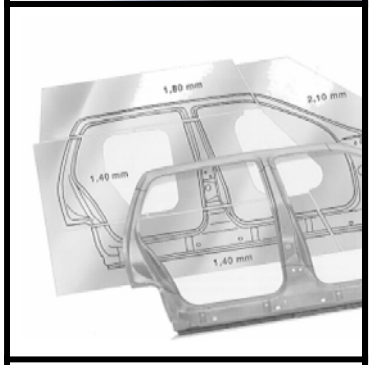

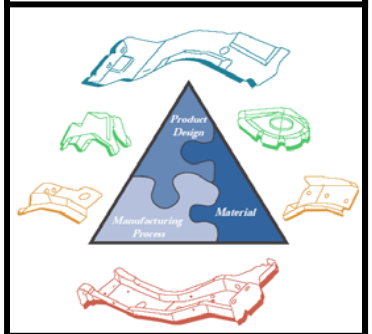

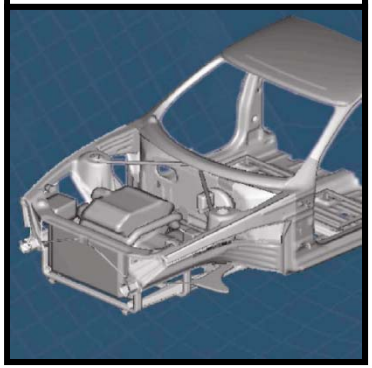

Auto/Steel Partnership:
Fatigue of AHSS
Strain Rate Characterization

Dr. Roger A. Heimbuch
Auto/Steel Partnership

Project ID: lm_26_heimbuch

A/S P Auto/Steel Partnership

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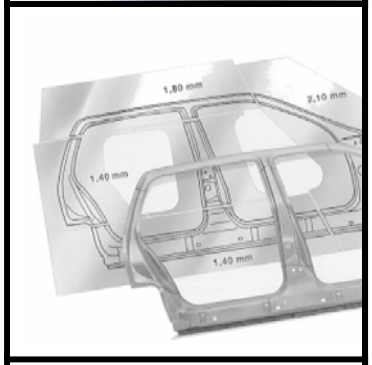

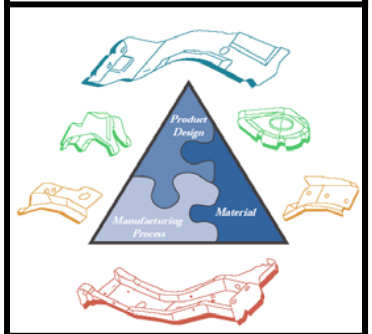

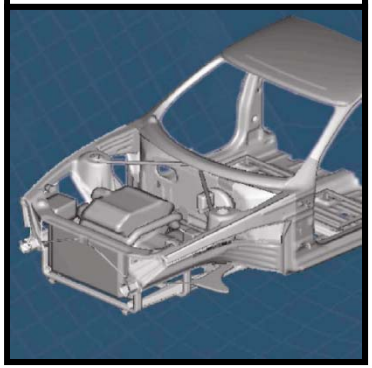

Fatigue of AHSS

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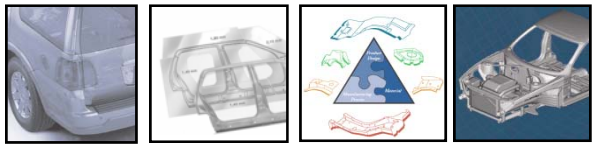


OVERVIEW

Timeline

- Start – 10/2001
- End – 09/2009
- 85% Complete

Budget

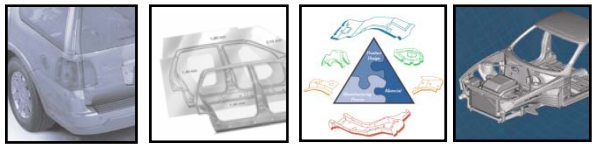
- Total Project Funding
  - DOE - $545K
  - Cost Share - $439K
- Funding for FY08
  - DOE - $106K
- Funding for FY09
  - DOE - $85K

Barriers

- Lack of fatigue data for AHSS base materials and joints

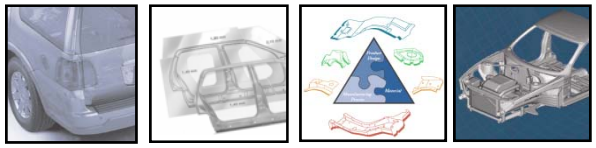
Partners

- University of Michigan



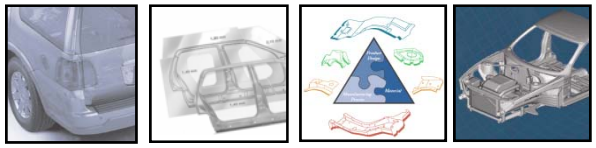
PROJECT GOALS

- Provide automotive manufacturers with design guidance and data for Advanced High Strength Steel (AHSS) fatigue applications to facilitate weight reduction initiatives:
  - Base materials
  - Spot welds
  - Adhesively bonded and weld-bonded joints
  - MIG welds
  - Laser welds
- Act as an enabler project for teams involved in frame and body construction as well those evaluating joint construction methodologies:
  - Lightweight Front End Structures
  - Lightweight Chassis Structures
  - Future Generation Passenger Compartment
  - Joining Technology
- Use the results to evaluate predictive methodologies



PROJECT APPROACH

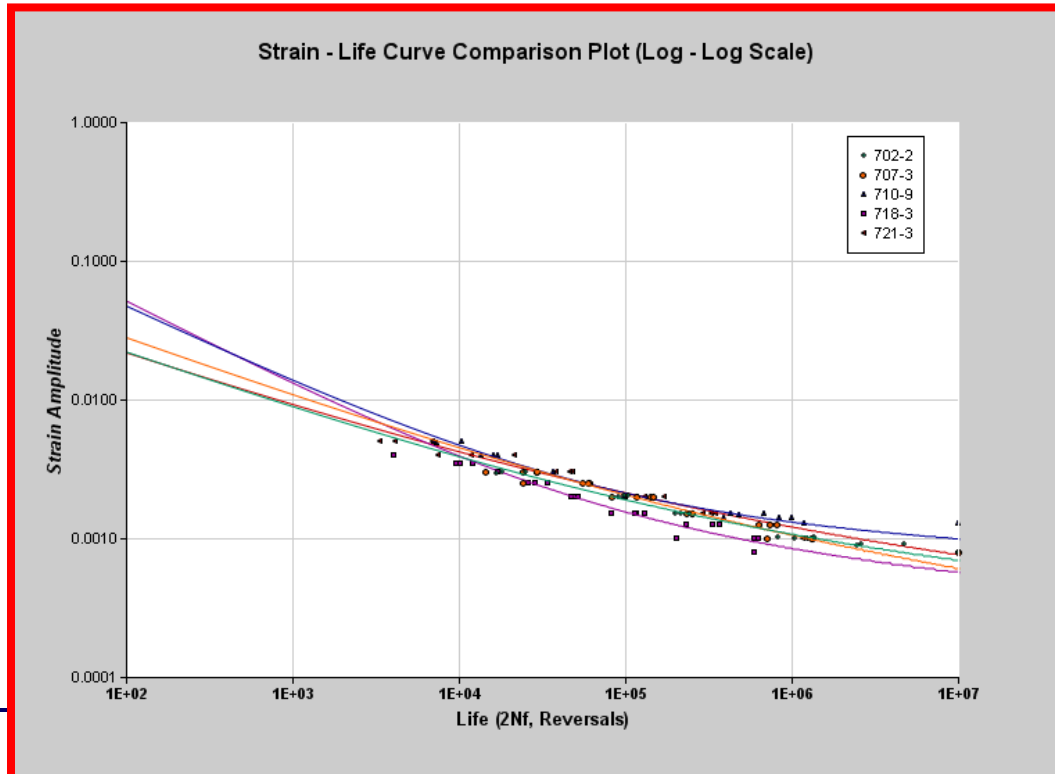
- Expand knowledge of fatigue performance of AHSS, especially that of joints
- Study Base Metal Fatigue (Completed)
- Study Spot Weld Fatigue: (Completed)
  - Study AHSS spot welds with conventional steels as a baseline
  - Evaluate the impact of gages, weld parameters, adhesives
  - Evaluate spot weld performance and validate predictive methodologies
- Study GMAW (MIG)/Laser Weld Fatigue: (Ongoing)
  - Study grades, gages, welding parameters, eccentric loading, coatings and prestrain effects using conventional steels as a baseline
  - Evaluate weld performance and predictive methodologies



PARENT SHEET METAL DATABASE

- Currently includes:
  - **IF-DDG-HDQ**
  - **DQSK-CRS**
  - **HSLA-50X**
  - **IF-REPHOS**
  - **SAE-940X**
  - **CQ-CRS**
  - **Hot-Stamped Boron**
  - **DP600**
  - **DP800**
  - **M1300**
  - **TRIP600**
  - **TRIP780**

- **Retrieve material data (chemistry, mechanical and fatigue properties)**
- **Compare various steel grades for judicious selection of material for desired application**
- **Examine variability of fatigue properties**



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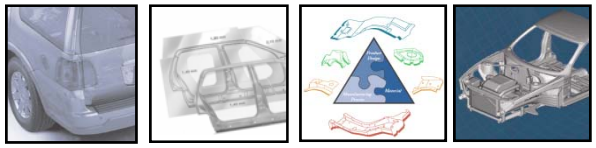
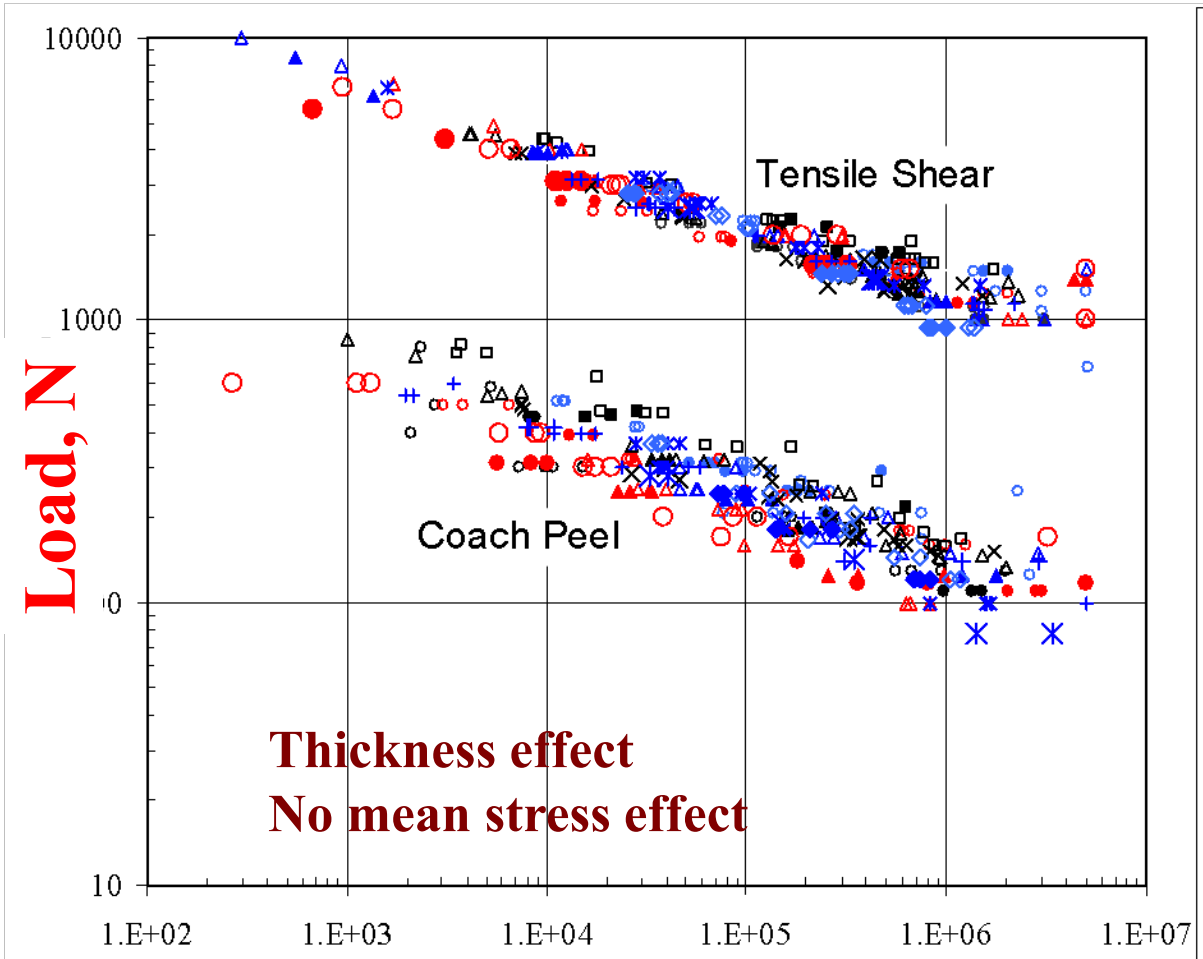
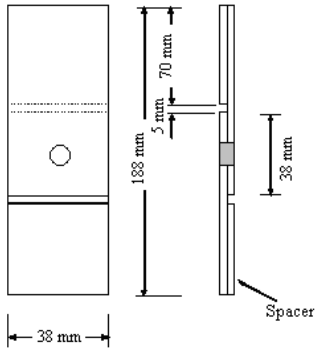
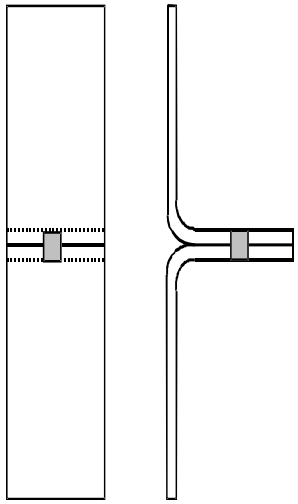


ALL SPOT WELD RESULTS





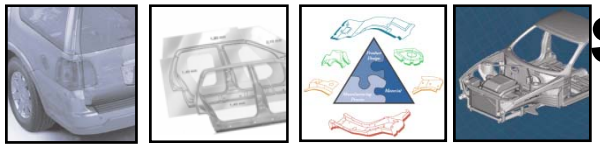
Tensile shear



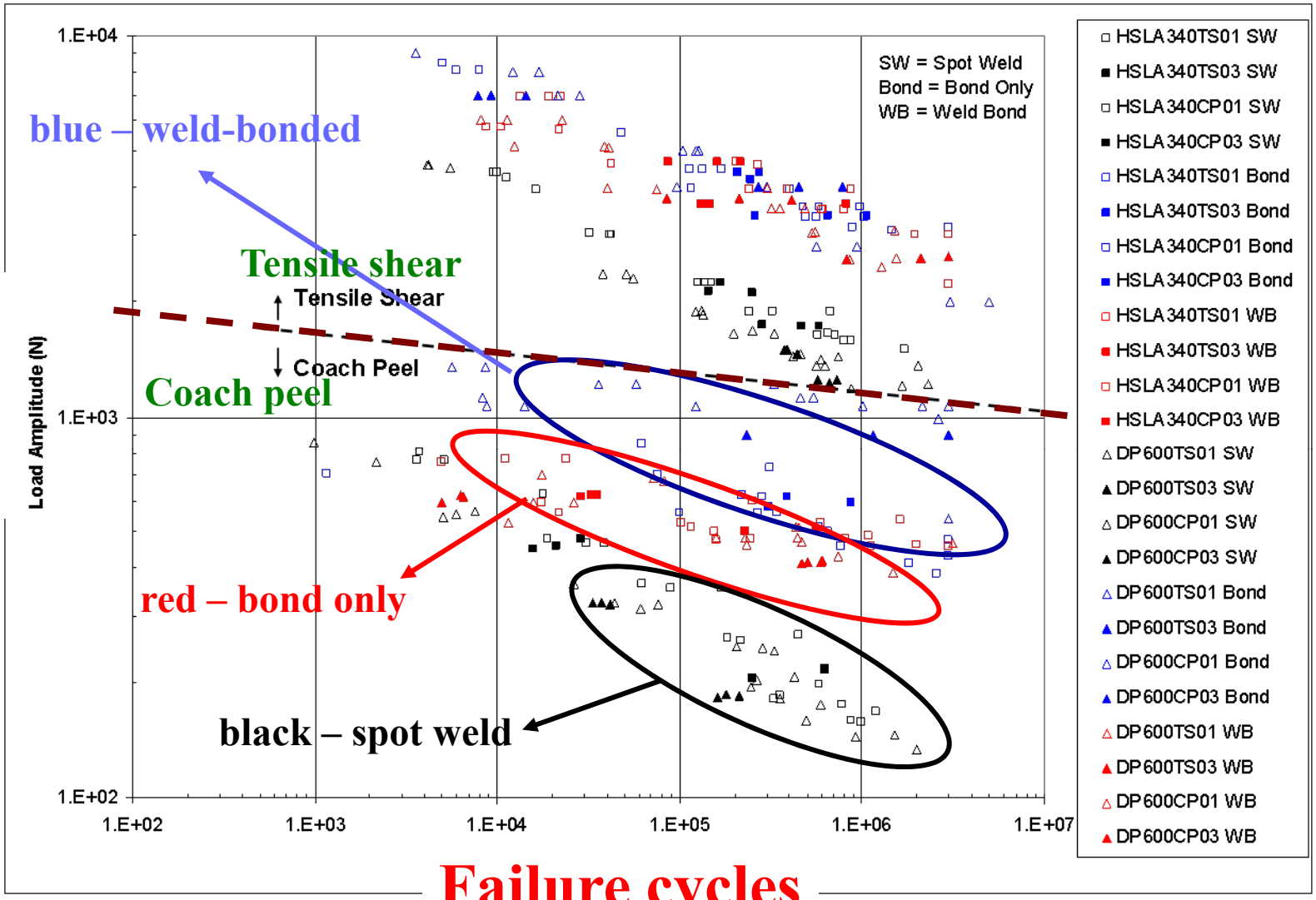
Coach Peel

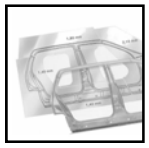
Failure cycles

nominal thickness -16mm

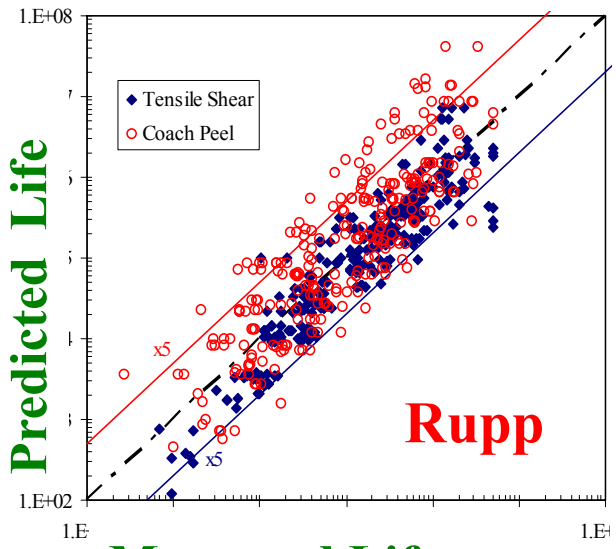


SPOT WELD, BOND-ONLY, WELD BONDED



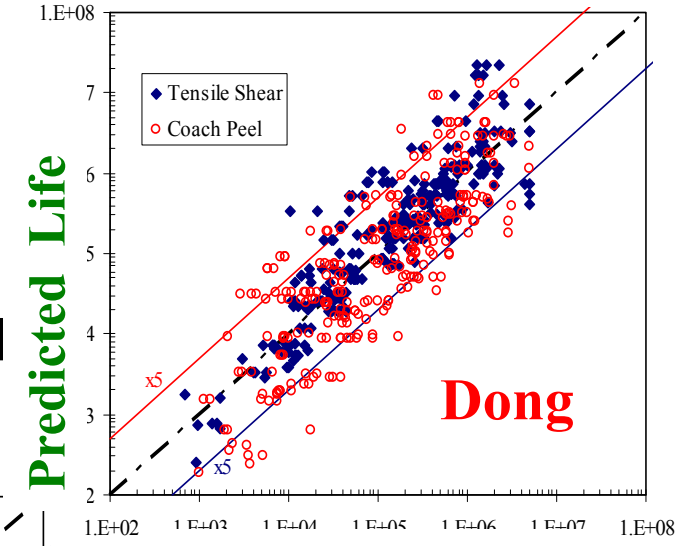
EVALUATION OF DAMAGE PARAMETERS

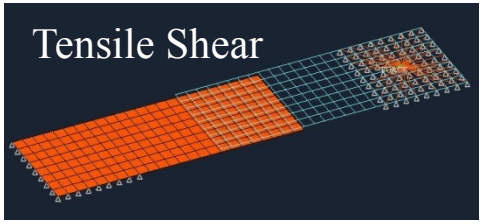


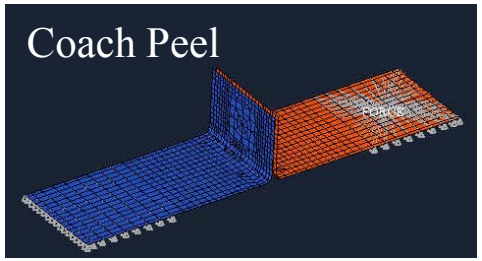
Uncertainty of Analysis

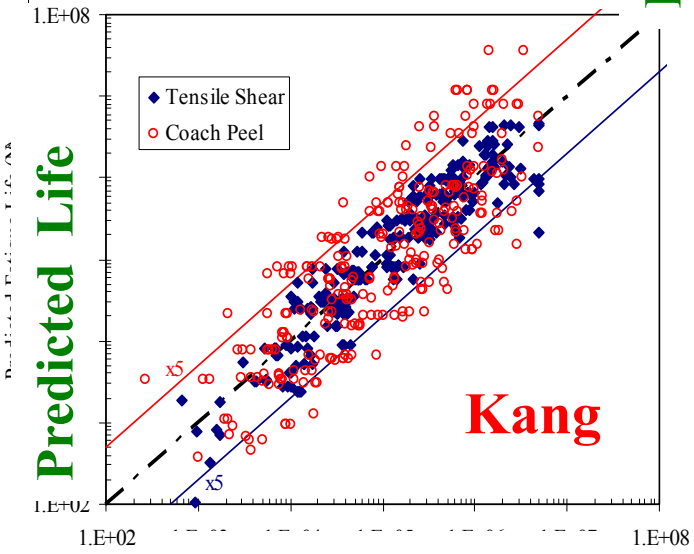
or

Scatter of Data due to Geometric Variability of Spot Welds Joints?



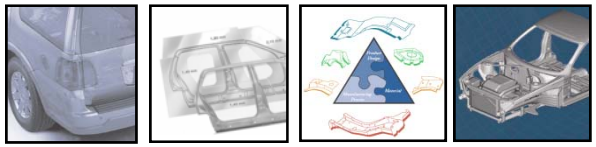






Bonnen et al, SAE Paper No 2006-01-0978

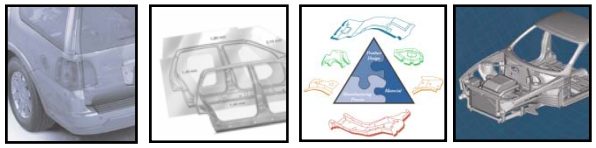
http://wwwa-sporg/publicationshtm



SPOT WELD - CONCLUSIONS

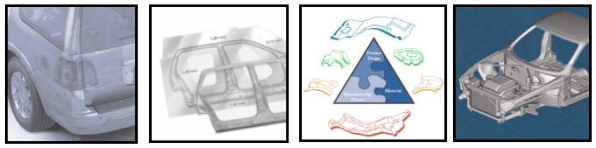
Spot Weld Fatigue Results:

- Insensitive to base metal composition, microstructure, and strength
- Behavior is mainly controlled by geometric factors
- Behavior is largely mean stress insensitive
- No effect of weld hold time (between 1 and a 90 cycles)
- No effect of paint bake cycle
- Adhesive bonding and weld bonding significantly improve fatigue behavior
- Pre-straining the parent metal has no impact on the fatigue performance
- Crucial parameters controlling the mechanics and physics uncovered, thus reducing uncertainty in prediction

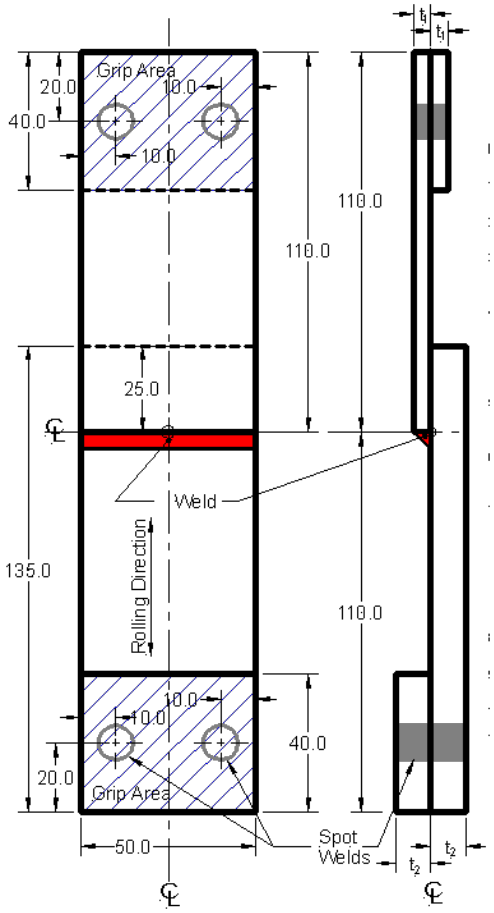


FUSION WELD - OBJECTIVE

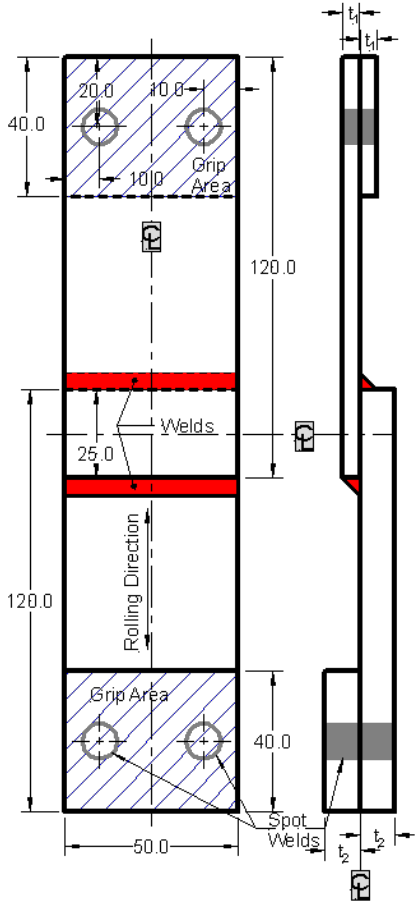
- Manufacture fatigue test specimens on selected high-strength and advanced high-strength steels (AHSS) utilizing gas-metal arc welding (GMAW) (Tight control on weld geometry)
  - -Single-Lap - Perch Mount - Double-Lap – Butt weld - Start-Stop
- Base material combinations of varying strength and composition
- Gage thickness of 16 and 34 millimeters
- New specimen designs to reflect applications and to enable development of predictive methodology



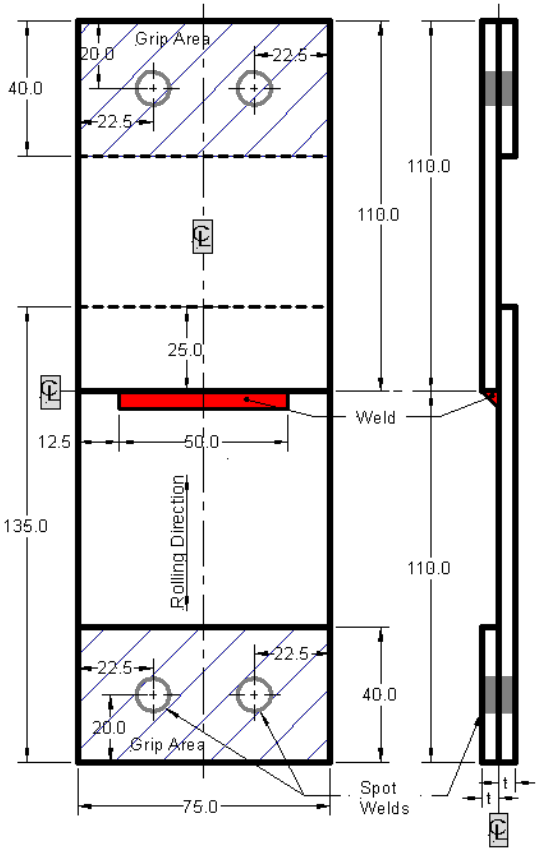
FUSION WELD – SPECIMEN CONFIGURATIONS



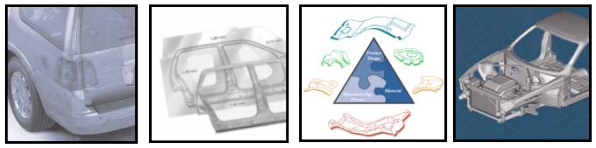
Single Lap Shear (w/o start-stop)



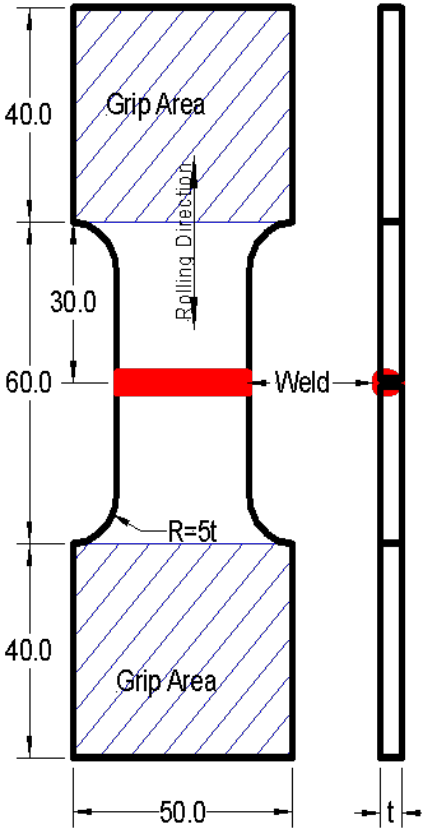
Double Lap Shear



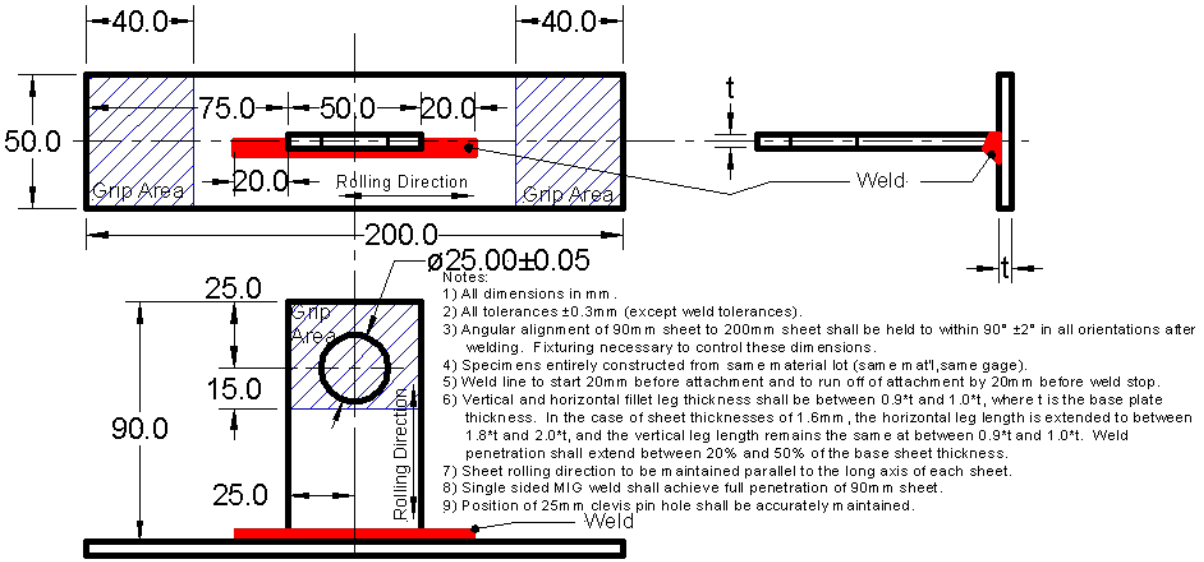
Single Lap Shear (with start-stop)



FUSION WELD – SPECIMEN CONFIGURATIONS



Butt Weld

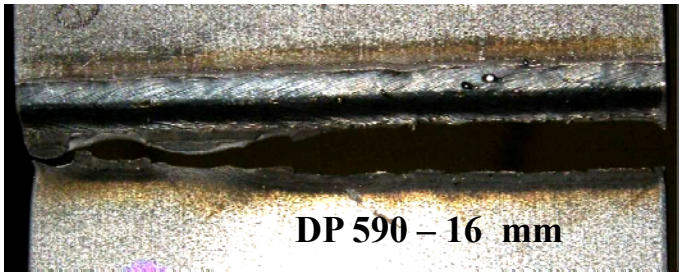


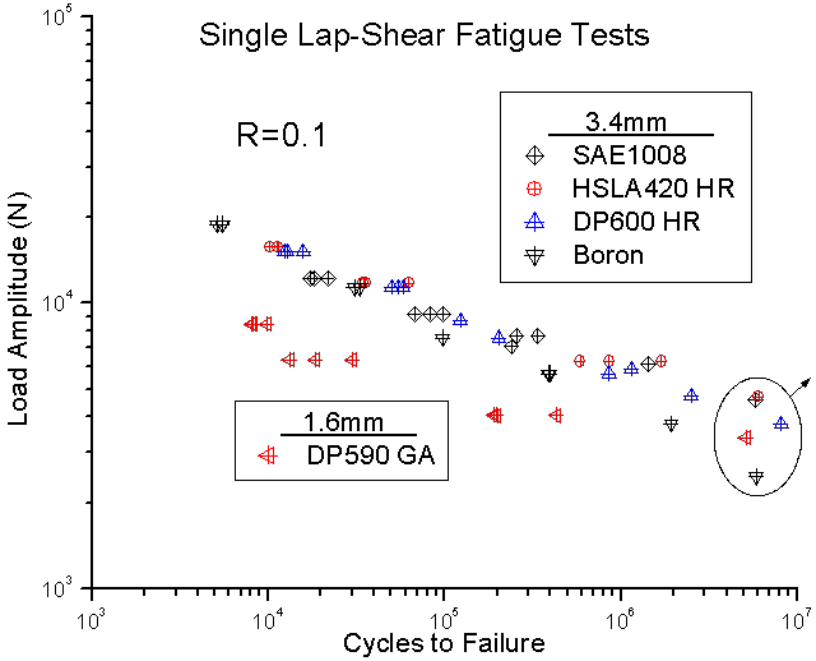
Perch Mount

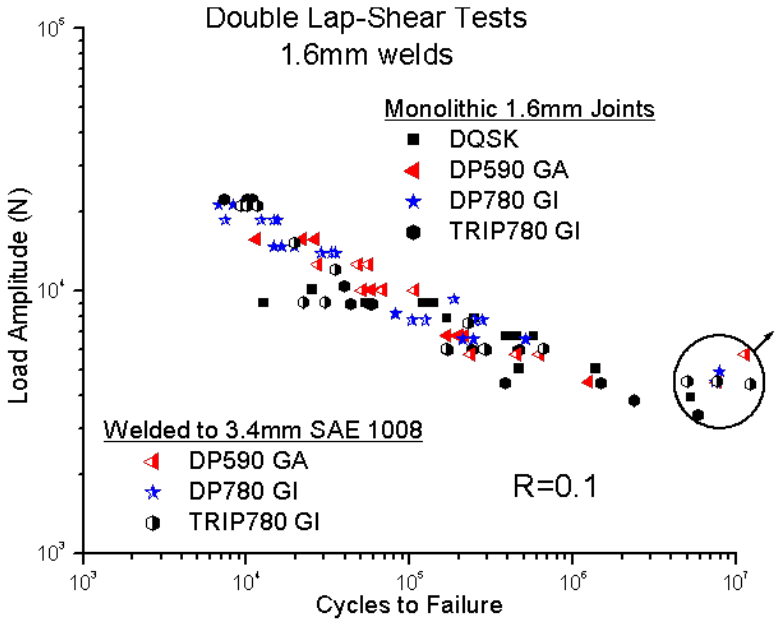
LAP-SHEAR WELDS – FATIGUE RESULTS

Typical Failure – Weld Toe

Typical Failure – Weld Toe

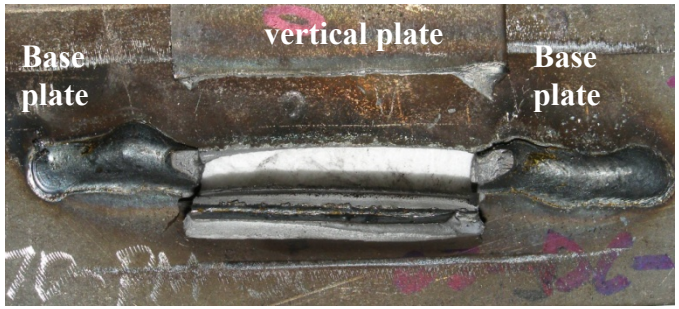


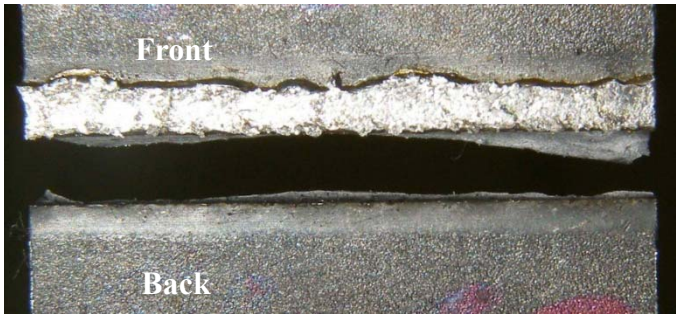


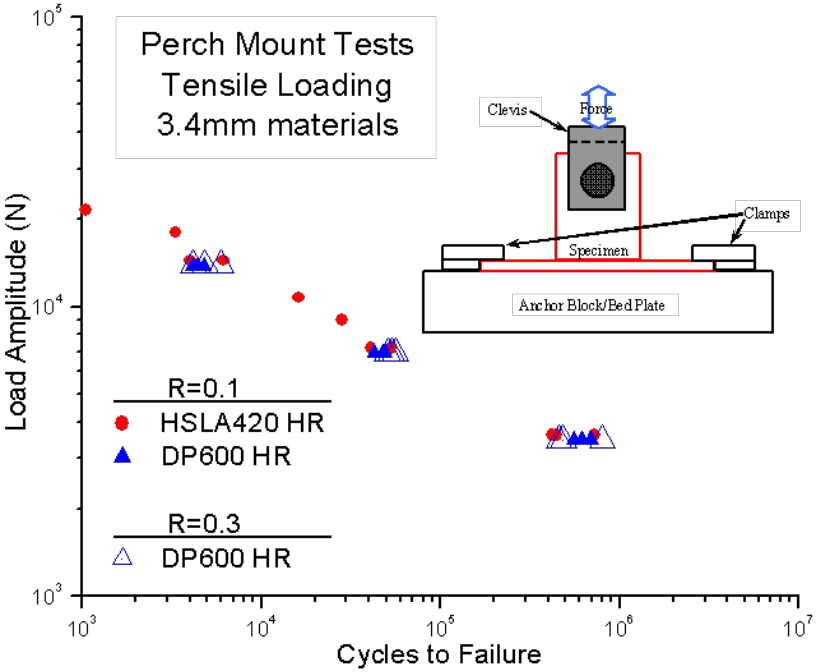


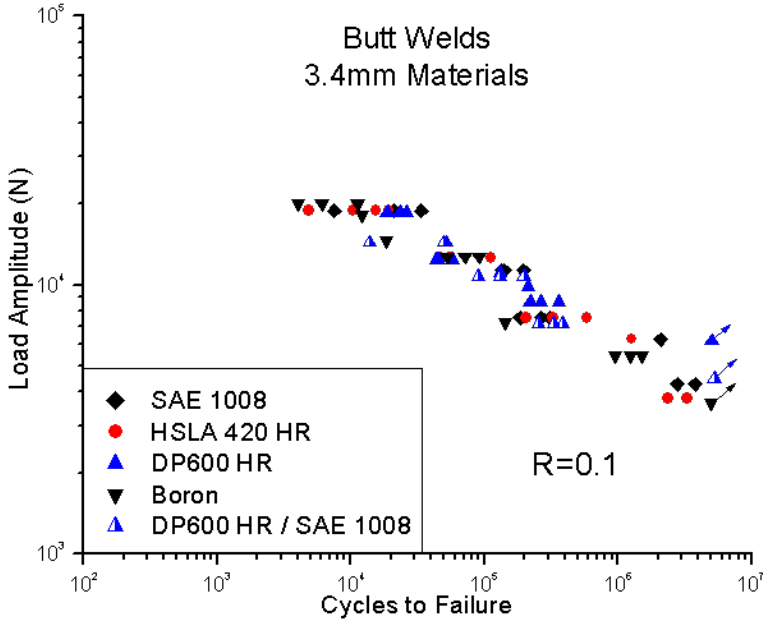
Fatigue lives influenced by sheet thickness However, for a given thickness, the fatigue data collapsed into a fairly narrow band, regardless of parent metal strength

PEARCH and BUTT WELDS – FATIGUE RESULTS

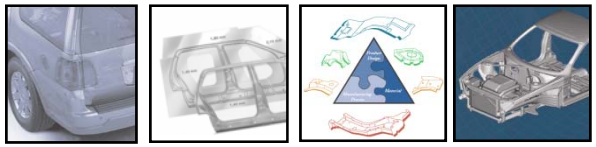






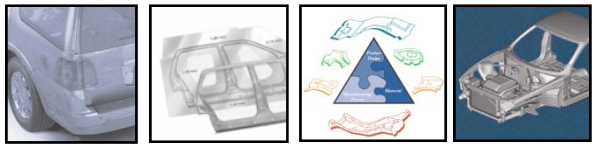


For a given thickness, the fatigue data collapsed into a fairly narrow band, regardless of parent metal strength



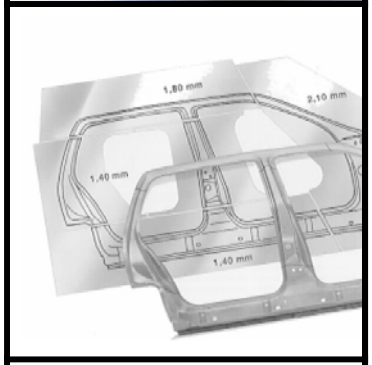
FUSION WELD - CONCLUSIONS

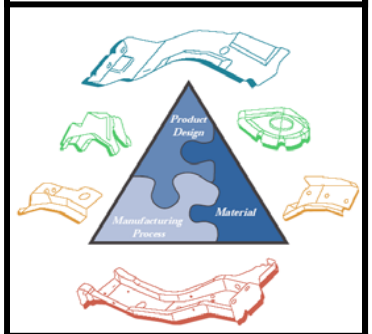
- Weld geometry is highly sensitive to small changes in welding parameters
- The observed inherent variability does not translate into significant scatter in fatigue data for single lap joints
- For a given joint configuration and specimen thickness, fatigue lives usually collapsed into a fairly narrow band, regardless of parent metal strength
- Given a consistent weld geometry, sheet thickness is a more dominant factor in the fatigue strength of GMAW joints than any other factor considered in this study

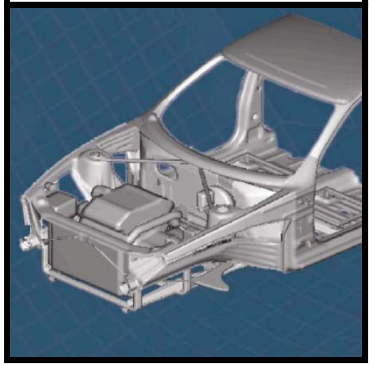


SUMMARY

- Representative experimental data sets available for:
  - Base materials
  - Spot welds
  - Adhesively bonded and weld-bonded joints
  - MIG welds
  - Laser welds
- Confirmed fatigue analytic methodologies' work







Strain Rate Characterization

Auto/Steel Partnership

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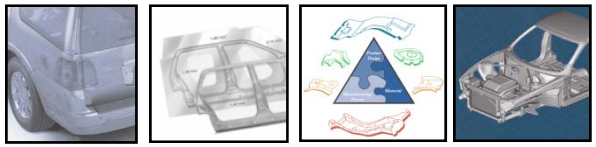


OVERVIEW

Timeline

- Start – 10/2001
- End – 03/2009
- 100% Complete

Budget

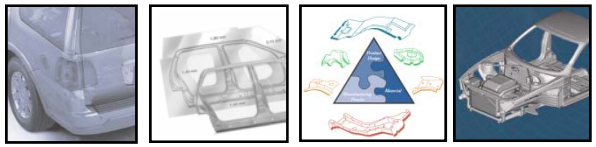
- Total Project Funding
  - DOE - $404K
  - Cost Share - $267K
- Funding for FY08
  - DOE - $91K
- Funding for FY09
  - DOE - $34K

Barriers

- Experimental test method to characterize rate dependent properties
- Experimental data base of rate dependent AHSS properties
- Modeling technology to replicate crash results with AHSS

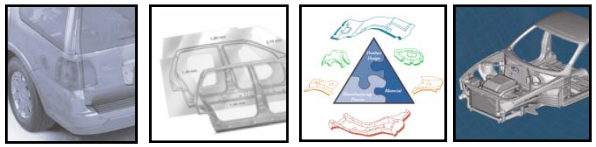
Partners

- Oak Ridge National Laboratories
- University of South Carolina
- University of Dayton Research Institute
- Los Alamos National Laboratories



PROJECT GOALS

- Develop experimental setups for characterization of the strain rate sensitivity of AHSS and components
- Establish rate dependent experimental database for AHSS, spot welds and components made of AHSS
- Develop modeling technology to replicate the crash performance of AHSS and spot welds
- Develop experiments to characterize the bake hardening effect of DP steels at high strain rates
- Ultimate Goal: Improve the accuracy of finite element crash analysis methods to enable the optimization of structures and material utilization, resulting in lighter, safer automotive structures of steel and other materials

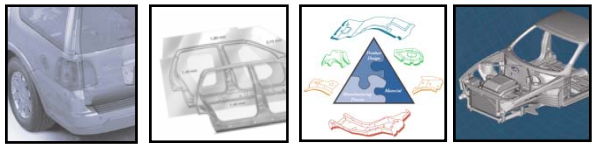


PROJECT TIMELINE

Deliverables

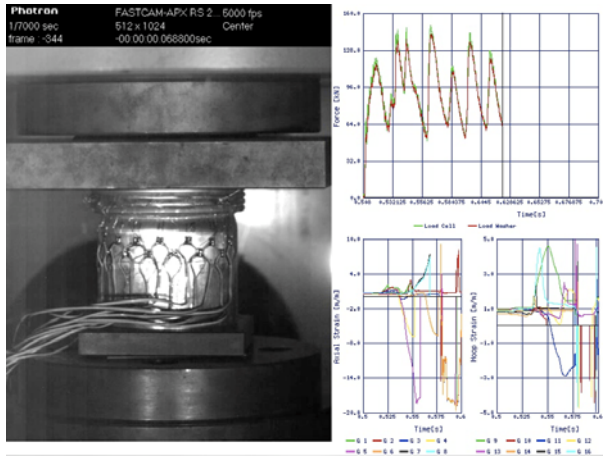
- DP steel bake hardening effect
- Spot weld impact testing and modeling
- Octagonal welded tube crush
- Web site of collected strain rate properties
- Circular tube crush
- Modeling the strain rate history effect
- UDRI double plate hinge testing
- Guidelines for modeling strain rate effects
- AISI strain rate tensile data (consultation)
- UDRI – Hopkinson tensile and intermediate rate tensile tests
- LANL – split-Hopkinson compression tests

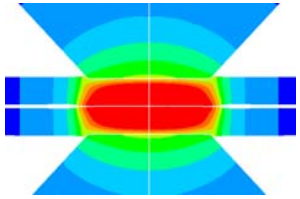
1995-2000 2000-2002 2003 2004 2005 2006 2007 2008 2009

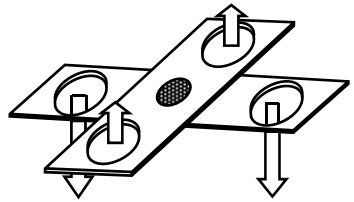


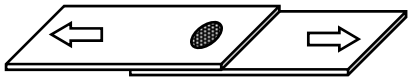
PROJECT APPROACH

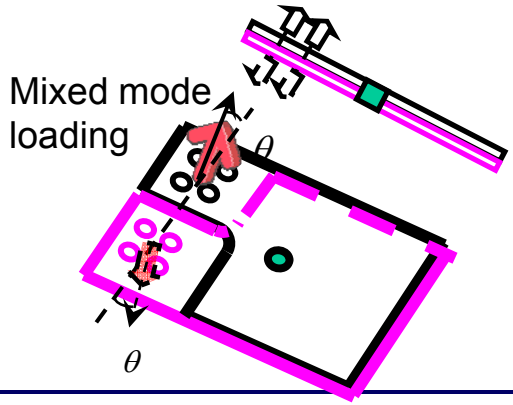
- Design of high rate material tests
- Design of component crush tests
- Tensile, shear and mixed mode spot weld coupon dynamic tests
- A new spot weld element and associated constitutive models
- Modeling and characterization of weld microstructure and property
- A common experimental database on the performance of AHSS, RSW and AHSS components during impact loading

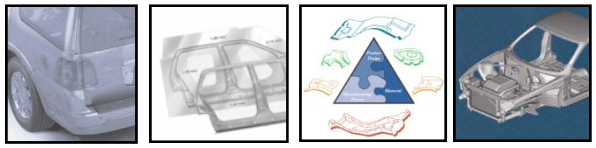








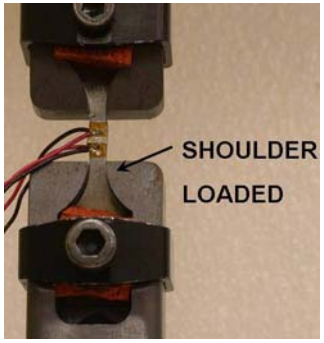


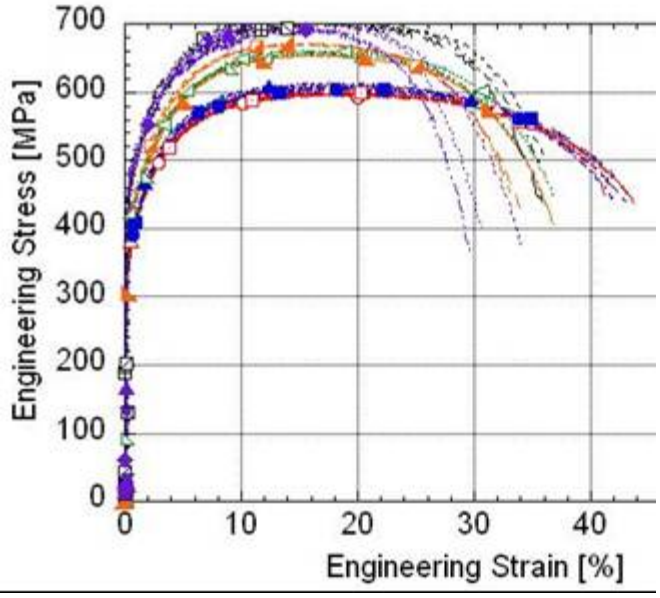


PROJECT RESULTS

- AHSS mechanical properties at high strain rates
- Double hinge plate, circular tube and Welded octagonal hat section crush test results
- Simulation results of above component crush tests using strain rate dependent advanced material model
- Spot weld dynamic test database and a new spot weld element formulation
- High rate test results of dual phase steels at various pre-strain and baking conditions
- A/SP ORNL website experimental database

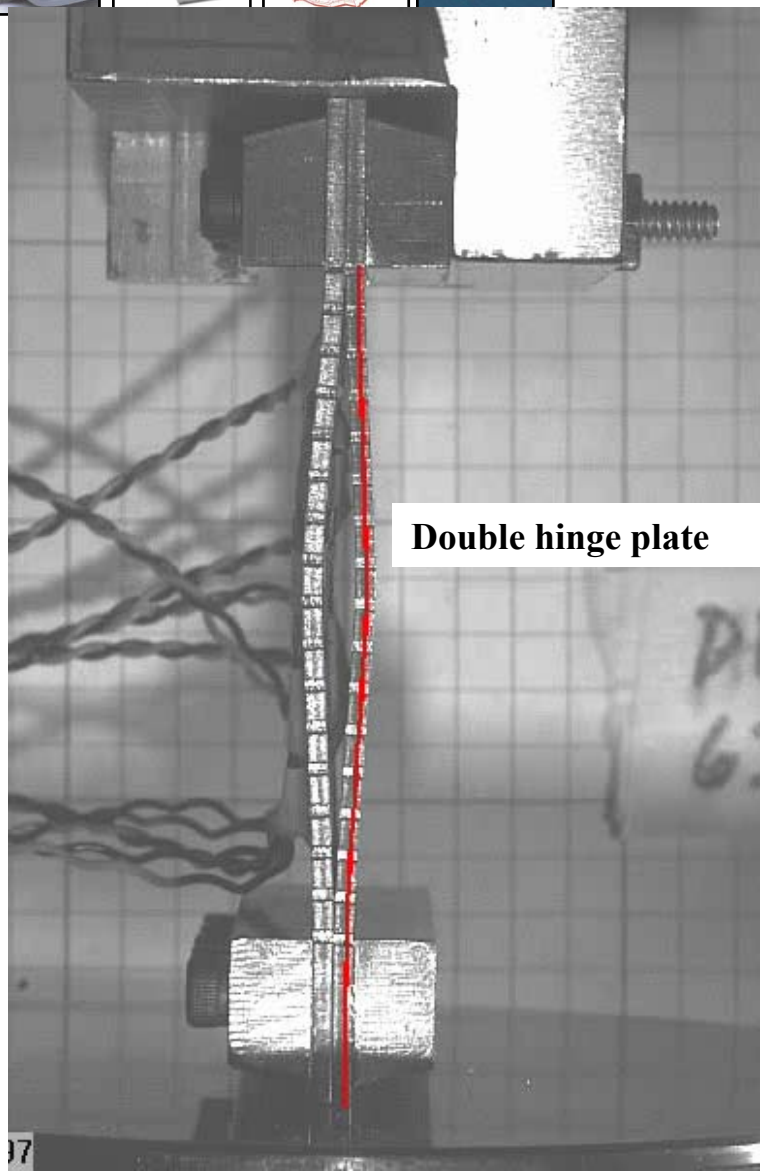
MECHANICAL PROPERTIES



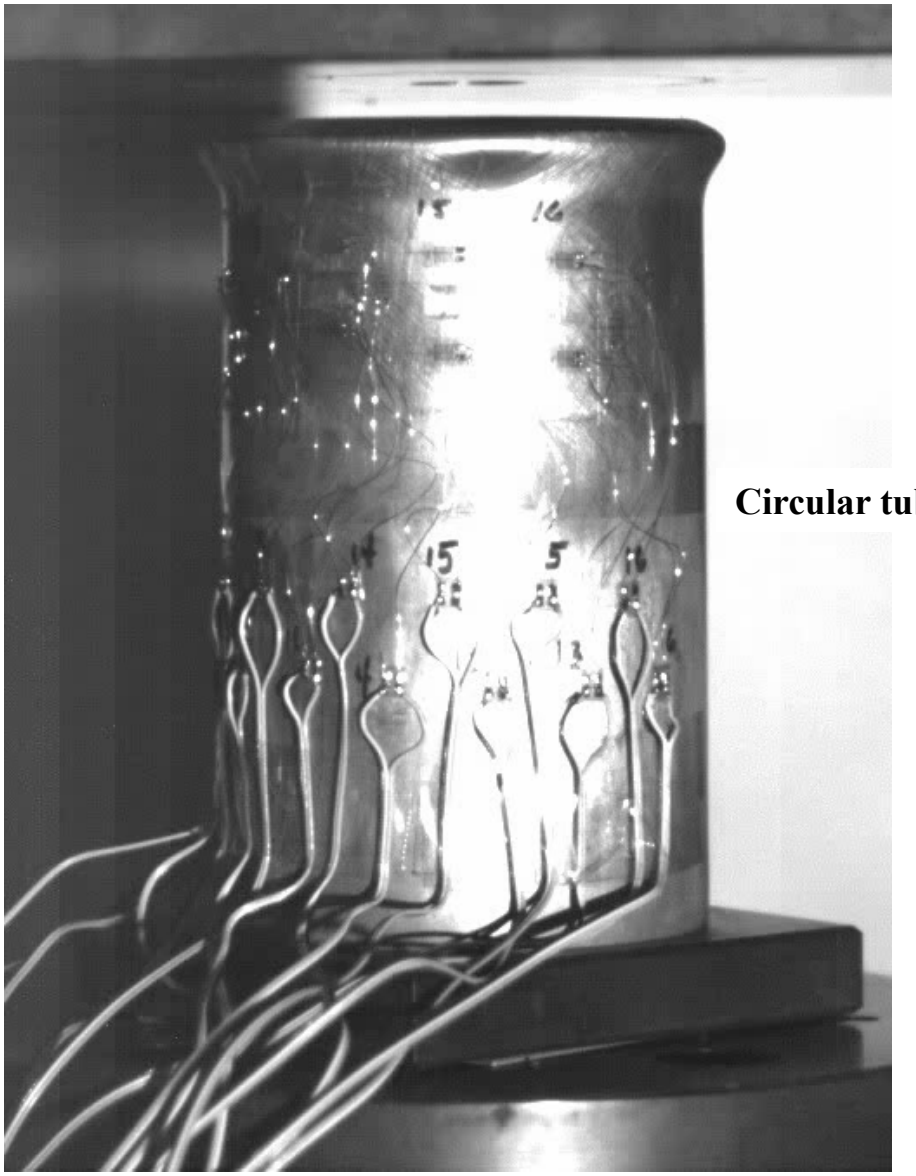


- High Rate Experiments
  - Early exploration with compression tests
  - High rate tensile tests conducted for all the available AHSS steel grades and PHS
  - Some steels tested at different facilities using different instrumentations
- Bake Hardening Project
  - DP600 & DP780
  - Pre-strain levels – 0%, 1%, 2%, 5%, 8%
  - Rates: 0001/s, 10/s, 500/s
  - As-is or baked @170°C for 20 mins

SIMPLE COMPONENT CRUSH TESTS

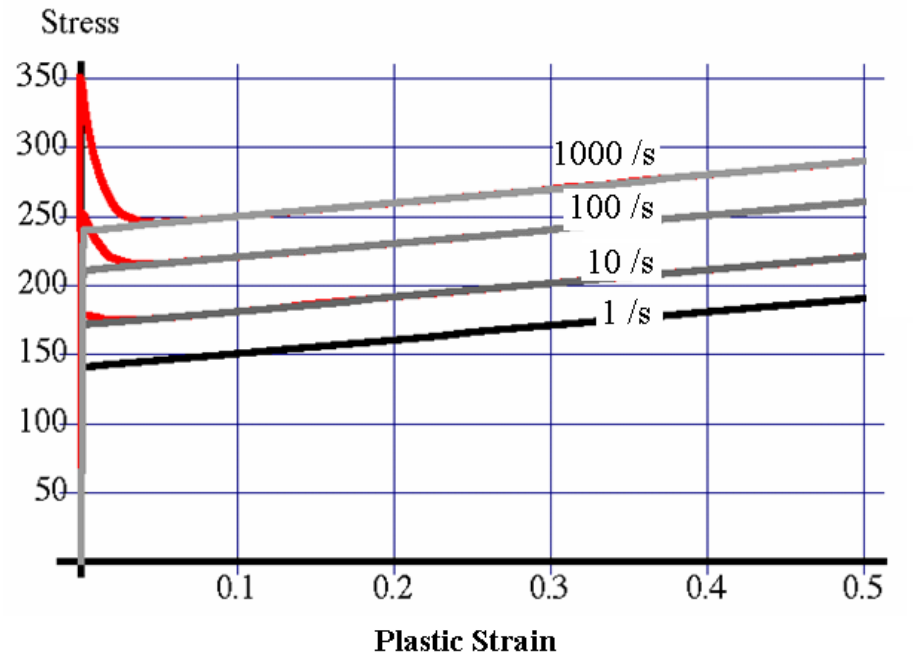


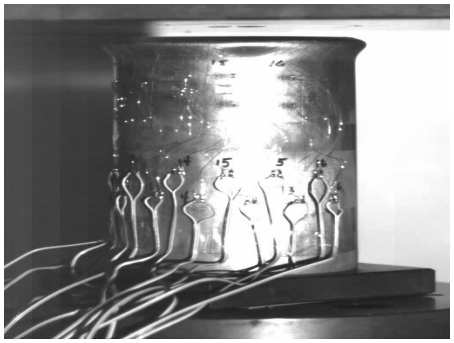
Double hinge plate

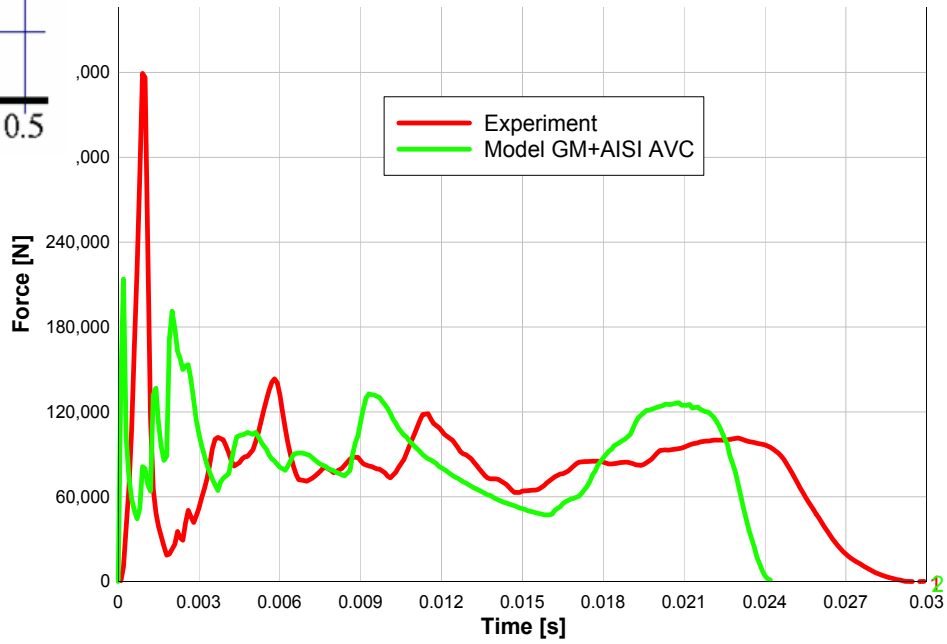


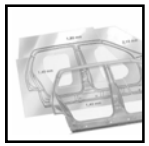
Circular tube

MODELING of the CIRCULAR TUBE CRUSH



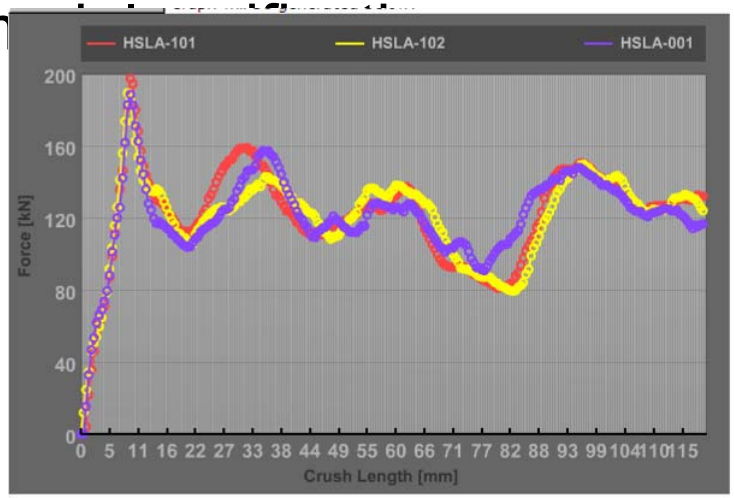


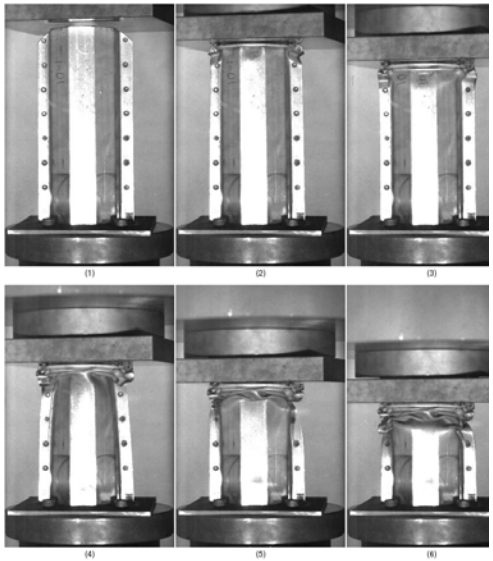


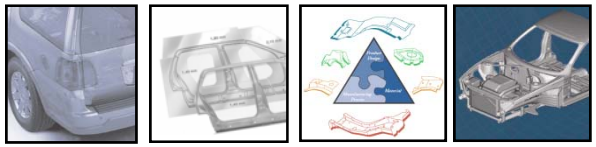



TMAC OCTAGONAL TUBE TEST RESULTS

- DQSK, HSLA, DP, TRIP plus other AHSS
- Large radius laser-welded specimens and spot welded tubes
- Crush speeds from quasi-static to 6 m/s
- Multiple strain gages around folds
- Investigated the folding formation and configuration and provided high-quality data for m

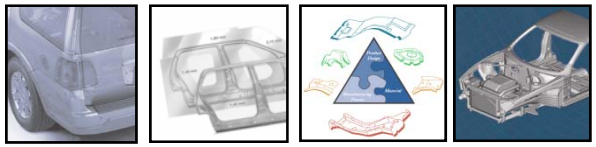






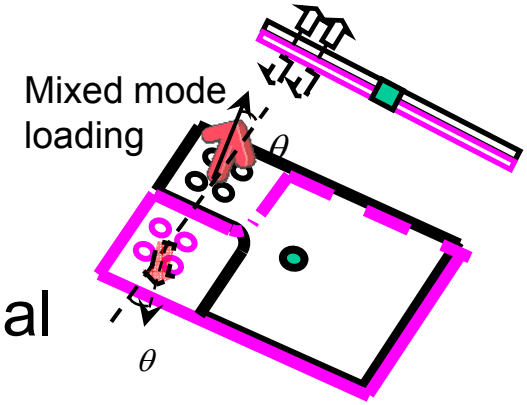
A/SP ORNL EXPERIMENTAL DATABASE

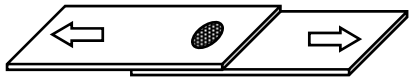
- Steels have been tested up to 100/s
- Currently investigating problems with 1000/s force measurement
- All the data is on ORNL website
- New version with added functionality will be up

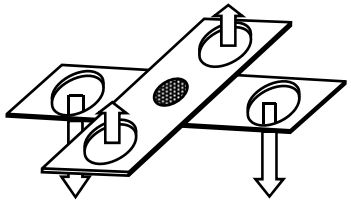


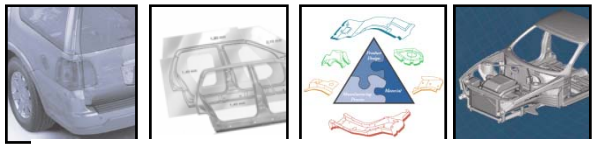
SPOT WELD DYNAMIC TESTS

- Two materials:
  - Mild steel – YS=210; UTS=340 MPa
  - DP780GA – YS=500; UTS=780 MPa
- Three weld nugget sizes for each material
  - Smaller; standard; and oversized
- Three geometries:
  - Cross tension (static and two dynamic velocities)
  - Lap shear (static and two dynamic velocities)
  - Mixed mode coupon (Three angles, two speeds, standard weld)
- Ran 2 to 4 samples for each test condition

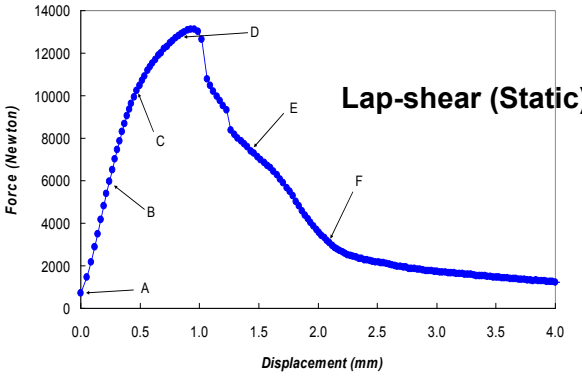


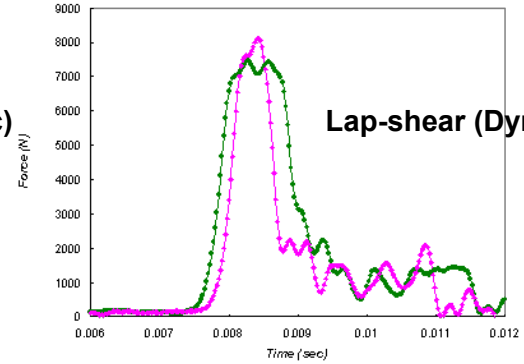




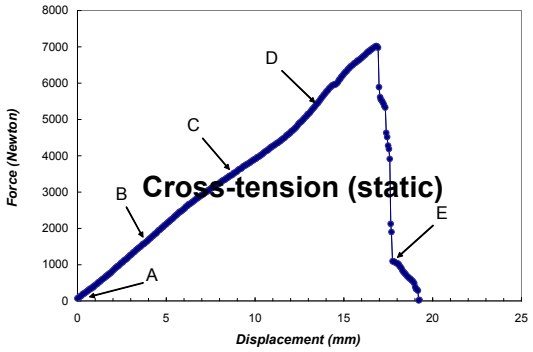


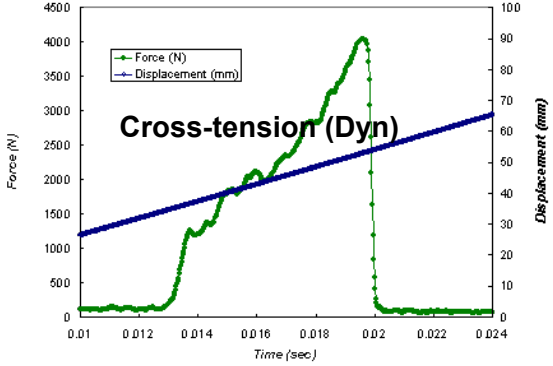
SPOT WELD DYNAMIC TEST RESULTS

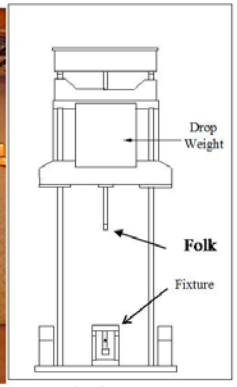




Broken sample

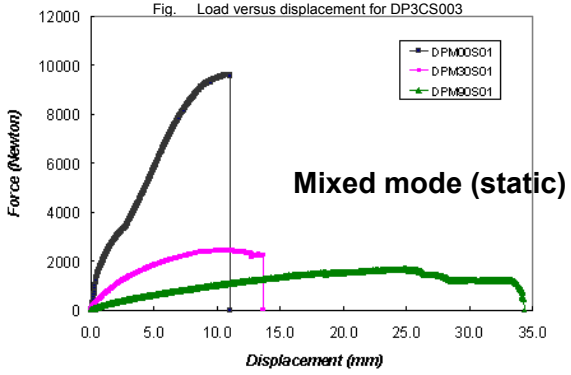


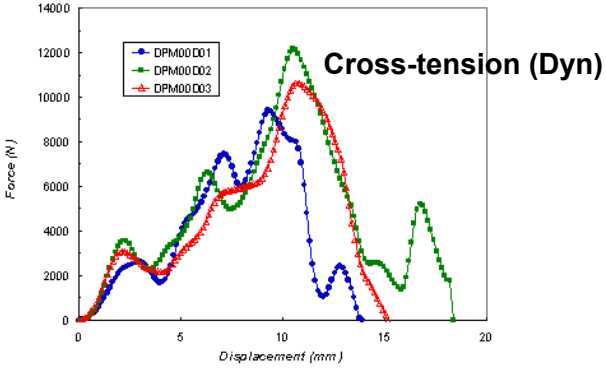


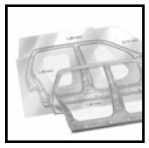


Drop weight

Fig. Load versus displacement for DP3CS003

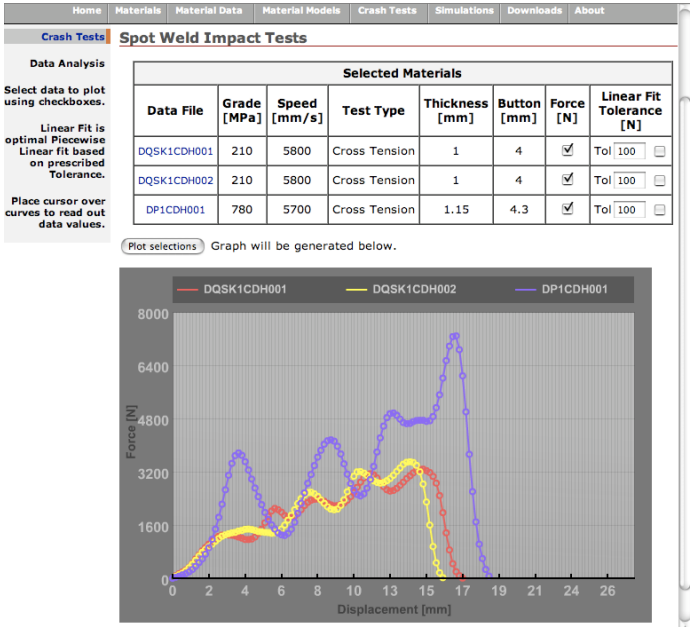


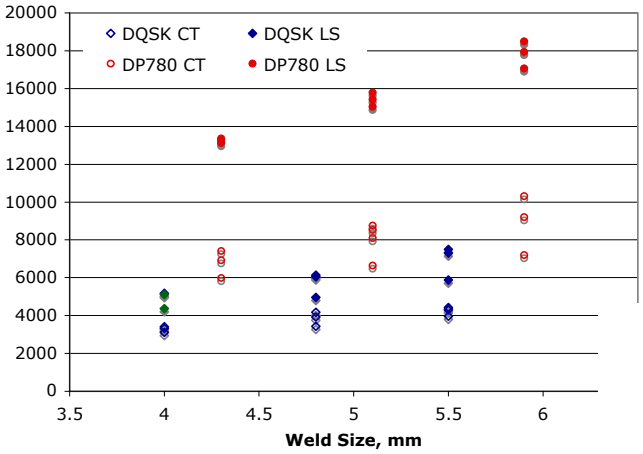


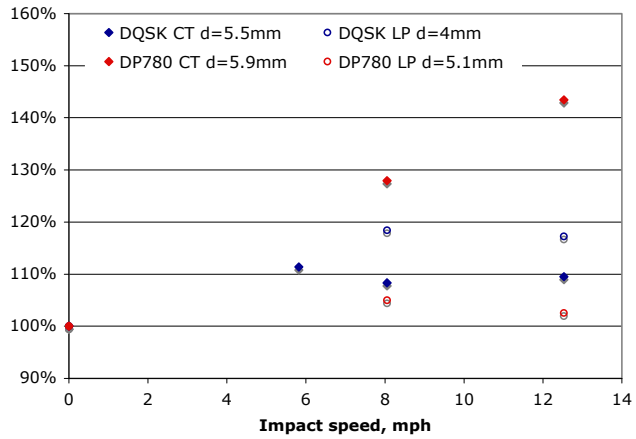



ANALYSIS of WELD DYNAMIC TEST DATA

- Tensile, shear and mixed loading mode tests up to 13 mph impact speed using a special testing apparatus
- Web-based test data collection and retrieval
- Failure mode and strength correlated to the weld attributes such as weld size and l



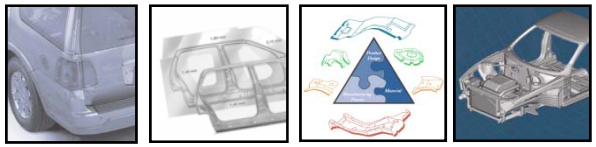




Spot Weld Impact Tests

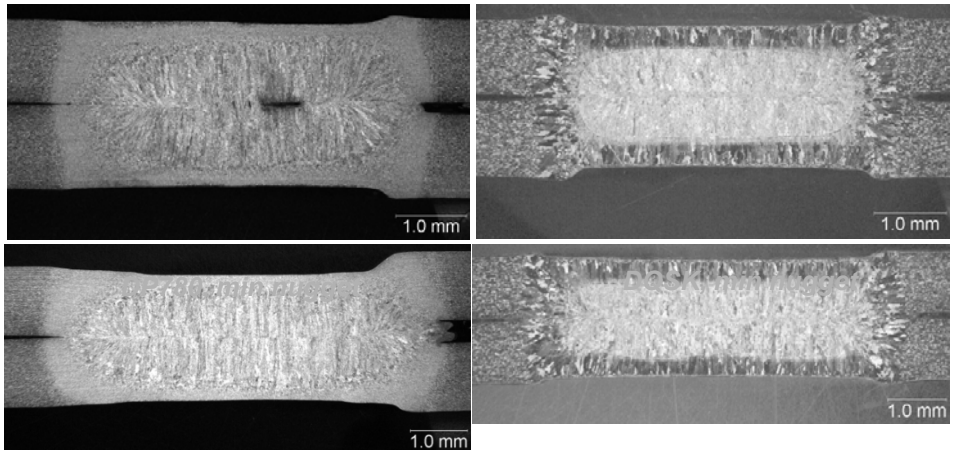
Mild Steel

Test Label	Grade [MPa]	Speed [mm/s]	Specimen Type	Thick. [mm]	Button [mm]	Failure Mode	Select
DQSK1CDH001	210	5800	Cross Tension	1	4	Pullout	
DQSK1CDH002	210	5800	Cross Tension	1	4	Pullout	
DQSK1CDL001	210	2500	Cross Tension	1	4	Pullout	
DQSK1CDL002	210	2500	Cross Tension	1	4	Pullout	
DQSK1CS001	210	0.0254	Cross Tension	1	4	Pullout	
DQSK1CS002	210	0.0254	Cross Tension	1	4	Pullout	
DQSK1LDH001	210	5600	Lap Shear	1	4	Interfacial	
DQSK1LDH002	210	5600	Lap Shear	1	4	Interfacial	
DQSK1LDH003	210	5600	Lap Shear	1	4	Interfacial	
DQSK1LDM001	210	3600	Lap Shear	1	4	Interfacial	
DQSK1LDM002	210	3600	Lap Shear	1	4	Interfacial	
DQSK1LDM003	210	3600	Lap Shear	1	4	Interfacial	
DQSK1LS001	210	0.0254	Lap Shear	1	4	Pullout both sides	



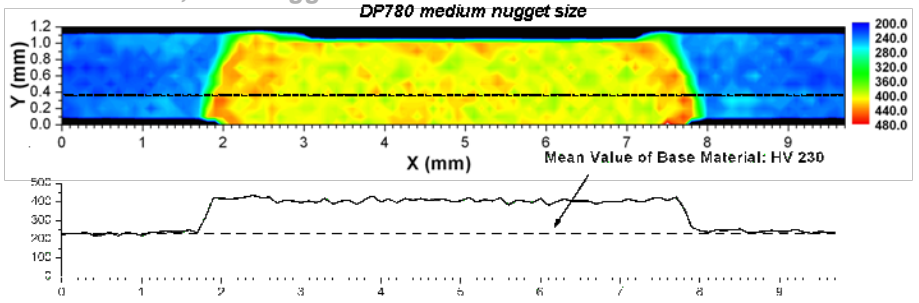
WELD MODELING & CHARACTERIZATION PROGRESS to DATE

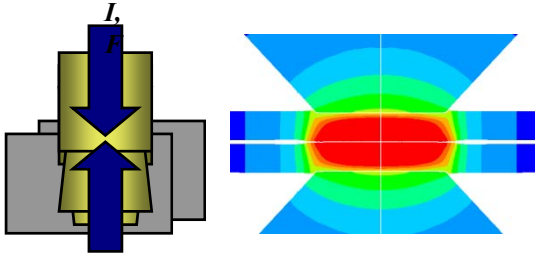
- Weld property gradients are determined and compared among different steels
- Weld size and other geometric attributes including defects are correlated to steel grade and welding conditions
- An incrementally coupled electric-thermal-mechanical-metallurgical model is being developed and under validation

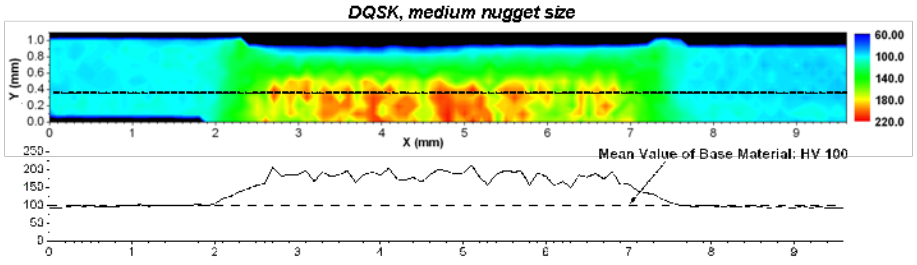


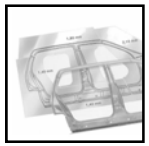
DP780, max nugget

DQSK, max nugget



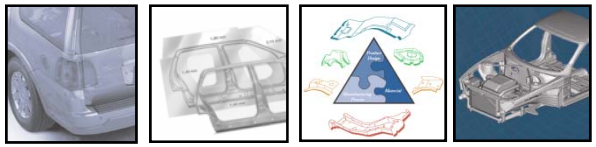




LIST of the RECENT PUBLICATIONS

1. S Simunovic, P Nukala, J R Fekete, D Meuleman & M Milititsky; Modelling of strain rate effects in automotive impact; SAE World Congress, 2009, Detroit, MI, SAE Paper: 2003-01-1383
2. S Simunovic, JM Starbuck, R Boeman, D Meuleman, P Nukala, ; Characterization of strain and strain rate histories in high strength steel during asymmetric tube crush; MS&T Conference, New Orleans, LA, 2004
3. S Simunovic, JM Starbuck, R Boeman, P Nukala, J Fekete, M Milititsky, G Jacob; High strain rate characterization of advanced automotive materials; SAE World Congress, Detroit, MI, 2004
4. S Simunovic, JM Starbuck, R Boeman, D Meuleman, P Nukala; Characterization of strain and strain rate histories in high strength steel during tube crush, SAE World Congress 2005
5. S Simunovic, P Nukala; Modeling of strain rate history effects in BCC metals, Third MIT Conference on Computational Fluid and Solid Mechanics, p 495-7, 2005
6. S Simunovic, J M Starbuck, P Nukala; Characterization and modeling of strain and strain-rate histories in steel structures during impact, International Auto Body Conference, IABC 2006, Society of Automotive Engineering (SAE), 2006
7. S Simunovic, J M Starbuck, P Nukala; Characterization of strain and strain-rate histories in steel structures during impact; 2007 SAE World Congress, Detroit, MI, 2007
8. S Simunovic, J M Starbuck, K Wang & P V K Nukala; Characterization of strain and strain-rate histories in HSS structures during progressive crush; MS&T Conference, Detroit, MI, 2007
9. Y J Chao, Kim, Y, Z Feng, S Simunovic, K Wang & M Kuo; Dynamic failure of resistance spot welds, SAE World Congress, 2009, Detroit, MI, SAE Paper 2009-01-0032
10. S I Hill, S H Kuhlman, K Wang, J Belwafa & XChen; Bake-Hardening Effect of Dual Phase Steels, SAE World congress 2009, Detroit, MI SAE2009-01-0796



SUMMARY

- Strain rate data available for AHSS steels and being used to model crash events
- Improved material models for AHSS available for analysis