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Friction Stir Spot Welding of Advanced High Strength Steels

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Project Overview

Project Timeline:

- Start - 4th Quarter FY06
- Finish - 4th Quarter FY09
- 85% complete

ALM Budget:

- Total project funding:
  - PNNL: $670k
  - ORNL: $670k
- FY08 Funding Received:
  - PNNL: $220k
  - ORNL: $220k
- FY09 Funding:
  - PNNL: $100k
  - ORNL: $100k

Targets

- The FreedomCAR target for weight reduction of the vehicle and its subsystems is 50%.
  - "technology-specific goals; weight reduction and affordability"

Barriers

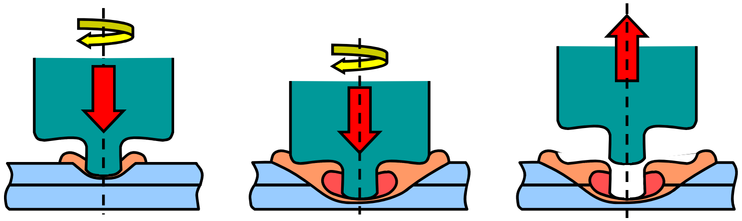
- AHSSs are seeing increased use in a strategy to down gauge the BIW while maintaining passenger crash protection. However many AHSS do not have a joining process that is reliable.
- Barriers to using FSSW in AHSS include:
  - Tool durability and cost
  - Cycle Time
  - Load limits of current robotic equipment

Partners

- OEM Steering Committee:
  - E. Hetrick (Ford), J. Quinn (GM), J. Beckham (Chrysler), S. Packer (Megastir), R. Bhatnagar (Mittal Steel), H. Andersson (Hardtech Gestamp)

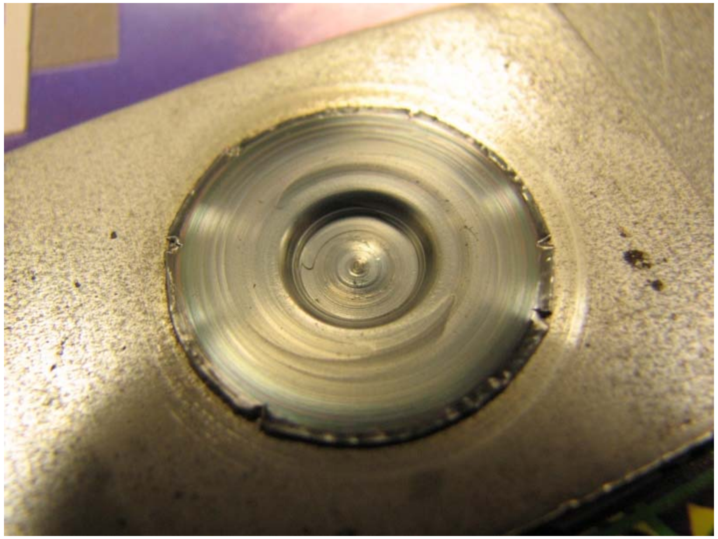
Objective: Evaluate the response of Advanced High Strength Steels to FSSW

- Previous years established viability of tooling and weld properties



Current Focus: Affordability of the Process

- Evaluate the effect of reducing weld times
  - Increased weld speed
- Determine the appropriate tool designs and materials
  - Lower tool costs (material or tool life)
  - Reduction in forge loads
  - Relaxed machine runout and stiffness
- Assess process robustness and tool durability
  - Repeatable mechanical properties
  - Applicability to variable surface conditions



FSSW in zinc coated DP780

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Milestones – FY2008 & FY2009

Month/Year	Milestone or Go/No-Go Decision
July 2008	Complete investigation into alternative tool materials and characterize wear performance of FSSW tooling
Sept. 2008	Compile database of FSSW performance in DP780 and HSBS steels including results of tool design studies
July 2009	Complete evaluation of the effects of tool materials on weld properties, and characterize comparative tool lifecycles.
Sept. 2009	Compile weld performance model addressing the influence of post-weld materials properties and static and dynamic loading conditions.

Approach to FSSW of AHSS

- Adapt FSW techniques used for steel to meet automotive FSSW requirements
  - defined by OEMs and existing FSSW technologies in Al alloys
- Validate available tool materials for application in several advanced high strength steels
  - Extensive testing of various operating parameters to determine efficacy and durability
- Evaluate the effect of tool materials & process parameters and joint performance
  - Verification of strength, durability and process repeatability
- Determine the effect of surface conditions, coatings, etc. of industrial applicable AHSS configurations
- Transfer results to industry

Recent Technical Accomplishments

- Completed investigation into alternative tool materials and selected Si_3N_4 as an alternative tool material
  - Based on tool life, mechanical properties and machine loads
- Compiled database of FSSW performance to date in DP780 and HSBS steels including process parameters, mechanical properties, and thermal and force feedback
- Evaluated the effect of reducing weld times
  - Weld times uniformly reduced to 4 seconds without reduction in mechanical properties
  - Further reduction possible for specific tool designs
- Assessed the effects of surface conditions including: as-received, surface ground, and coated conditions

Introduced Non-PCBN Tool Materials

- Only Si_3N_4 had acceptable performance
- Joint strengths comparable for Si_3N_4 and PCBN
- Si_3N_4 produced lower tool loads
- Lower process loads mean lower C-frame loading

Evaluated results of PCBN and Si_3N_4 Tools

All conditions are 4 second welds using a tapered 3-flat tool

Tool Material	RPM	# of Steps	Max Tool Load (kN)	Max Temp (°C)	Avg. LSS (kN)	Area (mm^2)
PCBN	800	1	32.5	410	4.4	7.7
		2	33.0	537	8.0	11.2
	1600	1	23.7	510	9.6	13.8
		2	31.3	641	11.2	15.2
*Si_3N_4	800	1	21.3	508	9.6	11.3
		2	30.1	681	10.6	14.1
	1600	1	20.1	649	6.6	9.2
		2	22.5	804	10.3	8.1

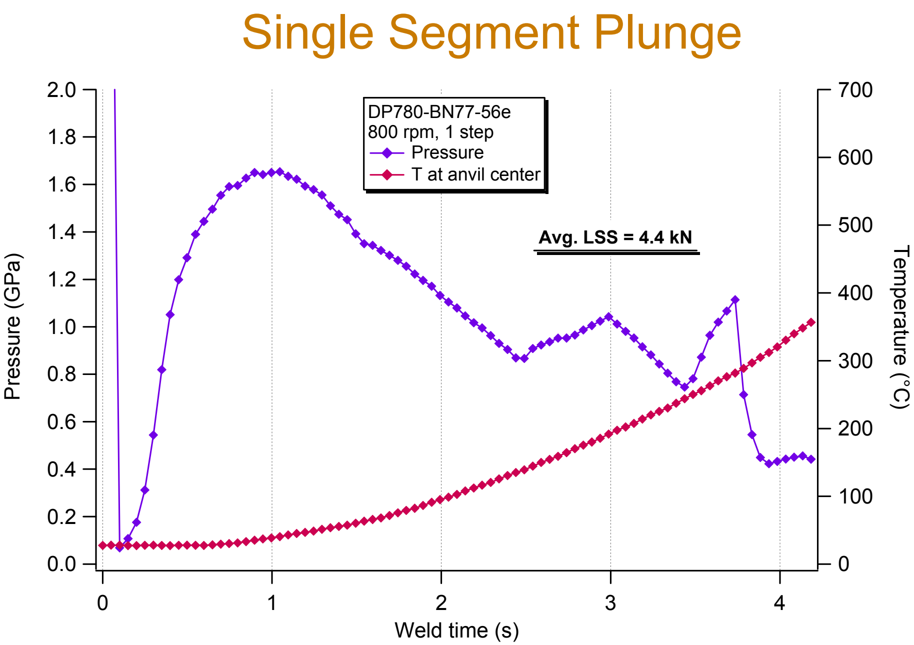
*Direct press and sintered Si_3N_4 tools can be volume fabricated at 5% of current PCBN tooling cost

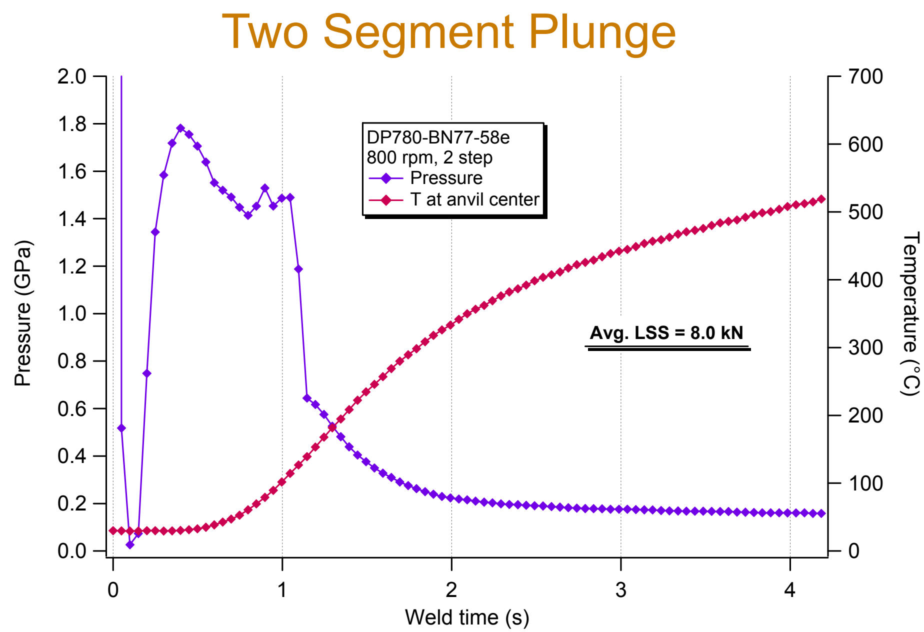
Weld Database - Tool Design: Effects on Process Loads and Mechanical Properties

Tool Designation	RPM	plunge steps (#)	Max Tool Load (kN)	Max Temp. (°C)	Avg. LSS (kN)	Failure Mode
BN77	800	1	32.5	410	4.4	Hook to Pin
		2	33.0	537	8.0	Hook to Pin
	1600	1	23.7	510	9.6	Hook to Pin
		2	31.3	641	11.2	Hook to Pin
BN97	800	1	27.6	453	12.7	Nugget pullout
		2	34.6	650	15.4	Nugget pullout
	1600	1	18.9	574	14.7	Nugget pullout
		2	21.7	767	15.2	Nugget pullout

- Second generation of PCBN tools designs increased heat in the weld yielding several benefits:
  - Increase in lap shear strength from 25%-65%
  - Reduction in process loads up to to 31%

Enabling Lower Weld Times: Pressure and Temperature Profiles





- *1-segment welds are characterized by pressure variability and modest temperature rise*
- *2-segment welds are characterized by steady pressures and higher temperatures*

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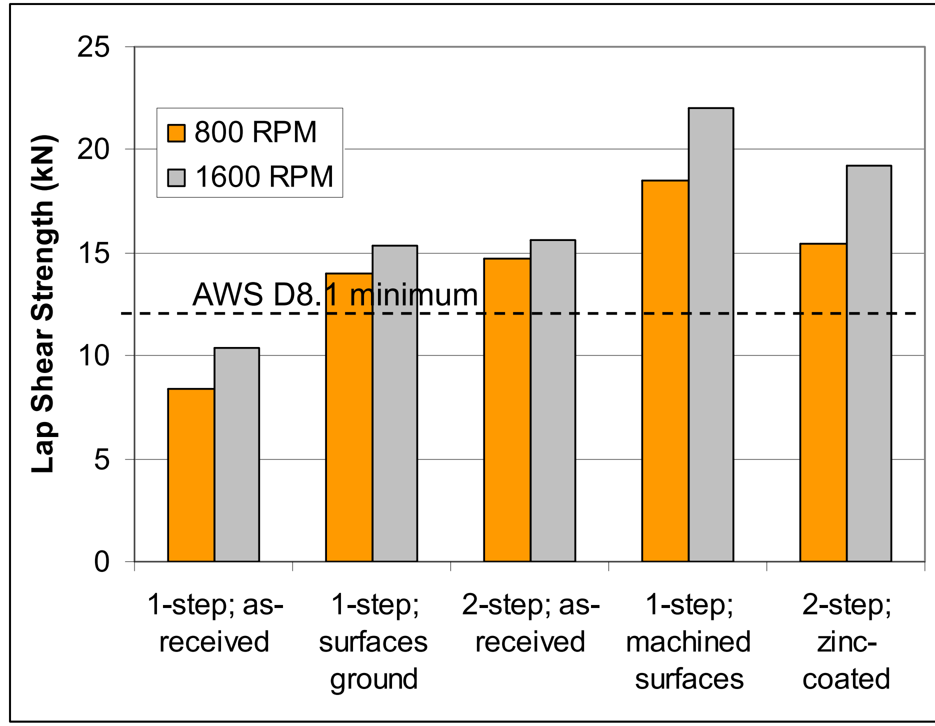
Reducing weld times: 4 second condition

- Extensive testing of 4 second condition
  - Acceptable tool loading for all tool designs
  - Several tool designs capable of further reductions
- AWS D8.1 minimum exceeded with various surface conditions:
  - Process parameters and tool design enabled lower weld times while maintaining adequate joint properties



Reported data based on average of 3+ welds with convex-scroll tool

Future Work – FY2009

<u>Project Close-out</u>

- FY09 milestones: includes work accessing tool life, fatigue, and performance model relating process parameters to joint properties
- Additional work: Based on OEM prioritization

<u>OEM Priorities:</u> "Cycle time and tool durability are critical for this technology to be used in automotive applications."

- (1) Cycle time minimization with a target of 2 seconds maximum.
- (2) Tool durability determination with testing continued until weld strength no longer meets the AWS minimum prescribed for RSW.
- (3) Fatigue testing
- (4) Non-symmetric stack-ups. Potentially beyond two-layer stacks to evaluate FSSW of three-layer stack-ups including thick-thick-thin combinations.
- (5) TRIP steel feasibility

Summary – FSSW of AHSS

Viability of Enabling Technology

- Hundreds of welds made in several AHSS
  - Data accumulated in a welding database documenting the effects of weld time, rpm, tool shape, appearance, bonding, fracture, microstructures, mechanical properties, and process loads
- Spot welds of high shear tension strength (beyond 22 kN) were obtained with redesigned tools
  - Strengths compare favorably with minimum of AWS D8.1 draft RSW standard

Affordability of Technology

- New tools materials have been successfully tested with the potential to greatly reduce tooling cost
- Welding times reduced to 4 seconds with further reduction possible
- Alternative tool materials and process parameters show favorable reduction in feedback loads trending toward the capabilities of existing robots