 ns
  - Rolling leads to irregularities in the thickness of the multilayers
    - Thicknesses vary ~ 30 μm

Experimental Setup

- Final experimental arrangement



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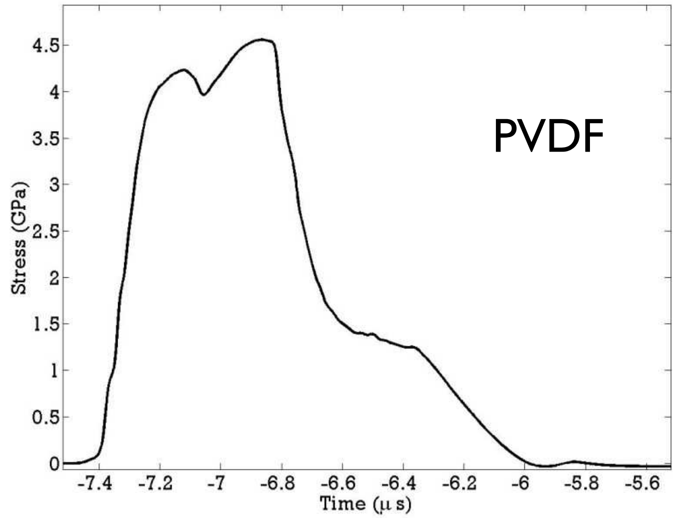
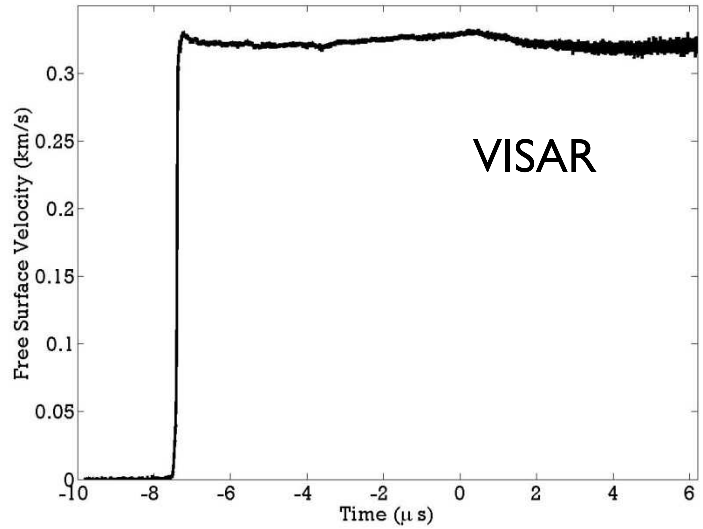
Diagnostic Response

- The effects of numerous wave reflections and interactions are seen the PVDF gauge stress record
  - Prohibits a determination of a steady state value
- VISAR shows consistent free surface velocity
  - Only first portion corresponds to the multilayer behavior





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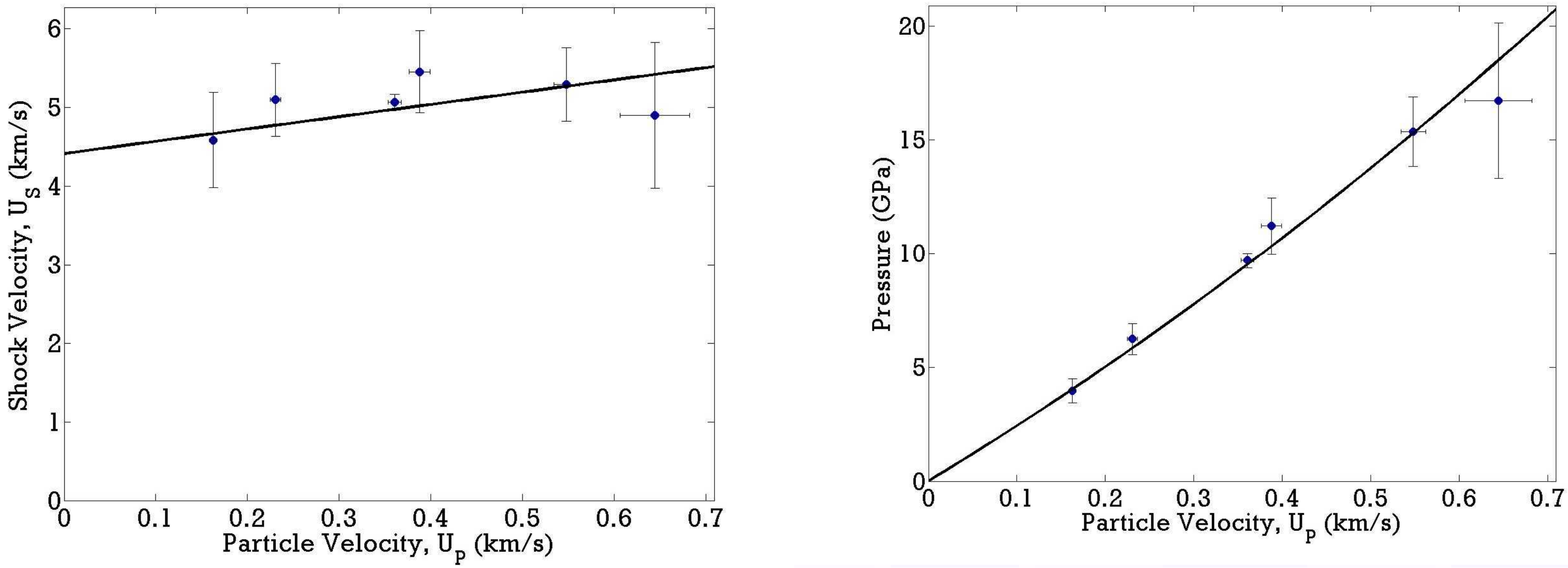
Experimental Results

- Large error in data due to thin, irregular nature of the samples
- No increase in wave speed indicative of reaction was observed
- Black curve corresponds to the computationally predicted Hugoniot [2]



[2] Specht *et al.* JAP, **111**,073527, (2012)

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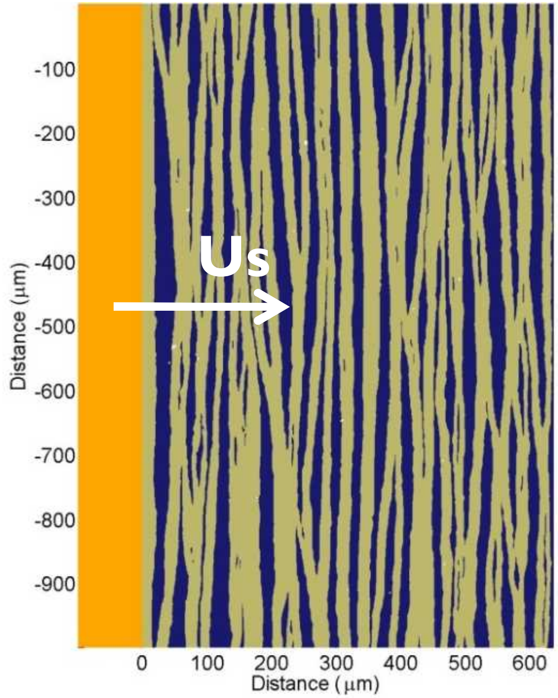
Simulation Parameters

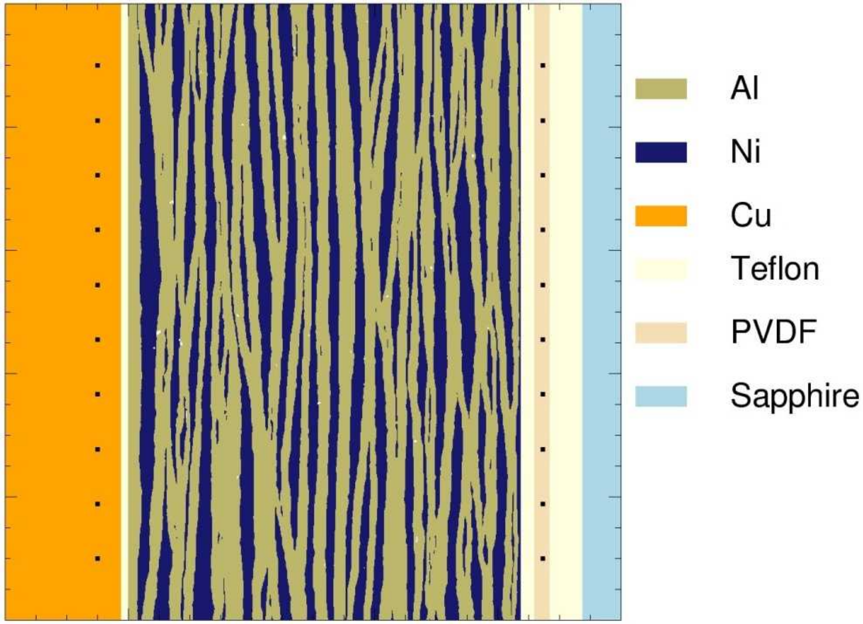
- Simulations were done in CTH on the longitudinal cross-section
- All materials were modeled with the Mie-Grüneisen equation of state
- Al and Ni were modeled with rate-independent Steinberg-Cochran-Guinan constitutive model [14]
  - Microhardness measurements were used to account for strain hardening imparted during rolling
- Cu driver was modeled as a rigid body
- Perfectly bounded interfaces
- Boundary conditions along the top and bottom (y direction) were periodic and semi-infinite on the right and left (x-direction)
- Square mesh with 0.8 μm per cell

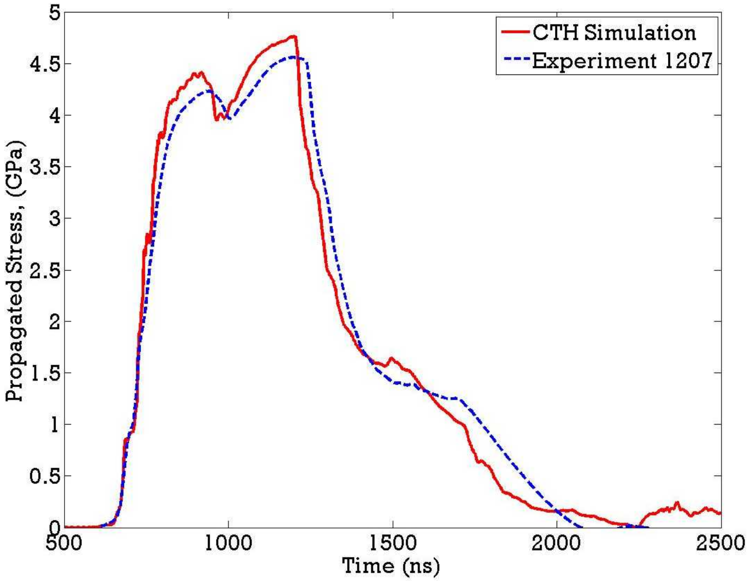


[3] D. Steinberg *et al.*, *J. Appl. Phys.* **51**, 1498-1504 (1980).

Simulation of Experimental Record

- To gain further validation want to computationally reproduce the experimental records
  - Simulate the experiment using the meso-scale microstructure and experimentally measured dimensions
  - PVDF gauge record is very accurately predicted





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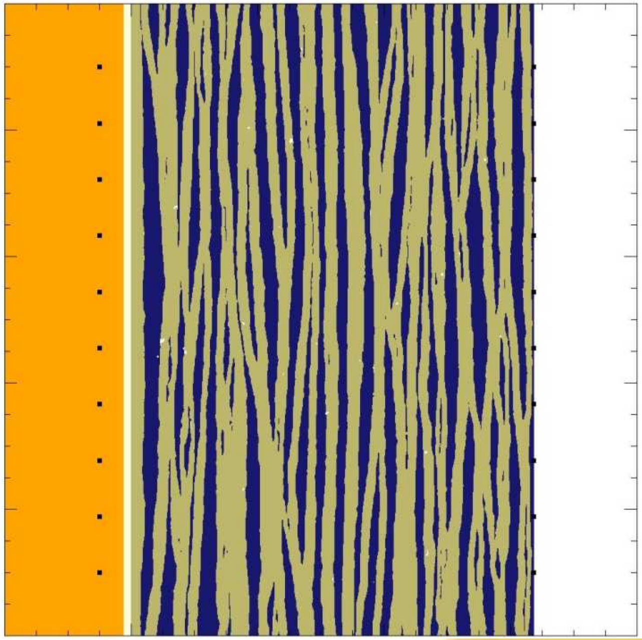
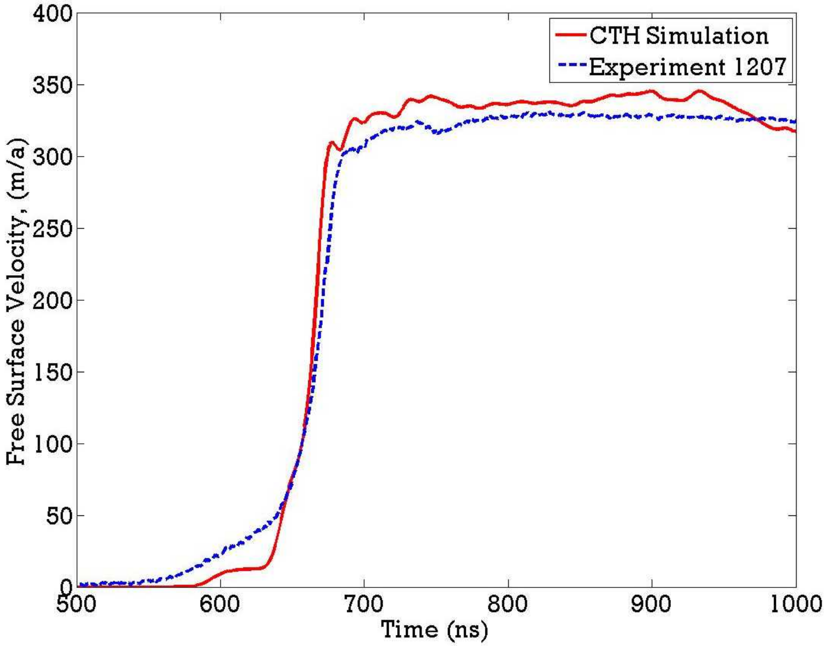
Simulation of Experimental Record

- To gain further validation want to computationally reproduce the experimental records
  - Simulate the experiment using the meso-scale microstructure and experimentally measured dimensions
  - VISAR record is also accurately predicted





Conclusions

- Simultations incorporating the heterogeneities of the multilayer microstructure where able to accurately capture the bulk material response in only two dimensions
  - This is despite the high degree of heterogeneity that exists normal to the transverse cross-sectional plane
- Uniaxial strain experiments showed no signs of reaction
  - Limited material mixing and heating due to fully dense nature
- Uniaxial strain experiments were complicated by the thin irregular nature of the samples leading to large errors in the determined Hugoniot
  - Necessitated a need to couple computational efforts for validation
  - With large error in Hugoniot measurements must also rely on accurately predicting experimental records computationally