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2015 Annual Merit Review

High Strength, Dissimilar Alloy Aluminum Tailor-Welded Blanks

YURI HOVANSKI

Pacific Northwest National Laboratory

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Project ID #LM099

Project Overview

Project Timeline

- Start: FY2015
- Finish: FY2017
- 15% complete

Technology Gaps/Barriers

- Capacity to rapidly join dissimilar alloy Al sheet is not developed for high volume production.
- Scientific understanding to enable thermal stability of work-hardenable and precipitation hardenable alloys during welding is lacking
- Supply chain for curvilinear geometries in dissimilar thickness and alloy combinations is non existent.

Budget

- Total project funding
  - DOE – $1.2 M
  - Industrial cost share $1.2M
- FY15 Funding - $400k (received)
- FY16 Funding - $400k
- FY17 Funding - $400k

Partners

- Automotive OEM
  - GM
- Tier I Supplier
  - TWB Company LLC
- Material Provider
  - Alcoa

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Relevance: Project Motivation

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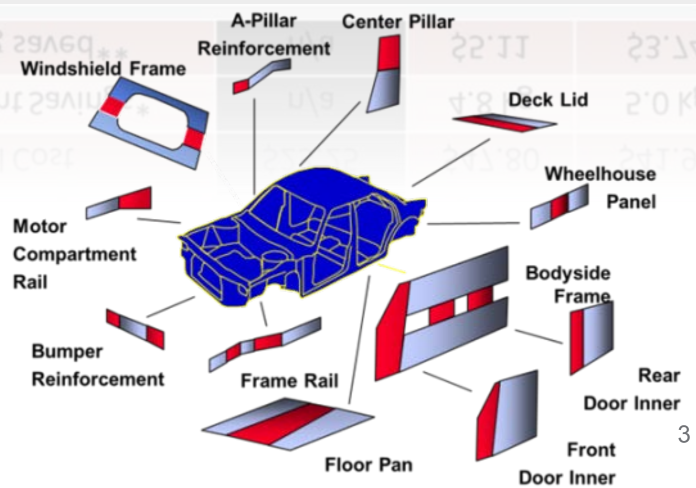
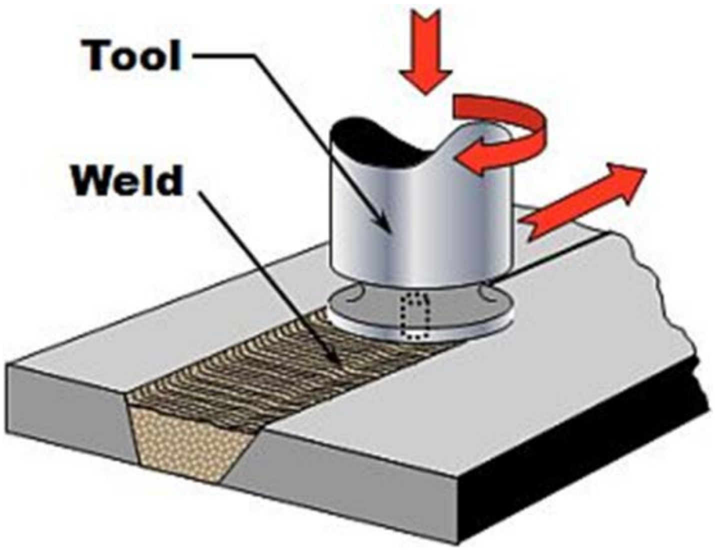
- EERE–Vehicle Technology Goal:
  - By 2015, demonstrate a cost-effective 50% weight reduction in passenger-vehicles compared to 2002 model
- VTO - Challenges and Barriers:
  - Cost, Manufacturability, Performance, Predictive modeling tools, tooling and prototyping, joining, inadequate supply base
- Project designed to address each of these issues as related to the production of Al-TWBs
  - Increase supplier base
  - Develop and validate predictive modeling tools
  - Develop new joining technique with lower cost and simplified assembly

Front Door Inner Example	Steel –TB 1.4 / .7 mm	Al – Assembly	AL – TB 2.0 / 1.1 mm
Gross Weight	14.5 kg	9.0 kg	7.4 kg
Net Weight	11.6 kg	6.8 kg	6.6 kg
Material cost ($1.25/kg vs $4.50/kg)	$18.13	$40.50	$33.30
Blanking & Welding	$3.12	$.70	$5.85
Stamping	$2.00	$3.60	$2.80
Assembly	$0	$3.00	$0
Total Cost	$23.25	$47.80	$41.95
Net Weight Savings*	n/a	4.8 kg	5.0 kg
Cost / kg saved**	n/a	$5.11	$3.74

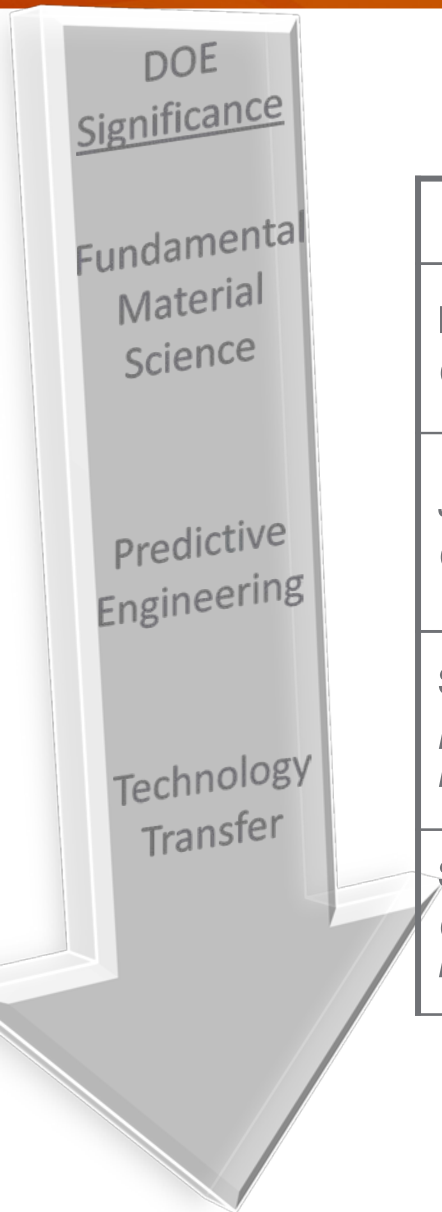


Relevance: Goals and Objectives

- Enable more wide-spread use of mass-saving aluminum alloys.
- Develop joining technology needed for high speed fabrication of high strength, dissimilar alloy Al-TWBs in linear and curvilinear geometries.
- Introduce curvilinear Al TWBs into the high-volume automotive supply chain.



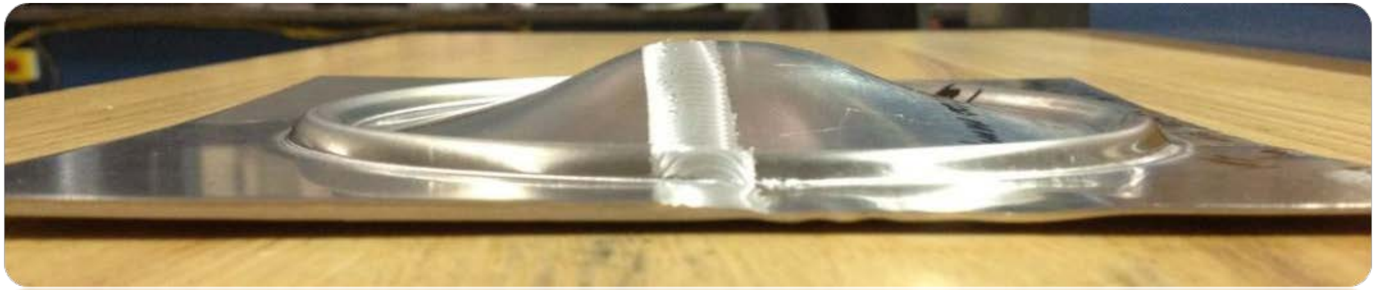
Relevance: Project Milestones



Month/Year	Milestone or Go/No-Go Decision
March 2015 ***Complete***	**Establish Predictive Formability** Establish FE modeling for predicting LDH height in welded sheet using Barlat coefficients
June 2015 ***Complete***	**Characterize Influence of Heat Input** Characterize HAZ relationships in 5x, 6x, and 7x aluminum alloys as a function of welding speed
Sept 2015 *Progress Milestone*	**Disseminate Information** Submit a publication on relationships of high speed FSW parameters on the magnitude & location of HAZ in welded blanks
Sept 2016 *Go/No-Go Decision Gate*	**High Speed Dissimilar Alloy** Demonstrate high-speed, friction-stir welded dissimilar alloy welded blanks between 5x & 6x alloys in linear and curvilinear geometries

Technical Approach

- **Task 1: Relating Weld Parameters & Material Properties**
  - Task 1.1. Base-metal sheet characterization
  - Task 1.2. FSW material characterization & properties
  - Task 1.3. Heat affected zone characterization and relationships
  - Task 1.4. Effects of sheet coatings on properties of weld and HAZ
  - Task 1.5. FSW characterization & properties of dissimilar alloy joints
- **Task 2: Dissimilar Alloy Friction Stir Welding Development**
  - Task 2.1. Dissimilar alloy weld development of AA5xxx and AA6xxx
    - Decision gate
  - Task 2.2. Dissimilar alloy weld development of precipitation strengthened alloys
  - Task 2.3. Dissimilar alloy weld development of 5x and 6x alloys to 7x
  - Task 2.4. Curvilinear high speed FSW development



Technical Approach (con't)

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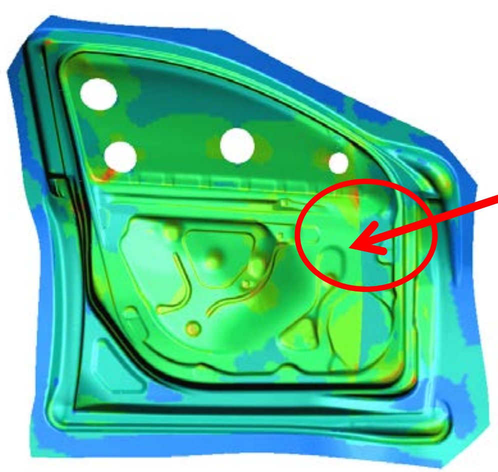
- **<u>Task 3: Production Readiness and Deployability</u>**
  - Task 3.1. Repeatability of high speed dissimilar alloy FSW
  - Task 3.2. Repeatability of high speed curvilinear FSW
  - Task 3.3. Tool durability
- **<u>Task 4: Weld Formability Modeling and Validation</u>**
  - Task 4.1. Developing Barlat Coefficients
  - Task 4.2. Simulating formability of dissimilar thickness Al TWBs
  - Task 4.3. Simulating formability of dissimilar alloy & thickness Al TWBs



Split Predicted

No Split, Actual

Technical Accomplishments: Thermal Effects on Aluminum Sheet

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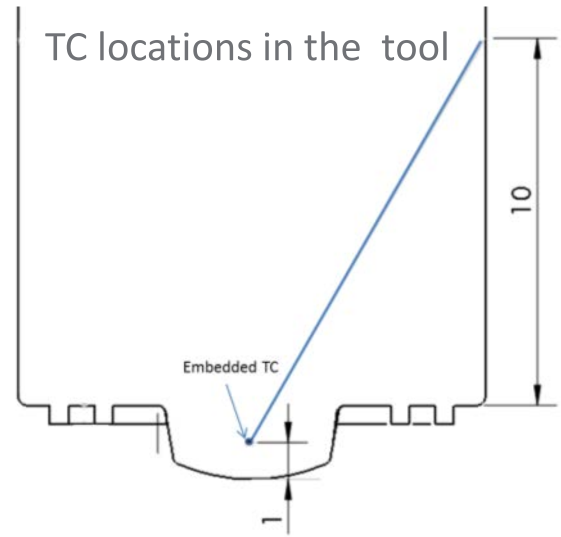
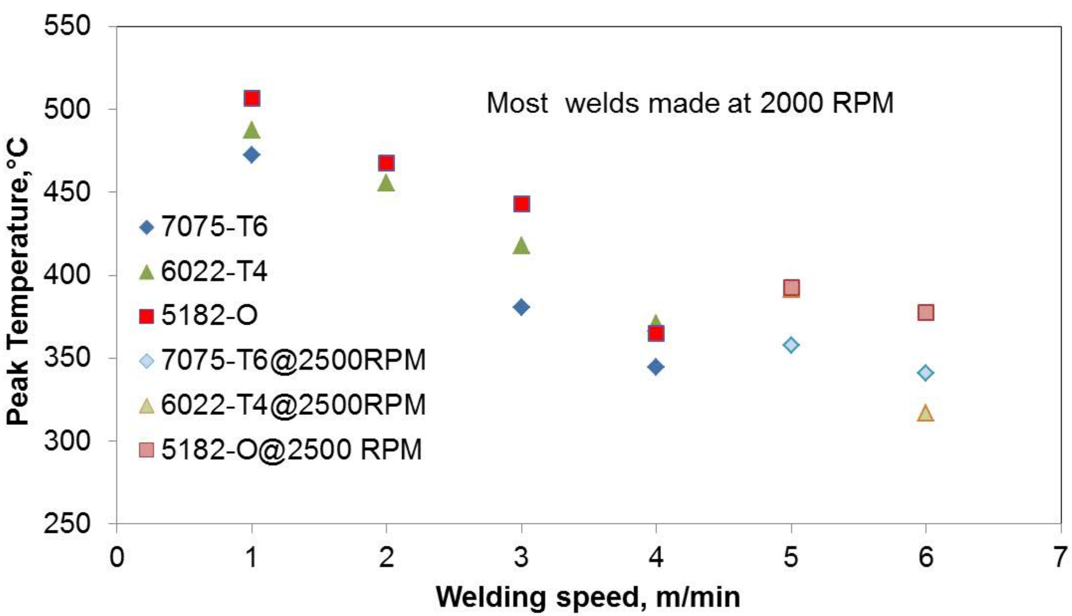
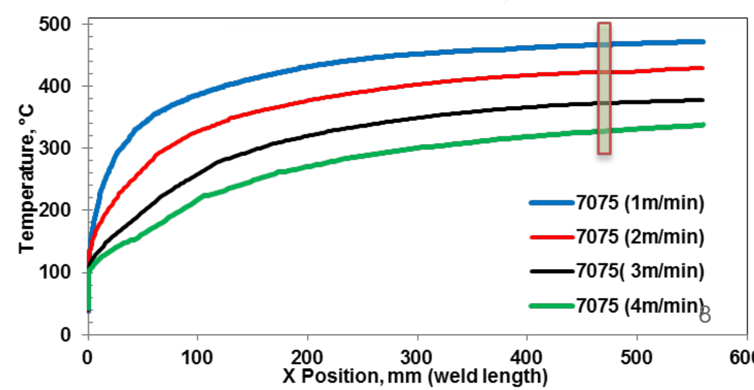
- Thermal monitoring during FSW from 1m/min to 6m/min in various alloys
  - 7075-T6, 6022-T4, 5182-0
- Goal: lower peak temperatures and shorter durations at temperature







Technical Accomplishments: Temperature Effects on HAZ (2015 milestone)

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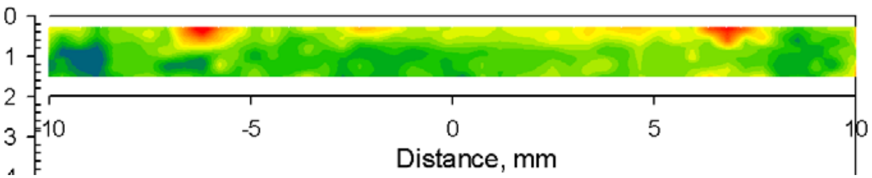
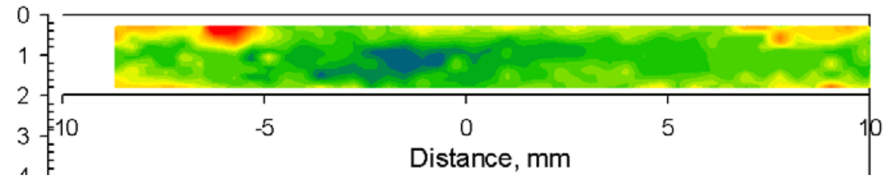
- Unlike fusion welding, Solid-state FSW can change thermal input to materials
  - Especially important to precipitation strengthened alloys
  - Microhardness maps from 2mm AA6022-T4, as welded shown below
    - Base metal hardness ~80

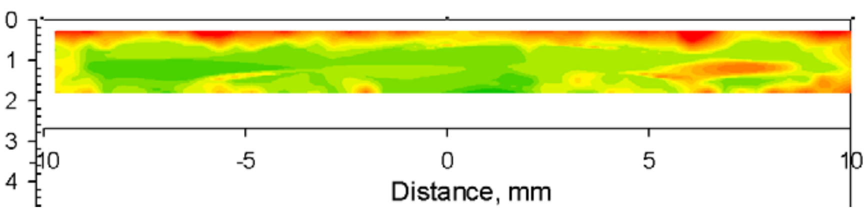
1m/min, 2000 RPM, Tool T= 483°C



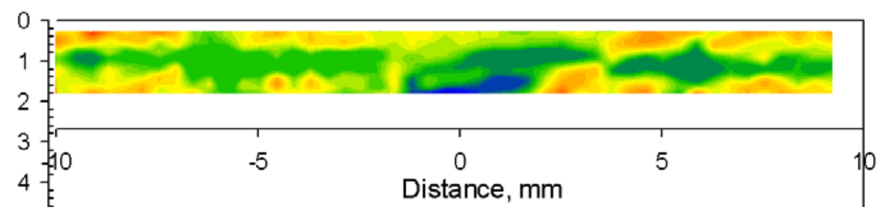
2m/min, 2000 RPM, Tool T= 447°C



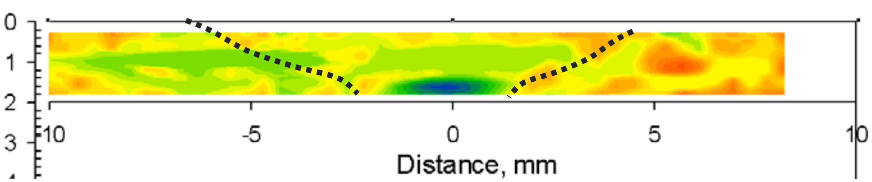
3m/min, 2000 RPM, Tool T= 406°C

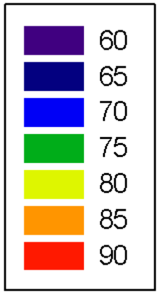


4m/min, 2000 RPM, Tool T= 356°C



5m/min, 2500 RPM, Tool T=370°C





Technical Accomplishments: Temperature Effects on HAZ (2015 milestone)

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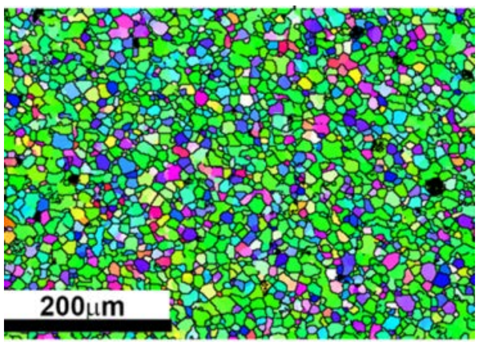
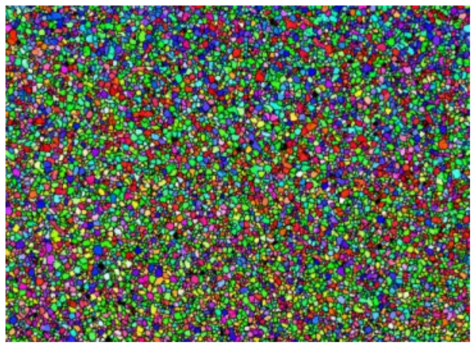
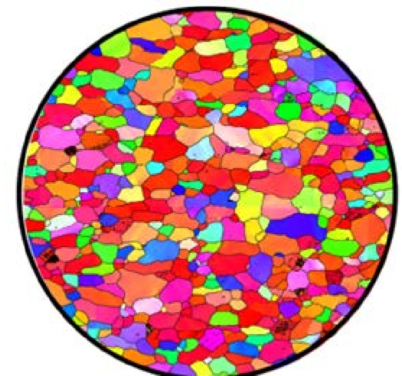
- Further effects of temperature on the weld nugget microstructure

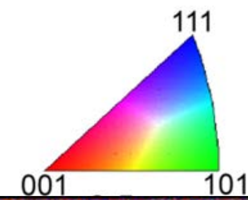
1m/min @ 1500 RPM
T_{max}=470°C
Average Grain Size: 8.7 µm,
Grain size variance: 27 µm

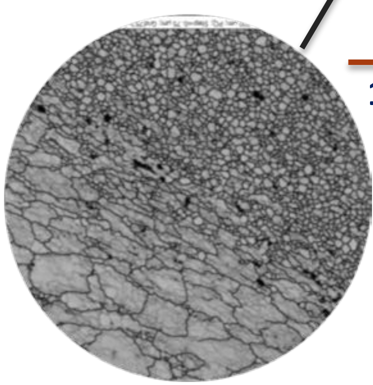
3m/min @ 1500 RPM
T_{max}=355°C
Average Grain Size: 5.6 µm,
Grain size variance: 8.3 µm



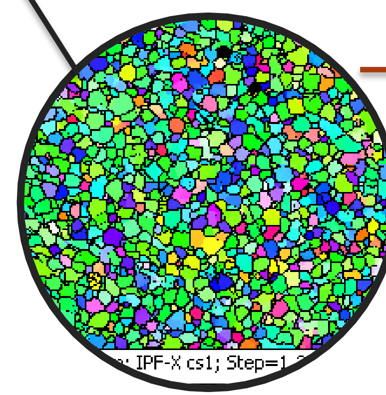






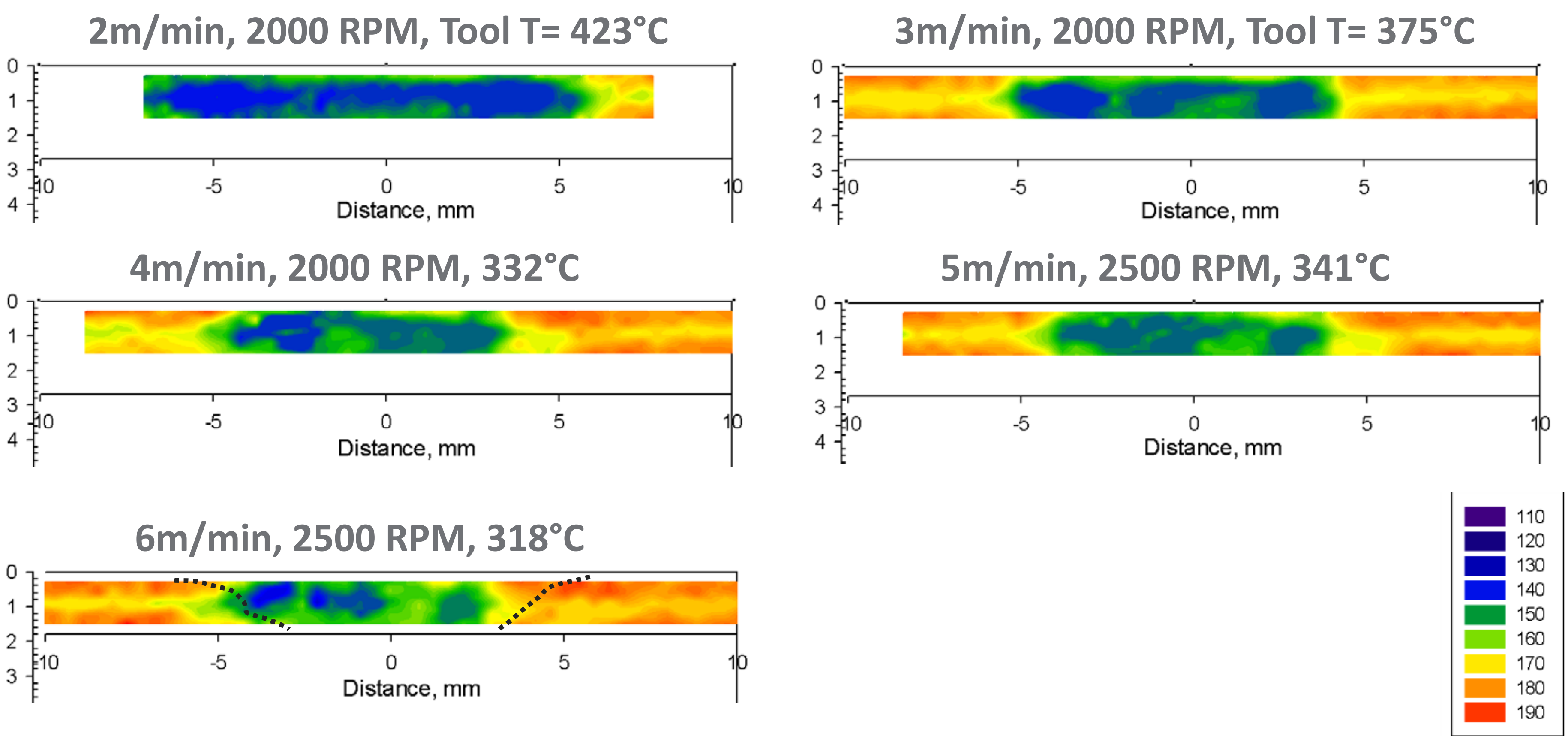


3m/min, 1950rpm, AA 6022



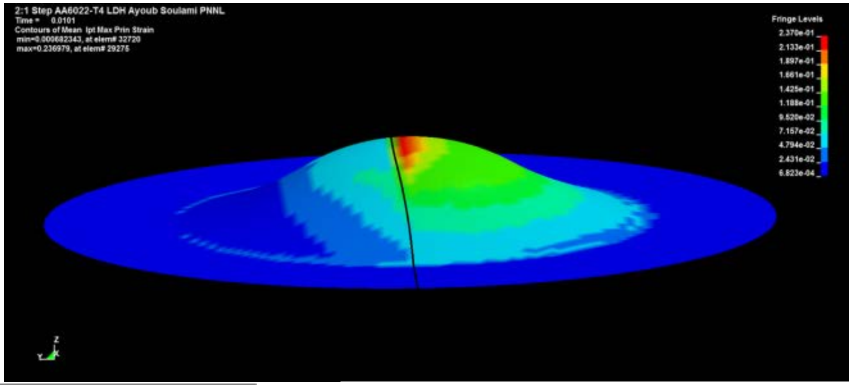
Technical Accomplishments: Temperature Effects on HAZ (2015 milestone)

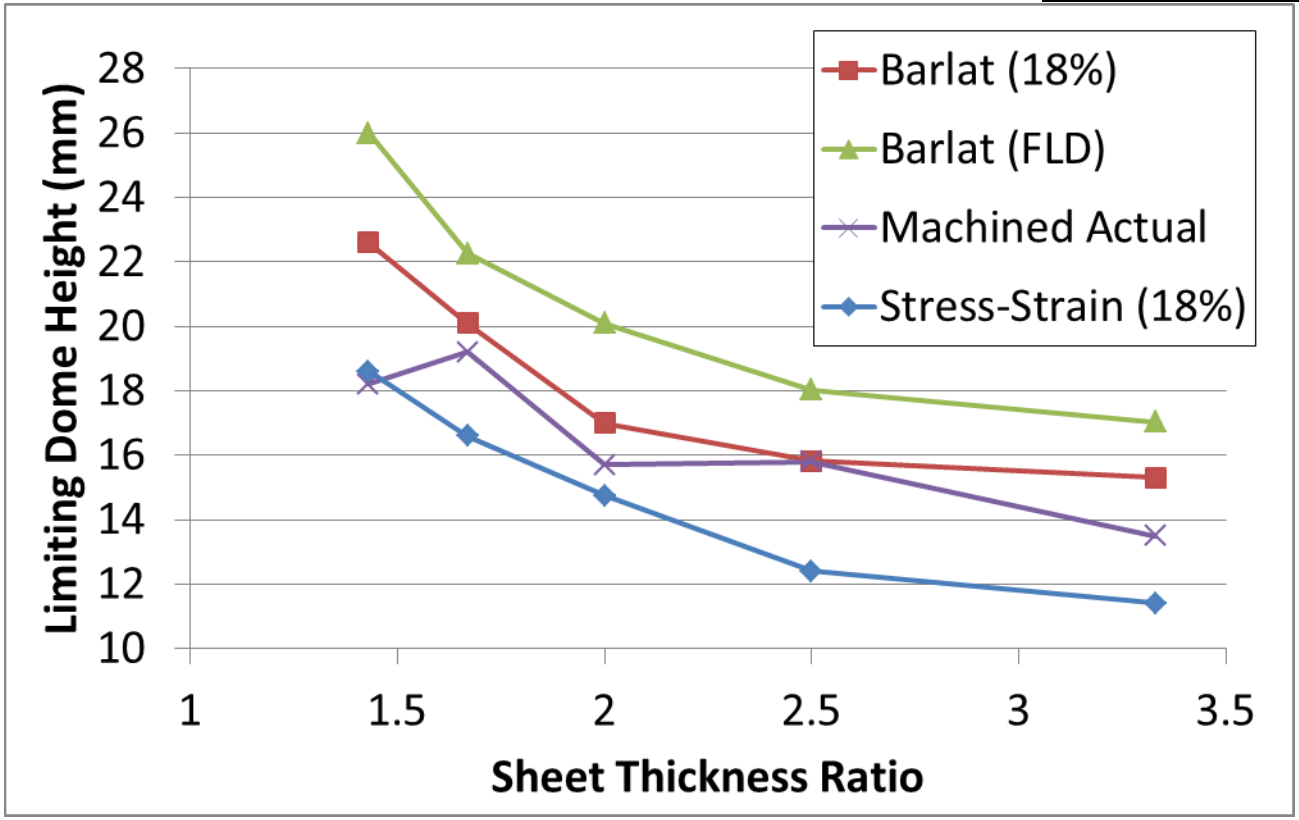
- Pronounced effect of high-strength alloys, as-welded 2 mm 7075-T6 shown below:
  - With a 12-mm diameter tool the transition from thin to thick sheets is at around 6-mm off of center
    - Need to avoid all the weakest segments aligning to achieve maximum formability

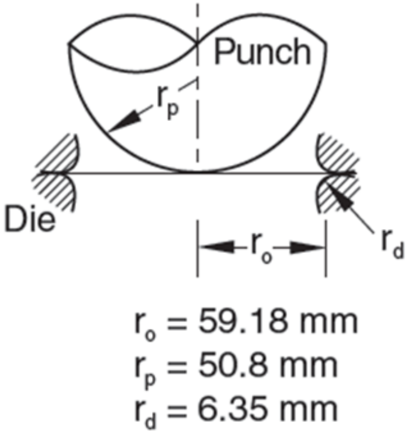


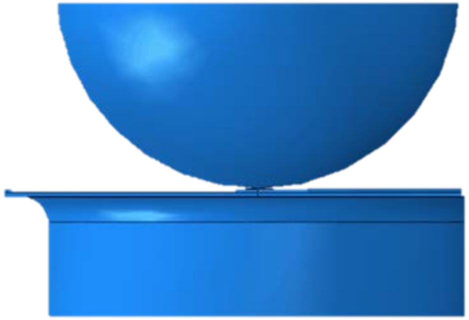
Technical Accomplishments: Weld Formability Modeling (FY15 Milestone)

- Introducing Barlat 2000 Coefficients to account for anisotropy and strain sensitivity
  - 8 anisotropy parameters for AA5182 -O









Technical Accomplishments: Weld Formability Modeling (FY15 Milestone)

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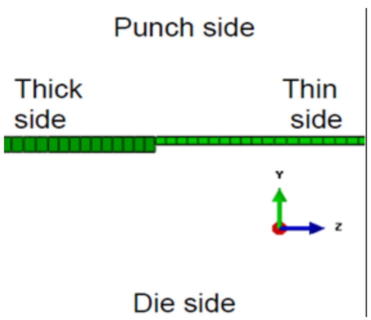
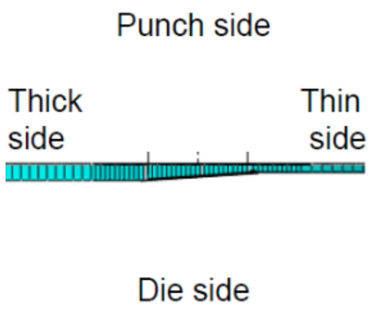
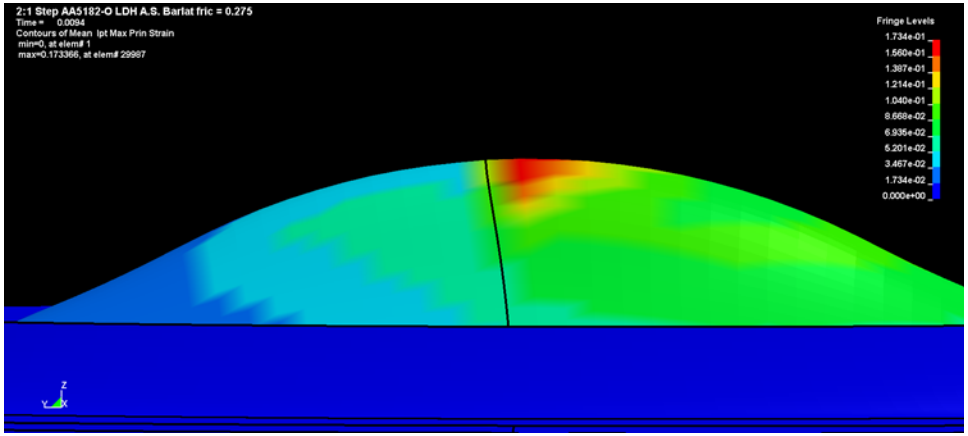
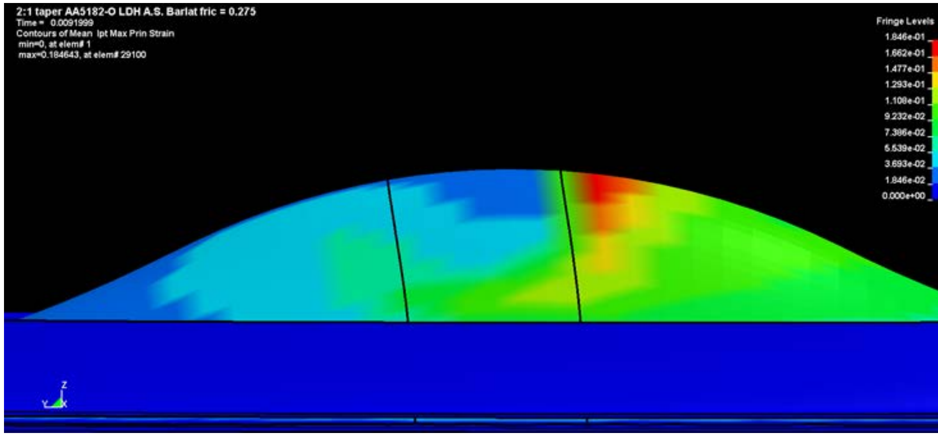
- Evaluating the influence of model complexities at the weld
  - Step interface at the weld is the current practice for TWBs
    - Less geometric complexity and less intensive calculation



Dome Heights (mm)		
Step	Taper	Exp.
17.0	17.19	15.7

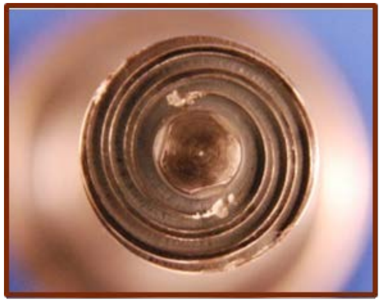




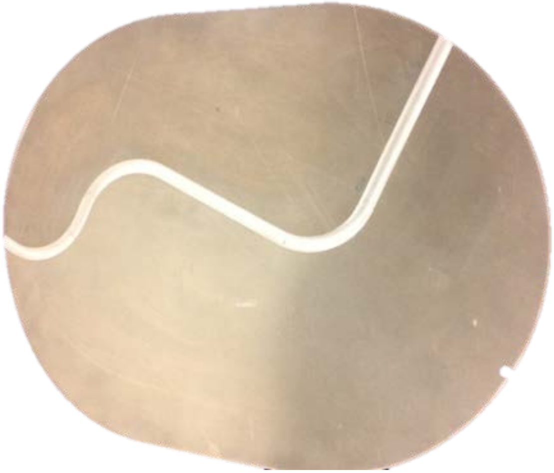


Technical Accomplishments: Curvilinear weld panels

- Weld parameters from previous high speed FSW work in dissimilar thickness AA5182-O applied
  - 2 mm to 1 mm thicknesses
  - 1 corner with 50 mm radius
  - 2 corners with 60 mm radius
- Beavertail die designed for linear weld seam
  - Didn't constrain edge buckling
  - Complete 55 mm die stroke



Pin with 3 Flats
Double scrolled shoulder,
Shoulder to pin ratio (S/P) =3



Responses to Previous Year Comments

This is a new project that was not reviewed last year

Collaboration and Coordination

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- University Collaborators
  - Washington State University
    - Characterization and analysis of process on properties
- Private Collaborations (complete automotive supply chain)
  - General Motors
    - Determine Barlat coefficients for weld material, product specific formability modeling, and market relevance, component stamping
    - High speed thermal evaluation
  - TWB Company, LLC.
    - High speed linear and curvilinear blank production, repeatability evaluations, tool durability during high volume production
  - Alcoa
    - Material provider, high temperature material properties, Barlat, formability

Remaining Challenges and Barriers

- Balancing differences in high temperature flow stresses of dissimilar alloys during high-speed FSW -
  - Will be addressed in the following tasks:
    - Task 1.5 – charactering joint properties & material flow of dissimilar alloys
    - Task 2.1 – combining work hardenable & precipitation hardenable alloys
    - Task 2.3 - combining 7xxx series alloys with others
- Although linear deployment is underway, high-speed curvilinear deployment needs to be fully enabled for automotive suppliers
  - Will be addressed with Task 2.4
- Production Readiness and Deployability of dissimilar alloy blanks
  - Addressed in Task 3 addressing repeatability at the suppliers facilities
- Predictive engineering tools need to accommodate a combination of dissimilar alloys and dissimilar thicknesses
  - Addressed specifically in Task 4 – combined effort from PNNL, GM & Alcoa

Proposed Future Work (planned)

- Summer 2015: Complete investigation of weld parameters on HAZ including dissemination in archival publications (FY15 milestones)
  - Determine the ideal parameter ranges to minimize effects of heat in precipitation-strengthened alloys
- Fall 2015: Curvilinear weld development (FY16 milestone)
  - Demonstration of curvilinear welding on supplier's machine
  - Evaluation of properties and post-weld formability
- Spring 2016: Validate predictive modeling tools for dissimilar thicknesses (FY16 milestone)
  - Introducing discretized properties for base metals and weld metals.
- Summer 2016: Demonstrate high-strength, dissimilar alloy Al TWBs, including weld stability, quality and formability (FY16 Decision Gate)
  - Develop weld parameters to support joining 5xxx and 6xxx alloys using high-speed FSW
  - Demonstrate weld quality with acceptable surface roughness, strength and post-weld formability

FY15 Project Summary

- Initiated project to overcome the technical challenges associated with high volume production of high-strength, dissimilar alloy Al TWBs
  - Complete automotive supply chain engaged in overcoming technical challenges and moving to complete deployment
- Evaluated the influence of weld parameters on the HAZ of Al sheet
  - Demonstrated weldability to 6 m/min in each alloy class (5x, 6x, 7x)
  - Quantified the relationships between weld parameters and the size and magnitude of the HAZ
- Demonstrated similar alloy, dissimilar thickness curvilinear capability
- Upgraded predictive modeling tools using Barlat 2000 coefficients demonstrating more accurate fit than with stress-strain behavior alone.
  - Prepared for future inputs from weld materials, allowing for further increases in overall predictive accuracy.

Technical Back-Up Slides

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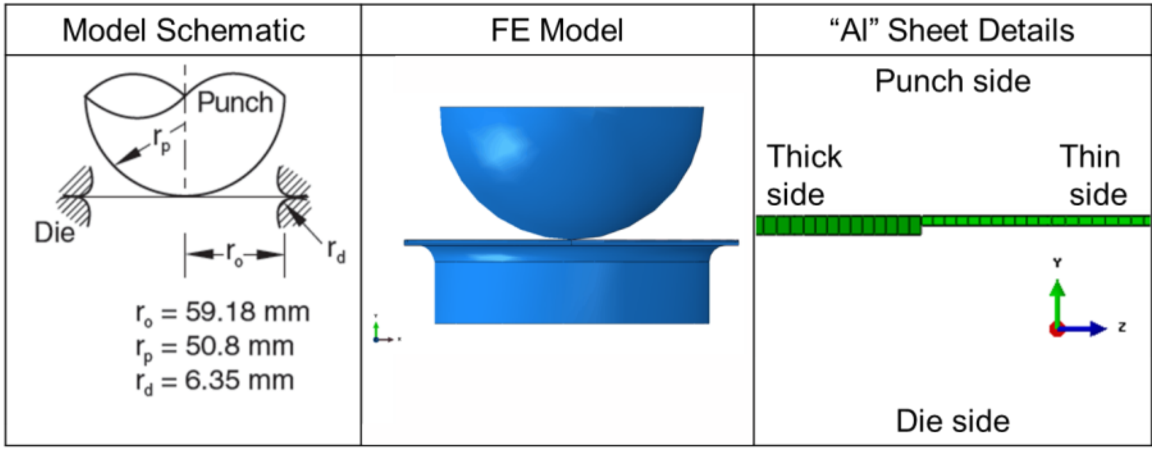
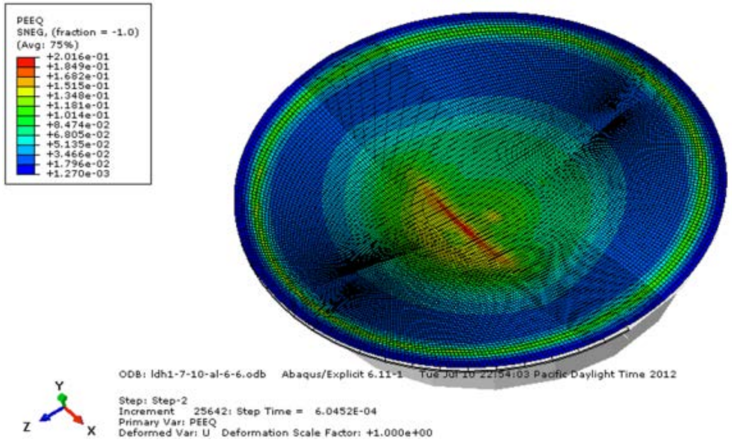
Formability Modeling – LDH Foundation

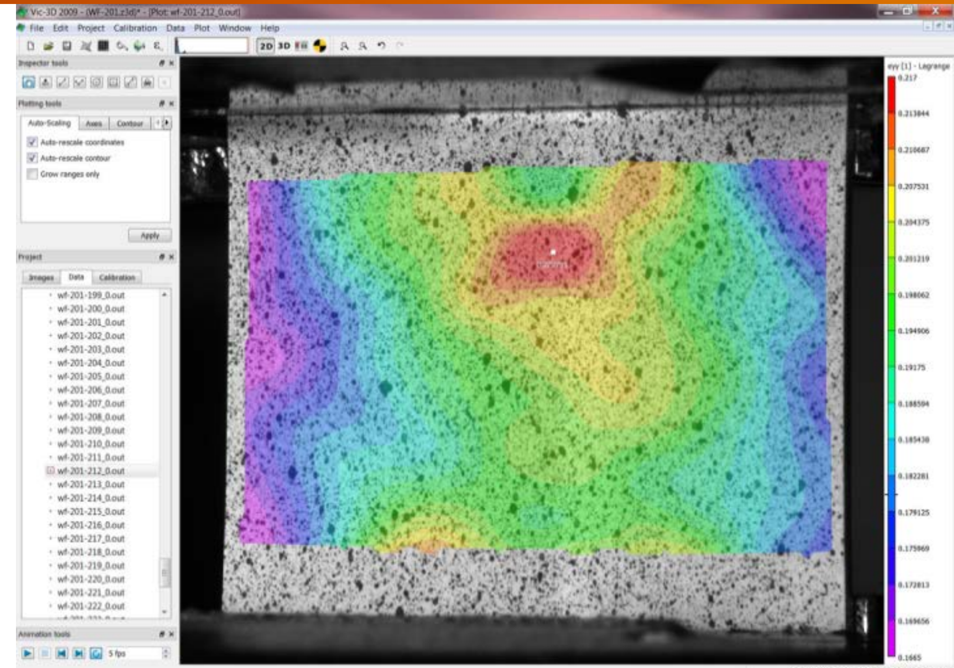
- Formability Screening of dissimilar thickness welded blanks
  - Height & load at failure measured
  - Predicted failure was outside weld in the thin sheet for 2-mm to 1-mm joints
    - Failure related to geometric discontinuity rather than the weld

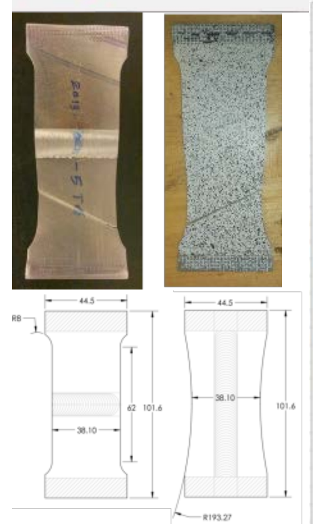




Establishing Failure Criteria Probabilistic Formability Limits

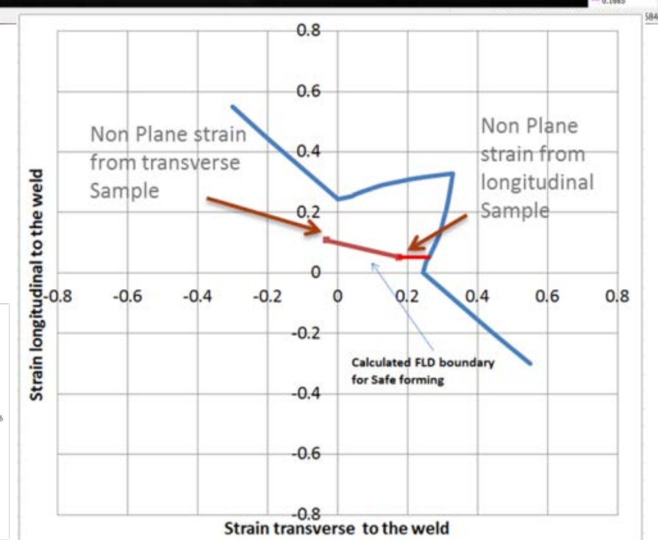
- 30 sets of tensile coupons prepared to evaluate available strain in dissimilar thickness welded aluminum blanks
  - Transverse & longitudinal
- Speckle pattern interferometry
  - Strain evaluation
  - Determines maximum safe strain available to each specimen
  - Max e_{yy} and corresponding e_{xx} are recorded
    - Lagrangian strain conditions
- Probabilistic formability limit established for safe strain in the production of Al TWBs





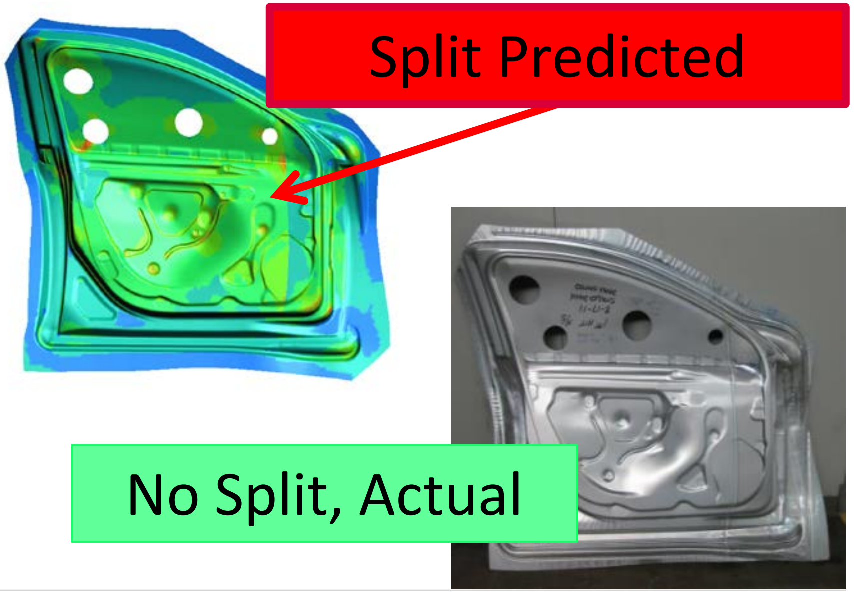
Transverse sample

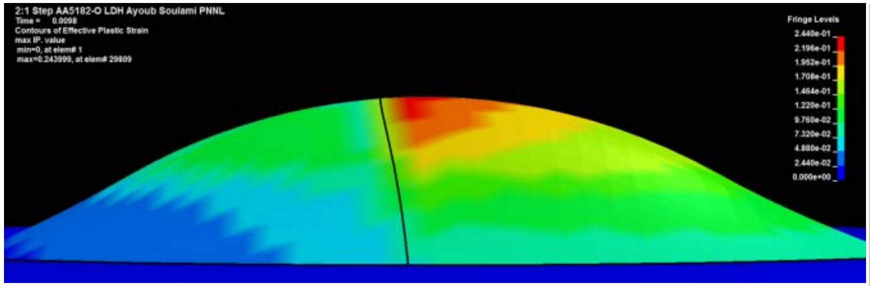
Longitudinal Sample

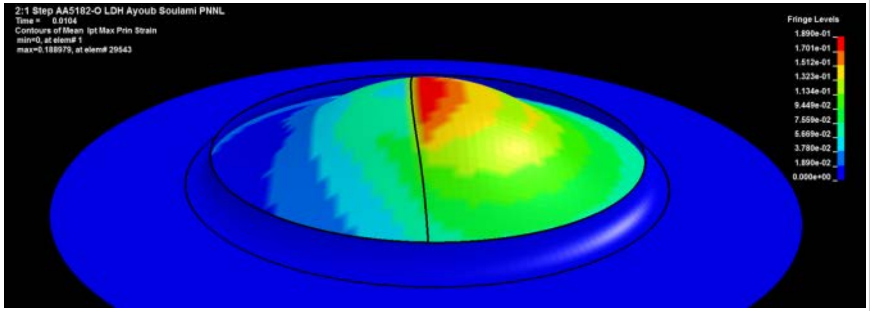


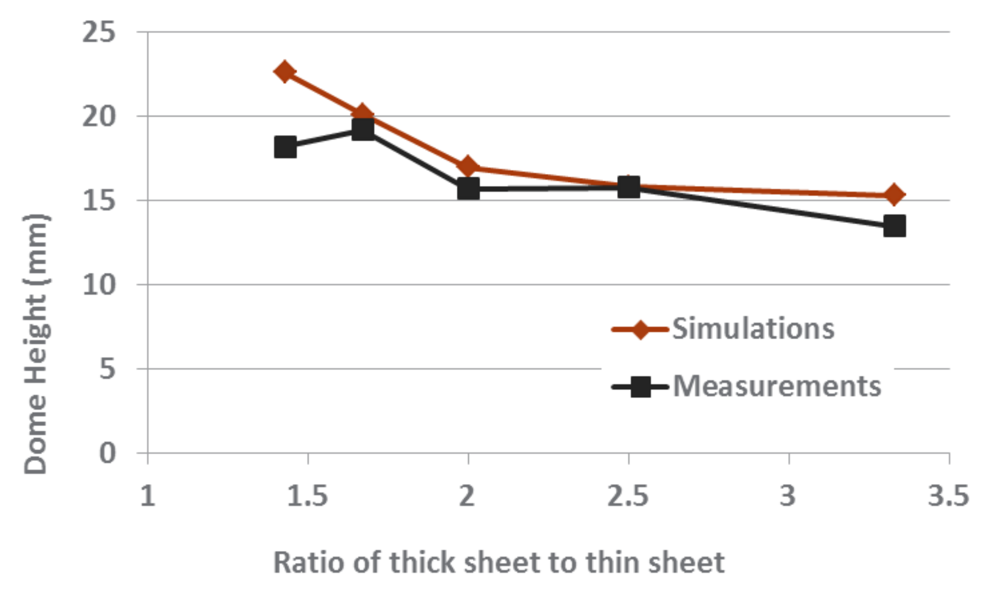
Numerically Predicted Post-Weld Formability

- Simulation capability being expanded to correct current numerical analysis
- LDH predictions show capability of trending across various sheet thickness ratios
- Modeling dome heights account for dissimilar thicknesses, but needs to be expanded for alloys and detailed part geometries





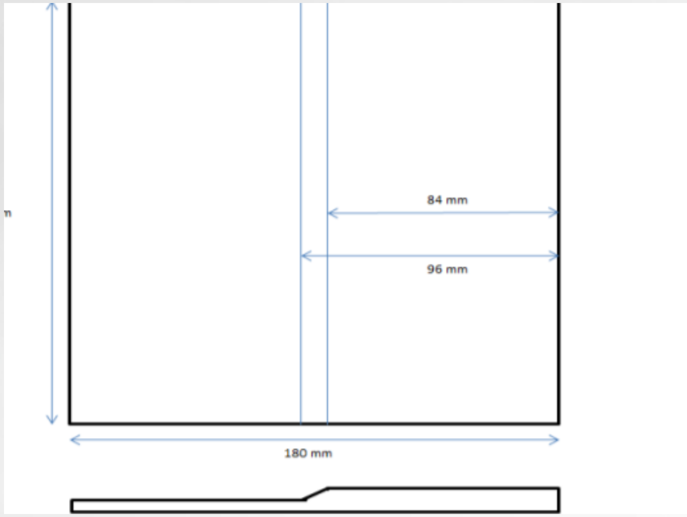




Simulations Schedule

- 2:1 thickness ratio with step and taper
  - Isotropic case with only base material (Al 5182-O)
  - Barlat 2000 Constitutive model
  - Limiting Strain set to 18%

- Five different thickness ratios with taper



Case	Thick Side (mm)	Thin Side (mm)	Ratio
a	2.0	0.6	3.33:1
b	2.0	0.8	2.5:1
c	2.0	1	2:1
d	2.0	1.2	1.67:1
e	2.0	1.4	1.43:1