2013 DOE Vehicle Technologies Program Review

Enhanced Room-Temperature Formability in High-Strength Aluminum Alloys through Pulse-Pressure Forming (PPF)

Co-P.I.: Richard Davies, (509) 375-6474, rich.davies@pnnl.gov
Co-P.I.: Aashish Rohatgi, 509 372-6047, aashish.rohatgi@pnnl.gov

Pacific Northwest National Laboratory

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Project ID: LM079

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Project Overview

Timeline (Phase I)

- Start – 3Q FY12
- Finish – 3Q FY13
- 85% complete

Budget

- Total project funding:
  - PNNL: $1200k
  - Industry in-kind: $645K
- Funding Received in FY12
  - $400K
- Funding received in FY13
  - $200K

Barriers

- Manufacturability: Heat-treatable, high-strength aluminum alloys do not possess sufficient formability at room temperature
- Predictive Modeling Tools: Lack of quantitative knowledge of strain-rates and strain-path during PPF has hindered development of validated models

Targets

- The DOE-VT target for weight reduction of the vehicle and its subsystems is 50%
  - Demonstrate formability enhancements of minimum 70% in high-strength 6xxx and 7xxx Al alloys

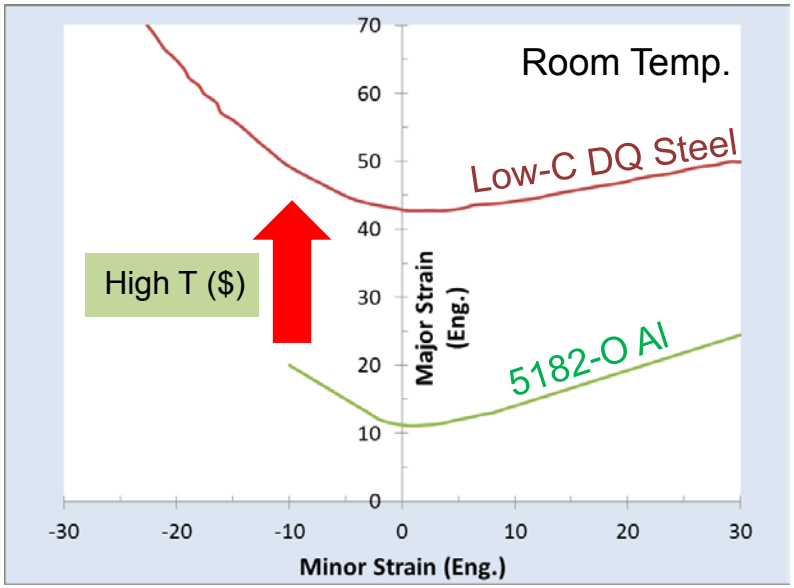
Partners

- OEM and Industry participants:
  - Anil Sachdev, Josh Campbell (General Motors)
  - Alcoa

Relevance/Objectives

Pulse-pressure forming can enhance the formability of Al alloys at room-temperature, i.e. without elevated temperature processing, and thus, lead to lightweighting by enabling the use of Al alloys instead of mild steel

Forming Limit Diagram (FLD)



Objectives

- Enable broader deployment of heat-treatable, high-strength, 6xxx and 7xxx aluminum alloys in automotive structural applications through extended formability
- Quantify the process window where enhanced formability in 6xxx and 7xxx Al alloys in feasible

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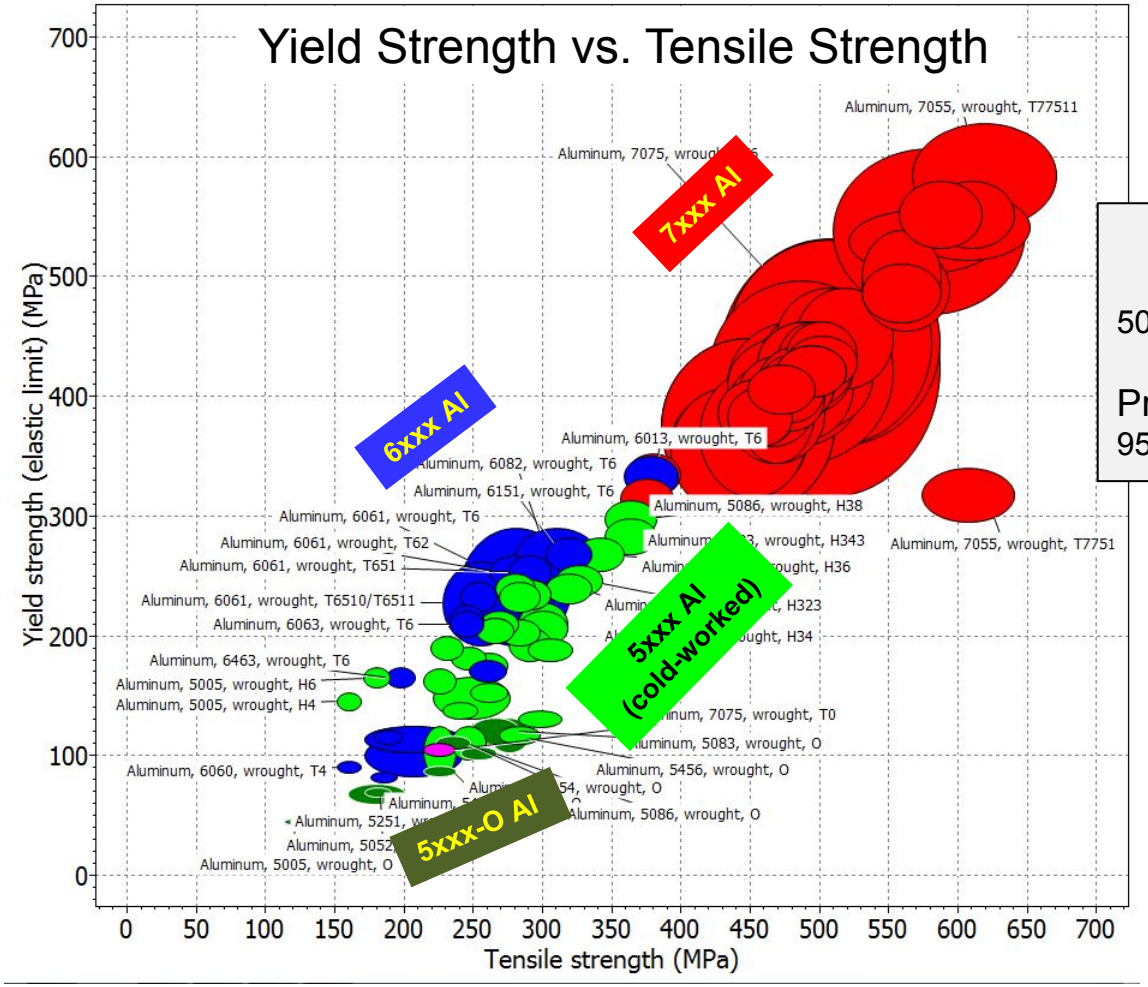
Opportunity with High-Strength Al Alloys



Strength/weight

7xxx Al

500 MPa/2.8 g/cc ~178

Press Hardening Steel

950 MPa/7.8 g/cc ~122

- **Can HIGH-STRENGTH 6xxx and 7xxx Al alloys formability be increased via PPF?**
- **Challenge: Strength α 1/Ductility**

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Project Technical Approach

Phase I (Year I)
- Alloy and PPF technique selection
- Formability and process-window determination (expt. & modeling)
- Go-No Go Gate

Phase II (Year 2)
- Design of prototypical part formed by PPF
- PPF process development

Phase III (Year 3)
- Prototype part fabrication
- Metal forming simulation capability development

Project Milestones & Deliverables (Phase I)

Milestone/ Deliverable	Description	Due	Status
Milestone #1	Demonstrate formability improvement of minimum 70% in AA6022-T4 and AA7075-T6 through PPF	12/2012	✓
Milestone #2 Gate	GATE (Technical): Demonstrate via a forming limit diagram that aluminum alloy AA7075 in the T6 or W temper conditions have sufficient formability to produce a typical automotive B-pillar component at strain rates below 10^4 /s GATE (Programmatic): Buy-in from GM Manufacturing	05/13	**Go/No-Go**

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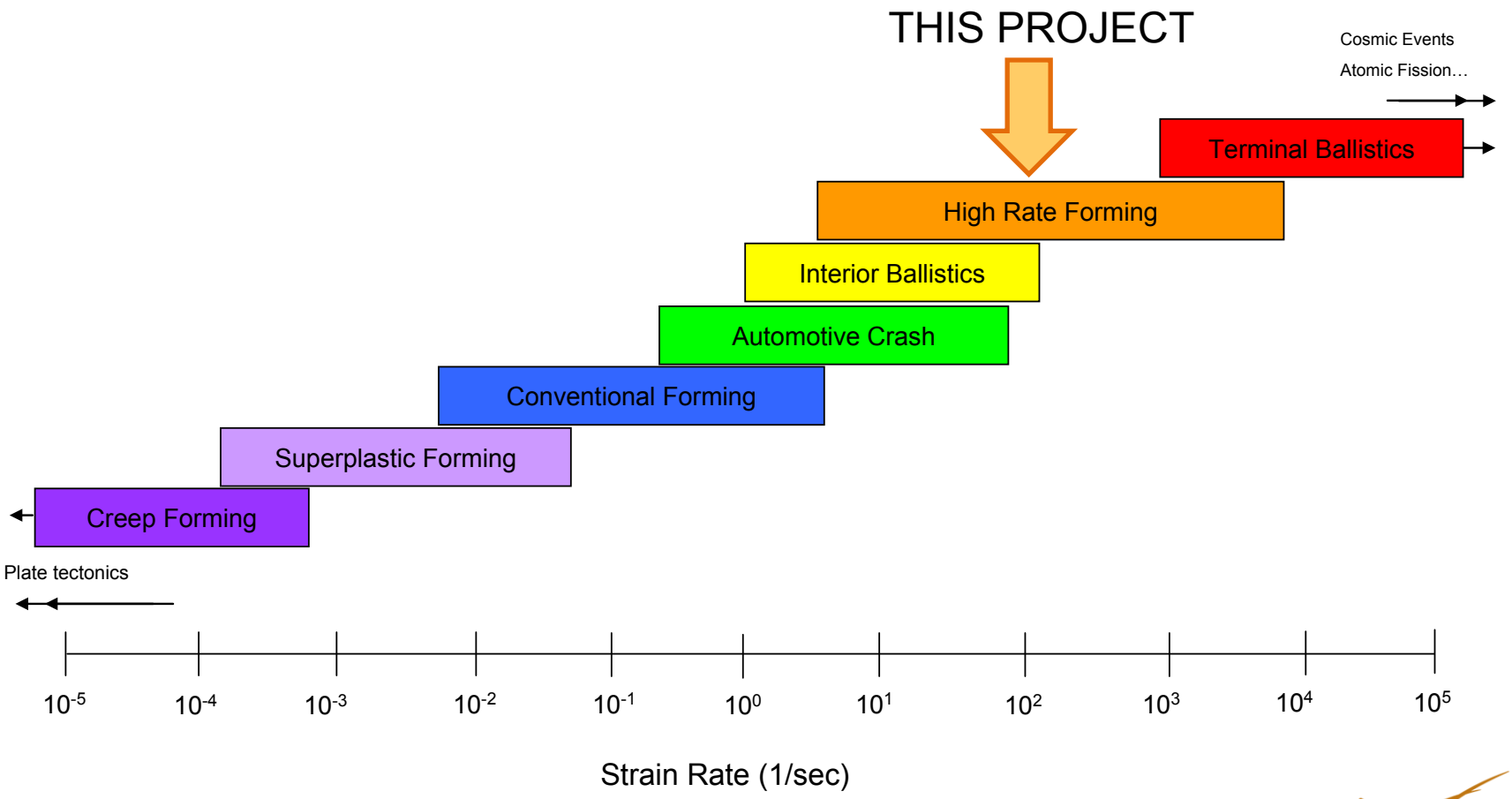
Background



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Background

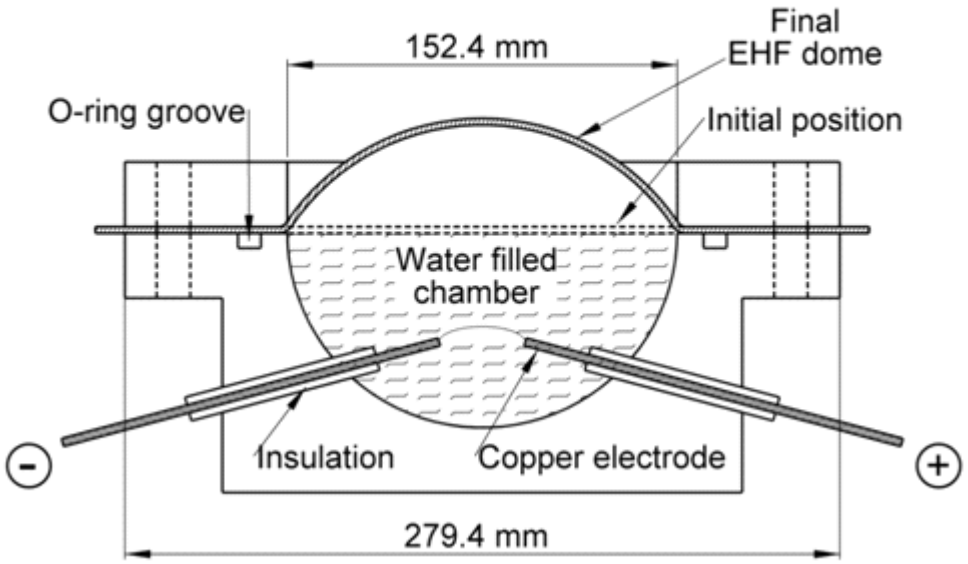
High Rate Forming Technologies

- Electro-hydraulic Forming (EHF)
- Electromagnetic Forming (EMF)
- Explosive Forming (classical)
- Laser Shock Forming (LSF)

Project Plan - Subject Materials

- AA6022-T4E32, 1.2 mm
- AA7075-T6, 1 mm

PNNL's Electro-hydraulic Forming Tool



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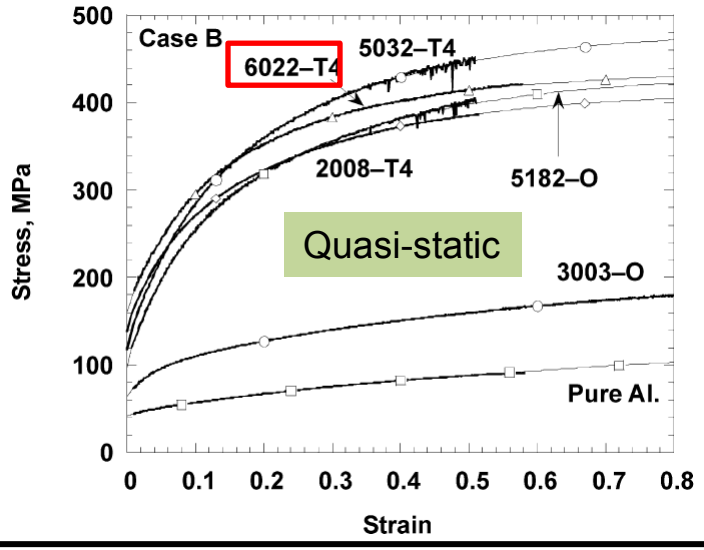
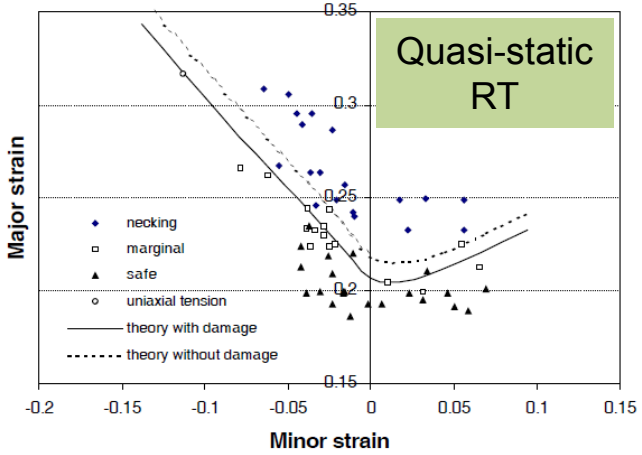
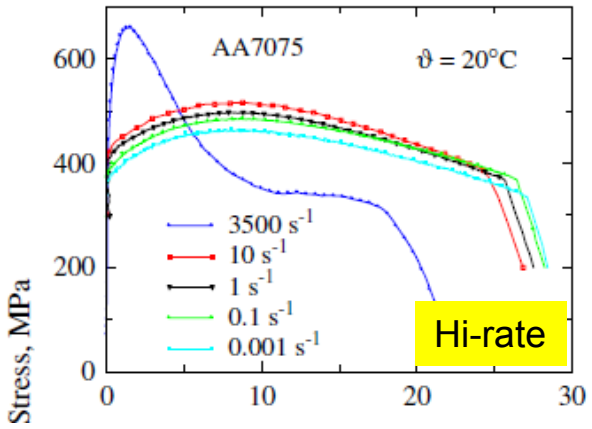
Literature: High-rate Data for 6xxx/7xxx

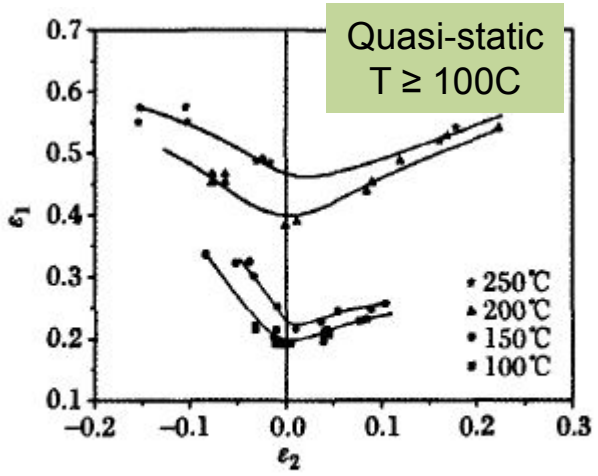
AA6022-T4





AA7075-T6

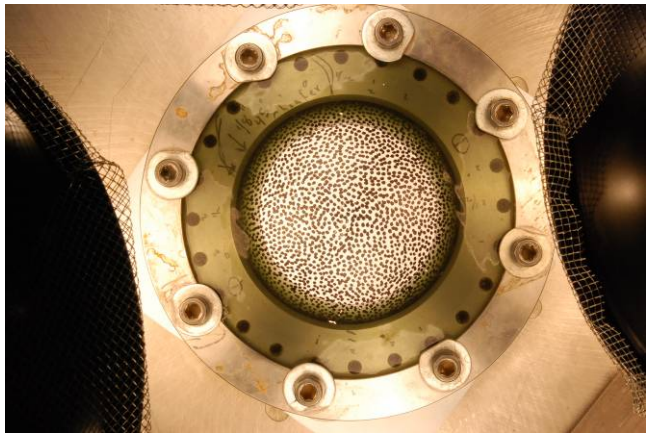




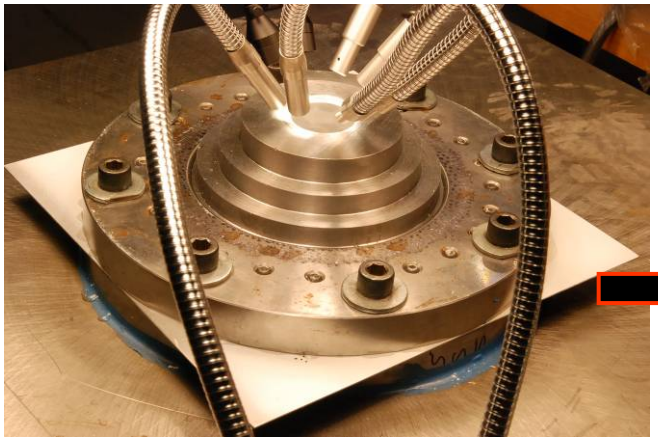
- **Limited/no high-rate data is available in literature**

PNNL High-Rate Capabilities

Top View: Free-Forming

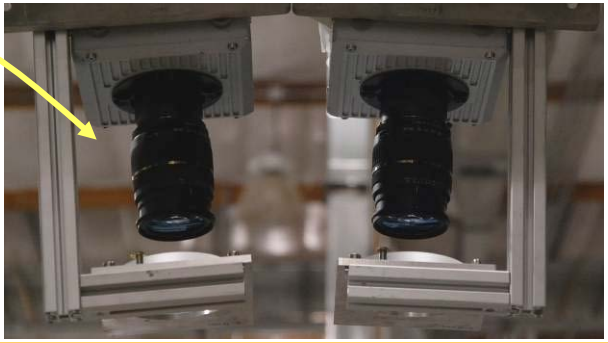


Side View: Cone Die



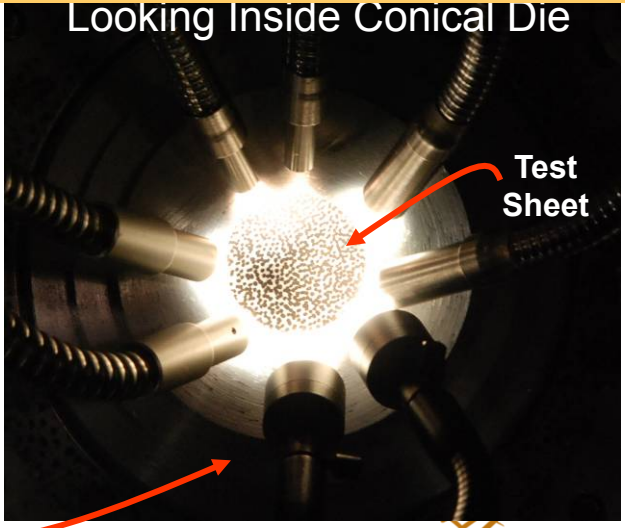
Imaging Setup

Close-up of Cameras



- Imaging at ~75000 frames/second (~13 microseconds per frame)

Looking Inside Conical Die



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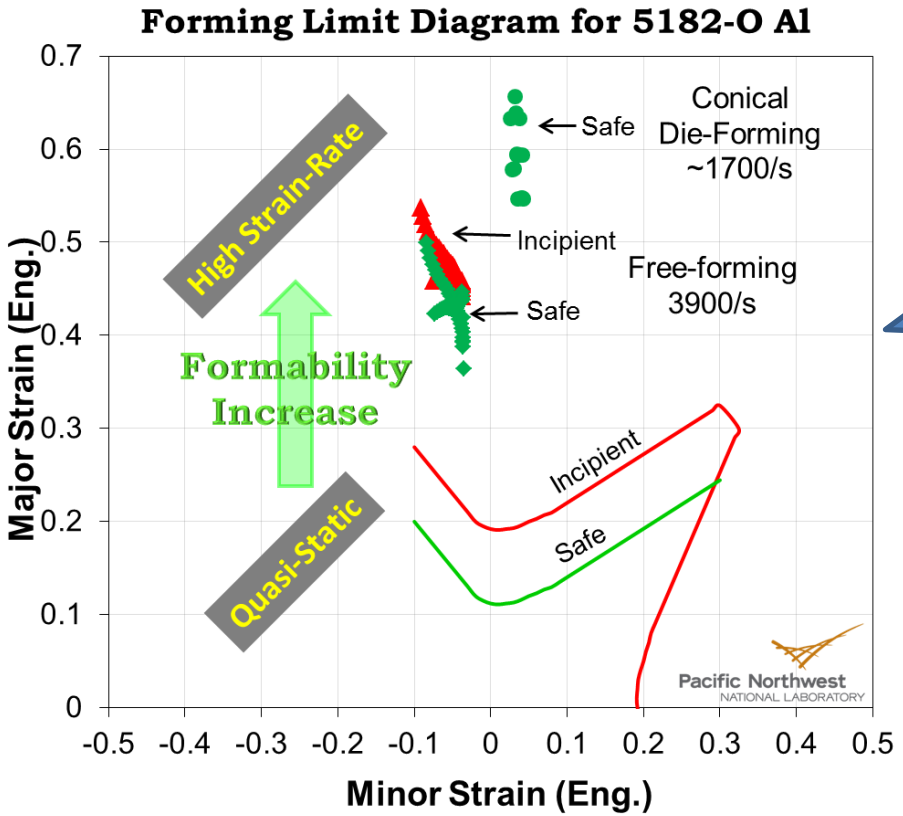
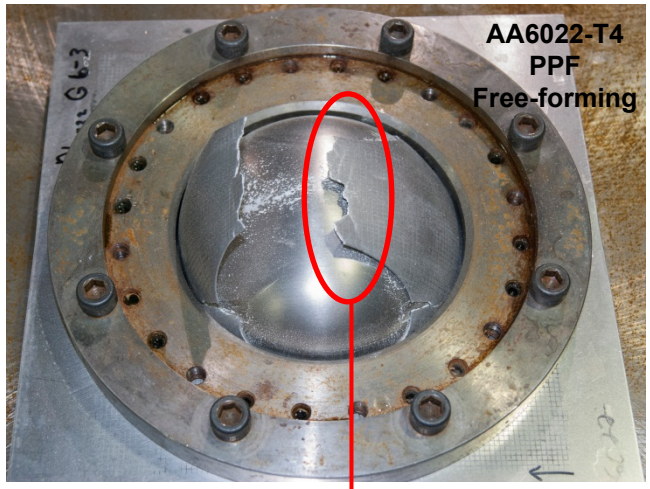
2x-6x Formability Enhancement: AA5182-O

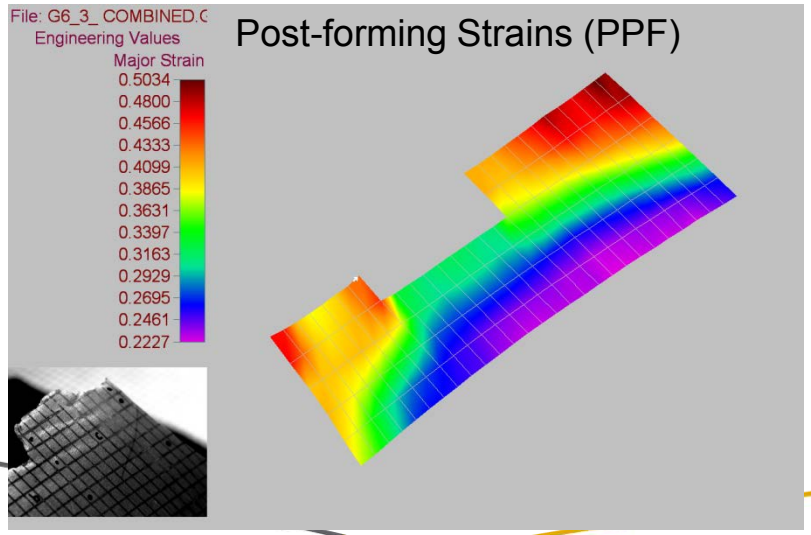


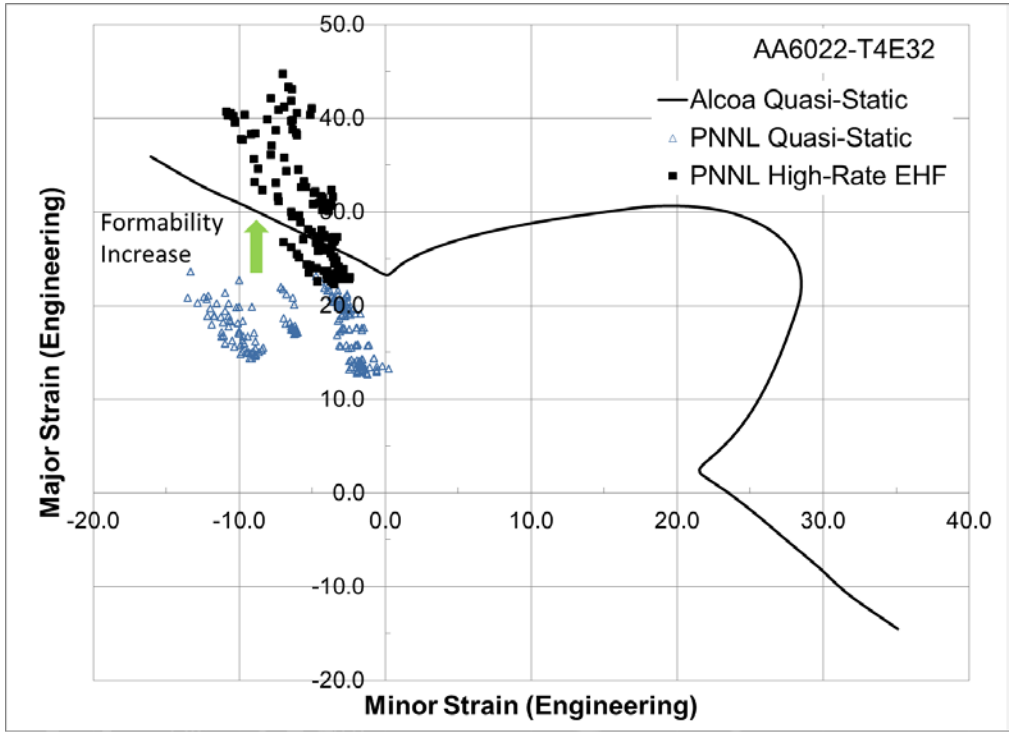
ROOM-TEMP

- **Strain-rates needed for enhanced formability were QUANTIFIED**
- **Unique capability developed at PNNL for QUANTIFYING high-speed events**

70% Formability Enhancement: AA6022-T4







PPF increased the formability by >70%, relative to quasi-static formability

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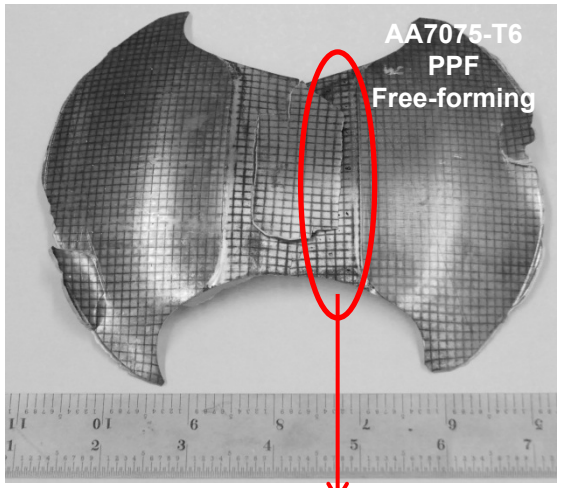
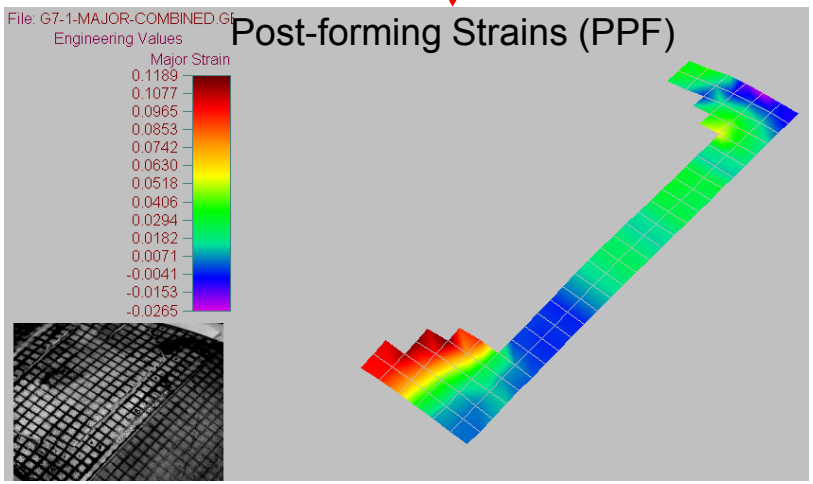
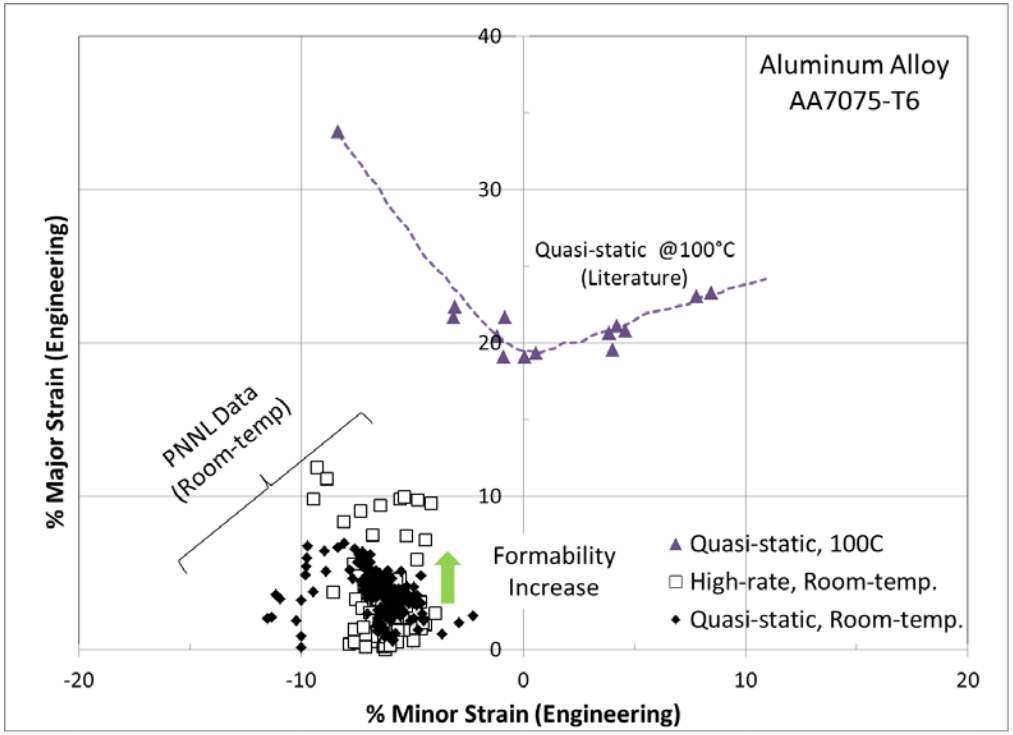
100% Formability Enhancement: AA7075-T6

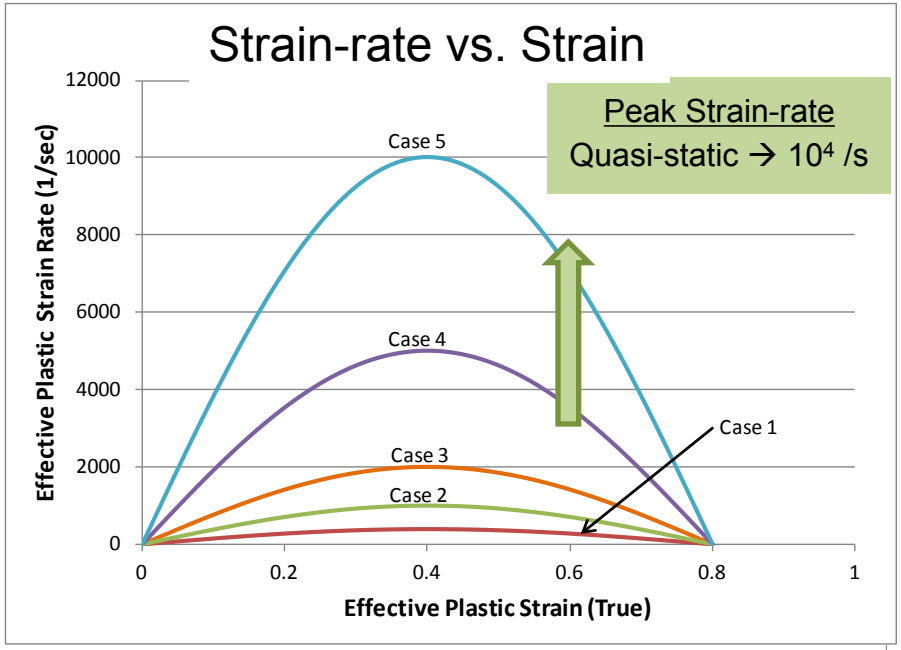






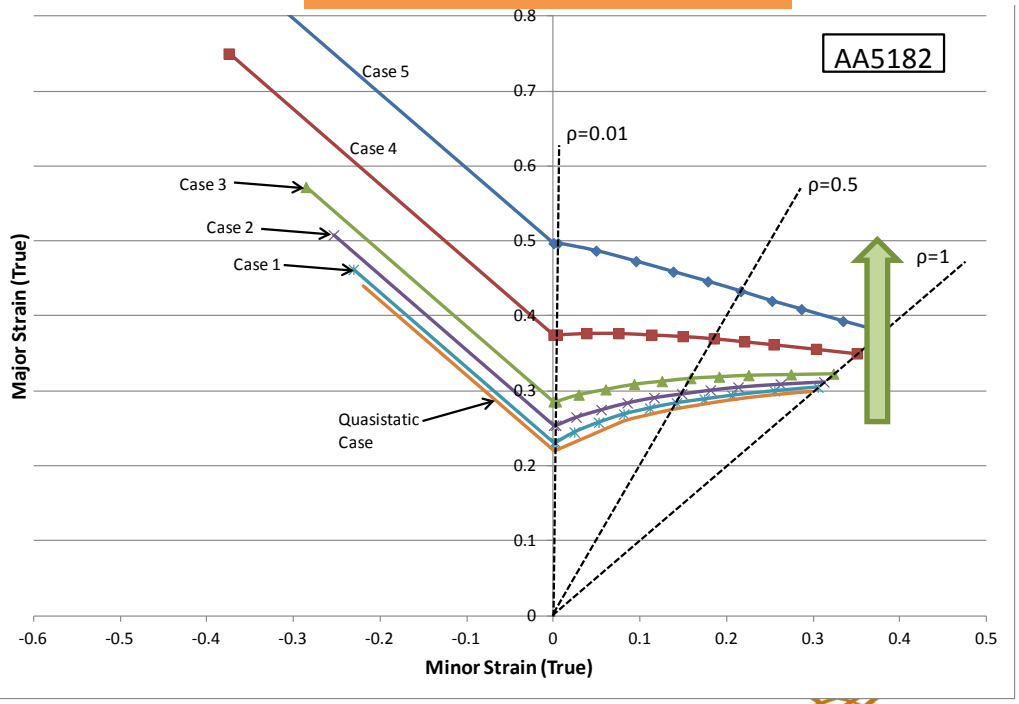
PPF increased the formability by ~100%, relative to quasi-static formability

Modeling Formability at High Rates



PNNL Model
Marciniak-Kuczynski Theory
Modified Hollomon eq.

Theoretical FLD
(Effect of Strain-rate)



Formability increases with increasing strain-rate

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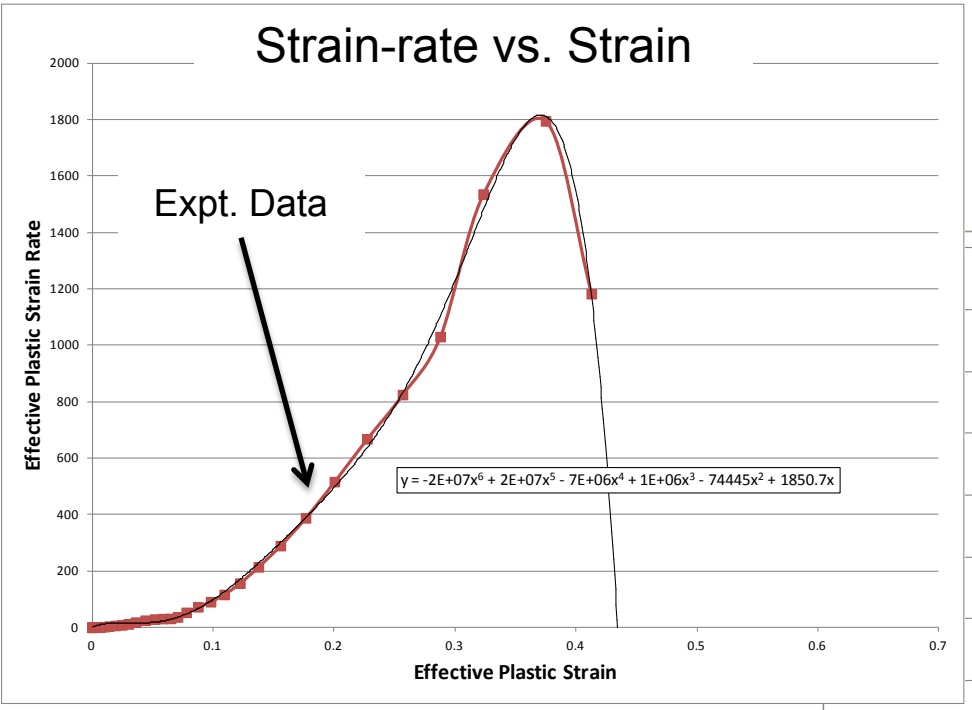
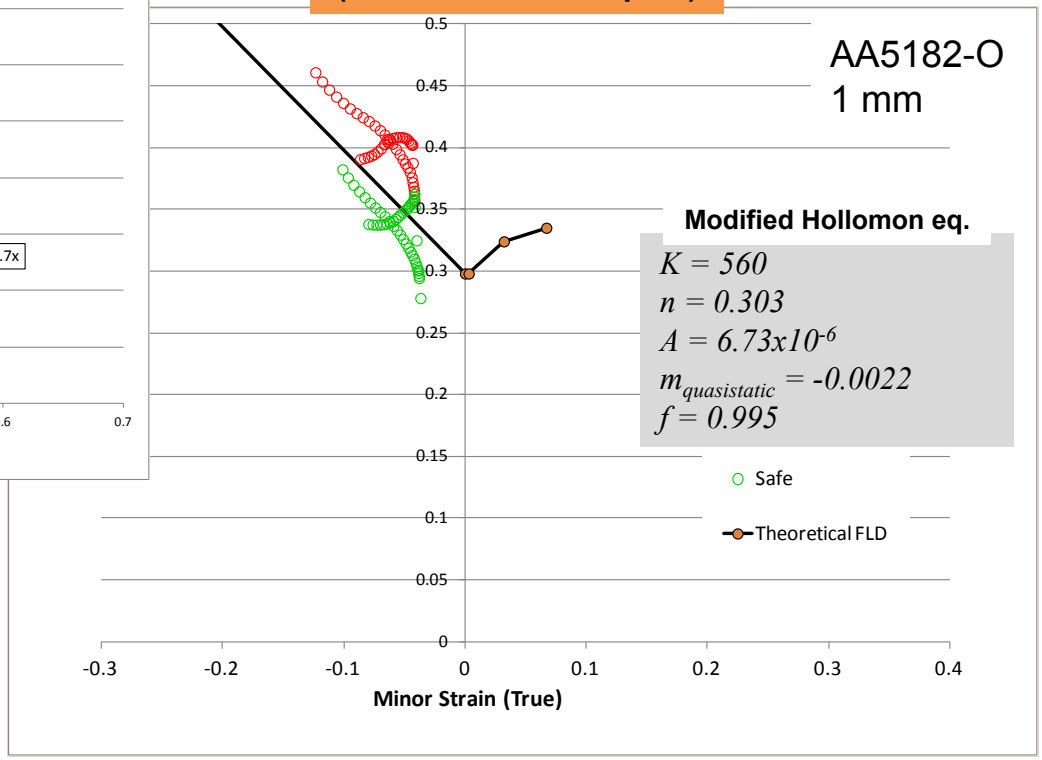
PPF#1: FLD Model Validation with Expt. Data



High-rate FLD
(Model vs. Expts)



Formability model validated by expt. data

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Collaboration

- GM
  - Prototypical component identification
  - Test material selection
  - Project path guidance
- Alcoa
  - Test material
  - Technical discussions on 7xxx alloys

Future of Pulse-Pressure Forming

- Hybrid approach for high-strength Al
  - High strain-rate + Warm temperature
- FLD for non plane-strain conditions
- Effect of sheet/die interactions
  - State of stress (hydrostatic, through-thickness shear)
  - Strain-path changes
- Damage mechanisms and model

Summary

- Demonstrated Formability Enhancements (Room-temp)
  - AA5182-O: ~2x-6x (Previous work)
  - AA6022-T4: >70% (Current work)
  - AA7075-T6: ~100% (Current work)
- Unique Experimental Capabilities Developed
  - Time-resolved measurements of full-field deformation during PPF
  - High-rate forming behavior quantified for Al and steel
- Formability Modeling
  - Applied the M-K method model along with the newly develop constitutive model to accurately predict experimentally observed formability results (AA5182-O)
  - Conducted a parametric analysis show the effect of strain rate on formability