SAND2007-0576P

Layered Ballistic Protection System

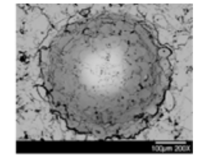
Key elements:

- lightweight state-of-the-art metallic materials
  - load spreading
  - high strength to prevent perforation
  - energy absorbing layers
- modular design
  - panels/plates for vehicles
  - personnel “scales” for vital organ protection
    - integrated into uniform or vest
    - tailorable (threat specific)
    - replaceable

Layered Ballistic Protection System

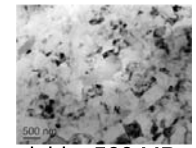
making use of state-of-the-art metallic components

- *hard layers*
  for energy dissipation & spreading
  (eg. amorphous metal coatings)



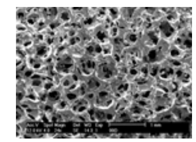
strength ~ 2000 MPa

- *high-strength, lightweight alloys*
  core structural component
  (eg. 7075 Al, Al-50%B4C composites, nanocrystalline Al)



yield > 500 MPa

- *metal foams* for energy absorption
  (tailorable properties)



YR 1: *Proof of Principle*

- Material selection & characterization
- Model development
- First impact test specimens

YR2: *Demonstration*

- 1st generation ballistic system
- Testing and modeling validation

YR3: *System Production*

- System optimization
- Layered construction & manufacturability

$500K/year

Leverages existing SNL programs

- physical and mechanical metallurgy of nanocrystalline Al alloys
- high strain rate testing
- material and system structural modeling

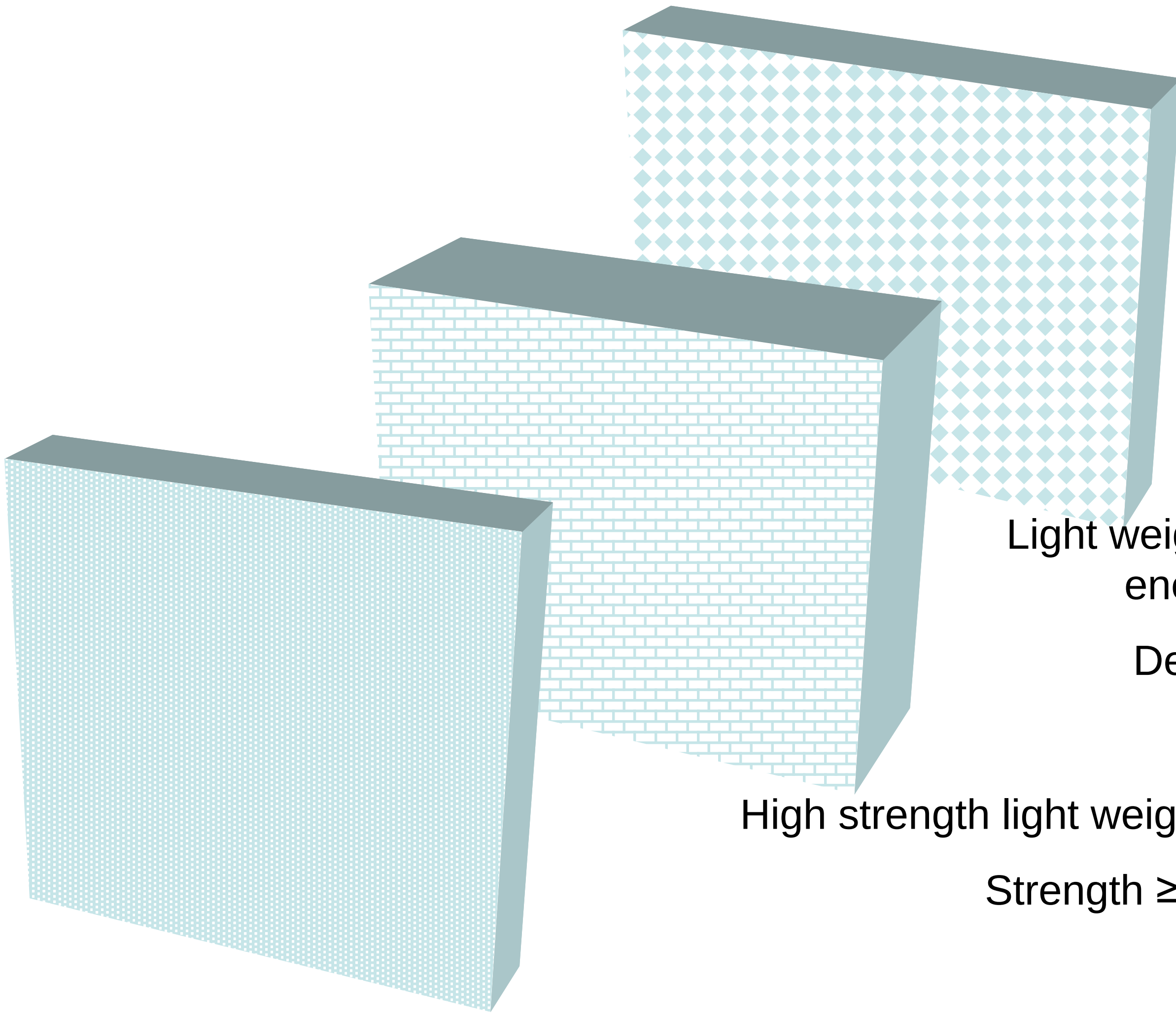
Leverages existing expertise of staff

- physical and mechanical metallurgy of Al-based composites and foams

Integration of experience and tasks

- materials science
- mechanics

Preliminary concept of layered barrier system



Light weight aluminum foam for energy absorption:

Density < 1 g/cm^3

High strength light weight structural aluminum:

Strength ≥ 400 MPa

Hard coating for energy dissipation and spreading:

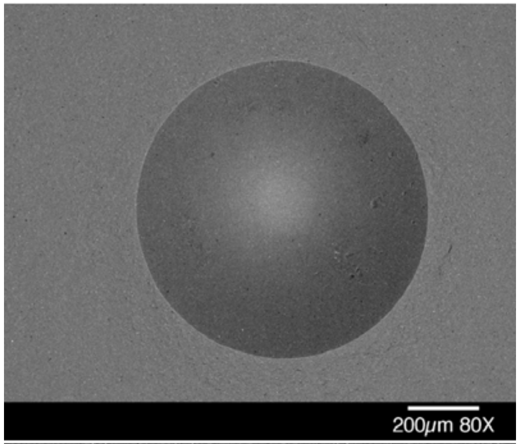
Strength ~ 2000 MPa, ≤ 1 mm thick

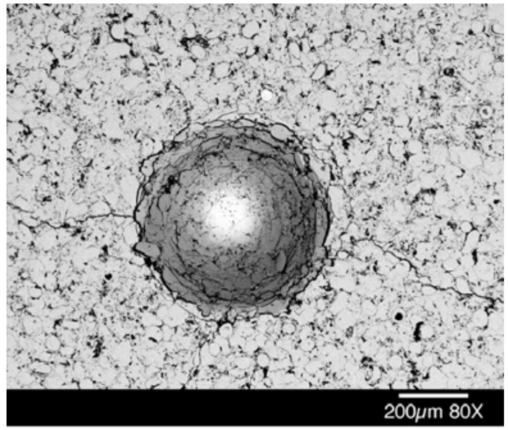
Background

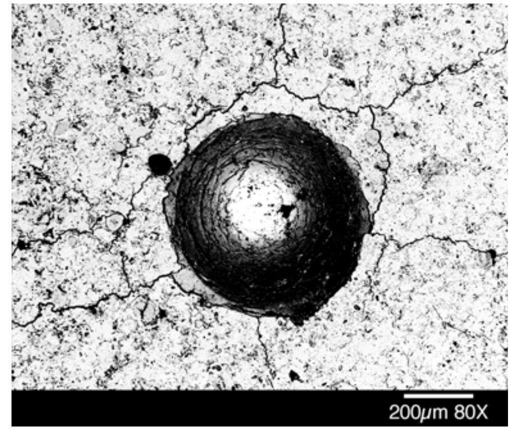
Materials

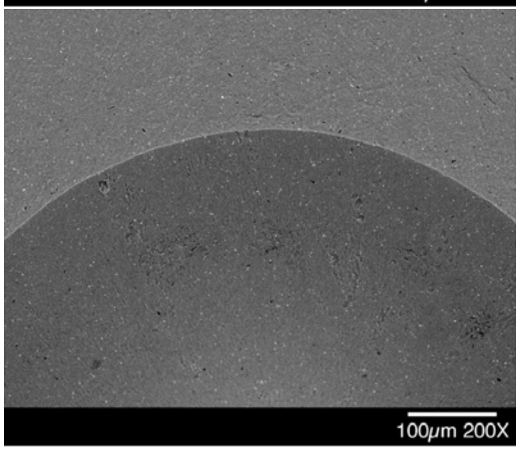
- hard layers
- high-strength Aluminum-based materials
- aluminum foams, tailorable

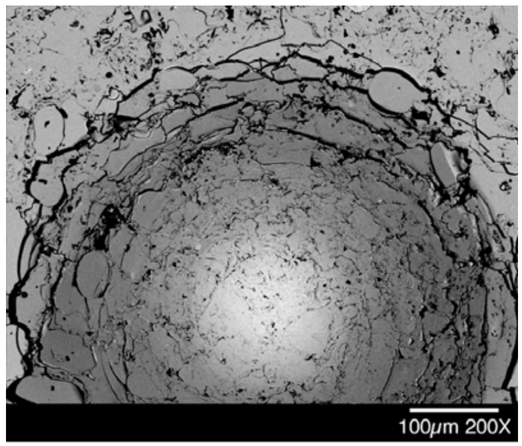
Compare 100Kg Diamond NC-1651-2x5

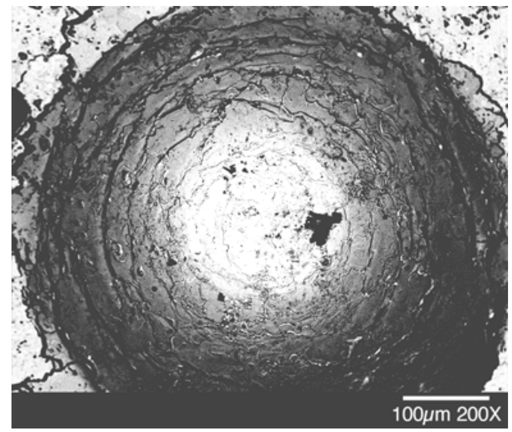


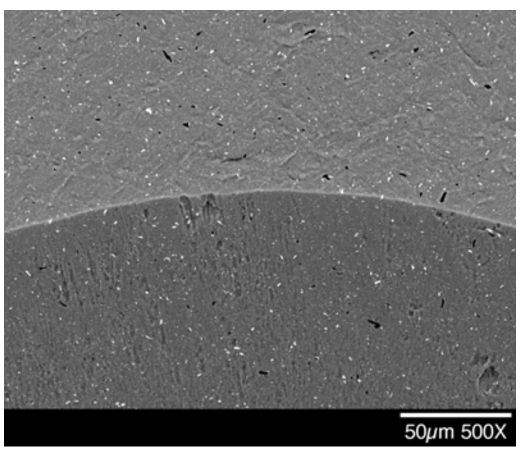


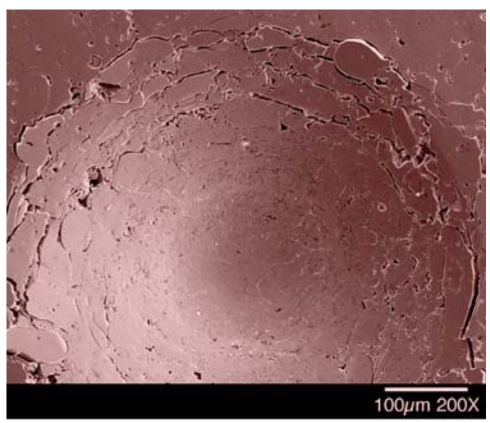


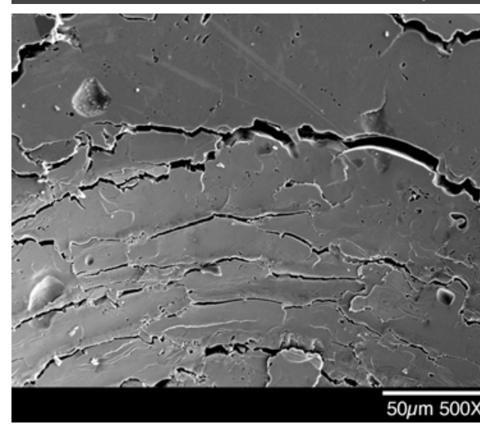




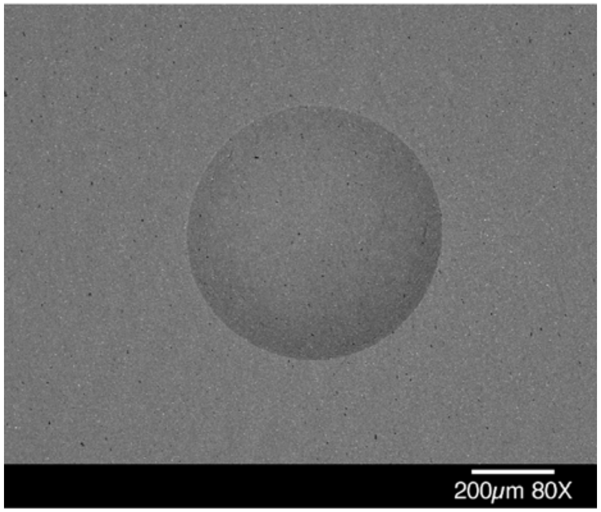


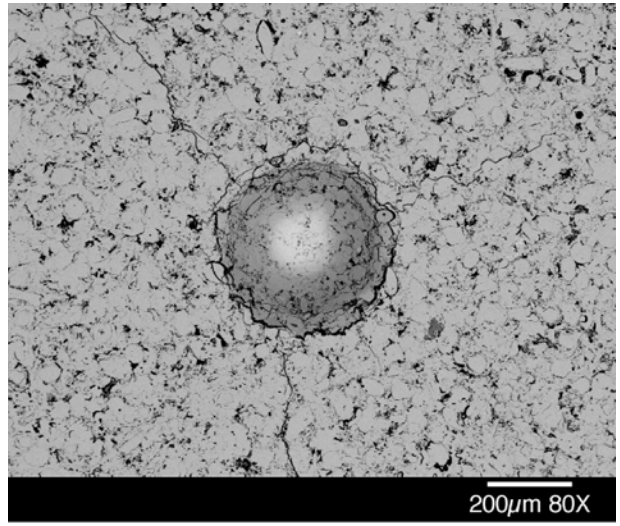


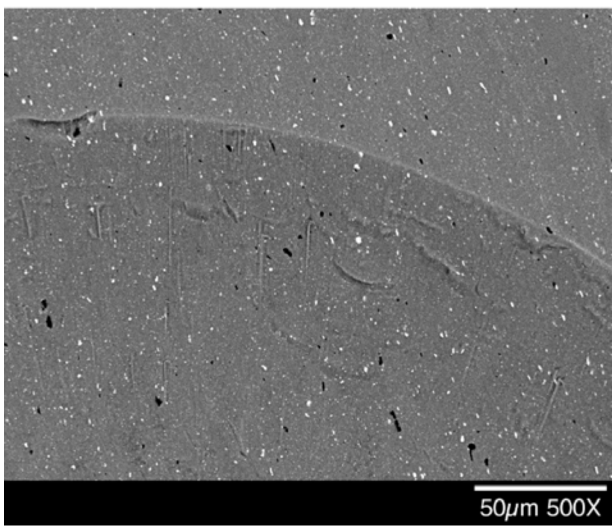


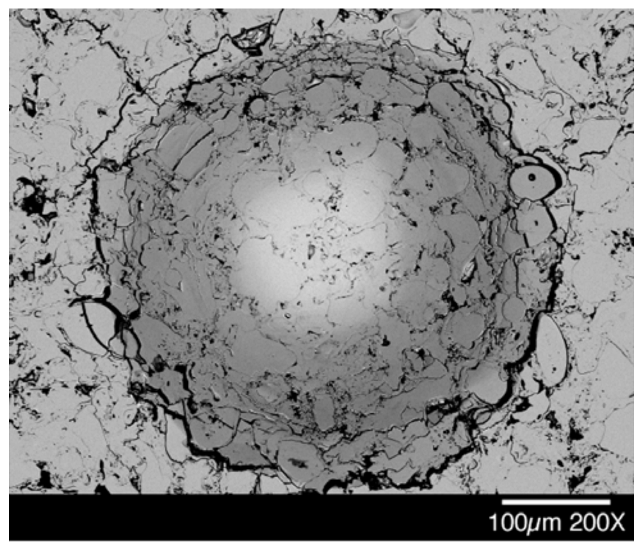


NC 5083-1651 80x BEI

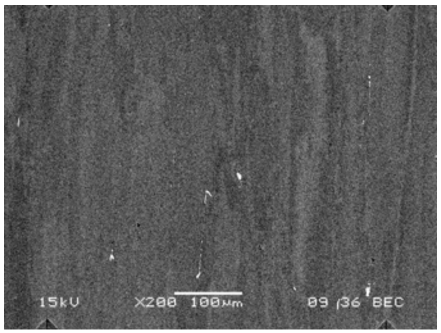






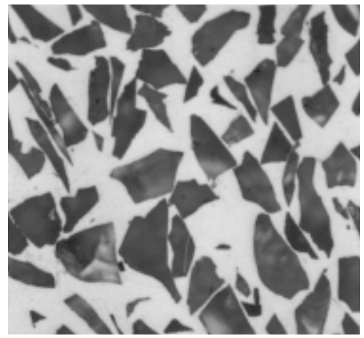


High-strength aluminum-based alloys



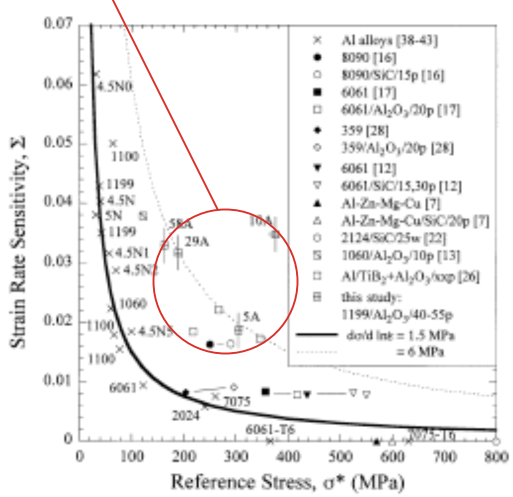
Conventional high-strength aerospace grade aluminum alloys

- combination of high strength and high toughness
    - YS > 400 MPa
    - K_{IC} > 35 MPa $m^{1/2}$
- relatively inexpensive

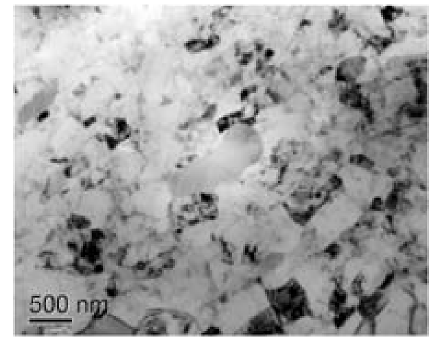


Composites

- high strain rate sensitivity
- strength can be improved

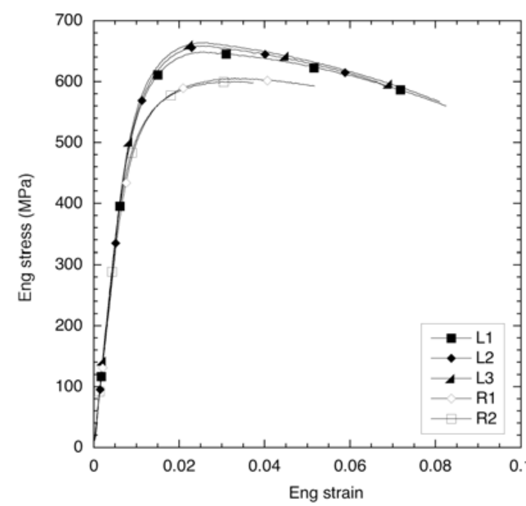


Ref: San Marchi, *Mater Sci Eng* A337 (2002) 202-211.



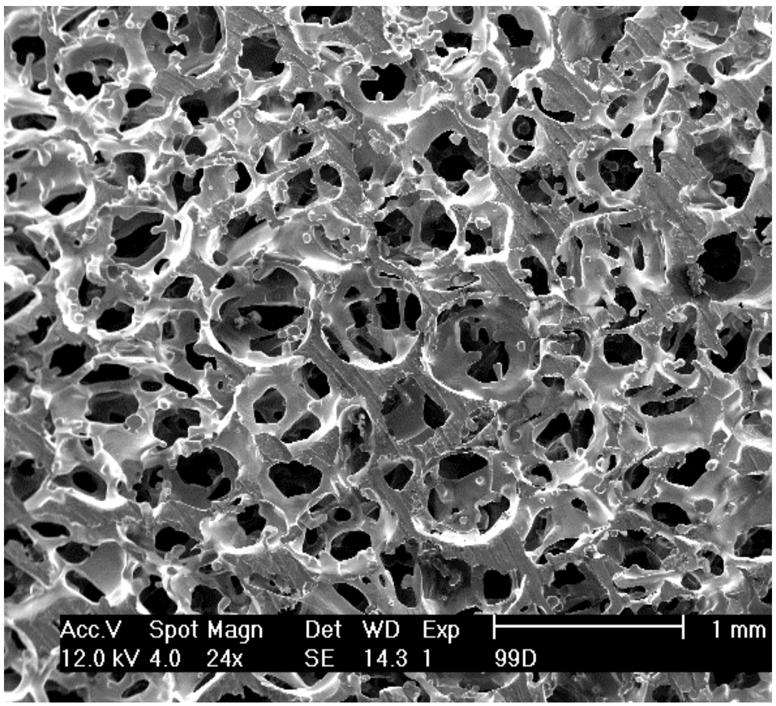
Nanocrystalline alloys

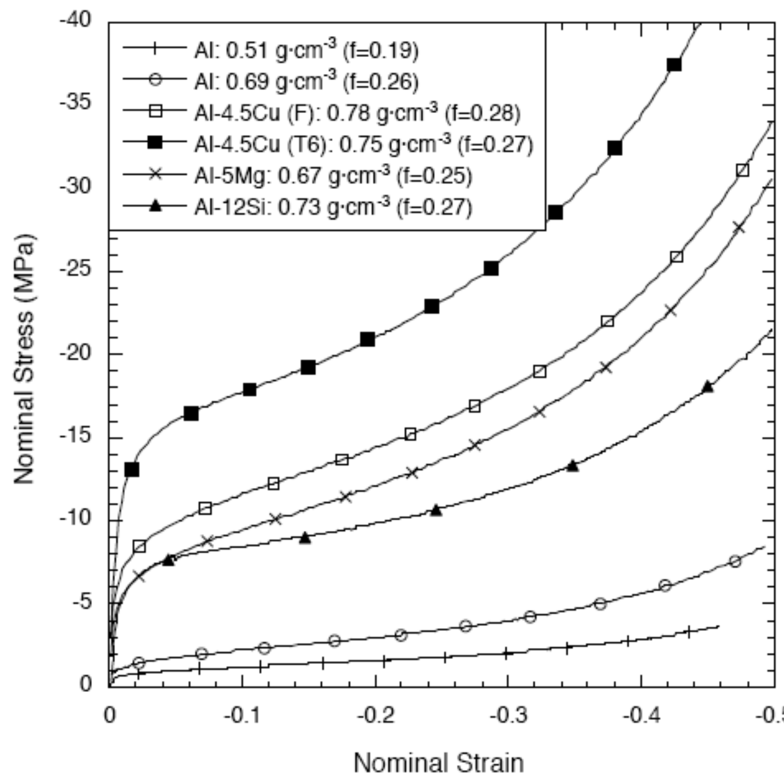
- combination of high strength and high ductility



Aluminum-based foam materials

- high energy absorption
- tailorable properties





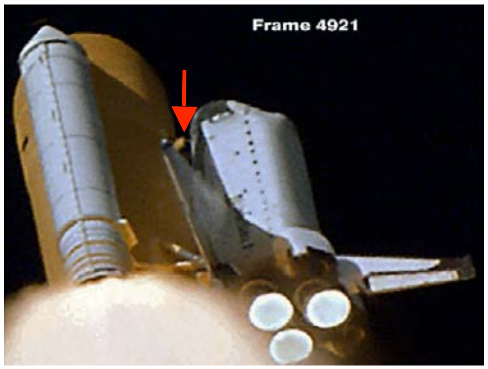
Ref: San Marchi, in Handbook of Cellular Metals: Production, Processing, Applications, H.P. Degischer, B. Kriszt, editors, Wiley-VCH, Weinheim, 2002, pp. 43-56.

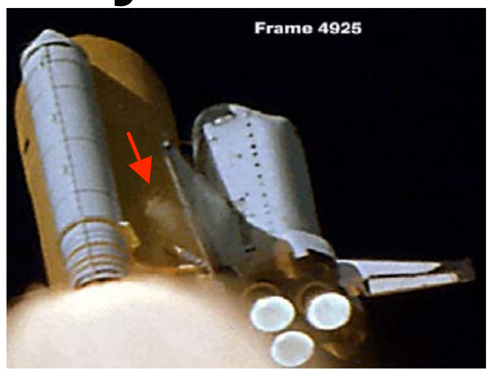
Background

<u>Mechanical testing</u>

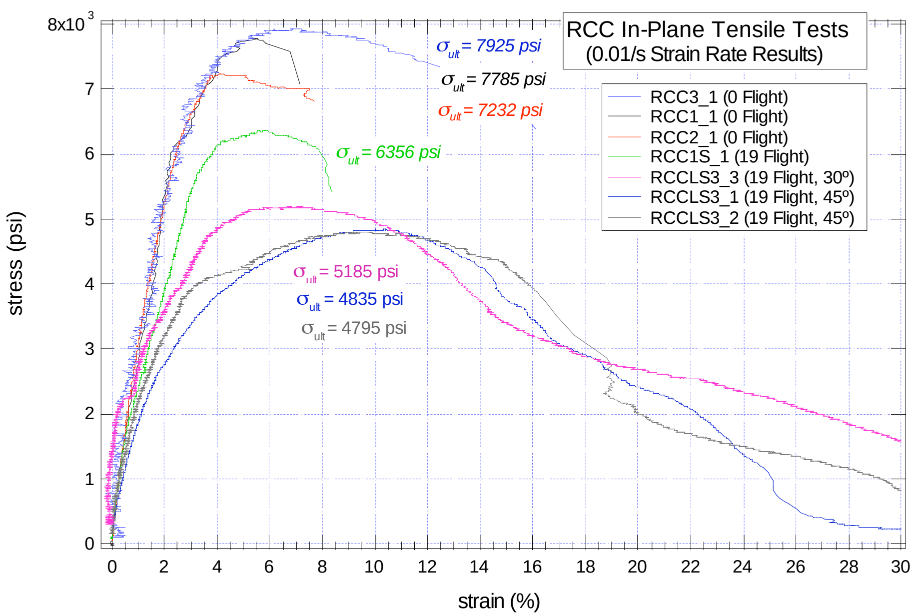
- high strain rate testing
  - materials characterization
- impact testing (gas gun)
  - Component performance

Material Characterization Of Shuttle Thermal Protection System For Impact Analyses





Tested RCC specimens



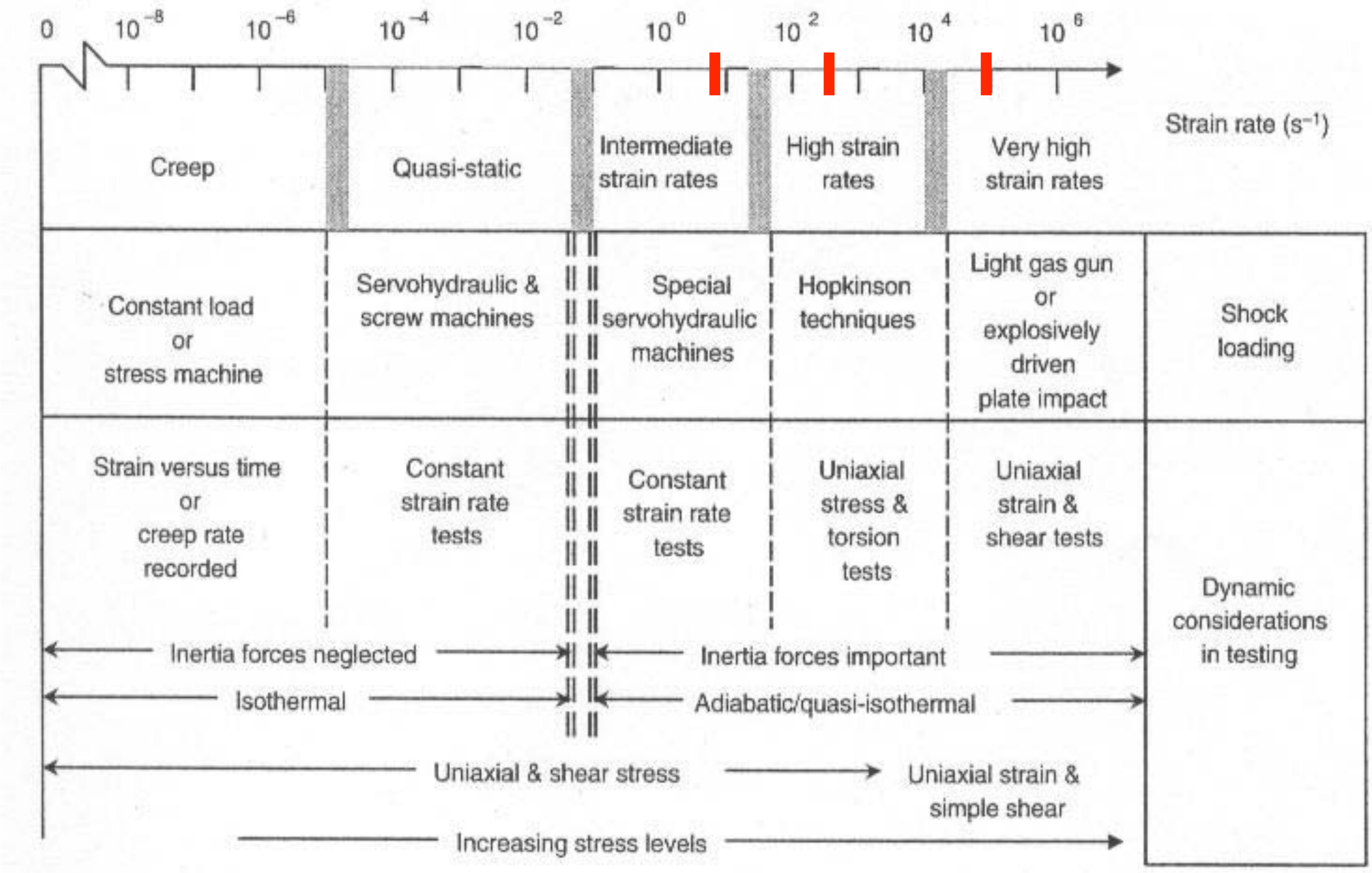
ANALYTICAL IMPACT MODELS AND EXPERIMENTAL TEST VALIDATION FOR THE COLUMBIA SHUTTLE WING LEADING EDGE PANELS

Winner of the Otto Hamberg Technical Paper Award, the 22nd Aerospace Testing Seminar

W-Y Lu, B. Antoun, J. Korellis, SNL/CA

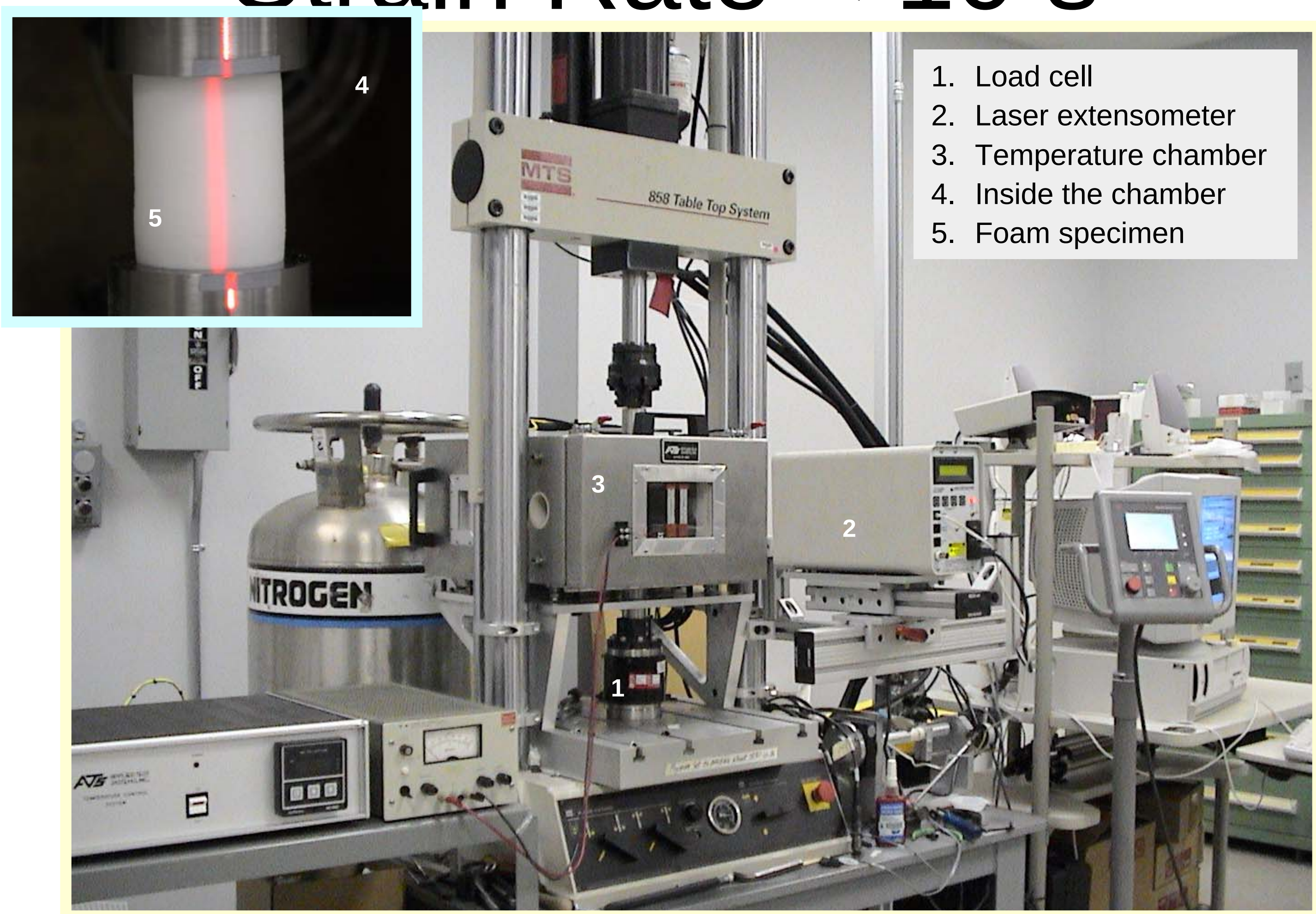
K. Gwinn, K. Metzinger, SNL/NM

High Strain Rate Testing



Nemat-Nasser, 2000

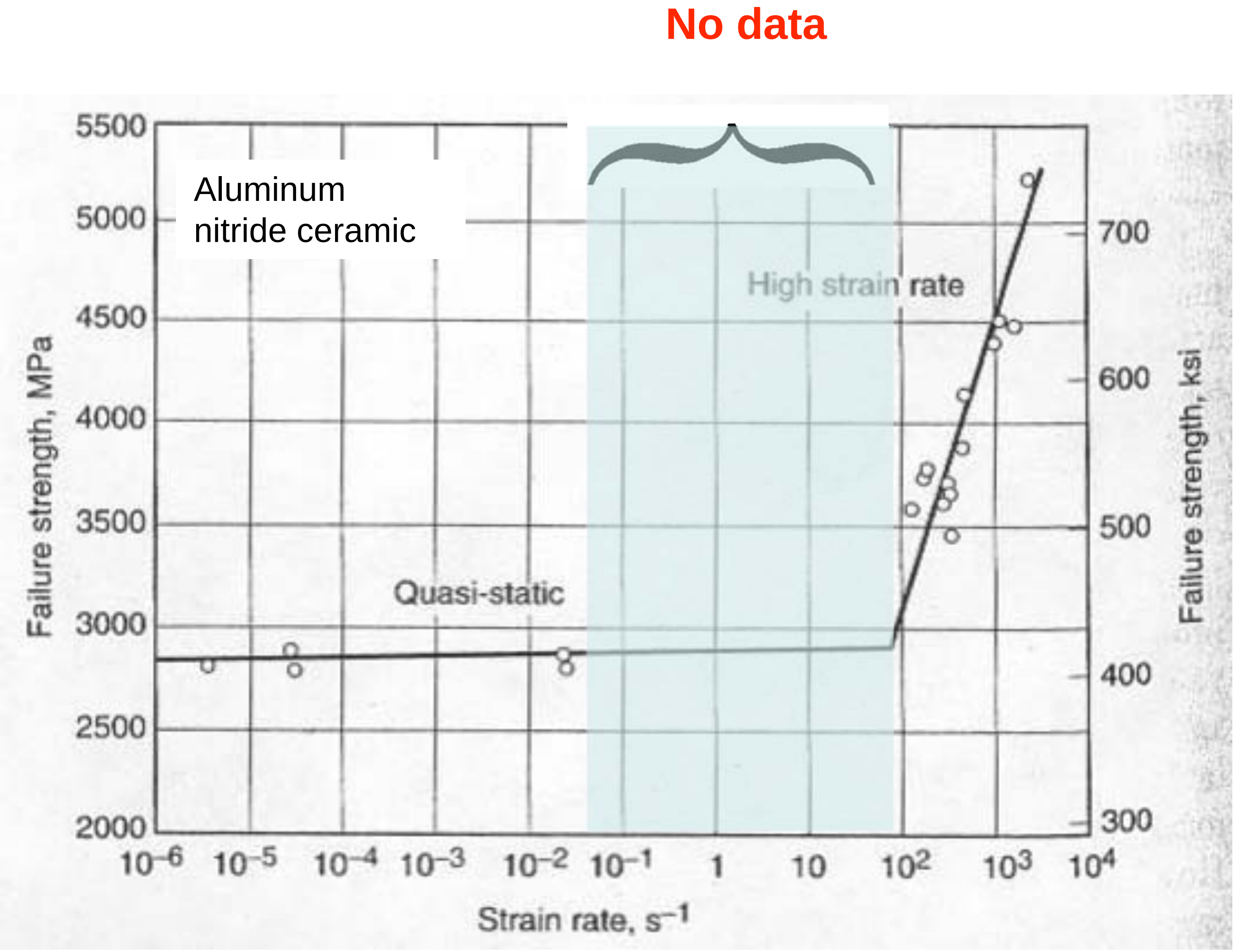
Strain Rate < 10 s^{-1}



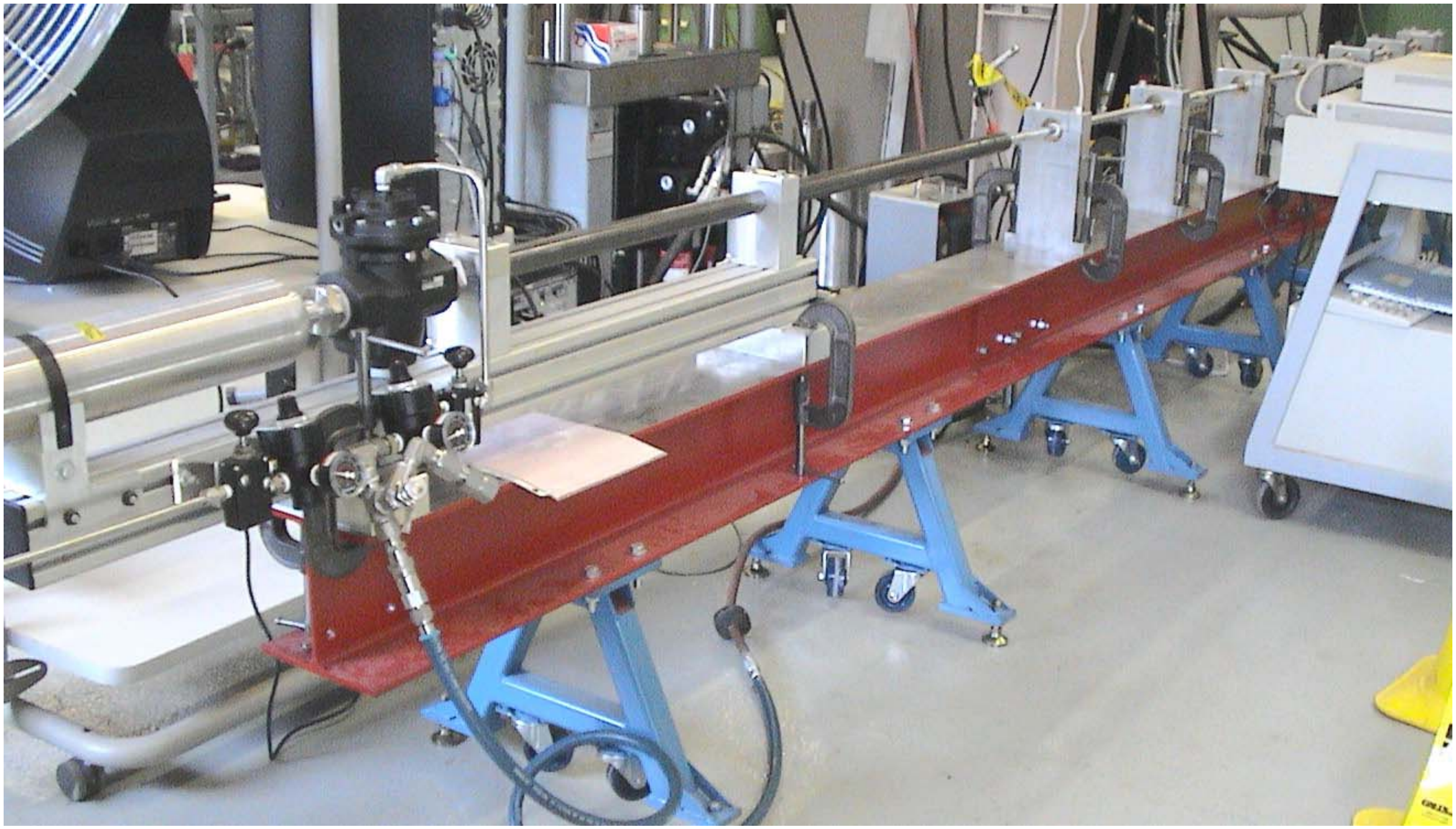
1. Load cell
2. Laser extensometer
3. Temperature chamber
4. Inside the chamber
5. Foam specimen

10 s^{-1} < Strain Rate < 500 s^{-1}

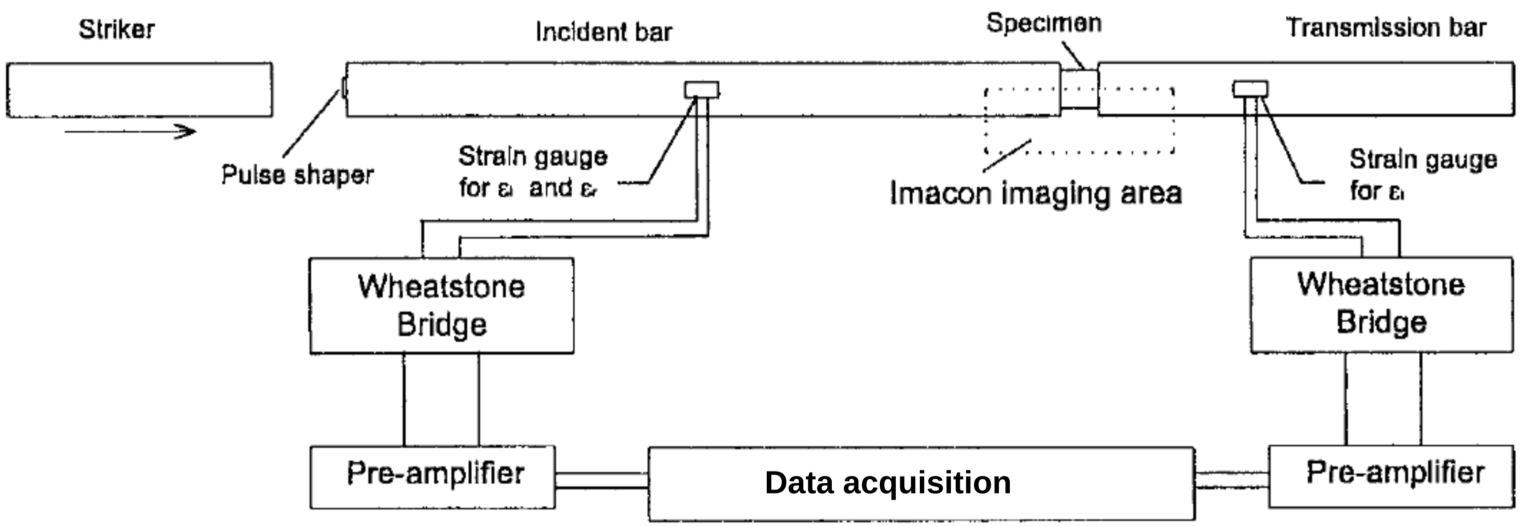
High Rate Data

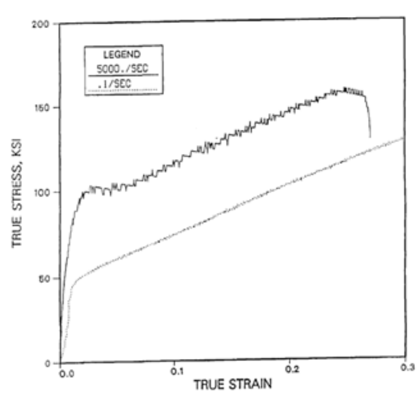


$10^5\ s^{-1}$ > Strain Rate > $500\ s^{-1}$



Schematic Diagram of SHPB



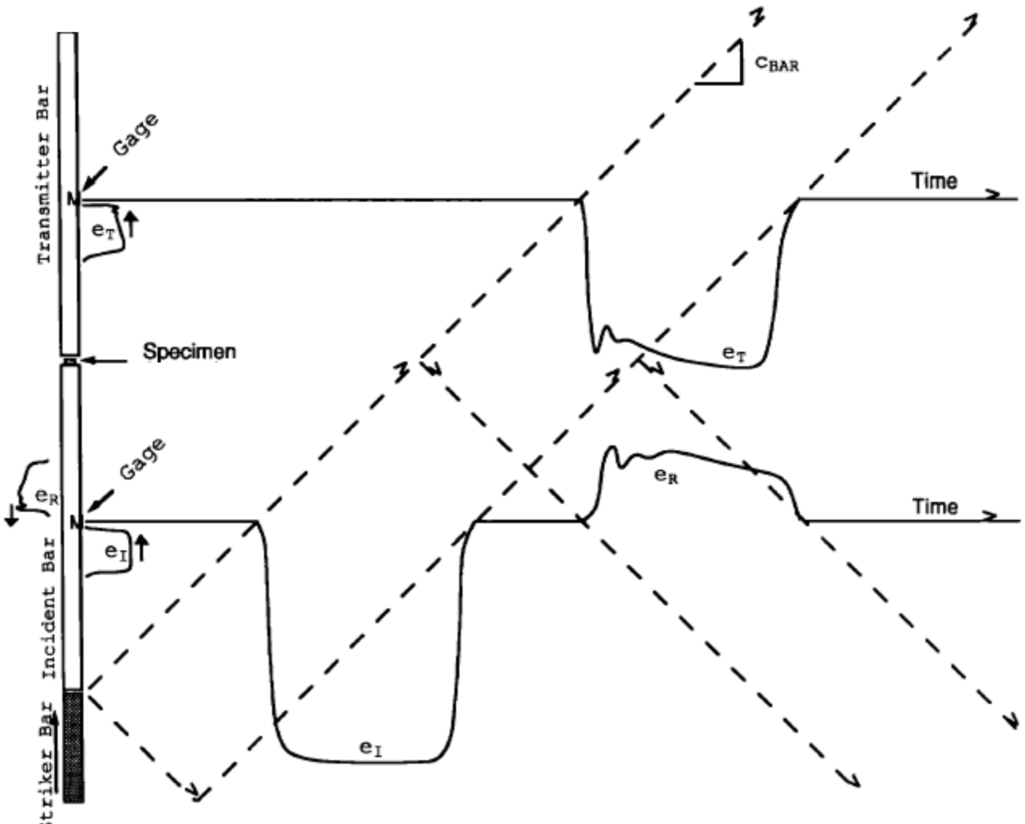


- Characterization experiment
- Calibrate model parameters

Strain-rate sensitivity of 304L

Wendell Kawahara, SAND91-8215

Strain History of SHPB



Wendell Kawahara, SAND91-8215

$$\dot{\varepsilon}(t) = -2C_B / L_S \cdot \varepsilon_R(t)$$

$$\sigma(t) = E_B \cdot A_B / A_S \cdot \varepsilon_T(t)$$

ε_I: Incident Wave (Compressive)

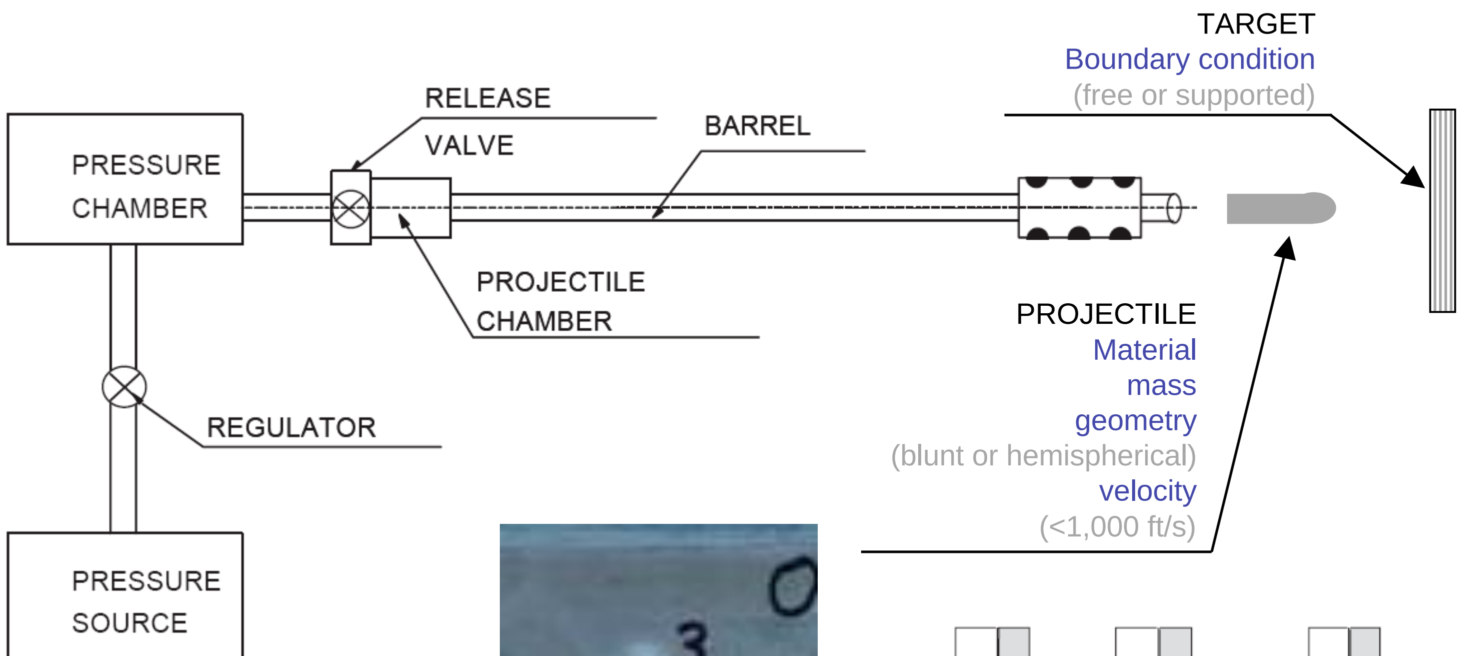
ε_T: Transmitted Wave (Compressive)

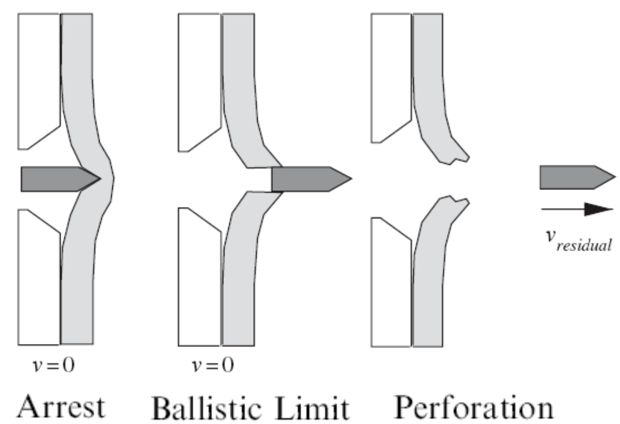
ε_R: Reflected Wave (Tensile)

Ξ_B: Bar

Ξ_S: Specimen

Schematic Diagram of Gas Gun





- Model validation
- Performance evaluation
- Microstructure characterization of post-experiment specimen

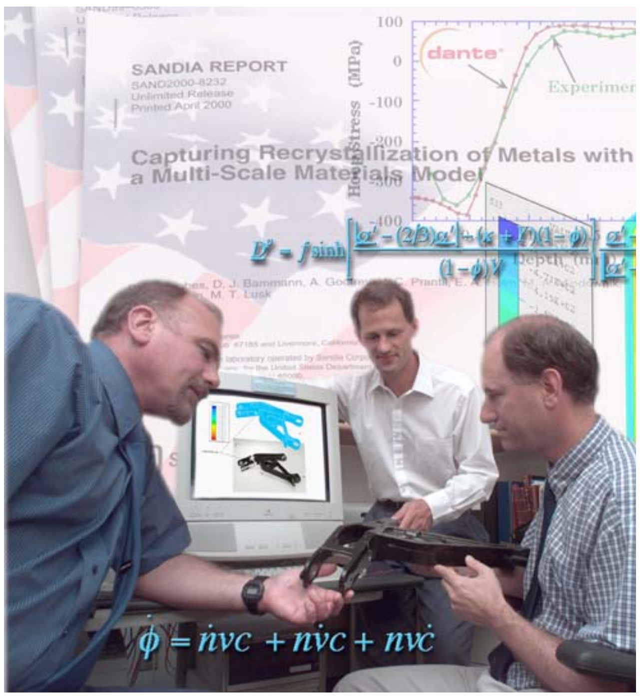
Background

<u>Modeling</u>

- expertise in
  - materials characterization
  - dynamically loaded structures

Material Modeling Team - R&D 100 Award

Microstructure-Property Model Software Package —precisely predicts the stress state and failure during manufacturing processes.



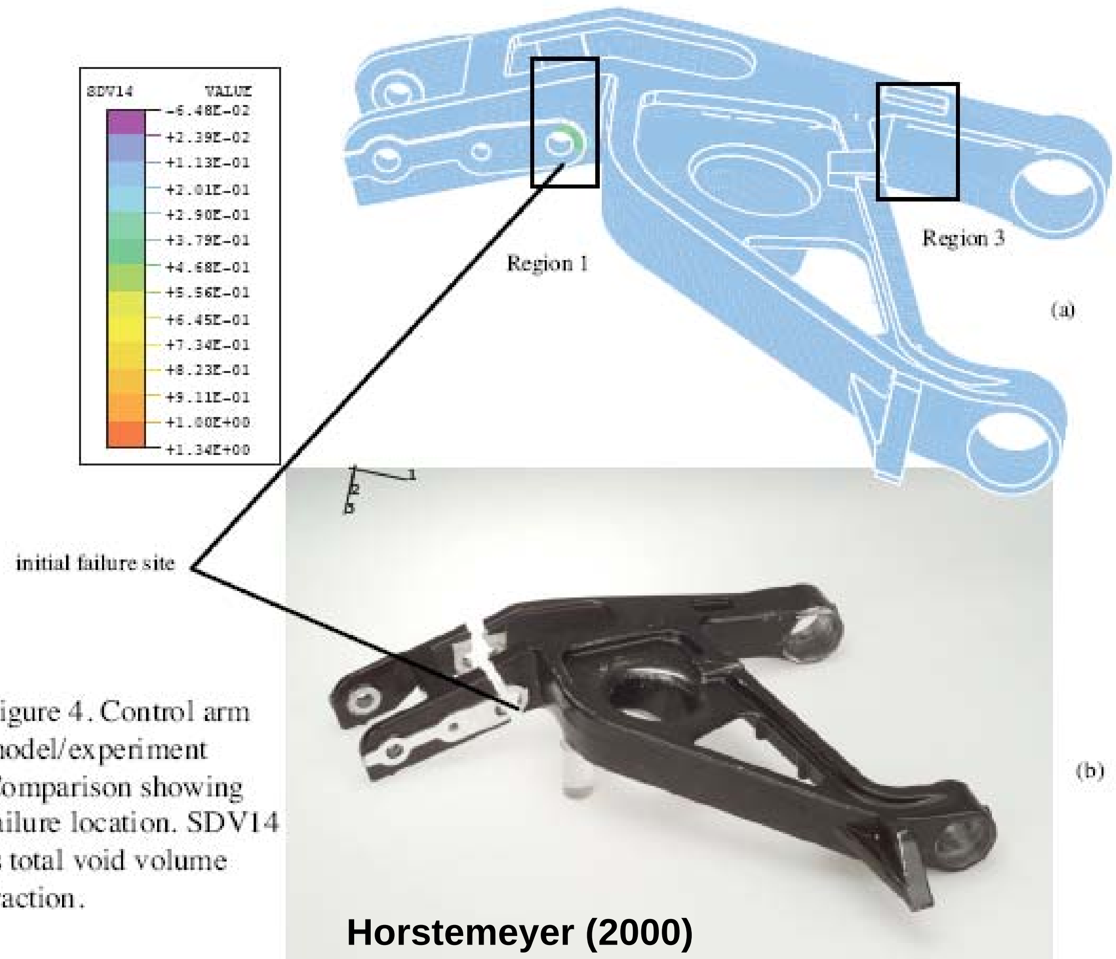
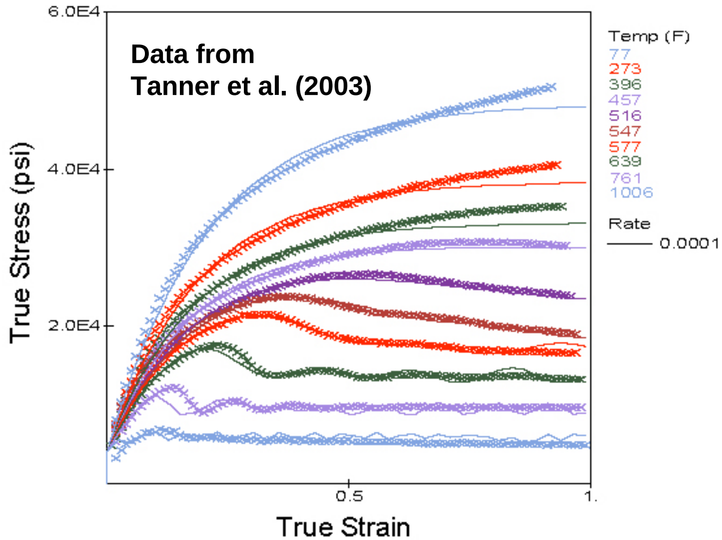
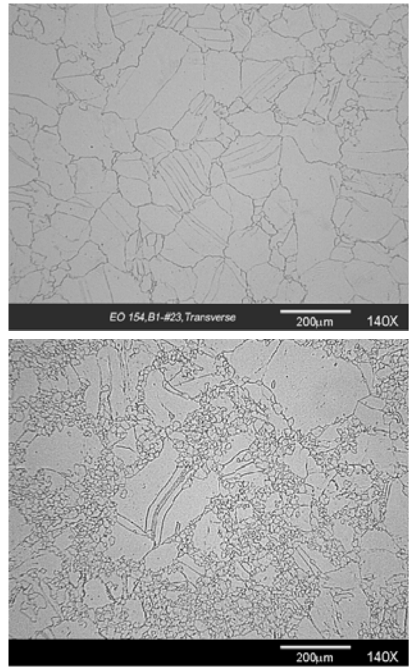


Figure 4. Control arm model/experiment Comparison showing failure location. SDV14 is total void volume fraction.

Extensive Material Modeling Capabilities

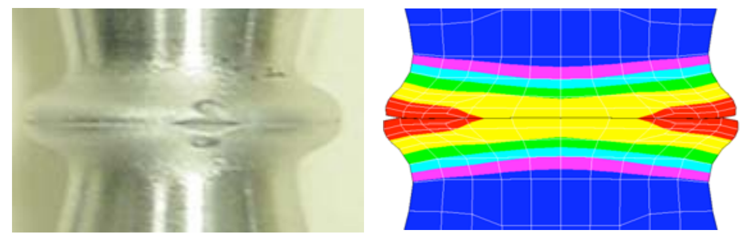
Temperature Sensitivity



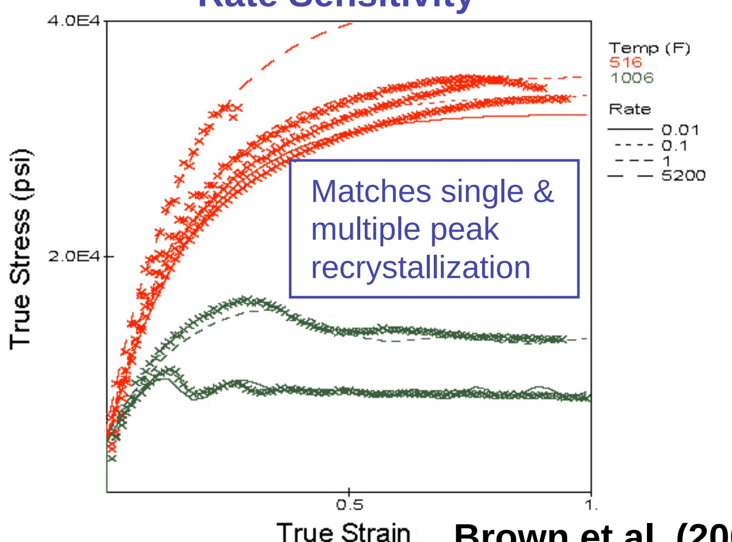


Advanced material models can predict microstructural processes like recovery, recrystallization, and grain growth.

Recrystallized Volume Fraction

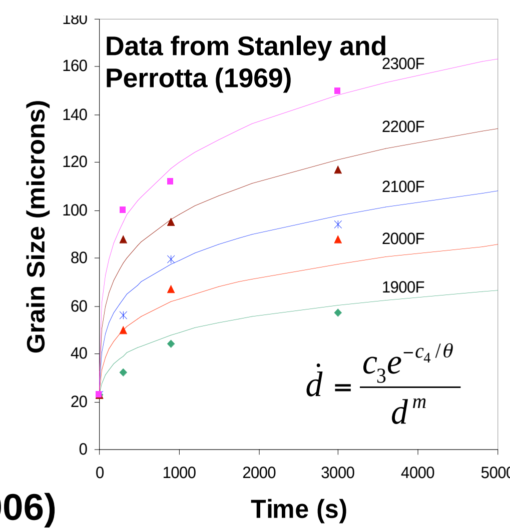


Rate Sensitivity

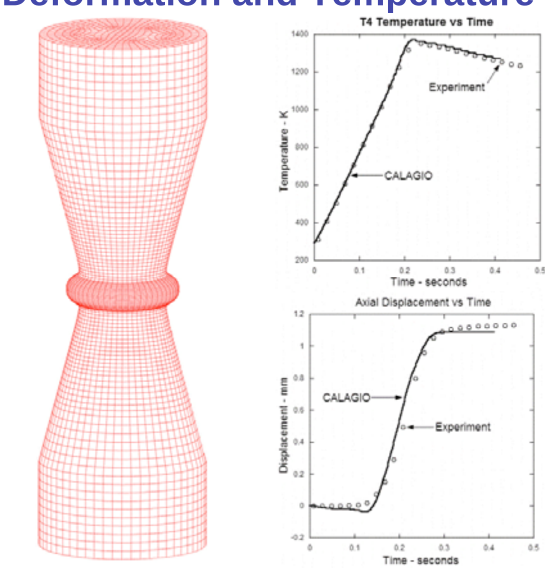


Brown et al. (2006)

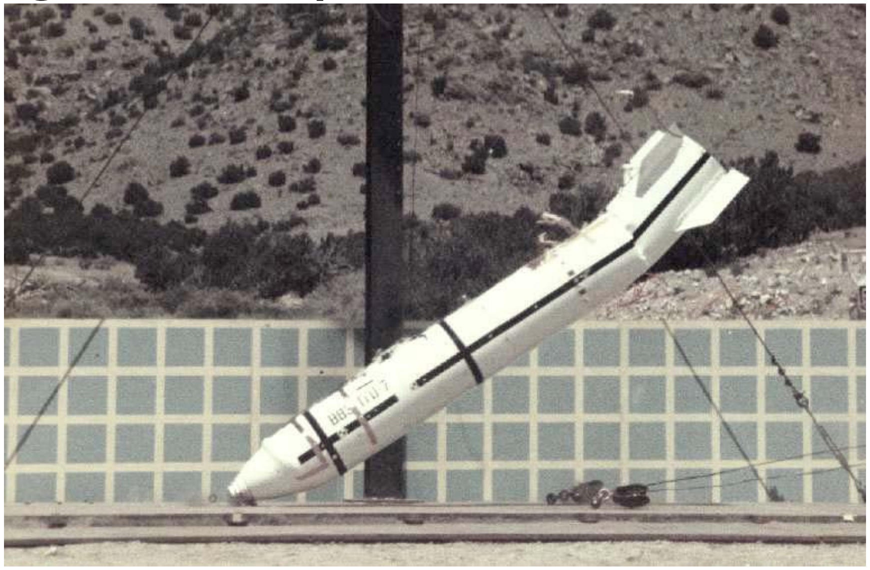
Grain Growth



Deformation and Temperature

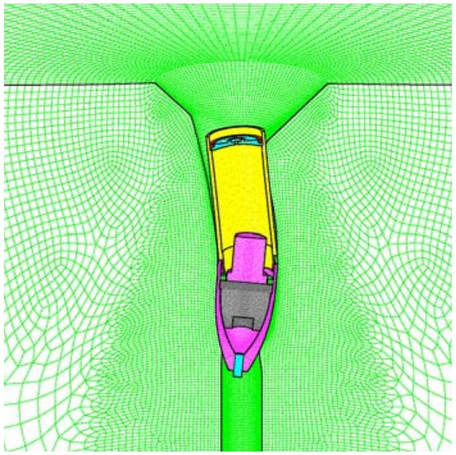


Modeling Structures Subjected to Dynamic Loading and Impact

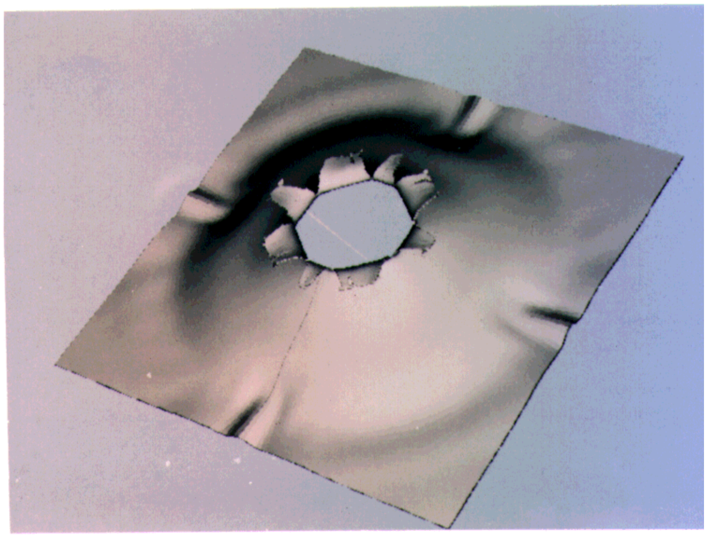


Analysis

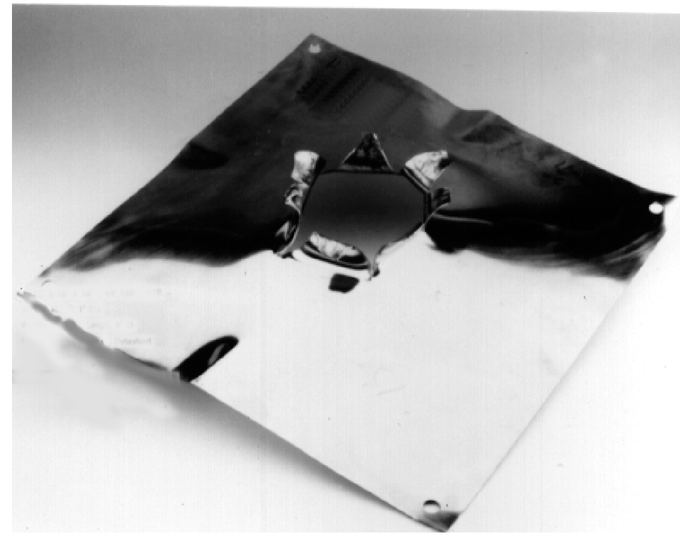
- Linear and nonlinear dynamic response
- Modal analysis
- Large deformation modeling
- Failure modeling
- Blast loads on structures
- Component isolation



Example: Submarine Vulnerability Experiments (Steel Plates Loaded by Focused Blasts)



Analysis



Experiment

Problem:

Predict response of steel (HY100) plate with initial 1 inch diameter hole loaded by blast wave produced by 38 grams of explosive.

Technical Approach:

- Model blast pressure time history with Eulerian code.
- Apply the BCJ constitutive model, utilizing the strain rate and temperature dependence and ductile failure capabilities