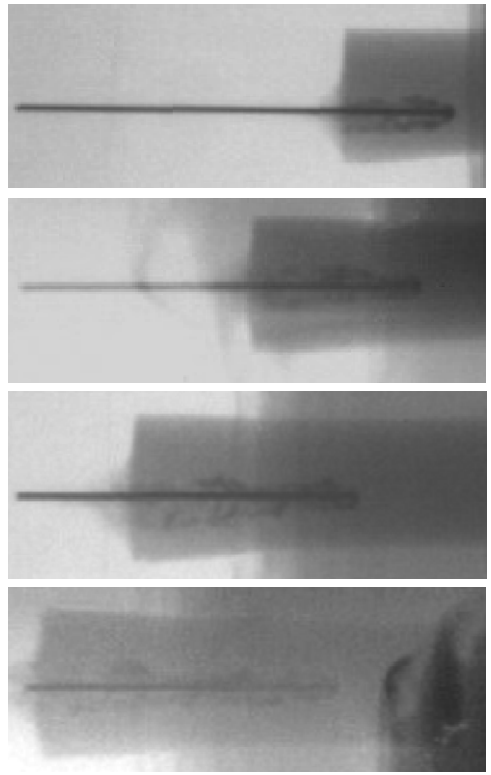
Long-Rod Penetration into Intact and Pre-Damaged SiC Ceramic



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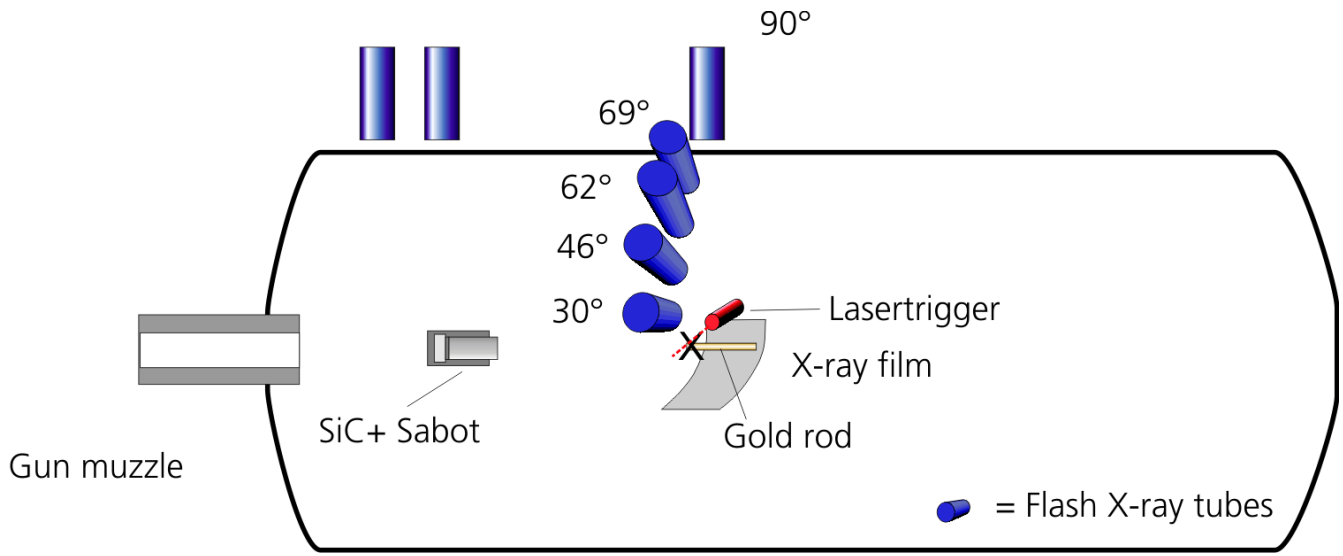
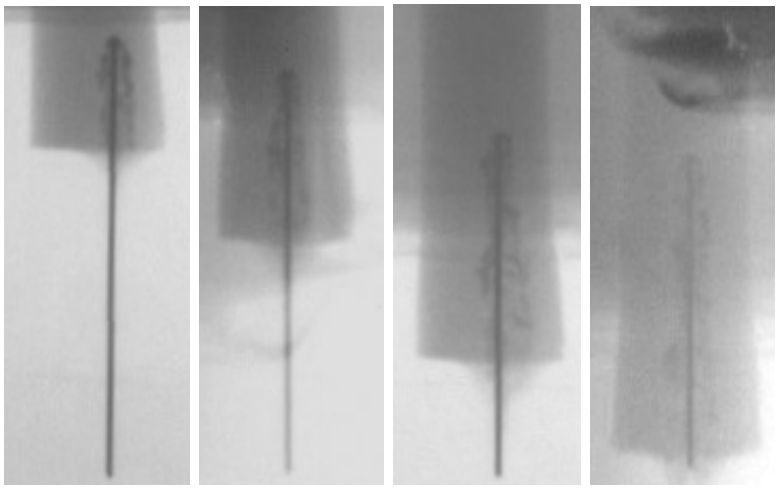
September 2008

Experimental Set-up

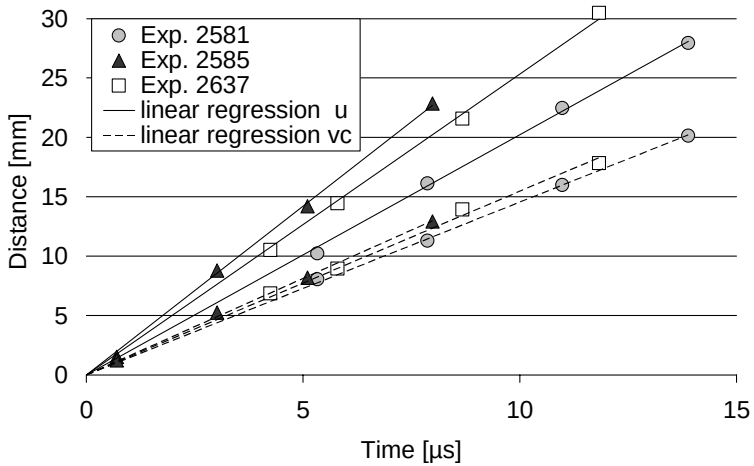


- *Reverse ballistics experiments*
- *Flash radiography used to measure position of nose and tail of rod versus time*

Penetration Experiments

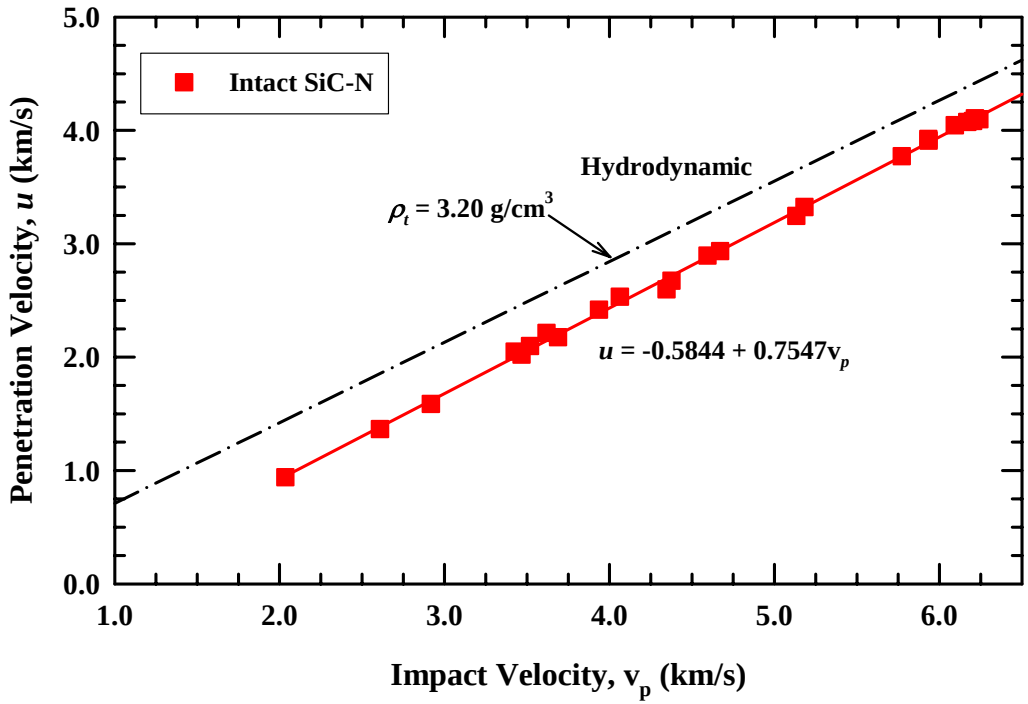


Expt 2581



- *Regression fits*
  - *Penetration vs. time*
  - *Rod length vs. time*
- *Slopes of regression fits*
  - *Penetration velocity*
  - *Consumption velocity*

Penetration Velocity vs. Impact Velocity



Experiments & Analysis: 2002 - 2005

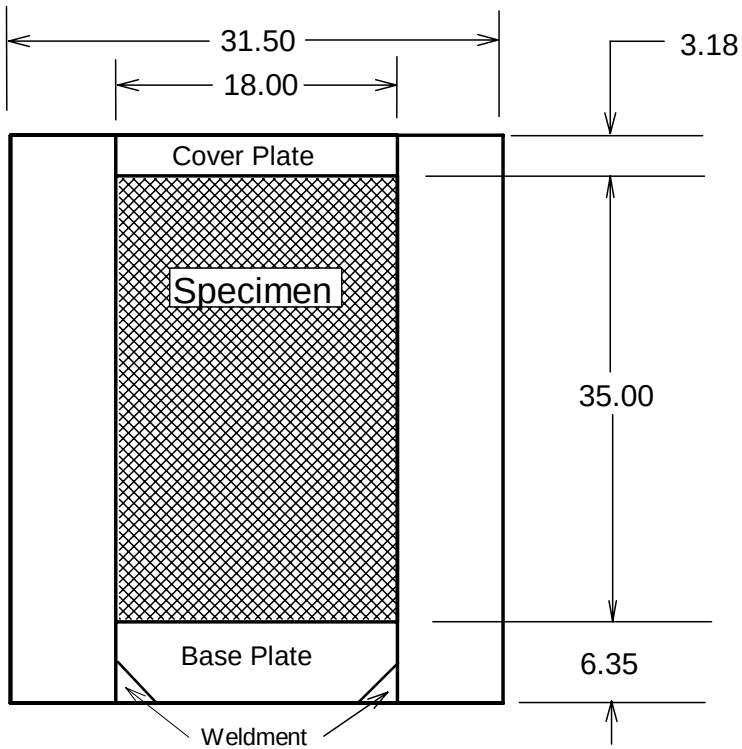
Experiments to Explore Penetration of Damaged Ceramic

- *Conflicting interpretations for strength of damaged ceramic*
- *Designed experiments to investigate penetration response of various "damaged" SiC*
  - *Pre-damaged (thermal cycles that induced cracks)*
  - *In-situ comminuted (thermal cycle plus load/reload cycles in a MTS machine)*
  - *Compacted powder*

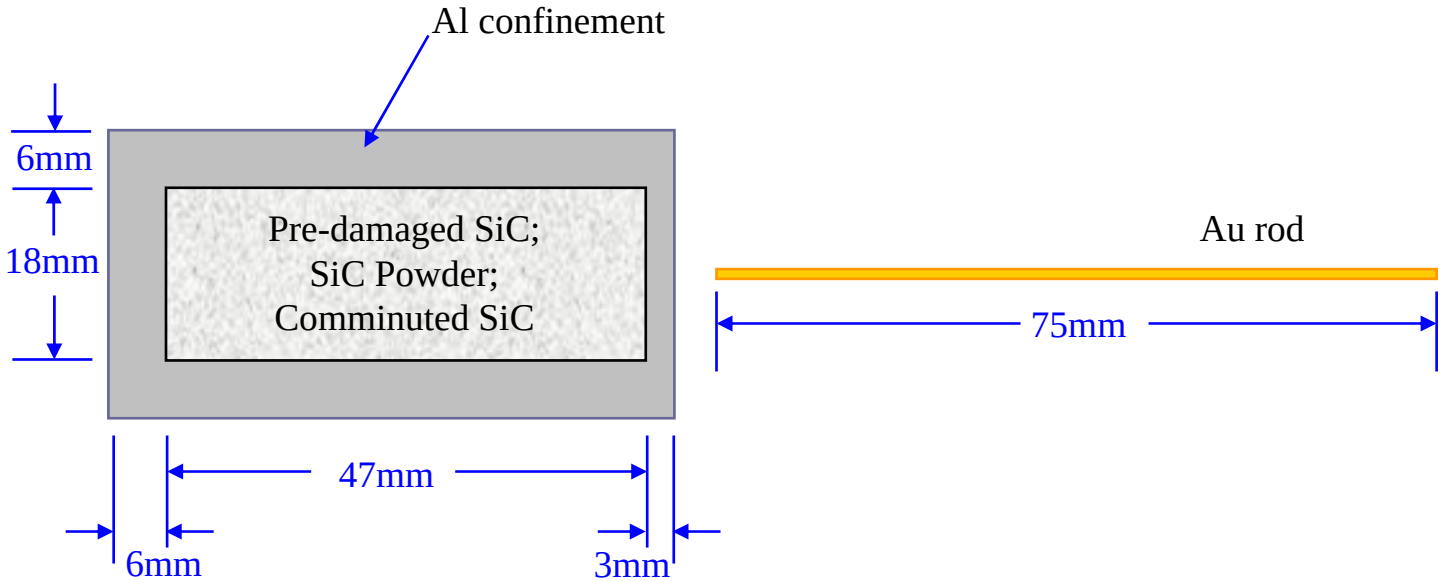
Experiments & Analysis: 2006 - 2007

Target Design

- *7075-T6 aluminum sleeve*
- *Base plate welded*
- *Cover plate press-fit w/superglue*

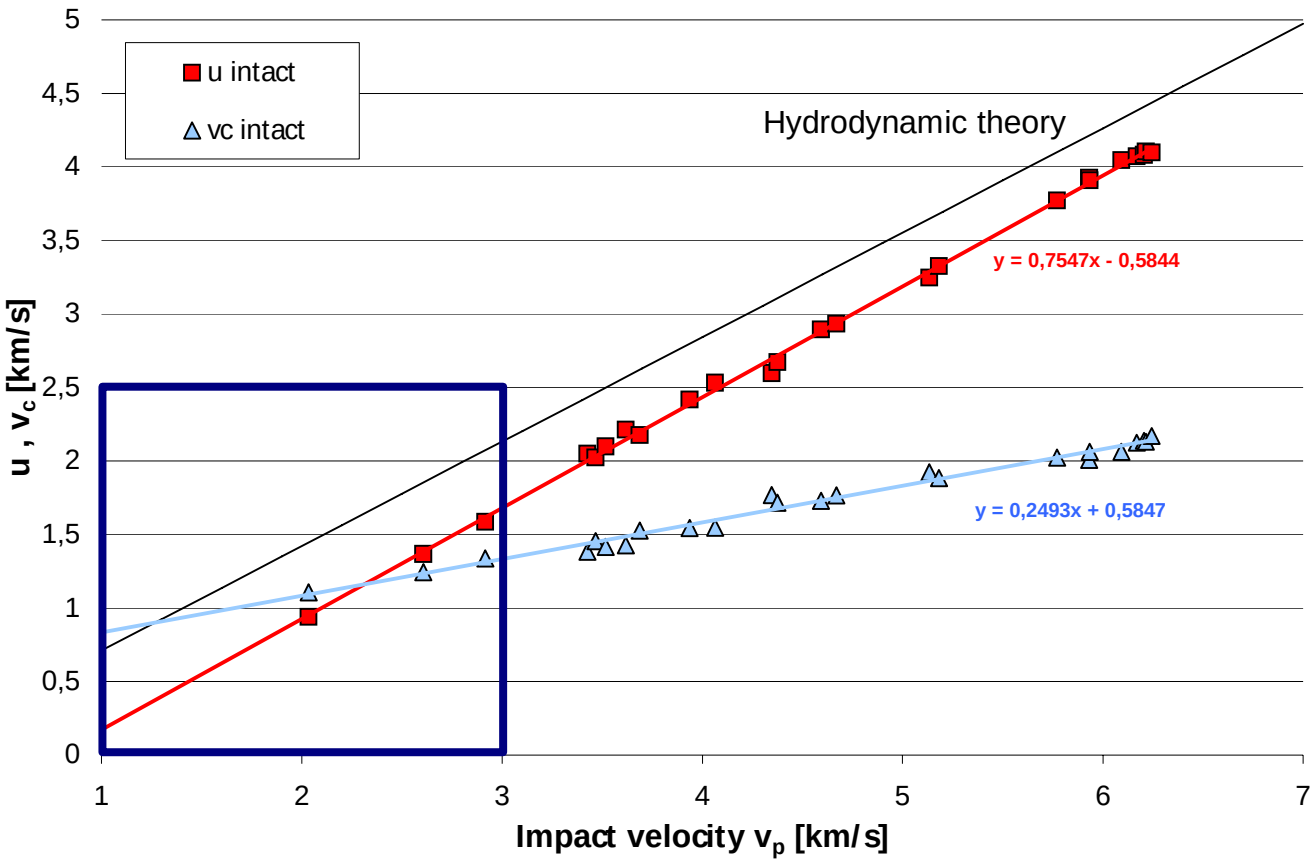


Schematic of EMI Experiments

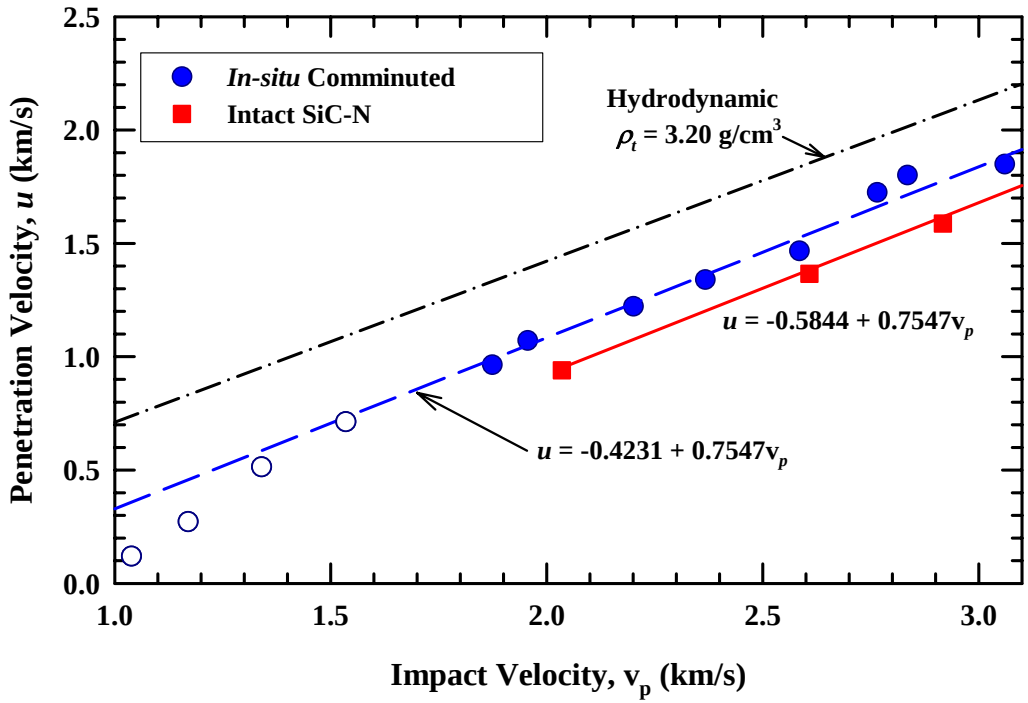


- *Differences in experiments relative to previous experiments*
  - *Aluminum confinement w/cover plate*
  - *1.00-mm diameter Au rod instead of 0.75-mm diameter rod*

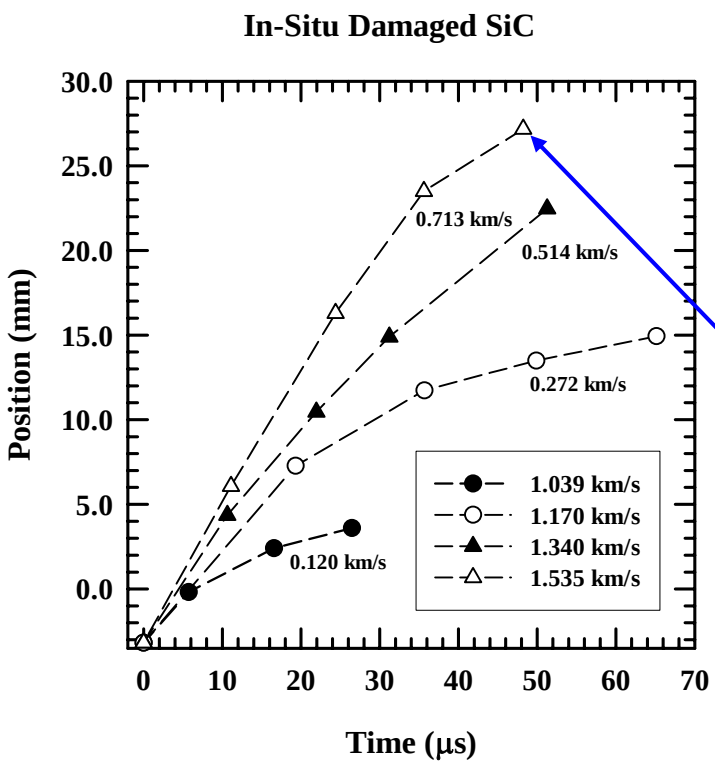
Velocity Range

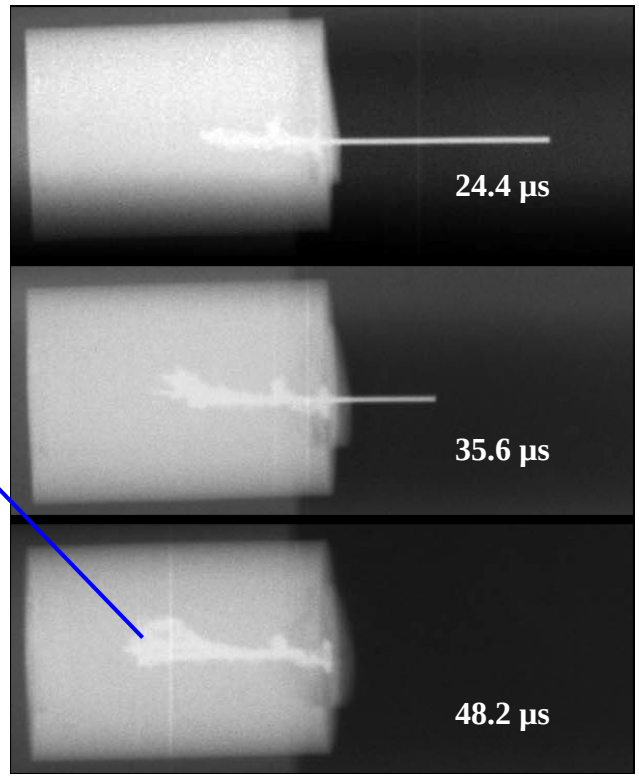


In-Situ Comminuted SiC



Lowest Impact Velocities

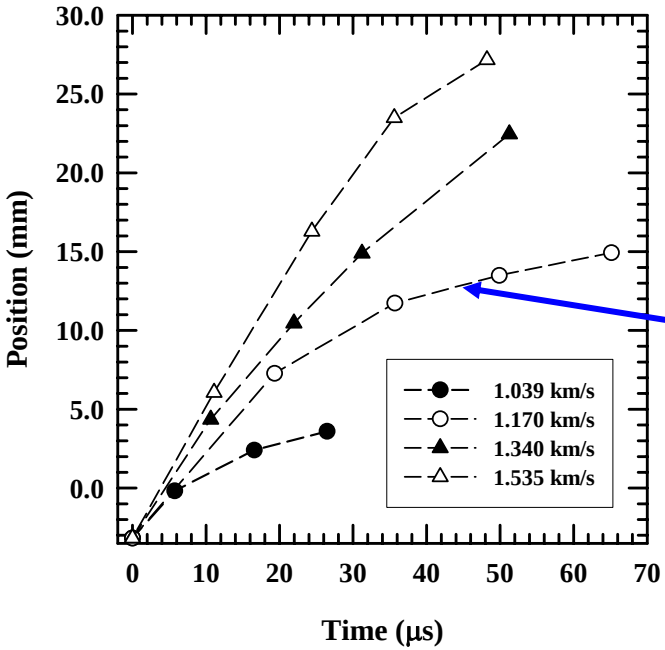


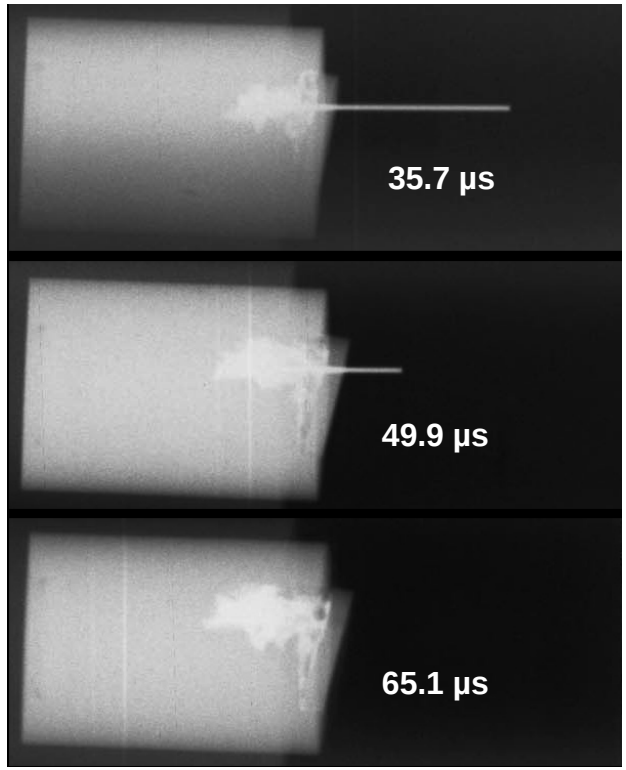


v_p = 1.535 km/s

- *When $u \leq v_c$, nonlinear penetration response*

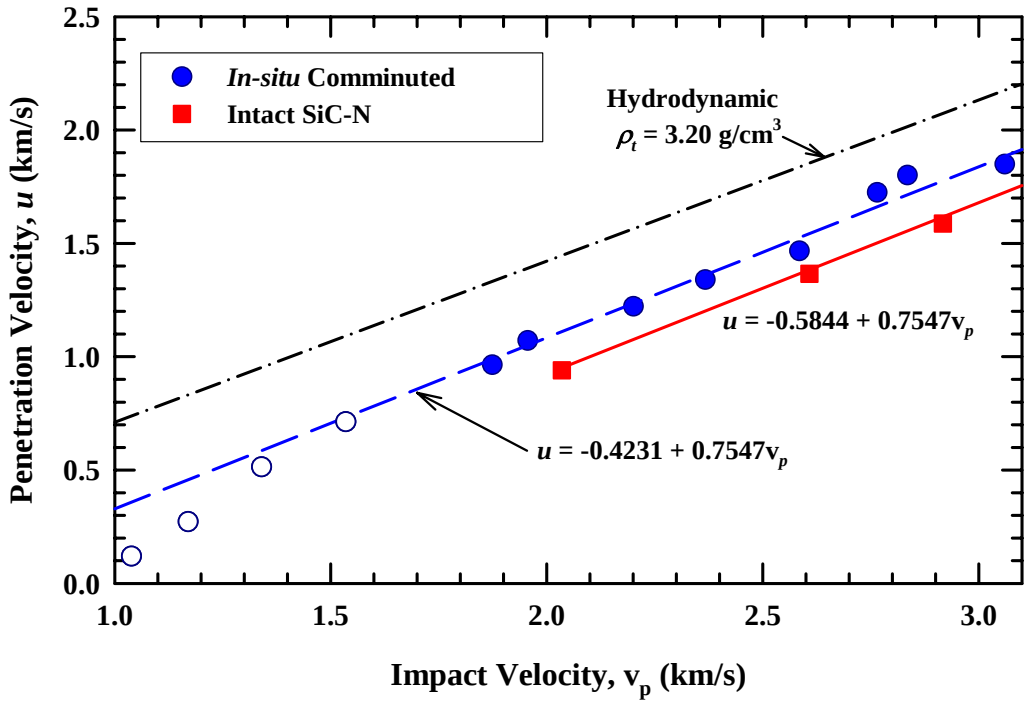
Dwell-Like Behavior



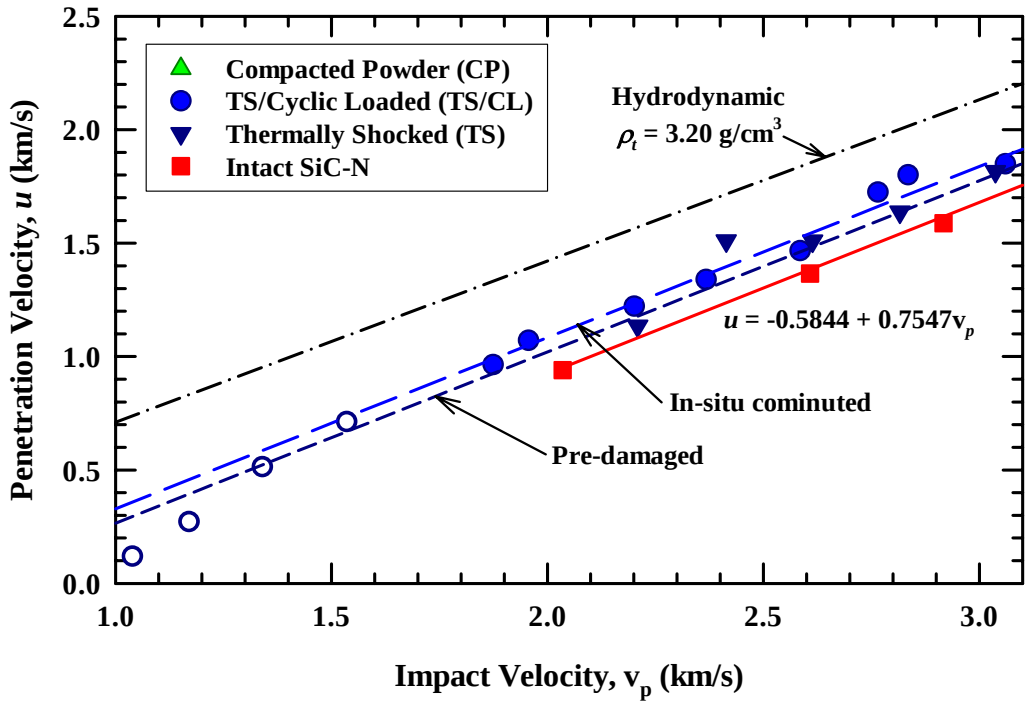


v_p = 1.170 km/s

In-Situ Comminuted SiC

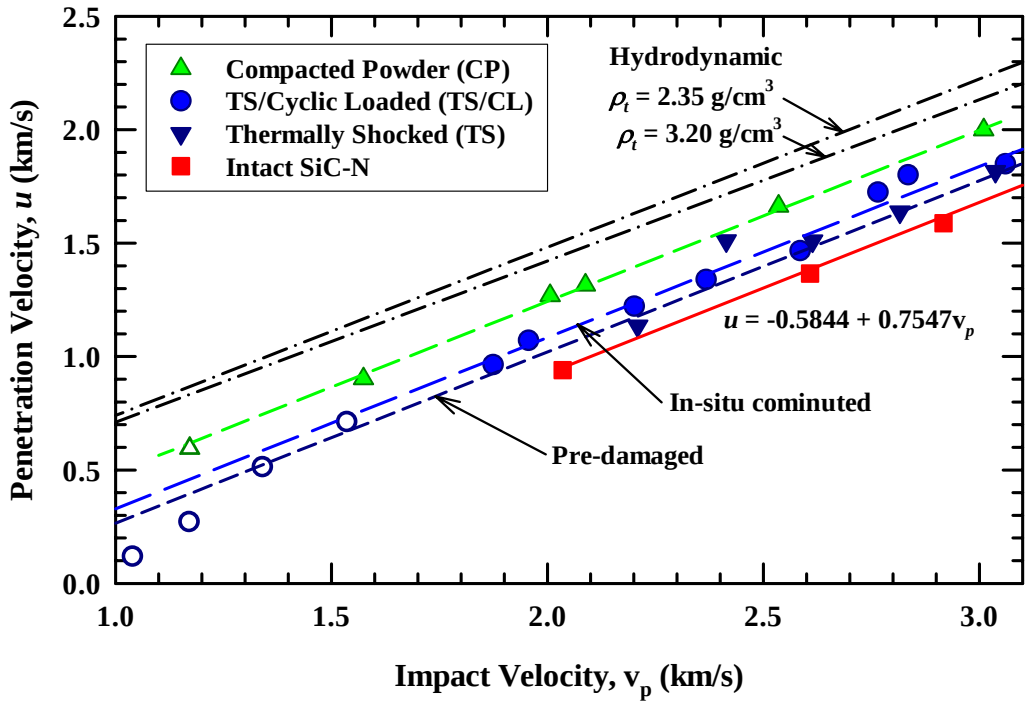


Thermally Shocked SiC



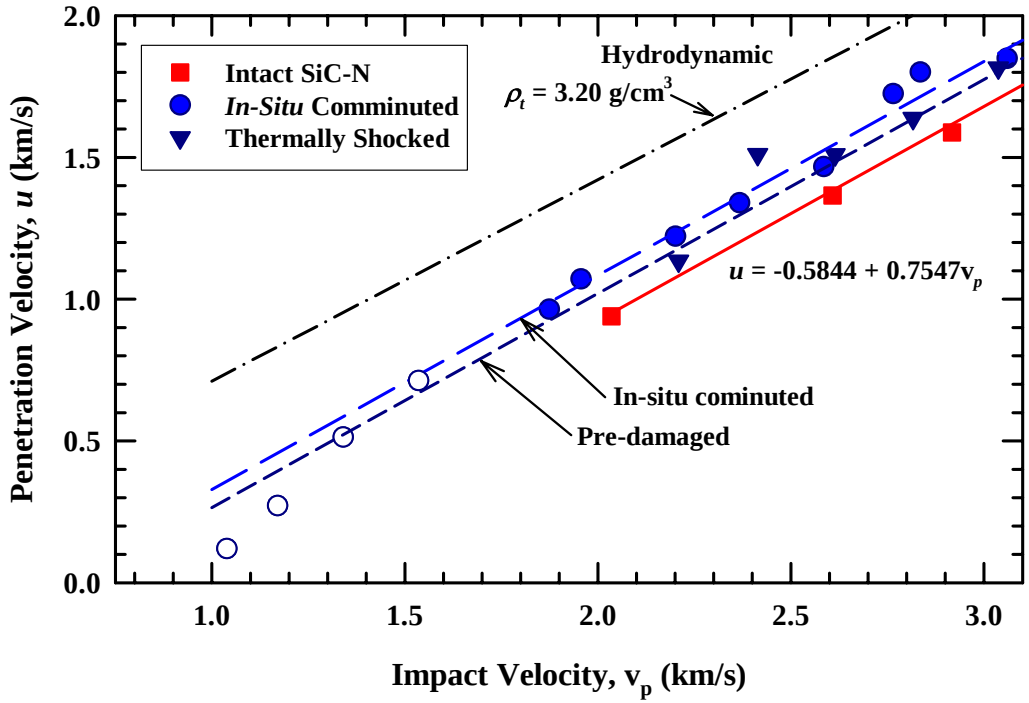
- *Regression fit through pre-damaged results ignored the datum point at 2.4 km/s*

Compacted SiC Powder



- $u_{intact} < u_{predamaged} < u_{comminuted} < u_{powder} < u_{hydro}$

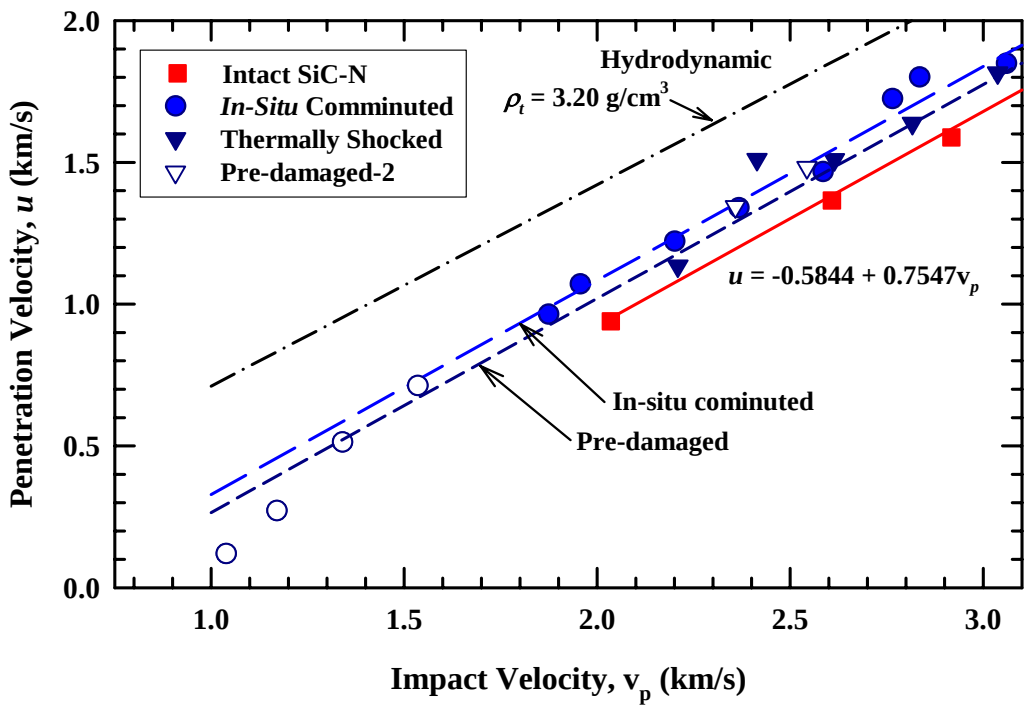
New Experiments



- *Extend pre-damaged sleeved data to lower impact velocities*
- *Check to see if data point at 2.4 km/s is an outlier*
- *Demonstrate that bare and sleeved intact ceramic have the same penetration response*
- *Extend intact data to lower impact velocities*

Pre-Damaged SiC Results

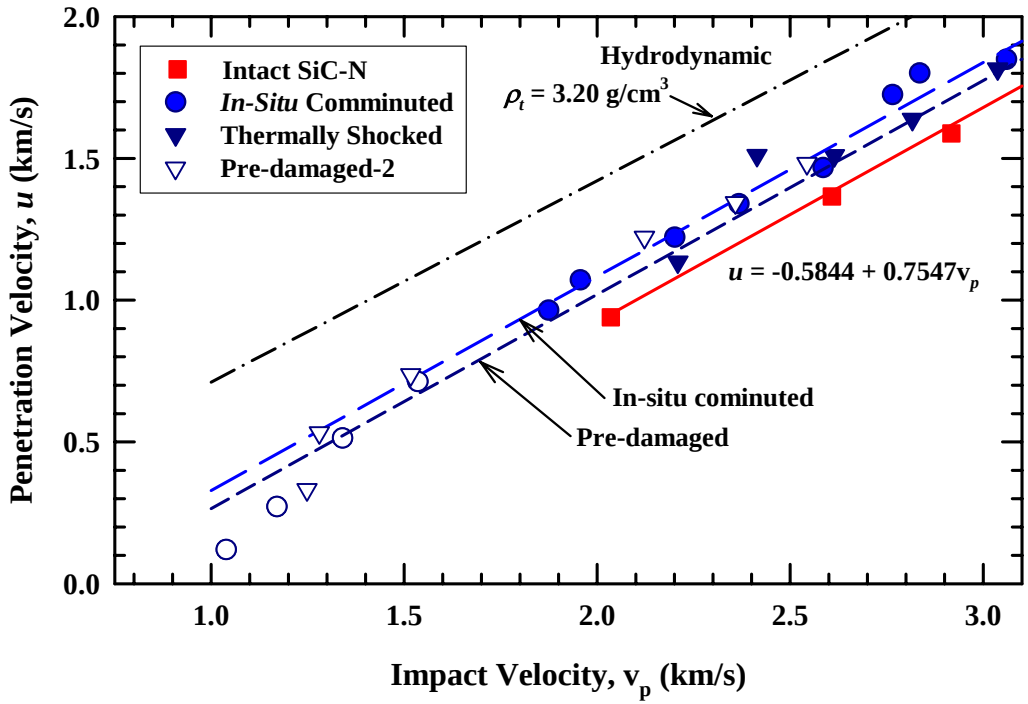
- *Was datum at 2.4 km/s anomalously high?*



- *Yes, it appears to be!*

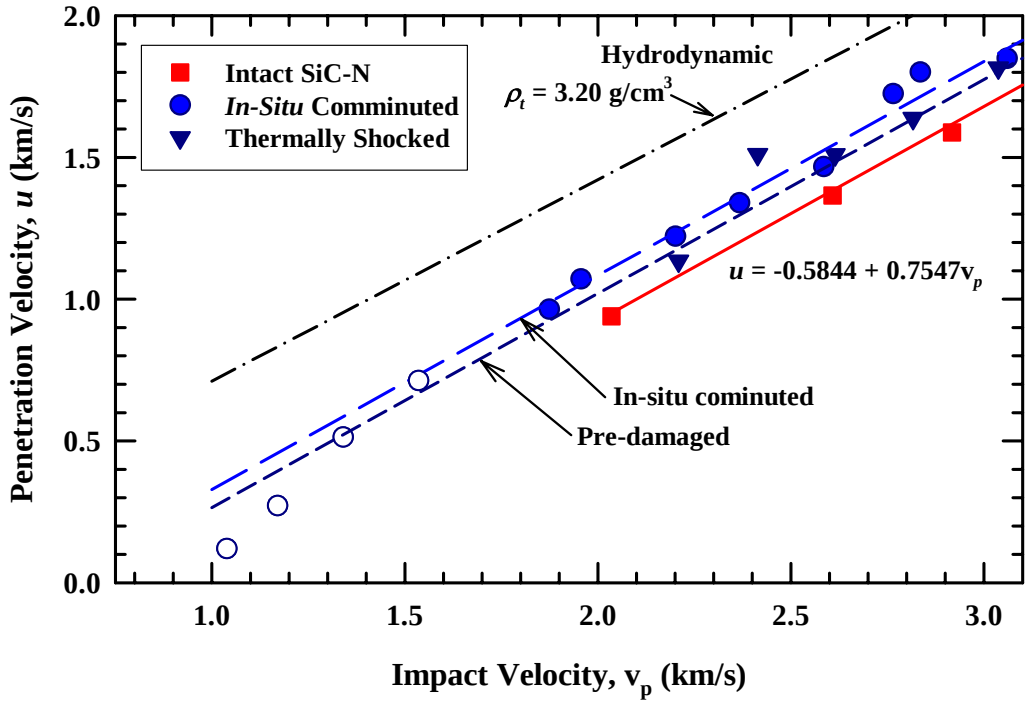
Pre-Damaged Results

- *Extend results to lower impact velocities*



- *Cannot differentiate between pre-damaged and in-situ comminuted experiments (within data scatter)*

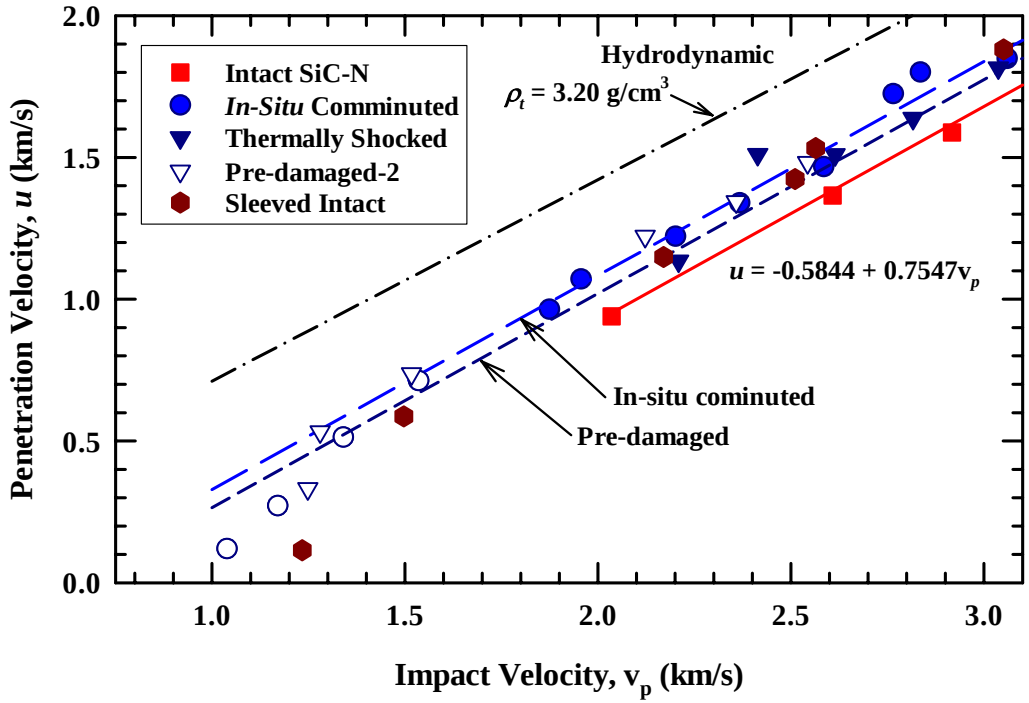
New Experiments



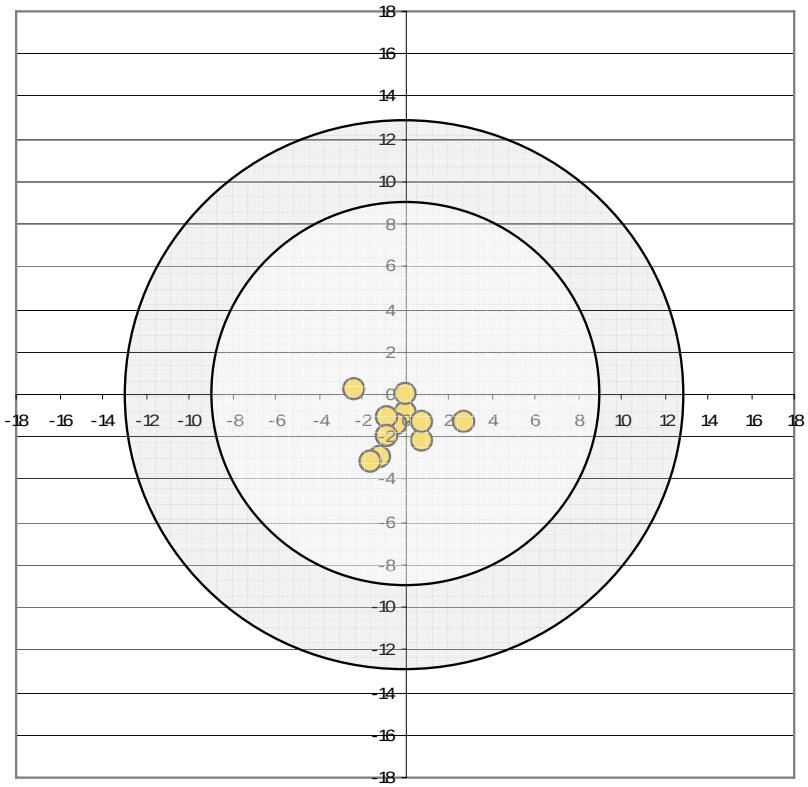
- *Extend pre-damaged sleeved data to lower impact velocities*
- *Check to see if data point at 2.4 km/s is an outlier*
- *Demonstrate that bare and sleeved intact ceramic have the same penetration response*
- *Extend intact data to lower impact velocities*

Sleeved Intact SiC

- *Begin experiments at high impact velocity (results should be independent of confinement)*

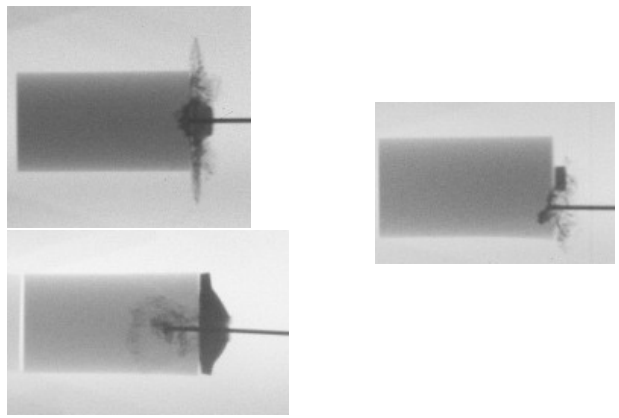


Good Impacts

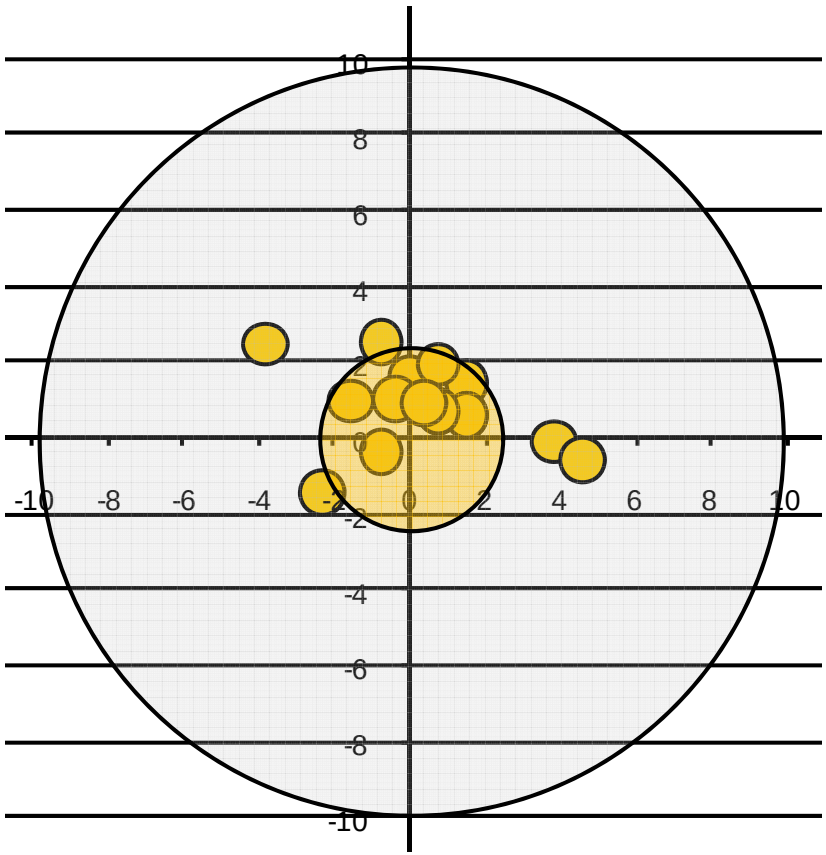


Results

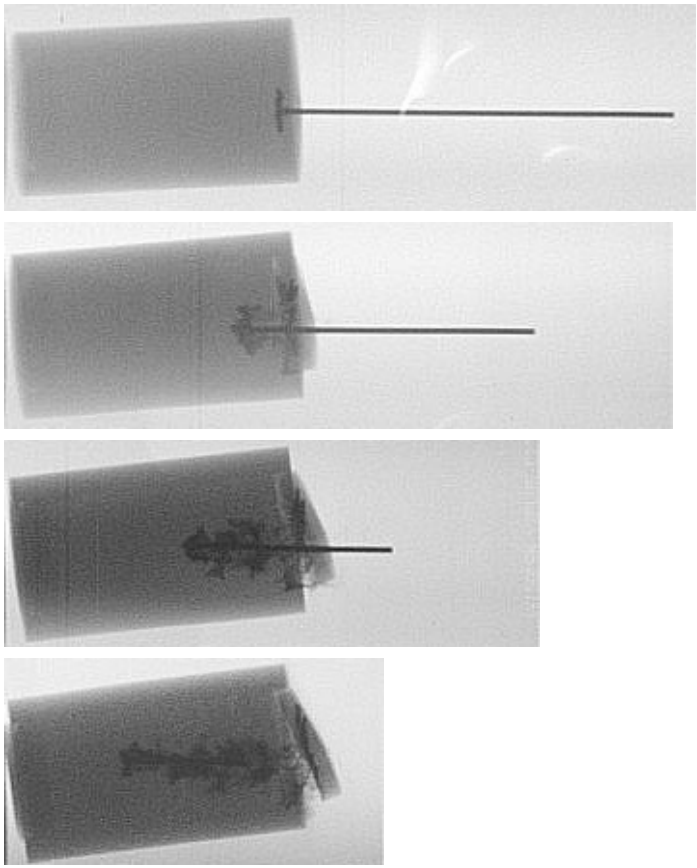
- *Cannot differentiate intact data from pre-damaged and in-situ comminuted data*
- *The new experiments were encased in the aluminum sleeve*
- *Had additional experiments to investigate interface defeat*
  - *Unconfined ceramic*
  - *With and w/o Cu buffer*
    - *Cu nub*
    - *Cu plate*



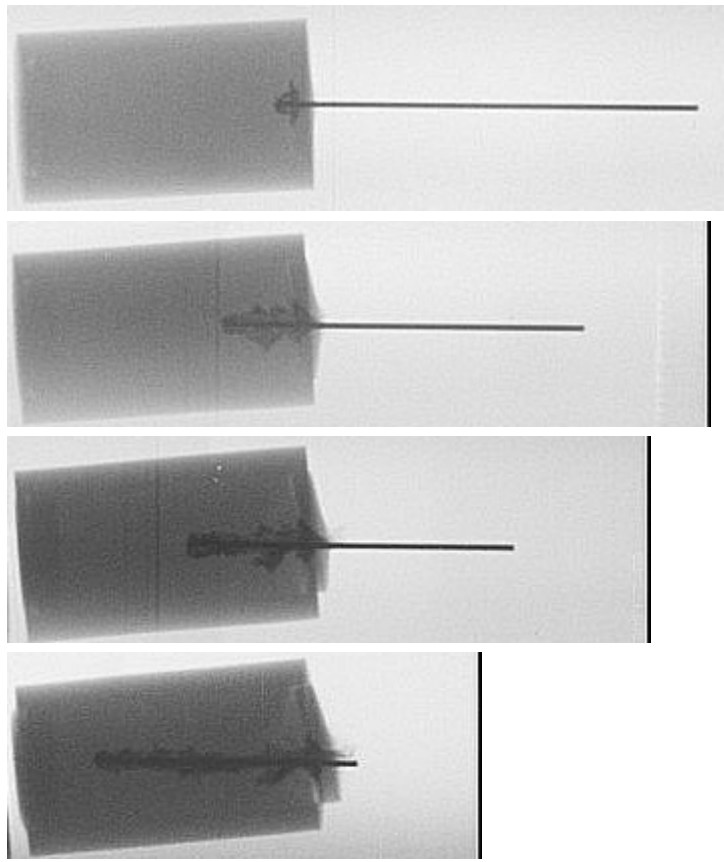
Impact Locations



Incipient Dwell w/Cover

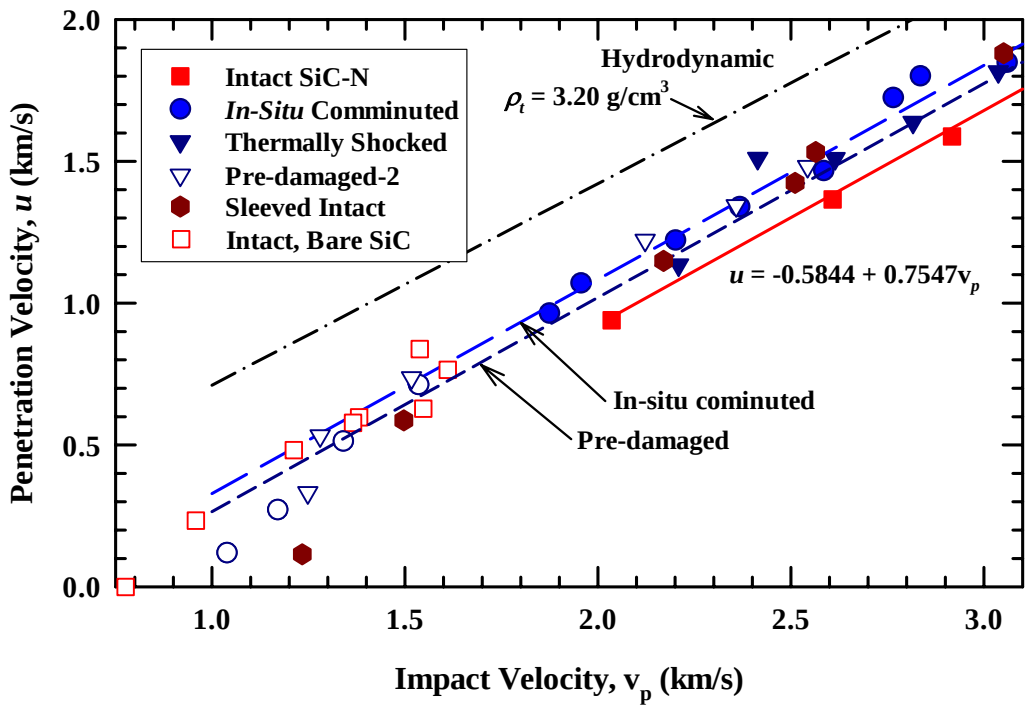


Test 11340
v_p = 1.497 km/s

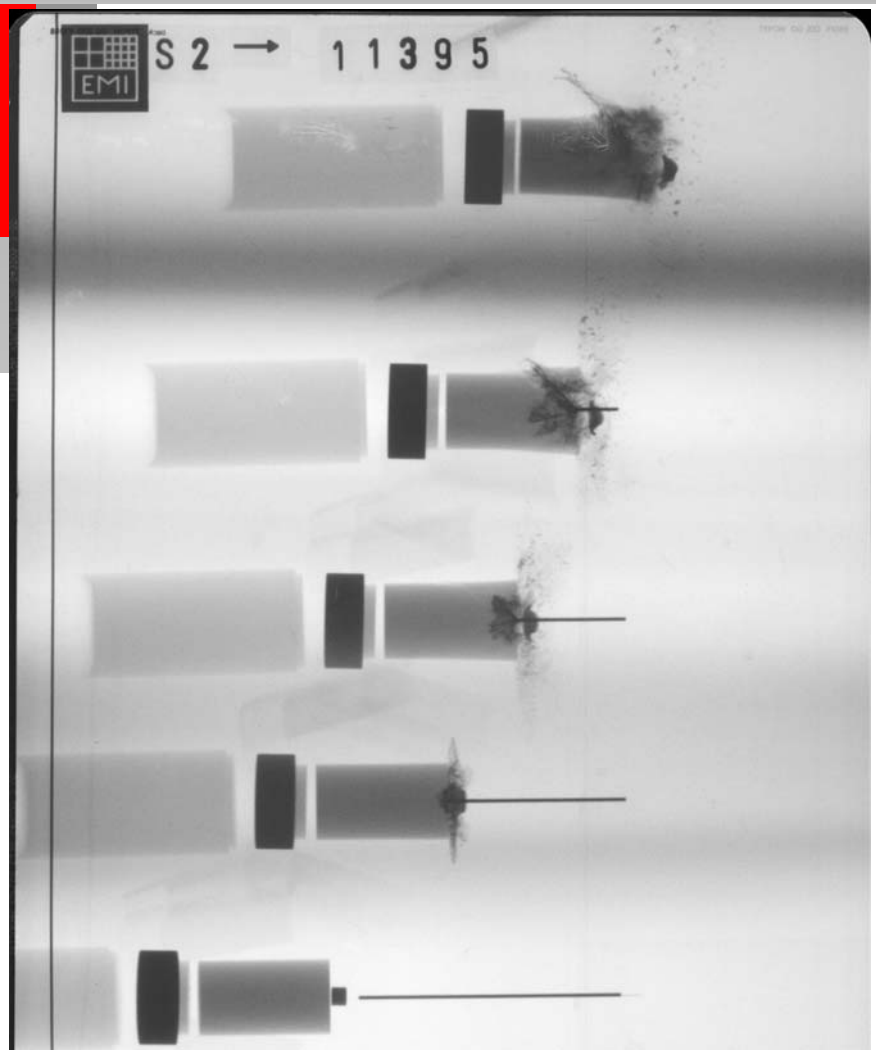


Test 11342
v_p = 2.170 km/s

Interface Defeat Expts.

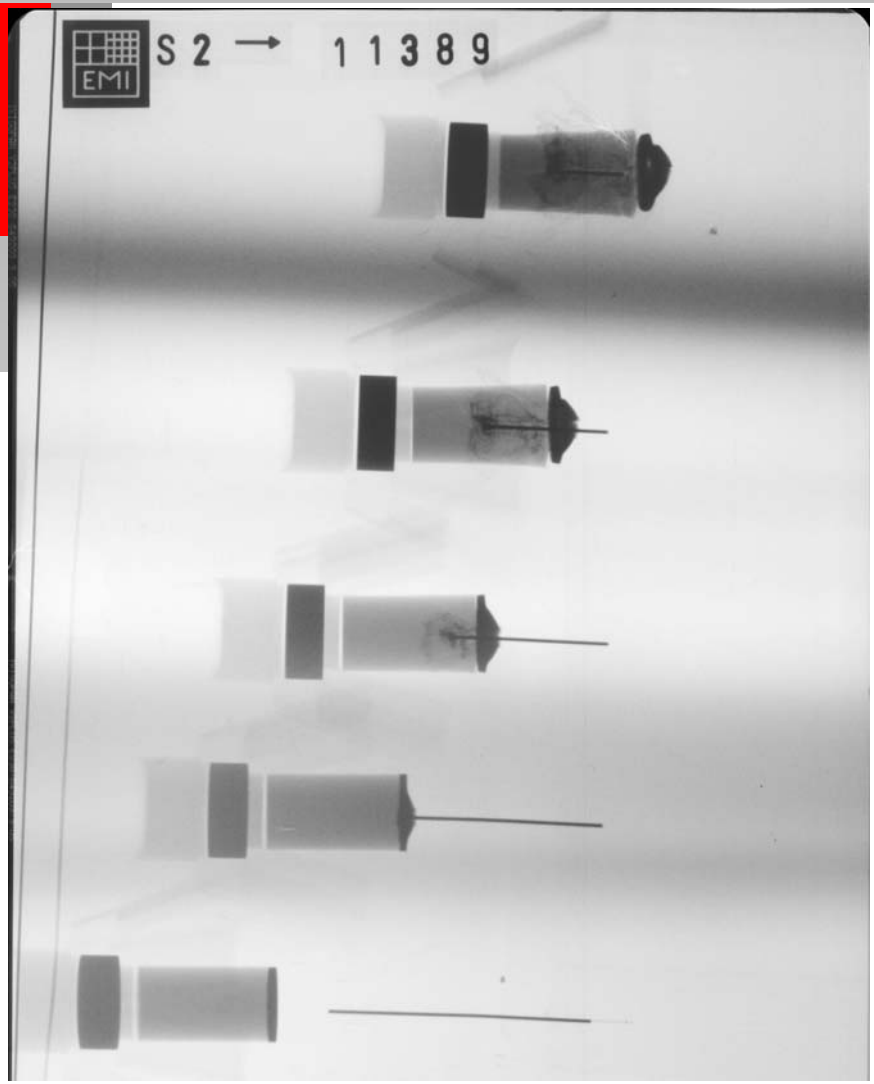


Dwell Experiment



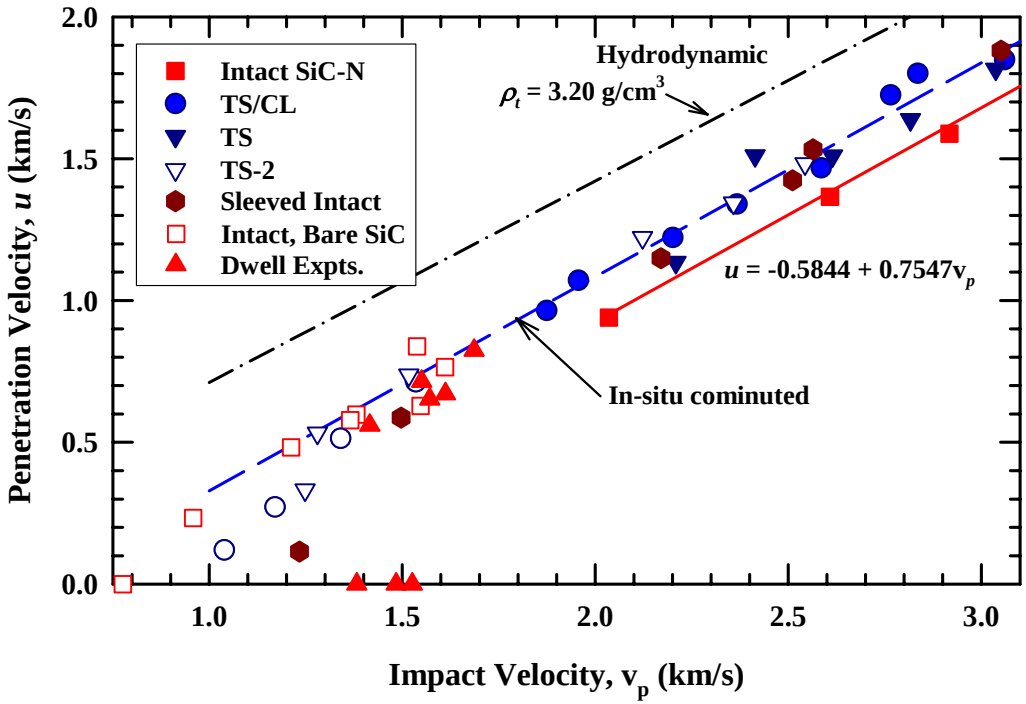
- *Test 11395*
- *Cu buffer*
- *Impact velocity: 1.526 km/s*
- *Dwelled for ~10.4 μs*

Dwell Experiment



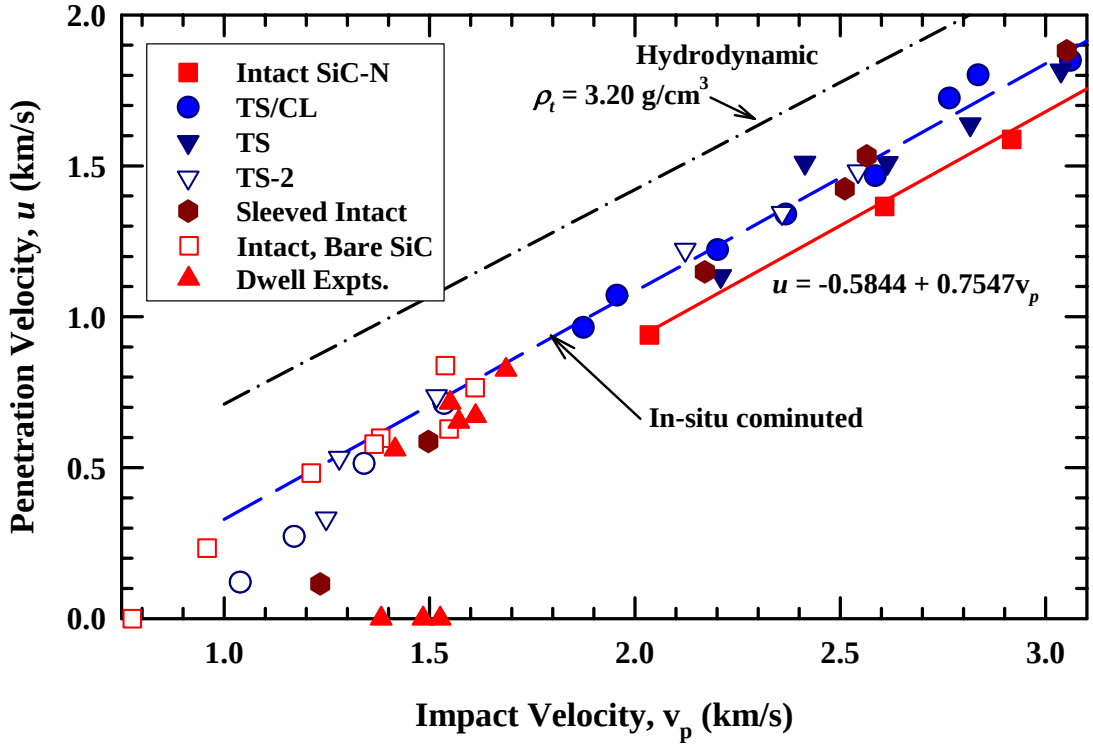
- *Test 11389*
- *Cu plate*
- *Impact velocity: 1.571 km/s*
- *Dwelled for ~11 μs*

Transition from Dwell to Penetration



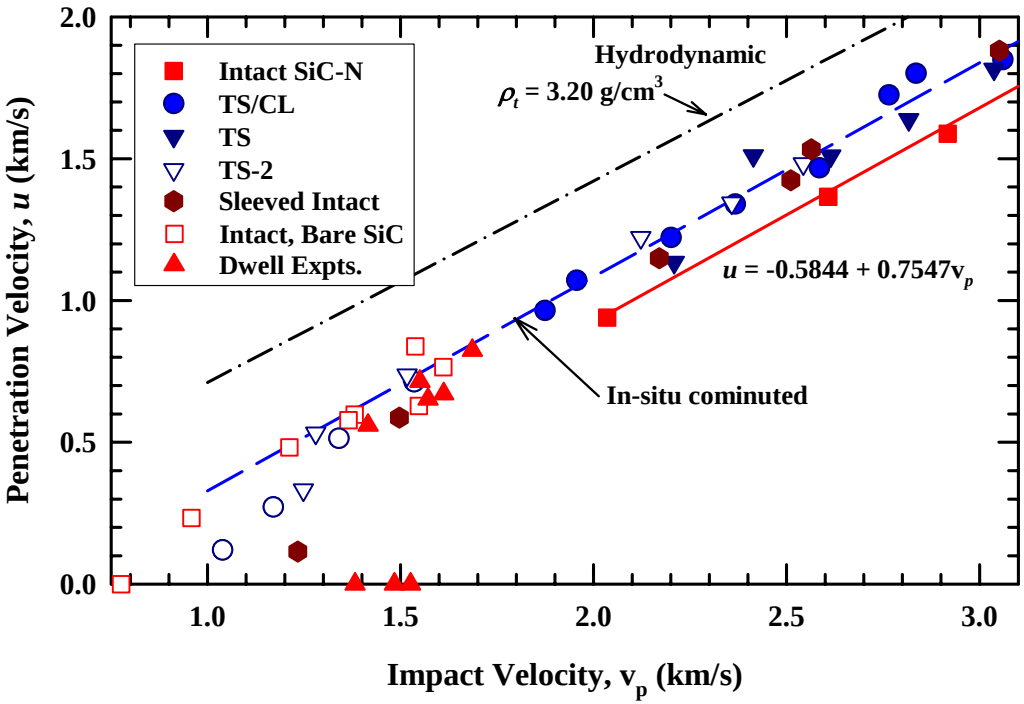
- *Within data scatter, $u_{1.00}$ for intact, pre-damaged, and in-situ comminuted are the same (sleeved or bare)*
- *$u_{1.00} > u_{0.75}$*
- *Once begin penetrating, experimental data and high-speed photography imply penetrating failed material*

Summary of Data



- ~~$u_{intact} < u_{predamaged} < u_{comminuted} < u_{powder} < u_{hydro}$~~
- $u_{intact} = u_{predamaged} = u_{comminuted} < u_{powder} < u_{hydro}$

Further Experiments



- *20-mm diameter, bare, SiC-N cylinders*
- *Impact velocity: ~2.2 – 3.0 km/s*
- *Conduct ~5 experiments with 0.75-mm diameter Au rods*
- *Conduct ~5 experiments with 1.00-mm diameter Au rods*

In physics, you don't have to go around making trouble for yourself—

Nature does it for you

- Frank Wilczek