Friction Stir Spot Welding of Advanced High Strength Steels

Presenter, Glenn Grant and Yuri Hovanski
Pacific Northwest National Laboratory
&
Michael Santella
Oak Ridge National Laboratory

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
## Milestones – FY2008 & FY2009

<table>
<thead>
<tr>
<th>Month/Year</th>
<th>Milestone or Go/No-Go Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 2008</td>
<td>Complete investigation into alternative tool materials and characterize wear performance of FSSW tooling</td>
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<tr>
<td>Sept. 2008</td>
<td>Compile database of FSSW performance in DP780 and HSBS steels including results of tool design studies</td>
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<tr>
<td>July 2009</td>
<td>Complete evaluation of the effects of tool materials on weld properties, and characterize comparative tool lifecycles.</td>
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<tr>
<td>Sept. 2009</td>
<td>Compile weld performance model addressing the influence of post-weld materials properties and static and dynamic loading conditions.</td>
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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$_3$N$_4$ 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$_3$N$_4$ had acceptable performance
- Joint strengths comparable for Si$_3$N$_4$ and PCBN
- Si$_3$N$_4$ produced lower tool loads
- Lower process loads mean lower C-frame loading
Evaluated results of PCBN and Si$_3$N$_4$ Tools

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

<table>
<thead>
<tr>
<th>Tool Material</th>
<th>RPM</th>
<th># of Steps</th>
<th>Max Tool Load (kN)</th>
<th>Max Temp (°C)</th>
<th>Avg. LSS (kN)</th>
<th>Area (mm$^2$)</th>
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</thead>
<tbody>
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<td>1</td>
<td>32.5</td>
<td>410</td>
<td>4.4</td>
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<td>33.0</td>
<td>537</td>
<td>8.0</td>
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<td></td>
<td>1600</td>
<td>1</td>
<td>23.7</td>
<td>510</td>
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<td>2</td>
<td>31.3</td>
<td>641</td>
<td>11.2</td>
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<td>*Si$_3$N$_4$</td>
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<td>21.3</td>
<td>508</td>
<td>9.6</td>
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<td>10.3</td>
<td>8.1</td>
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</tbody>
</table>

*Direct press and sintered Si$_3$N$_4$ tools can be volume fabricated at 5% of current PCBN tooling cost
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
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

![Graph showing Lap Shear Strength (kN) for different conditions and speeds.](image)

Reported data based on average of 3+ welds with convex-scroll tool.
Future Work – FY2009

Project Close-out

FY09 milestones: includes work accessing tool life, fatigue, and performance model relating process parameters to joint properties

Additional work: Based on OEM prioritization

OEM Priorities: “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