Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

High Speed Joining of Dissimilar Alloy Aluminum Tailor Welded Blanks

YURI HOVANSKI

Pacific Northwest National Laboratory

May 15, 2013

Project ID #LM075

Project Overview

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

Project Timeline

- Start: FY2012
- Finish: FY2014
- 33% complete

Technology Gaps/Barriers

- Capacity to rapidly join Al sheet in dissimilar thicknesses and alloys is not developed.
- Supply chain doesn't exist for high volume joining of automotive aluminum sheet.
- Characterization of post-weld formability must be tied to the process to allow the entire supply chain to successfully integrate the technology.

Budget

- Total project funding
  - DOE – $0.9 M
  - Industrial cost share >$0.9M
- FY12 Funding - $300k
- FY13 Funding - $300k
- FY14 Funding - $300k

Partners

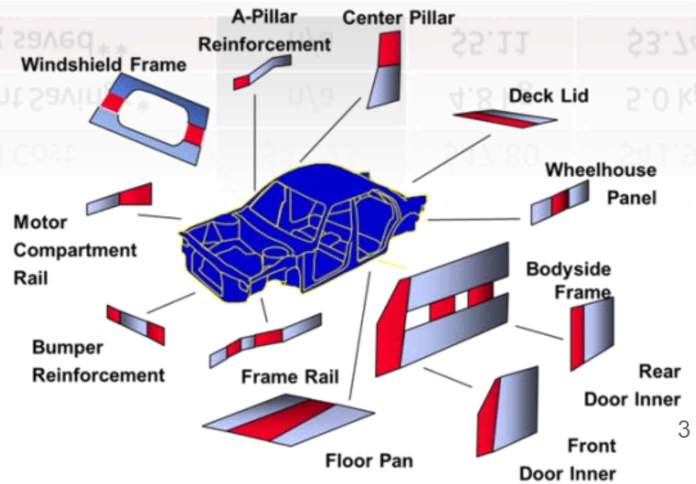
- OEM
  - GM
- Tier I Supplier
  - TWB Company LLC
- Material Provider
  - Alcoa

Relevance: Project Motivation

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

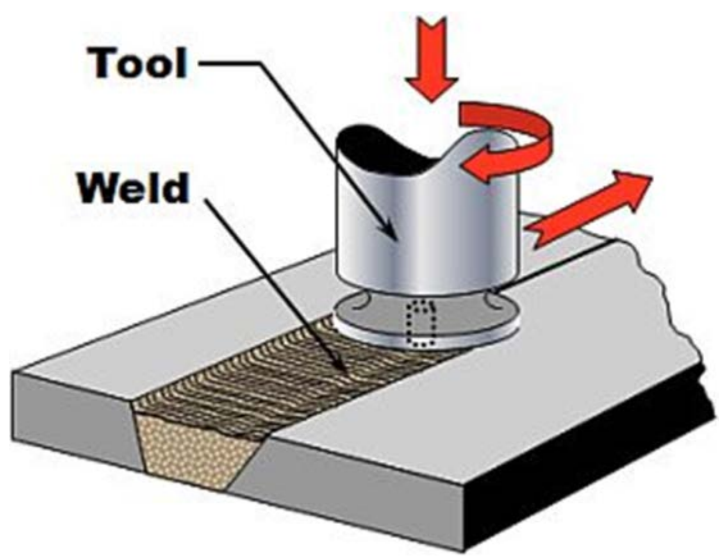
- By 2015, demonstrate a cost-effective 50% weight reduction in passenger-vehicle body and chassis systems
  - Critical technology gaps in all advanced materials systems must be overcome to meet the multi-material lightweight vehicle challenge
  - Multi-material joining was identified as a key technology gap
    - Aluminum is a near-term material solution for lightweighting
    - Aluminum welded panels provide further potential for weight reduction

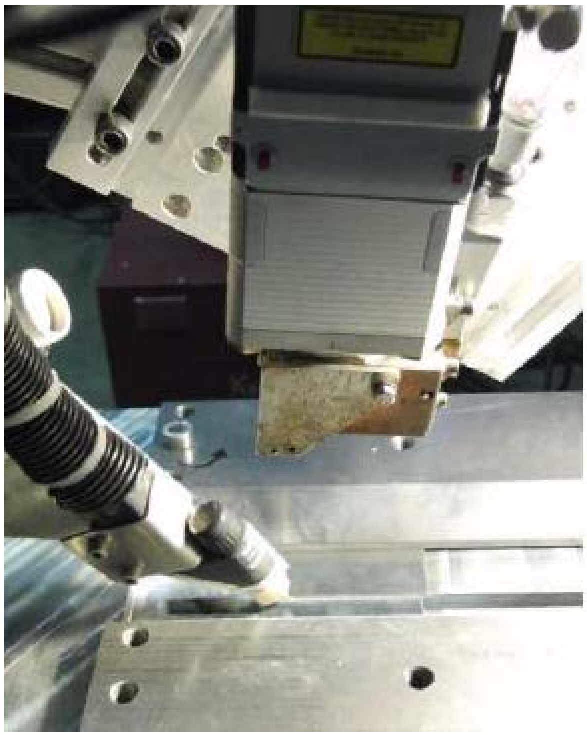
Front Door Inner Example	Steel –TB 1.4 / .7 mm	Al – Assembly	AL – TB 2.0 / 1.1 mm
Gross Weight	14.5 kg	9.0 kg	7.4 kg
Net Weight	11.6 kg	6.8 kg	6.6 kg
Material cost ($1.25/kg vs $4.50/kg)	$18.13	$40.50	$33.30
Blanking & Welding	$3.12	$.70	$5.85
Stamping	$2.00	$3.60	$2.80
Assembly	$0	$3.00	$0
Total Cost	$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 Al-TWBs.
- Introduce Al TWBs into the high volume automotive supply chain.

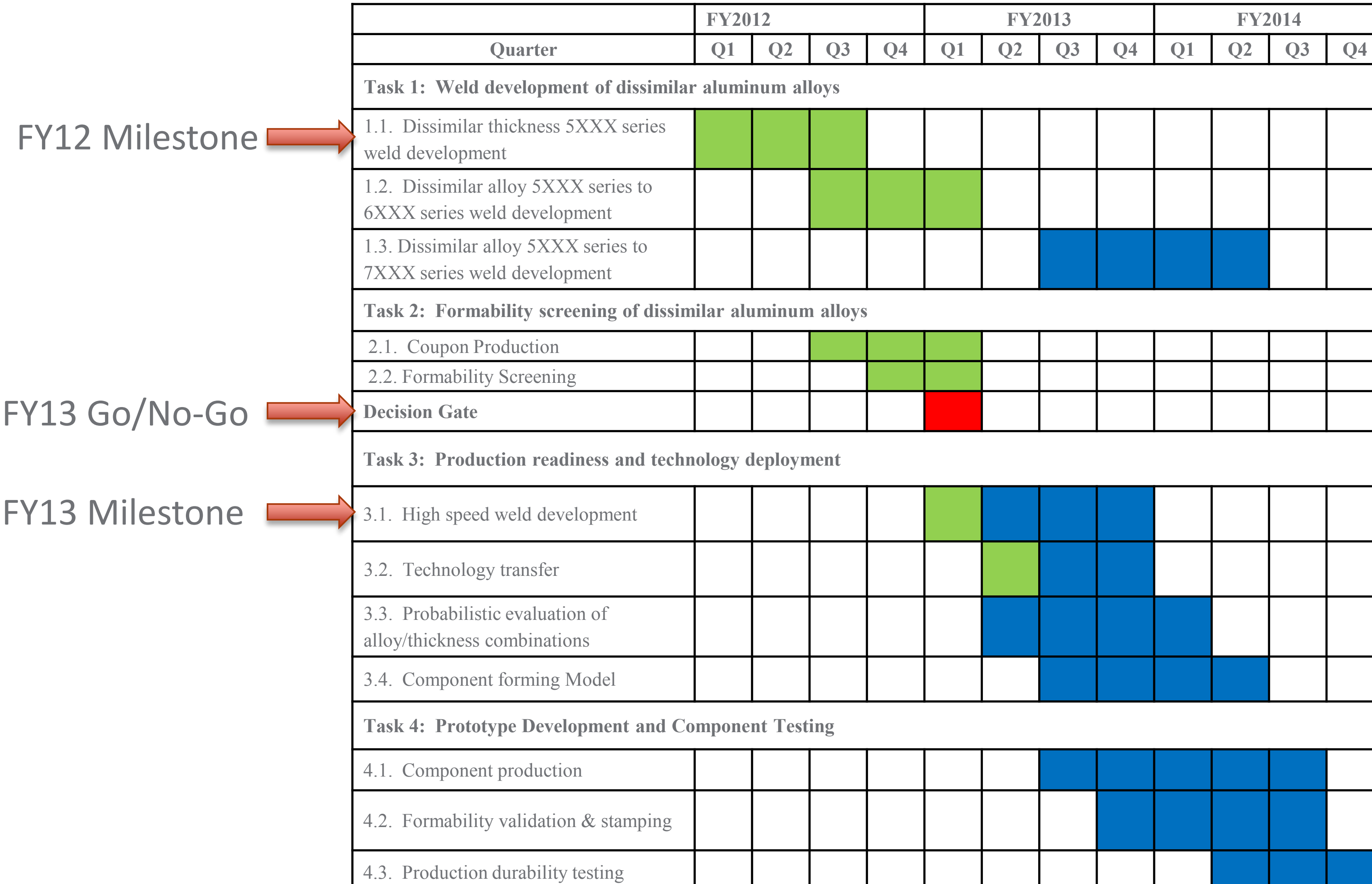




Evaluating Laser – single spot & double spot, laser-hybrid, and friction stir welding

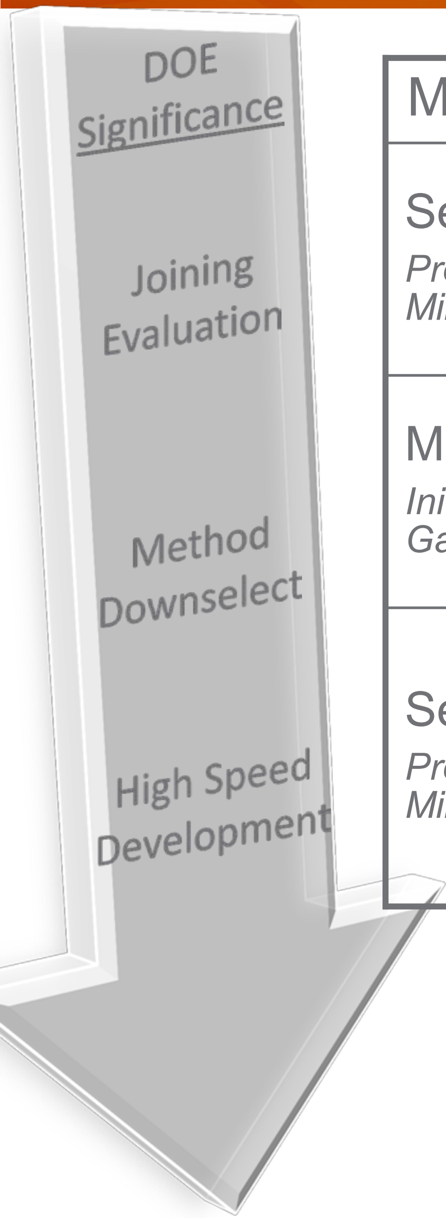
Project Schedule and Progress

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*



Relevance: Project Milestones

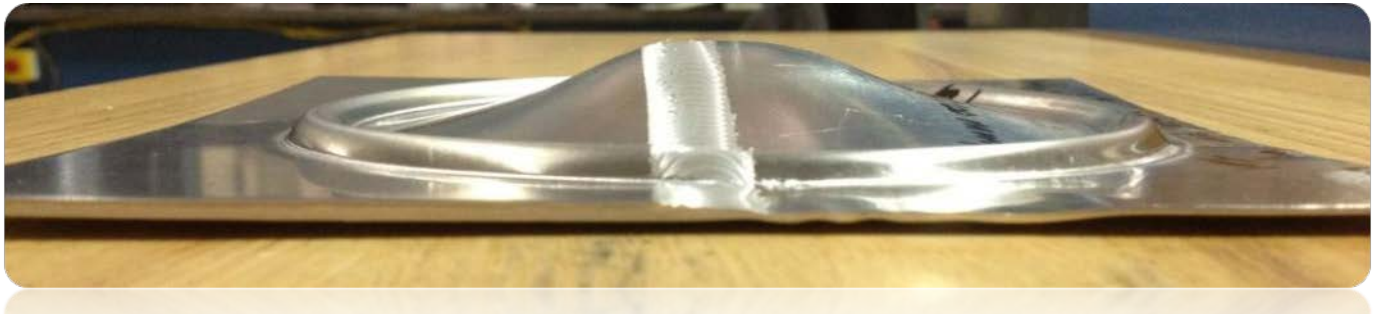
Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965



Month/Year	Milestone or Go/No-Go Decision
Sept. 2012 *Progress Milestone*	**Complete Initial Joining Comparison** Evaluate the performance of best in class laser, laser/hybrid and friction stir welding technologies for joining dissimilar aluminum TWBs.
May 2013 *Initial Decision Gate*	**Down-select Joining Method** Choose the joining method best suited for high speed quality blank production based on geometric weld quality criteria, surface finish and formability
Sept 2013 *Progress Milestone*	**Initiate high speed weld development** Develop weld parameters demonstrating a 30% increase in weld speed with reduction in formability or other quality criteria.

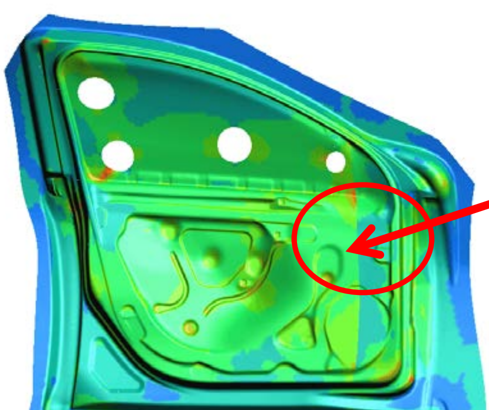
Technical Approach

- **Task 1: Weld development of dissimilar aluminum alloys**
  - Task 1.1. Dissimilar thickness 5XXX series weld development
    - Evaluate current welding methods for welding dissimilar thickness
  - Task 1.2. Dissimilar alloy 5XXX series to 6XXX series weld
    - Evaluate current welding methods for welding dissimilar alloy
  - Task 1.3. Dissimilar alloy 5XXX series to 7XXX series weld development
    - Evaluate FSW for high strength alloy combinations
- **Task 2: Formability screening of dissimilar aluminum alloys**
  - Task 2.1. Coupon Production
  - Task 2.2. Formability Screening
    - **Decision Gate:**
      - **Determine the appropriate welding method from laser, laser-hybrid, laser-plasma, & FSW**



Technical Approach (con't)

- **Task 3: Production readiness and deployability**
  - Task 3.1. High speed weld development
  - Task 3.2. Technology transfer
    - Transfer welding technology into the supply chain (TWB Company)
  - Task 3.3. Probabilistic evaluation of alloy/gauge combinations
  - Task 3.4. Component forming Model
    - Feed forward probabilistic bounds into the forming model to more accurately predict weld failures in the stamping process
- **Task 4: Prototype Development and Component Testing**
  - Task 4.1. Component production
  - Task 4.2. Formability validation & stamping
  - Task 4.3. Production durability testing

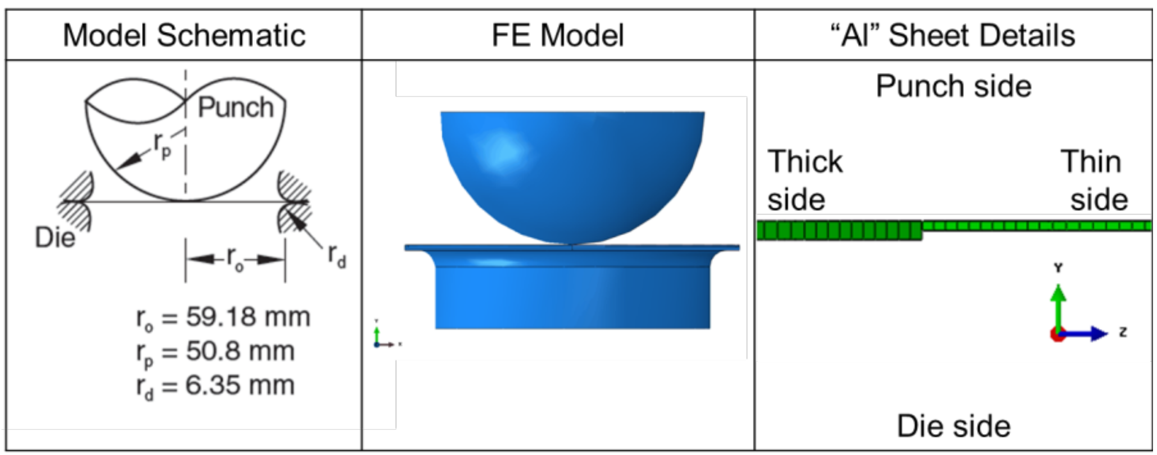


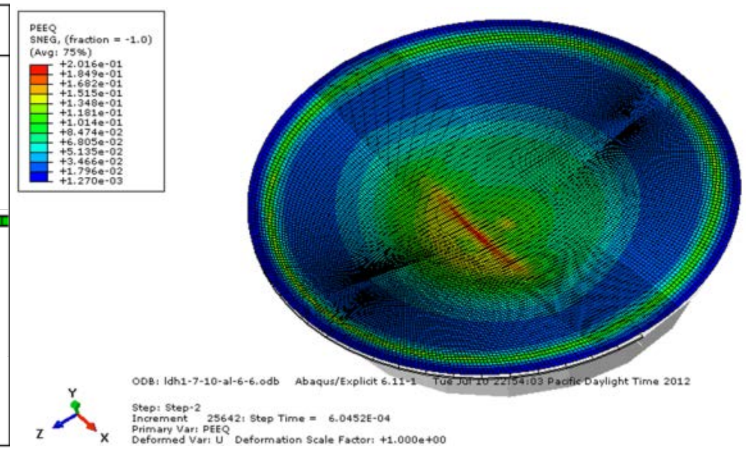
Split Predicted

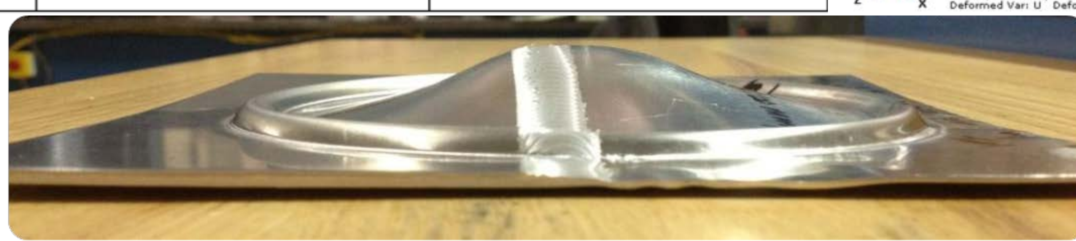
No Split, Actual

Technical Accomplishments: Limited Dome Height Testing

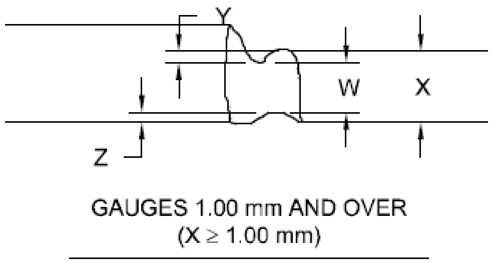
- Formability Screening of dissimilar thickness welded blanks
  - Height & load at failure measured
  - Predicted failure was outside weld in the thin sheet for 2-mm to 1-mm joints
    - Failure related to geometric discontinuity rather than the weld







Technical Accomplishments: Applying Weld Quality Specifications

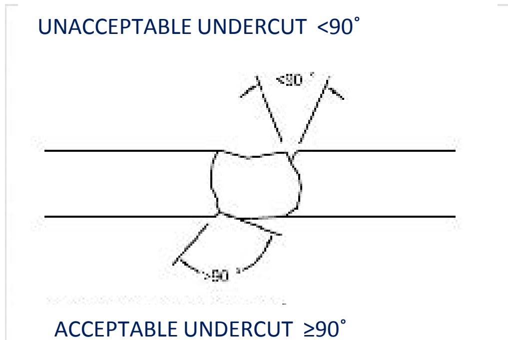


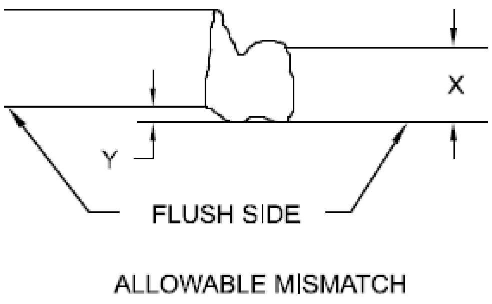
$\frac{Y}{X} \leq 0.20$

$\frac{Z}{X} \leq 0.20$

$\frac{Y+Z}{X} \leq 0.20$

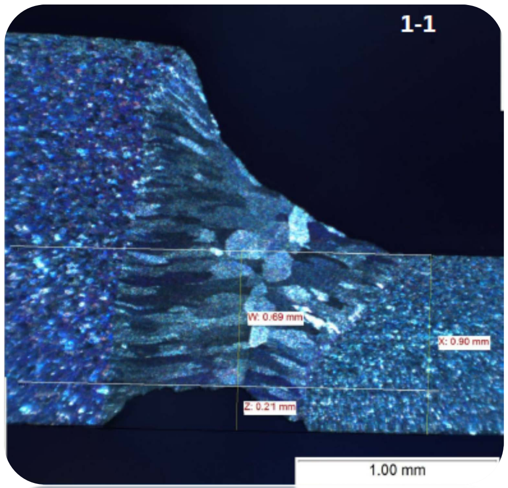
$W \geq 0.80$ OF X



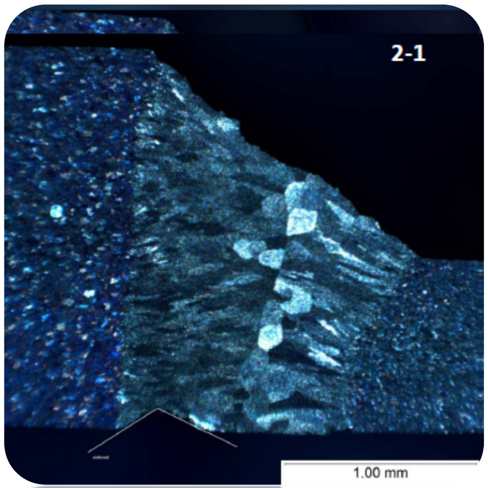


$\frac{Y}{X} \leq 0.10$

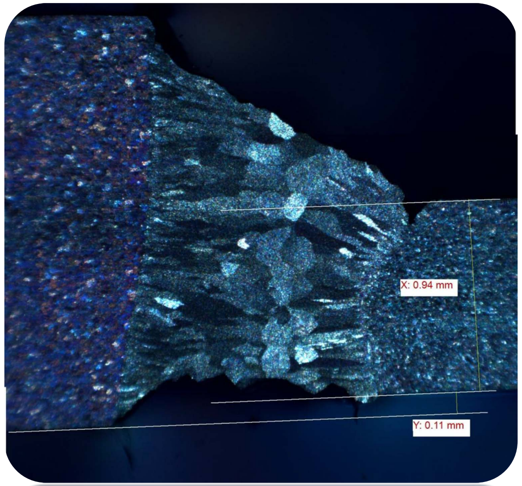
Single Spot - Concavity



Twin Spot - Undercut



Twin Spot - Mismatch



Technical Accomplishments: Down Selecting a Joining Technology

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- FSW maintained the highest formability in LDH screening tests
  - Laser twin spot (across the joint) performed similarly at higher weld speeds
  - Weld materials
    - 2.0-mm 5182-O to 0.9-mm 5182-O
- LDH screening tests alone were insufficient to determine most suitable welding method

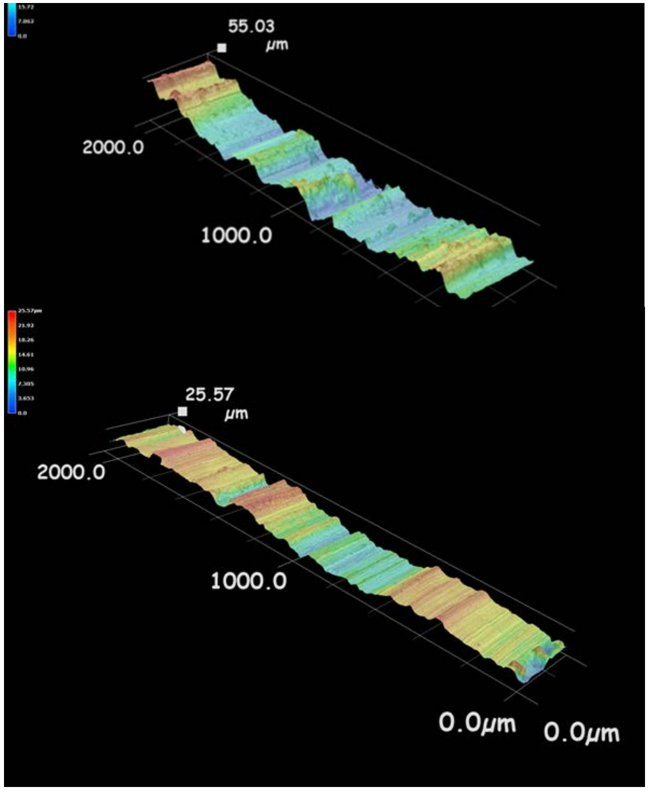
Weld Process	Dome Height (mm)	Concavity (Z/X ≤ 0.2)	Convexity (Z/X ≤ 0.1)	Mismatch (Y/X ≤ 0.1)	Undercut (Angle ≥ 90˚)
Single Spot	11.7 ± 0.3	0.22 – 0.23	/	/	/
Twin Spot (across weld)	15.1 ± 0.4	/	/	0 – 0.21	116 - 180
Twin Spot (along weld)	14.3 ± 1.0	0.19 – 0.36	/	0.12 – 0.25	51 - 180
Laser-Plasma	11.9 ± 4.0	0 – 0.28	0.31 – 0.69	/	/
FSW	15.4 ± 0.5	/	/	/	/

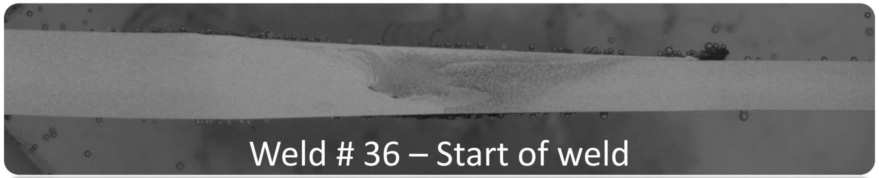
Technical Accomplishments: High Speed FSW Development

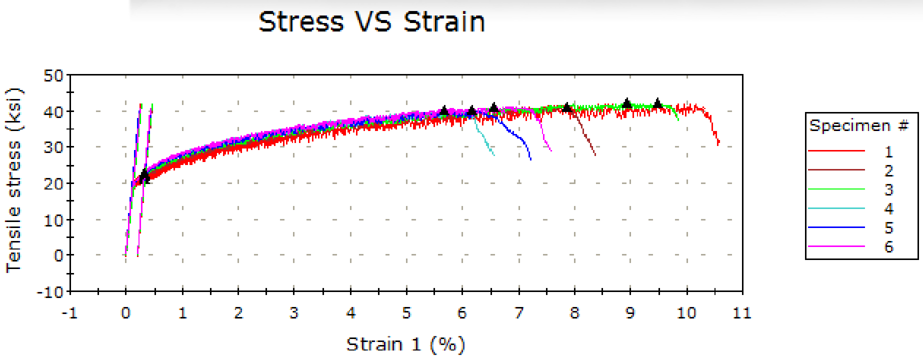
- 3-m/min and higher
- Taguchi Orthogonal Array Design L36
  - 8 factors
  - 36 runs
  - 2 repeats
  - Total tests 144
- Avoids the Sheer number of tests with traditional factorial DOE
  - 864 variations with no repeats for each material set
  - 3,456 to cover same test set

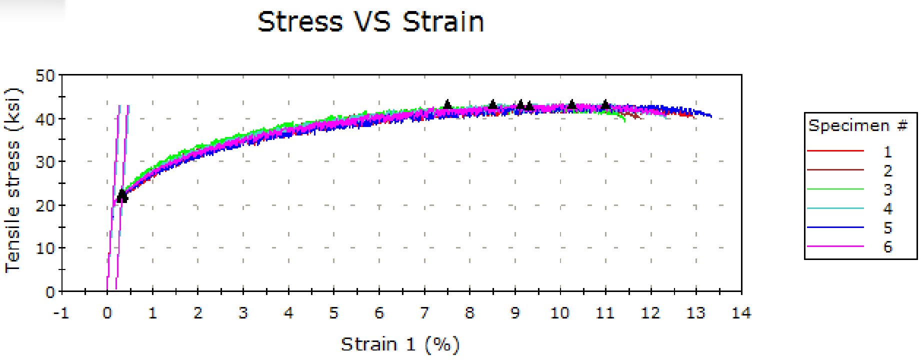
Technical Accomplishments: Numerically Driven Evaluation

- DOE designed to evaluate the statistical effects of 8 factors
  - Quantify the responses to the following:
    - Surface roughness & Flash
      - Weld #29 (±25μm)
      - Weld #36 (±15μm)
    - Formability
    - Mechanical Properties
      - Repeatability, failure mechanism, values









Collaborations

- University Collaborators
  - Washington State University
    - Characterization and analysis of process on properties
  - Mississippi State University
    - Real time defect detection in FSWs
- Private Collaborations (complete automotive supply chain)
  - General Motors
    - Laser Welding Evaluation, Formability Modeling & Durability
  - TWB Company, LLC.
    - Welding, stamping evaluation, high speed production
  - Alcoa
    - Material provider, high temperature material properties, formability

Proposed Future Work

- Summer 2013: Initial stamping run produced at PNNL
  - Stamp 25 door inners made from dissimilar thickness AA5182 welded at 3 m/min
  - Stamp 25 door inners made from dissimilar alloy AA5182/AA6022 welded at 3 m/min
- May 2013 – Dec 2013: High Speed Development
  - Develop weld parameters for 4 m/min and beyond (goal of 6 m/min) in both dissimilar alloy and dissimilar thickness alloy combinations
  - 4-5 m/min welds scheduled for development at GM R&D center
  - 6 m/min welding trials to be develop at TWB Inc., Monroe MI (supplier)
- FY13 – FY14: Probabilistic evaluation of alloy/gauge combinations
  - Develop Component forming Model based on statistical FLD
    - Feed forward probabilistic bounds into the forming model to more accurately predict weld failures in the stamping process

Project Summary

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- When evaluated side-by-side, friction stir welding was the only joining technology to pass all weld quality specifications for Al TWBs
  - Formability screening alone for 2:1 applications was inconclusive
- Wide range of parameters exists for welding at 3 meters/min
  - Evaluation of quantitative effects allows for numerically driven selection
    - Limited Dome Height, stamping
    - Mechanical properties, microhardness, surface roughness
- Technology Transfer: High speed 5-axis FSW machine being pursued by TWB Company for production FSW of aluminum tailor-welded panels
  - Capable of curvilinear welding
  - Goal: FSW weld speeds at 6 m/min with more accurate formability modeling

Technical Back-Up Slides

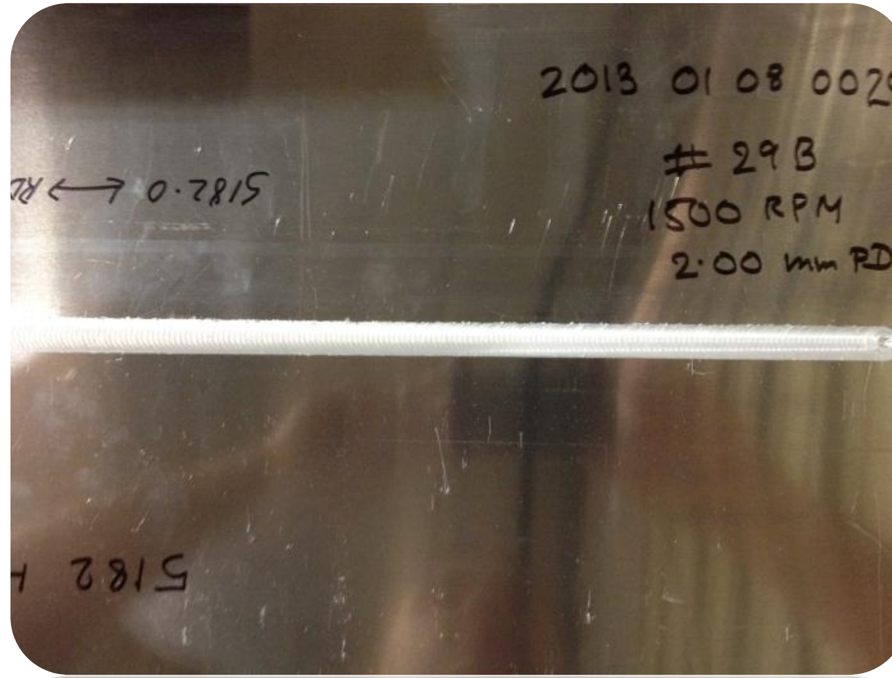
Initial Taguchi DOE: Welds at fixed 3 m/min

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

- Plunge Depth
  - High (1.85-mm), Low (2.00-mm)
- Tool Tilt
  - High (1º), low (zero tilt)
- Anvil Tilt
  - Tangent (3.82º), less (3.00º)
- Pin Diameter
  - High (2.5:1 S/P ratio), Low (3:1 S/P ratio)
- Number of Shoulder Scrolls (2 or 1)
- Rotational Velocity
  - High (1950), Med (1500), Low (1100)
- Pin Features
  - Taper, Flats, Threads
- Pin Length
  - 1.5-mm, 1.75-mm, 2.0-mm

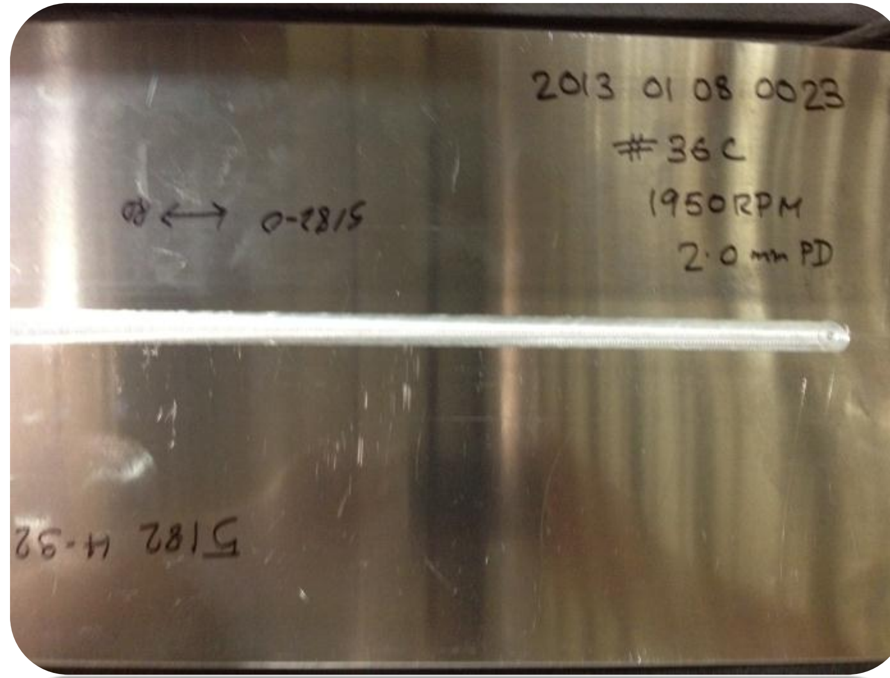
Weld #29B-C: 1.2-mm 5182-O to 2.0-mm 5182-O

- Tool: H13-2.0-TA-1F-3:1-A
- Rotational Velocity: 1500 RPM
- Plunge Depth: 2.00-mm
- Z-actual: -1.79-mm
- Tool Tilt: 1º
- Anvil Tilt: Less than Tangent (3º)
- Minor intermittent flash ret. Side
- Possible NDE candidate



Weld #36B-C: 1.2-mm 5182-O to 2.0-mm 5182-O

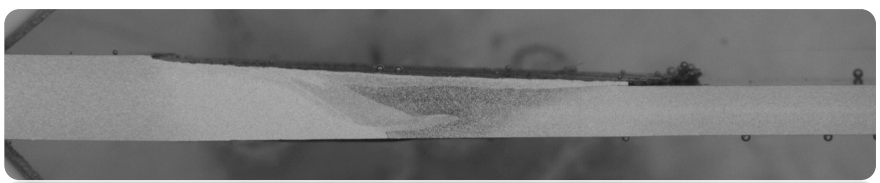
- Tool: H13-2.0-FL-2F-3:1-A
- Rotational Velocity: 1950 RPM
- Plunge Depth: 2.00-mm
- Z-actual: -1.75-mm
- Tool Tilt: 1º
- Anvil Tilt: Tangent (3.82º)
- Nice looking weld
- Good for NDE



Comparison of Cross-section: #29 vs #36

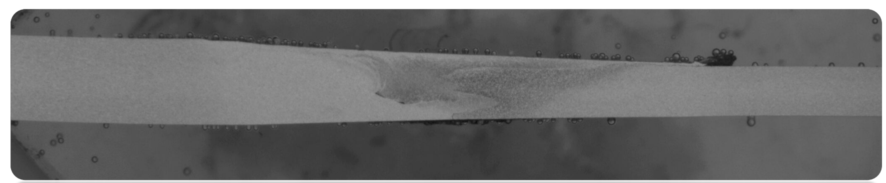
- 610-mm weld panels (24")
- Uniform weld conditions across the length of the panel
- Pin and shoulder features varied (taper vs. flats / single vs. double)
- Rotational velocities differed (1500 vs. 1950)
- Weld #29 – less rotational velocity and less features
  - Lower overall heat input

Weld # 29 – Start of weld



Weld # 29 – end of weld

Weld # 36 – Start of weld



Weld # 29 – end of weld