Project ID: LM030

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Friction Stir Spot Welding of Advanced High Strength Steels II

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Project Overview

Project Timeline

- Start: 2010
- Finish: 2012
- 60% complete

Technology Gaps/Barriers

- FSSW of AHSS has only been demonstrated in limited capacity
- Tool life and Deployment issues have yet to be answered
- Many AHSS alloys and stack up geometries are problematic for RSW

Budget

- Total project funding
  - DOE – $1.0M
  - 50/50 Split with ORNL/PNNL
- FY10 Funding - $500K
- FY11 Funding - $500K

Partners

- USCAR Joining team
  - GM & Chrysler
- Commercial automotive sheet vendors
  - Arcelor Mittal, GeStamp-HardTech & US-Steel
- Tool Manufacturers / Material Providers
  - MegaStir & Ceradyne
- Universities
  - BYU and U. of Michigan

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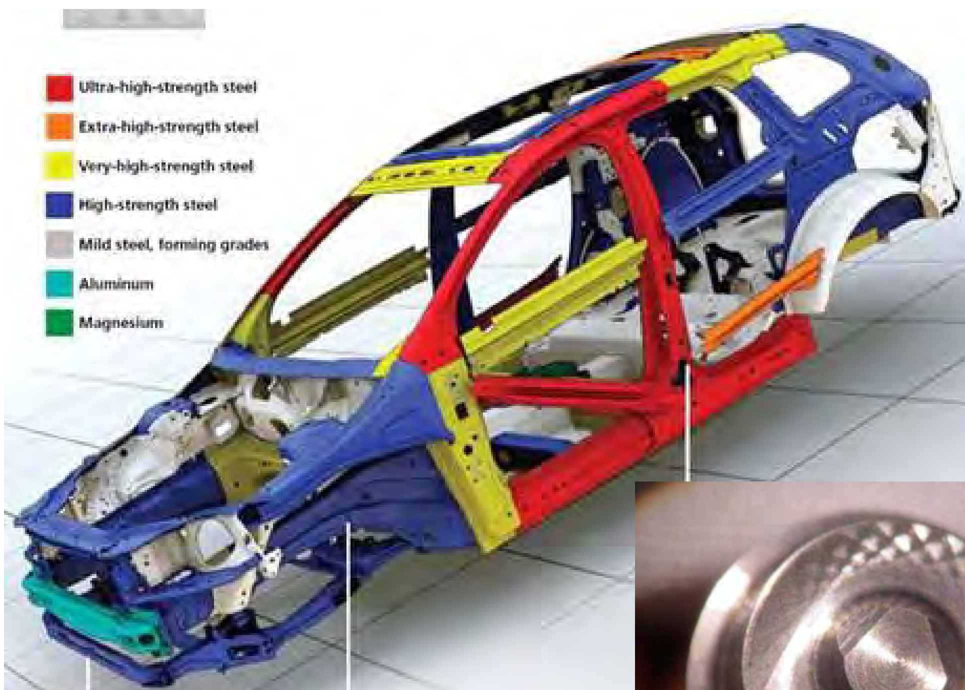
Relevance: Project Motivation

- Future B-I-W will be hybrid of many materials. Some of those, especially Advanced High Strength Steels, are presenting a challenge to conventional joining methodologies.
- FSSW may enable implementation of additional alloy combinations and stack-ups that provide additional weight and cost savings



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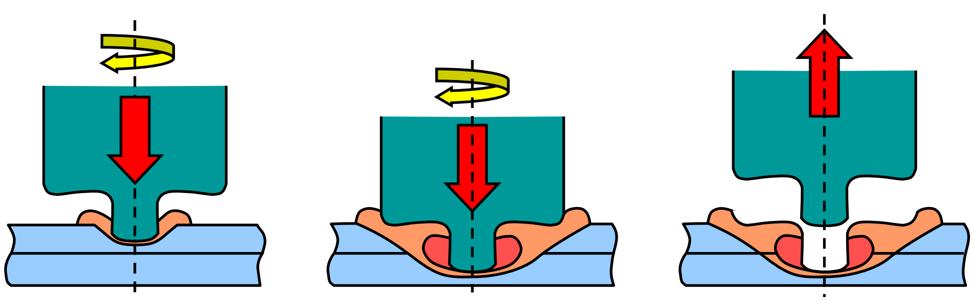
Relevance: Project Goal and Objectives

Demonstrate that friction stir spot welding (FSSW) is an acceptable, cost effective alternative for AHSS that are difficult to resistance spot weld (RSW) and that FSSW may enable down-gaging of sheet thickness through unequal/dissimilar material stacks

Objectives:

1. Enable joining of AHSS alloys in unequal metal thickness stacks (which respond poorly to RSW techniques)
2. Develop more comprehensive information about mechanical properties including T-peel behavior, cross-tension strength, fatigue strength, impact behavior, of AHSS joints produced via FSSW.
3. Determine comparative information related to stir tool durability, weld quality and supply chain
4. Identify remaining issues preventing high production deployment



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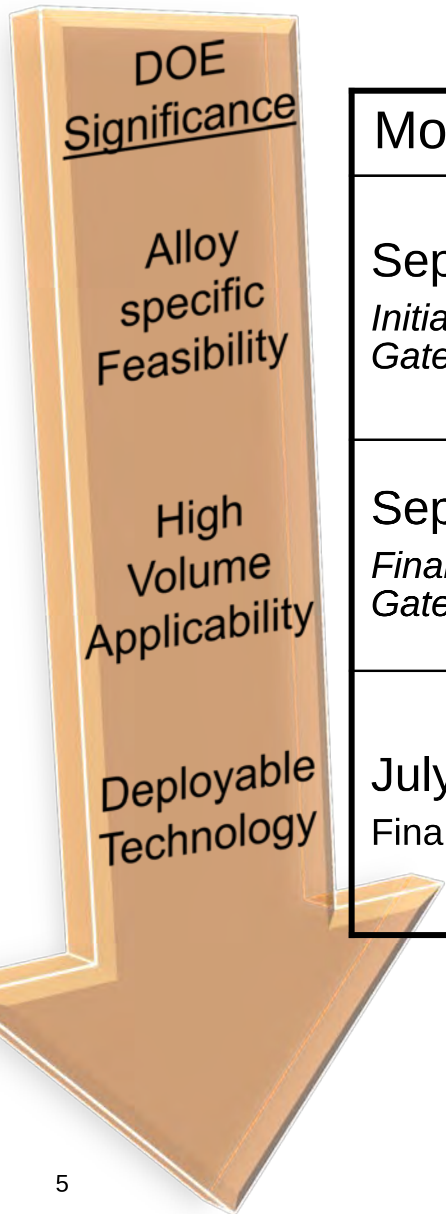
Relevance: Project Milestones



Month/Year	Milestone or Go/No-Go Decision
Sept. 2010 *Initial Decision Gate*	**Achieve Structural Joints with FSSWs in AHSS that are problematic to RSW** Achieve the minimum tensile strength criteria specified in AWS D8.1 in down selected alloys (standard is material/ thickness/property/size specific)
Sept. 2011 *Final Decision Gate*	**Demonstrate Tool Life of Probable Materials** Determine the joining cost associated with FSSW based on wear studies up to 5000 welds to update the comparative cost model.
July 2012 Final Milestone	**Complete Evaluation of Process Deployability** Determine compatibility with current machinery and manufacturing techniques including identifying possible “show-stopper” issues related to direct technology deployment.

Current Progress and Scheduled Work

- ✓ Completed Initial Evaluation of FSSW of AHSS (FY06-FY09)
- ✓ Demonstrated FSSW of Dissimilar AHSS alloys
- ✓ Accelerated Tool Material Testing
- ✓ Accelerated cost comparison and robot compatability

	Fiscal Year 2009				Fiscal Year 2010				Fiscal Year 2011				Fiscal Year 2012			
Quarter	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4
Task 1: FSSW Process Development for AHSS																
✓ 1.1 Material Selection																
✓ 1.2 FSSW property/process relationships for AHSS																
✓ **Decision Gate**																
Task 2: Characterization of Joint Interface																
2.1 Joint Characterization																
2.2 Zinc effects in weld																
Task 3: Evaluation of Tool Materials																
3.1 Determine test and tool																
3.2 Stir tool durability tests																
Decision Gate																
Task 4: Assessment of Deployment Issues																
4.1 Testing to compare welds made by FSSW and RSW																
4.2 Cost Model to compare FSSW with RSW																
4.3 Assess compatibility with existing robots and other assembly equipment																

Completed work

Completed Decision Gate

Future Decision Gate

Future Work

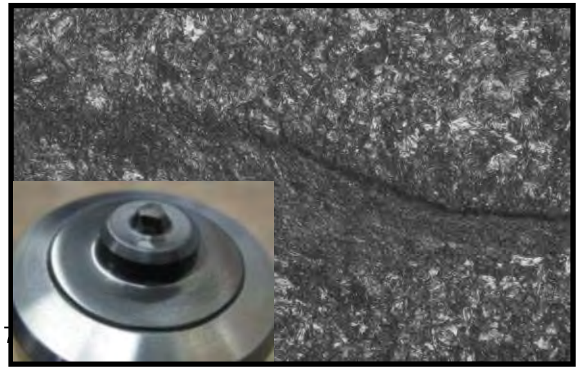
Near Term Gate

Technical Approach:

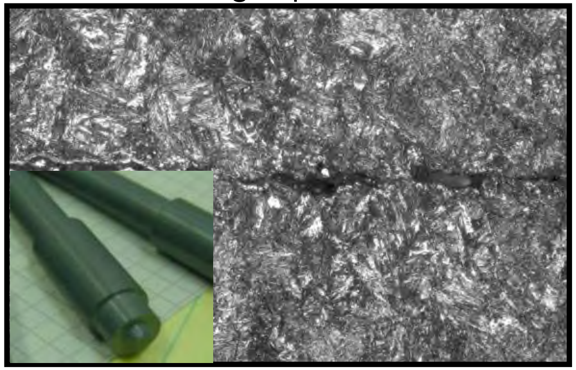
- Task 1: FSSW process development
  - OEM selected alloys
    - Alloys with problematic RSW performance
    - Dissimilar stack-ups (alloy/thickness)
  - Initial Strength Gate

- Task 2: Characterization of the Joint Interface
  - Determine the functional relationships between process parameters and joint properties
  - Evaluate the influence of coatings (TRIP – liquid metal embrittlement)

PCBN tool



Si_3N_4 tool



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Technical Approach:

- Task 3: Tool Durability
  - Evaluate tool life of PCBN & SiN tool materials and the influence on cost
  - Interim Milestone:
    - Demonstrate tool life in specific alloy combinations with strengths exceeding AWS strength minimums

Robotic Friction Stir Joining

Courtesy of Kawasaki Robotics

- Task 4: Assess Process Deployment
  - Collaborate with Equipment and Tool Manufacturers
  - Identify and evaluate remaining critical needs for industry embodiment of FSSW of AHSS
  - Validate FSSW parameter needs with existing industrial technology (robots, pedestal stations, etc.)

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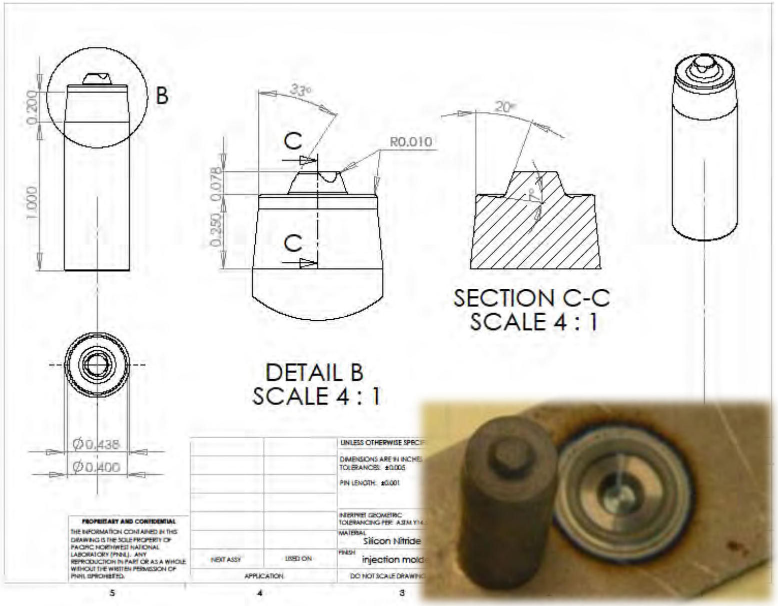
FY2010 Accomplishment: Low-cost Tooling Manufacturing Development

- Direct injection molding of Silicon Nitride
  - Introduces volume sensitivity
  - Production Cost Projections:

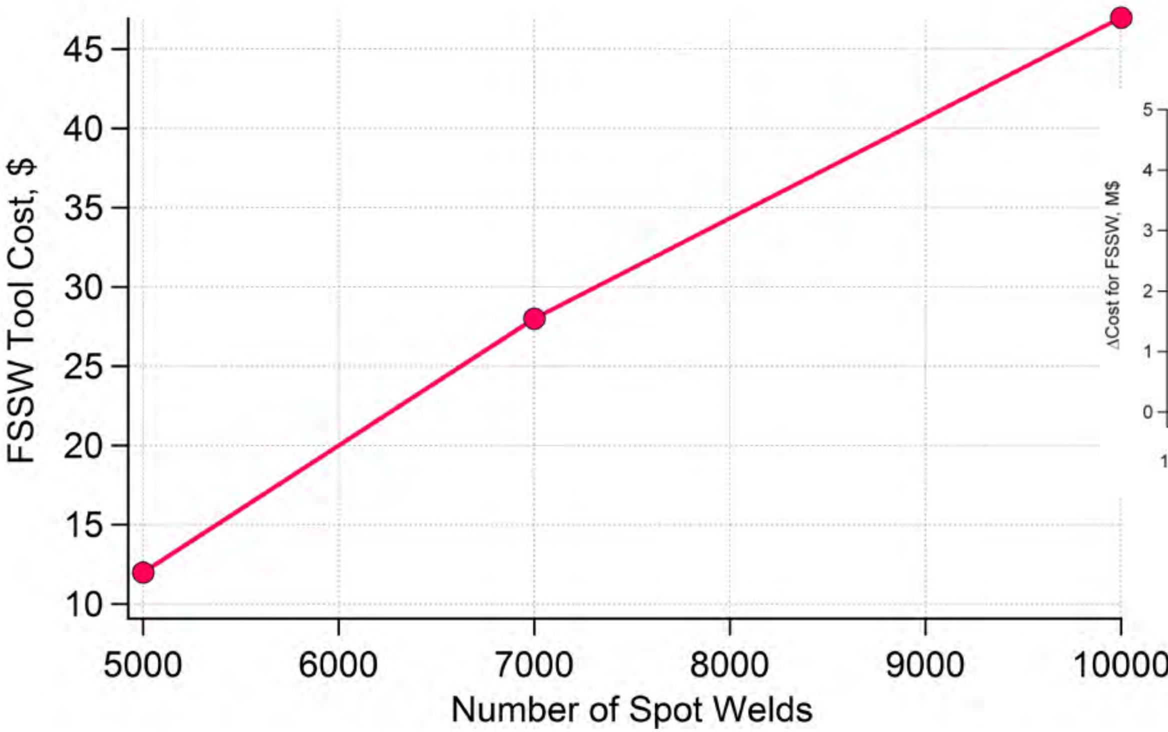
Silicon Nitride - Injection Molded
8-10 week lead time 25 pcs $100.00 / pc
8-10 week lead time 50 pcs $85.00 / pc
8-10 week lead time 100 pcs $75.00 / pc
10-12 week lead time 1,000 pcs $40.00 / pc
10-12 week lead time 10,000 pcs $27.00 / pc

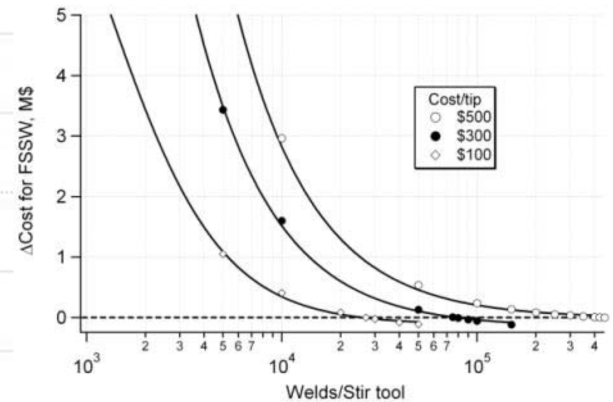


- PCBN tools are being designed for FSSW
  - Cost will be sensitive to volume, and amenable to scalable economics

FY2010 Accomplishment: Updated Cost Comparisons

- Plot demonstrating the functional relationship between tool cost and durability to reach cost parity with RSW

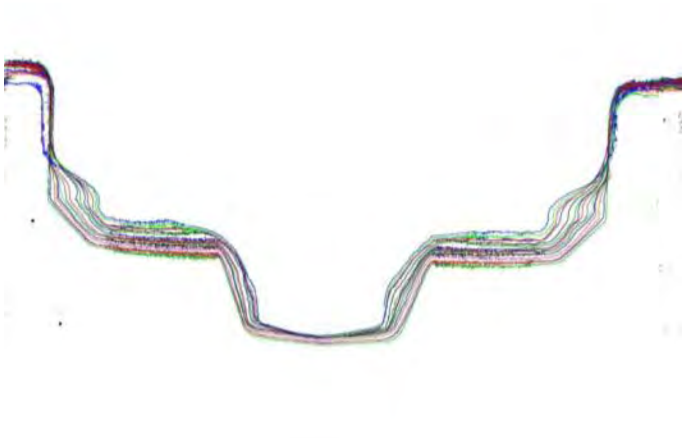


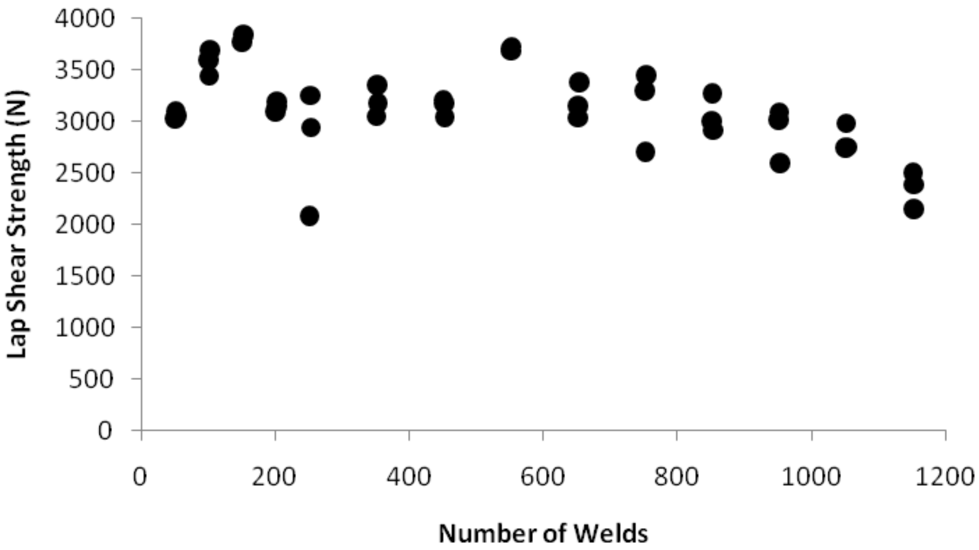


Cost comparisons between RSW and FSSW based on tools cost $100 and more

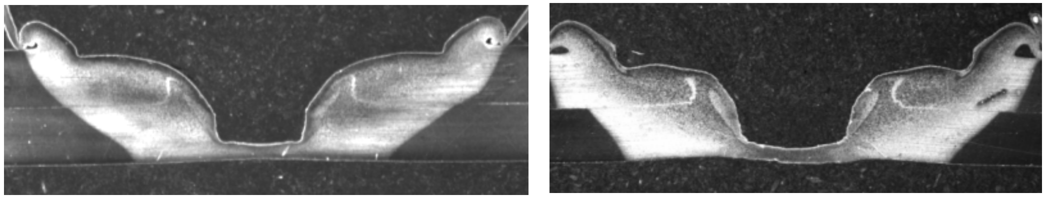
Previous estimates evaluated $100/tool as the stretch goal – today we're looking to $10

FY2010 Accomplishment: Tool Wear Characterization





- Wear Studies of PCBN Composite materials (Q60 & Q70 completed)
- Lap shear strength maintained above AWS minimum (11.09 kN / 2,493 lbs) for more than 1000 welds in DP980



Cross-sections after 1000 welds for Q60 (left) and Q70 (right) tools

FY2010 Accomplishment: Dissimilar Joining of AHSS

- AHSS combinations with near-term impact and applicability
  - TRIP 800 to DP1000 or HSBS
  - TRIP980 to HSBS, mild steel or similar
  - HSBS to mild steel, TRIP, DP

Rail Assembly – Roof Outer Side
Courtesy GM

AHSS Alloys	RPM	Plunge Steps	Max Tool Load (kN)	Max Temp (^{0}C)	Avg. LSS (kN)	AWS Minimum (kN)
TRIP590 to DP780	800	2	29.1	341	11.0	7.98 -10.32
DP780 to TRIP590	800	2	32.6	327	10.9	10.32-7.98
DP980 to TRIP780	800	1	20.8	204	11.4	11.09 – 10.32
HSBS to TRIP780	1600	2	15.1	305	5.7	12.22 – 10.32
DP780GA to HSBS	800	1	22.2	177	9.2	10.32 -12.22
DP780GA to HSBS	800	2	29.2	240	11.5	10.32-12.22

Sampling of Dissimilar FSSW Data

Collaborations

- DOE & University Collaborations
  - Joint project with 50/50 split between ORNL/PNNL
  - BYU – Tool wear characterization, high speed development
  - U. of Mich. – Fatigue testing of AHSS joints
- Private Collaborations
  - MegaStir - Tool Material Development
  - Ceradyne – low cost tool manufacturing using Dim process
  - GeStamp, ArcelorMittal, US-Steel – providing relevant materials
  - Chrysler – steering committee & provides relevant joint designs
  - GM – steering committee, relevant joint designs & coated materials

Proposed Future Work

- Tool Durability Characterization
  - Complete PCBN variations and test DIM SiN materials
- Low-cost tool manufacturing
  - Provide feedback (tool loads, wear characteristics, torque, etc.) to tool manufactures allowing for the next leap in tooling technology
- Dissimilar FSSW development
  - Determine functional relationships between process parameters, tool materials and joint strength
- Joint Characterization
  - Evaluate the joint interface, coating effects, and fracture surfaces to improve overall weldability
- Process Deployment Analysis
  - Work with equipment and tool suppliers to outline problems currently preventing deployment and identify final work needed commercialize the technology

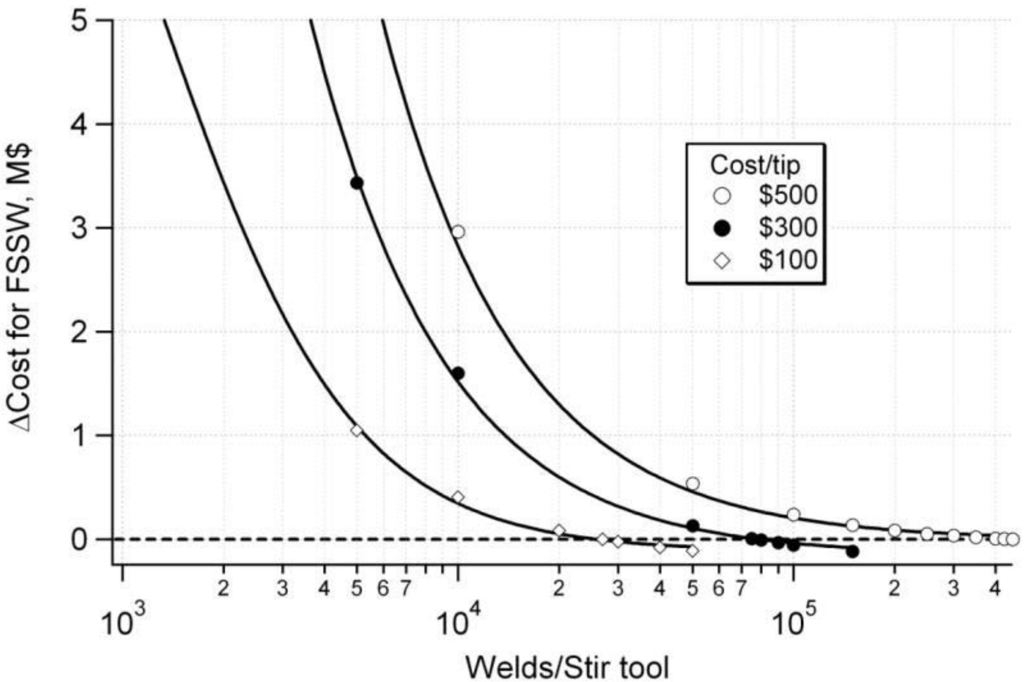
Summary and Status

- FSSW made in selection of dissimilar AHSS alloys compiled by OEM industry consultants
  - problematic alloys, combinations & coatings with near term applicability
- Tool Material Wear Testing
  - Characterization of both Q60 and Q70 materials completed
    - Validation of Q70 beyond 1000 welds at strengths exceeding AWS minimums
  - Additional materials are currently being tested
- Low cost tool manufacturing development
  - Direct injection molding process utilized with Silicon Nitride
    - Ceradyne process may provide two order of magnitude reduction in tooling cost for FSSW
    - Initial results using DIM tooling looks promising

Supplemental Slides

Modeling Cost Differentials: FSSW vs RSW

- Modeling Assumptions:
  - Component required 46 spot welds to build.
  - 3 pedestal stations making 23 welds, and 3 robotic stations making 23 welds.
  - Annual production volume was 320,000 requiring a total of 14,720,000 welds/year.
  - Production rate was 85 components/hour.
  - Energy consumption was 2.1 W-h/weld for FSSW, and 3.9 W-h/weld for RSW.
  - The same teardown criteria were used for both processes.
  - RSW electrodes cost $0.65/tip and have a 5000 weld life



**FSSW tools costing $100 would need to survive 26,000 welds for cost parity*

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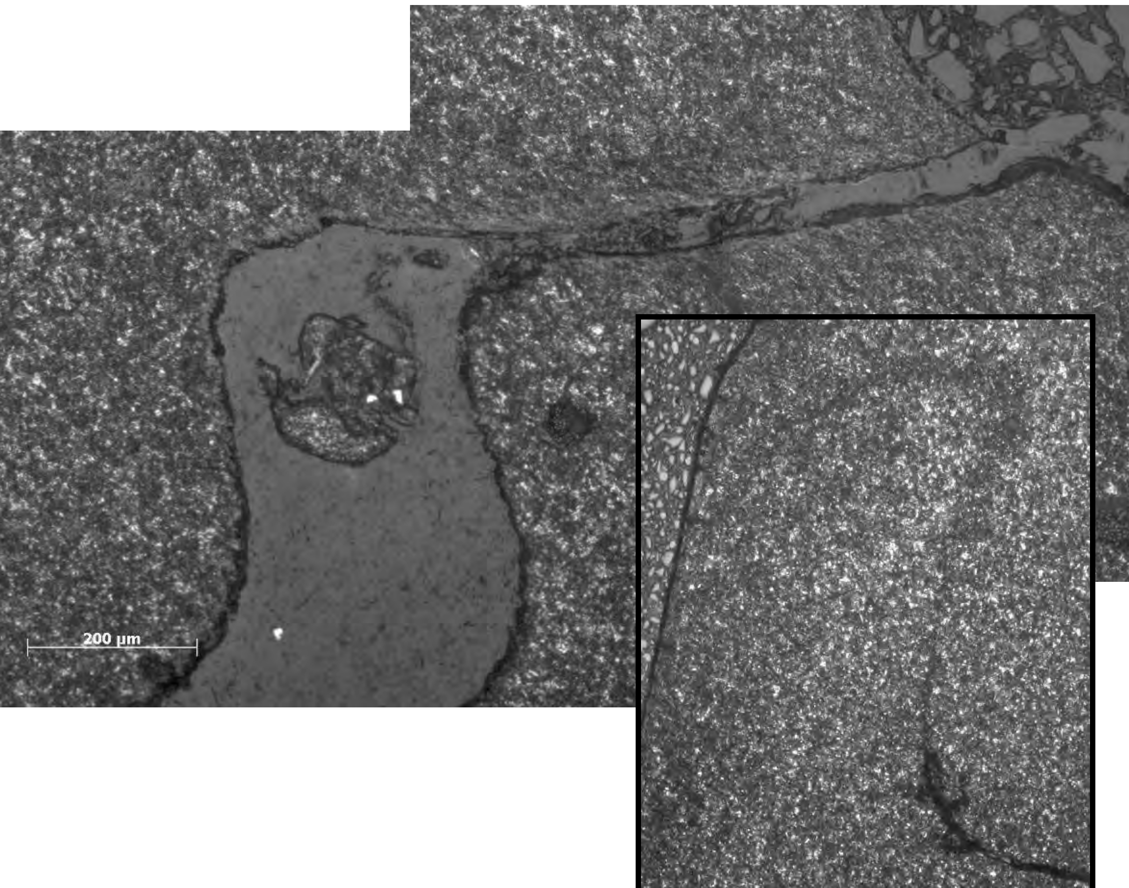
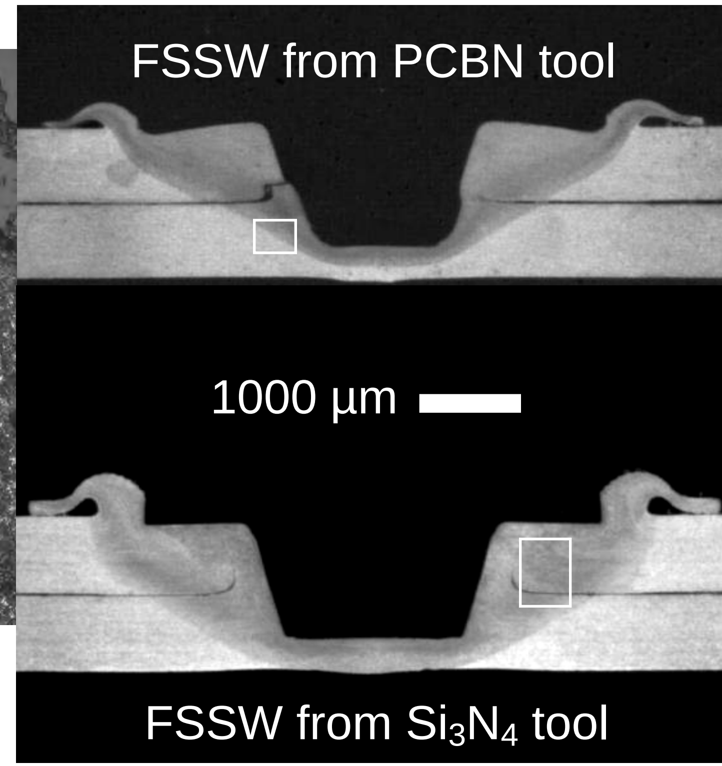
Tool Design	RPM	No. of Steps	Max. tool load (kN)	Max. temp. (°C)	Avg. lap-shear Strength with 95% CI (kN)
BN77	800	1	32.5	410	4.4 ± 0.25
SN77	800	1	21.2	508	9.7 ± 0.15





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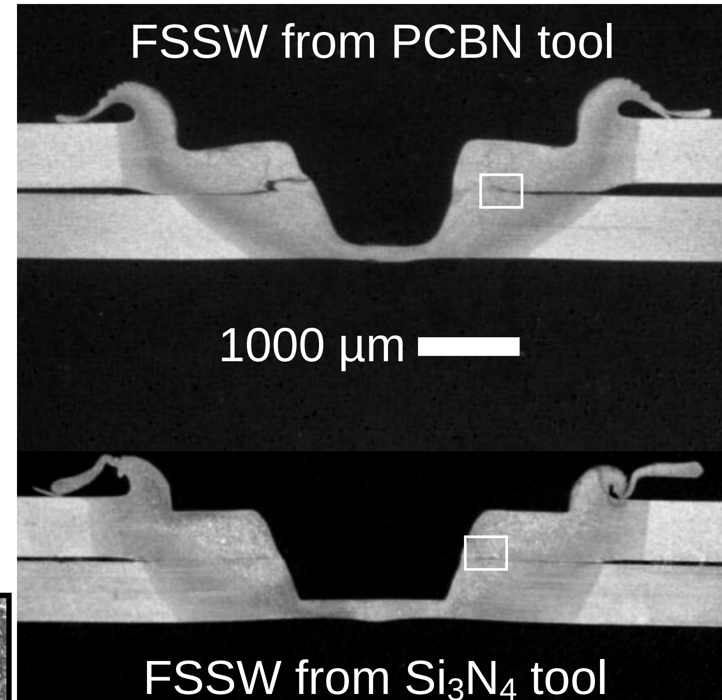
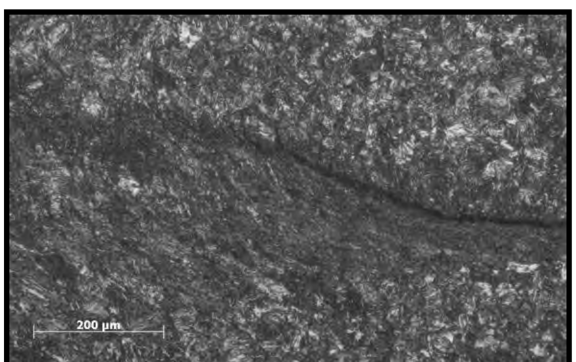
Tool Design	RPM	No. of Steps	Max. tool load (kN)	Max. temp. (° C)	Avg. lap-shear Strength with 95% CI (kN)
BN77	1600	2	31.3	716	11.1 ± 0.92
SN77	1600	2	20.1	806	6.8 ± 0.38

- Highest LSS using PCBN tool
  - Longest between hook and pin
- Unique failure using Si_3N_4 tool
  - Absence of any “hooked” surface l
  - Similar LSS to 800 RPM / 2 step with PCBN tool



PCBN tool



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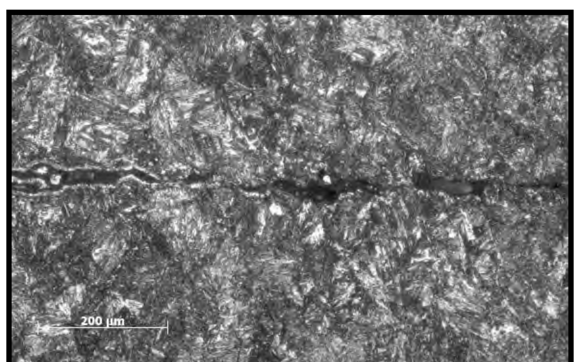

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