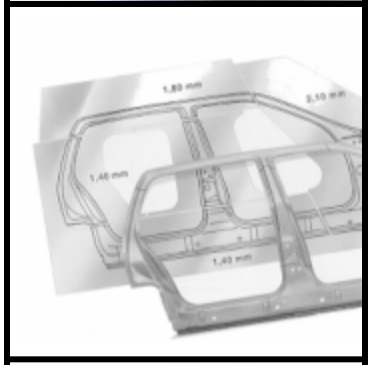

Auto/Steel Partnership:

AHSS Stamping
Strain Rate Characterization
Sheet Steel Fatigue
AHSS Joining

Dr. Roger A. Heimbuch
Auto/Steel Partnership

June 8, 2010

Project ID # LM019

Auto/Steel Partnership

www.a-sp.org

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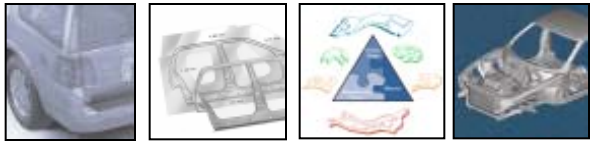


MEMBERS OF A/SP - Chartered in 1987

ArcelorMittal

AK Steel

GM

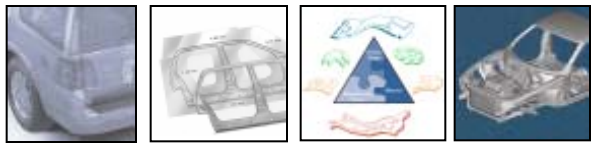
Severstal

CHRYSLER

USS

Ford

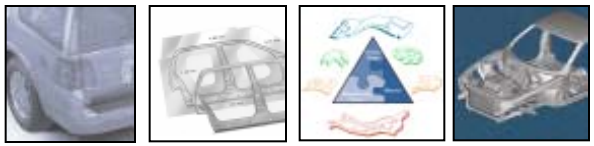
NUCOR



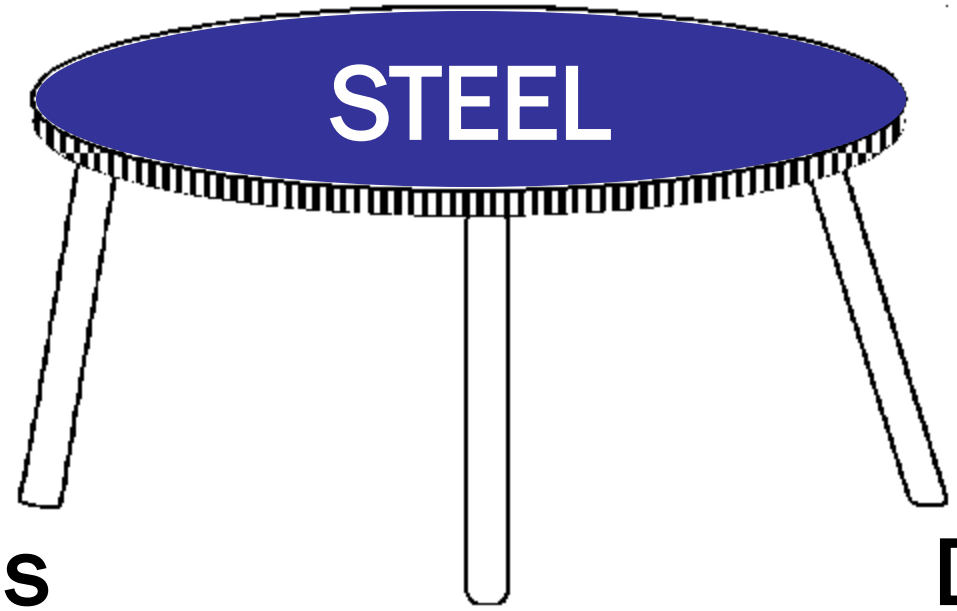
THE PARTNERSHIP LINKAGES

Auto/Steel Partnership

- Chrysler Group LLC, Ford Motor Company, General Motors Company
- AK Steel, ArcelorMittal, Nucor Corporation, Severstal North America, United States Steel Corp
- Contractors
- Academia
- AISI, IISI, WorldAutoSteel Consortia Partnerships
- Department of Energy (DOE)
- CANMET
- National Laboratories
- NSF



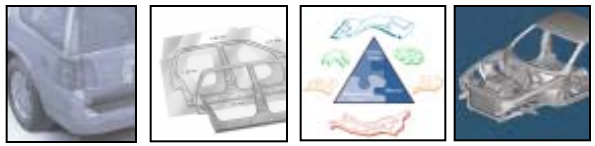
OVERALL STRATEGY



Materials

Design

Manufacturing



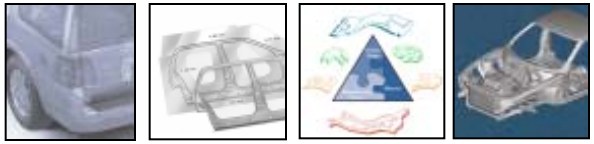
FreedomCAR & A/SP GOAL ALIGNMENT

FreedomCAR:

- 50% Mass Reduction
- Lifecycle Cost
- Performance/Reliability/Safety
- Recyclability
- Develop/Transfer Technology

Auto/Steel Partnership

- 40% Mass Reduction
- Lifecycle Cost
- Performance/Reliability/Safety
- Recyclability
- Develop/Transfer Technology



2009 A/SP PROJECT PORTFOLIO

Lightweighting

- Lightweight Chassis Structures
- Future Generation Passenger Compartment Validation
- Mass Compounding
- Mass Efficient Architecture for Roof Strength (MEARS)
- Benchmarking

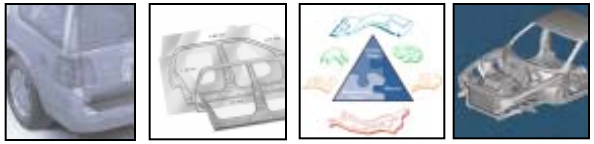
Enabling

- Advanced High-Strength Steel Stamping
- Hydroforming Materials and Lubricants
- Advanced High-Strength Steel Joining Technologies
- Joining Strategy Steering Committee
- Fatigue Characteristics
- Strain Rate Characterization
- Tribology
- 3rd Generation of AHSS (NSF)

On-Going

- AHSS Application Guidelines
- Technology Transfer

Indicates anticipated project completion 2009



2010 A/SP PROJECT PORTFOLIO

Lightweighting

- Benchmarking
- Lightweight Front Suspension

Enabling

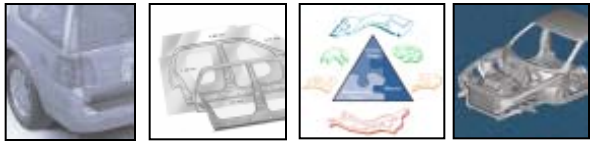
- Advanced High-Strength Steel Stamping
- Advanced High-Strength Steel Joining Technologies
- Joining Strategy Steering Committee
- Fatigue Characteristics
- Strain Rate Characterization
- Tribology
- 3rd Generation of AHSS (NSF)
- Precision Flow Form
- Nonlinear Strain Path

On-Going

- AHSS Application Guidelines
- Technology Transfer

Indicates anticipated project completion 2010

Indicates new projects 2010



Advanced High-Strength Steel Stamping

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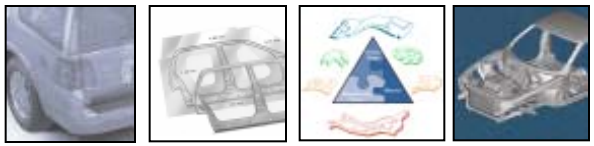


OVERVIEW

Timeline

- Start – 10/2001
- End – 09/2011
- 80% Complete

Budget

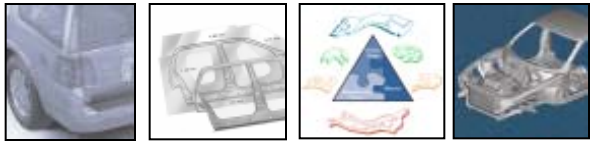
- Total Project Funding
  - DOE - $2,068K
  - Cost Share - $1,993K
- Funding for FY09
  - DOE - $245K
- Funding for FY10
  - DOE - $323K

Barriers

- Understanding forming characteristics of AHSS.

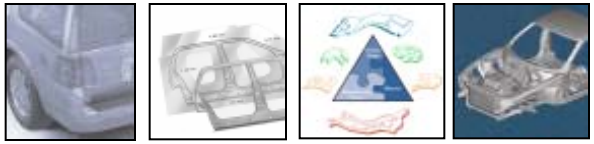
Partners

- Wayne State University
- Oakland University
- Autodie, LLC
- Ajax Tocco
- AET Integration Inc



PROJECT GOALS

- Evaluate springback prediction capability.
- Investigate die processes and part features for best part quality in AHSS:
  - minimum springback/curl/twist
  - minimum wrinkling
  - dimensional accuracy
- Assess impact of AHSS on press force/energy requirements.
- Support development of product/process design guidelines and failure criteria for AHSS.
- Provide for effective Technology Transfer.

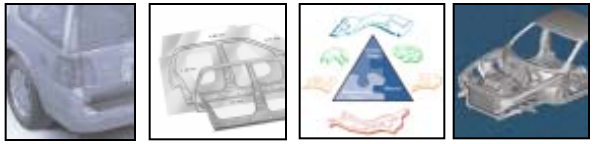


PROJECT TIMELINE

Deliverables

- Multifunction Master Shoe – Process Development
- Springback Compensation Validation
- EWI/OSU Drawbend Fracture
- Viscous Pressure Bulge σ/ε tests
- Flange Shear Affected Zone Study
- Edge Fracture in DP Steels
- DIC of Tensile Tests
- Sensitivity of AHSS Formability To Sheet Orientation

2006 2007 2008 2009 2010 2011+



PROJECT APPROACH

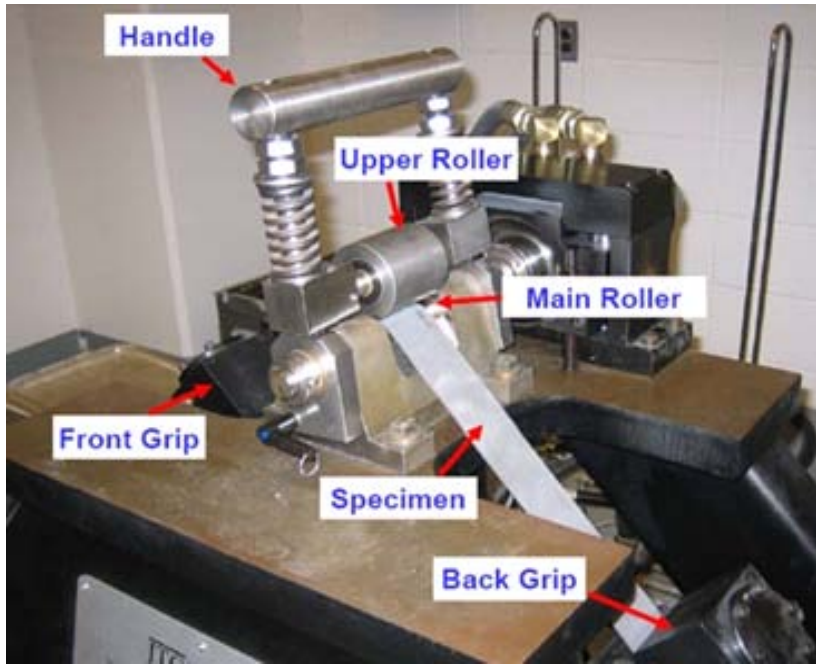
- Springback prediction:
  - Finite element modeling and correlation to experiment
  - Empirical constitutive modeling

- Springback reduction - Conception, execution and validation of process/product features resulting in:
  - Product design guidelines
  - Process design guidelines

- AHSS Fracture –Characterization of fracture during stamping of AHSS to guide stamping process and steel development.

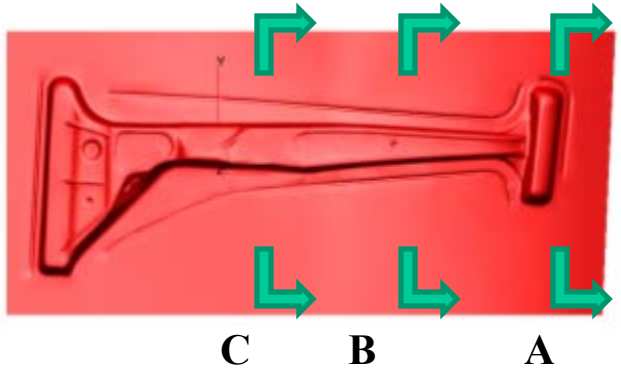
DRAW BEND SHEAR FRACTURE

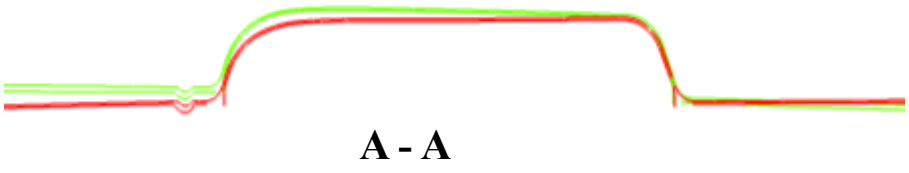
- Draw-bend test developed to emulate drawing a material over a die radius while increasing tension and displacement until failure.
- New constitutive material model (Holloman/Voce or H/V) developed to improve failure prediction by comprehending effect of temperature increase caused by work hardening.

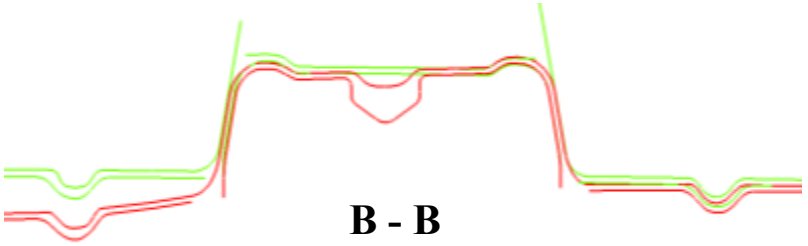


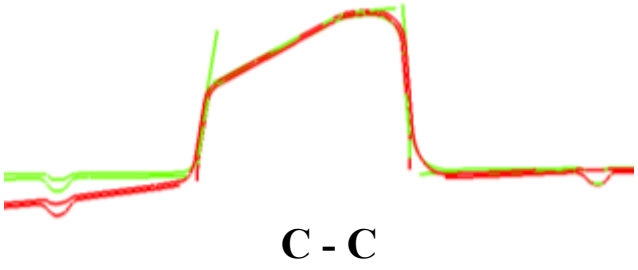
B-PILLAR SPRINGBACK COMPENSATION

- USAMP-developed software used to predict compensated surface.
- Predicted springback from original surface did not match scanned parts, so a tuning factor was used to match data and develop compensated surface.

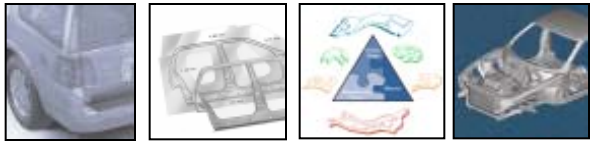






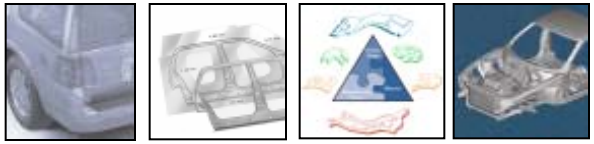


Red: Compensated Die
Green: Original Die



EDGE CRACKING

- Stretched-edge fracture an important problem in application of AHSS.
- Criteria appear to be different for small radius features (stretched and flanged holes) compared to larger radius features (flanges on body panel cutouts).

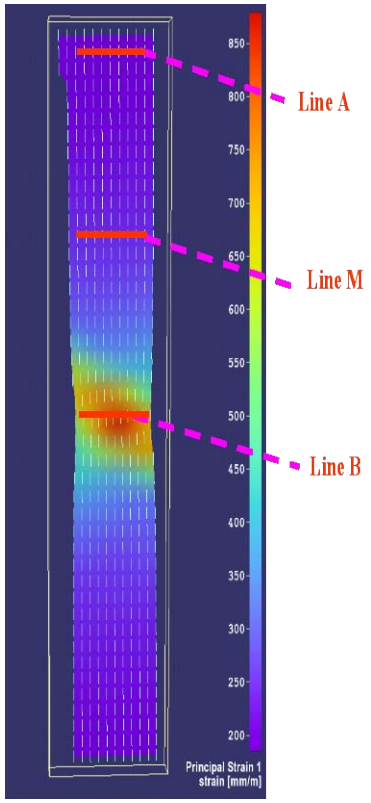


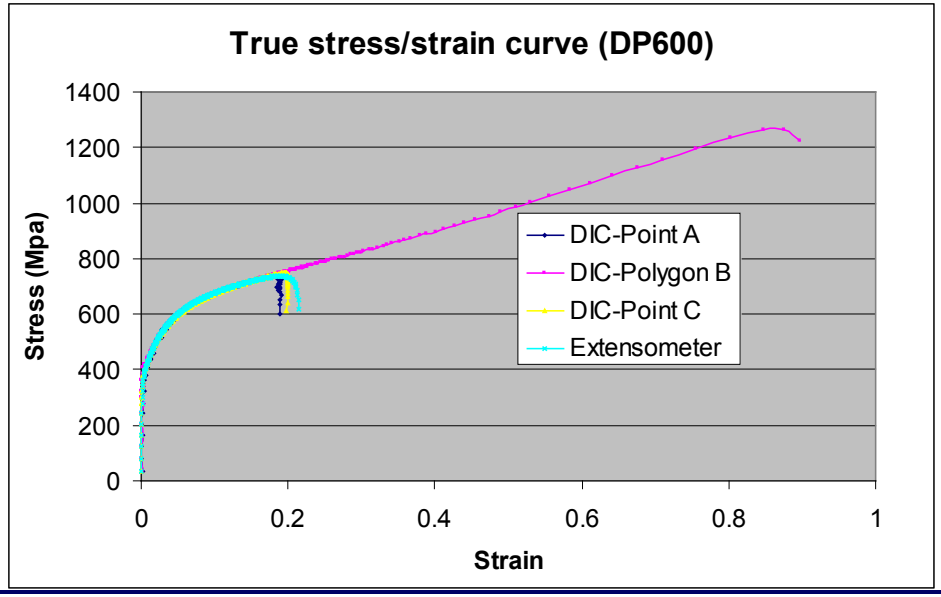
EDGE FRACTURE PROJECT ACTIVITY

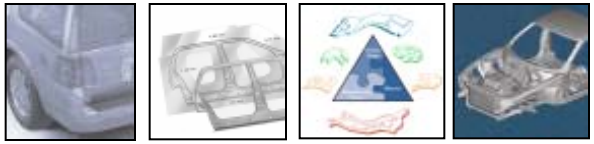
- Development of a flat punch hole expansion test to study AHSS edge fracture limits under various geometric, edge trimming and material thickness conditions to develop an empirical failure criteria.
- Empirical measurement of edge cracking for large size production AHSS stampings (and edge thinning).
- Study of the effect of material properties, microstructure and testing conditions on the empirical failure criterion of AHSS stretch drawing edge fracture (in conjunction with Wayne State University).

DIC MEASUREMENT OF TENSILE STRAINS

- Stress-strain behavior can be measured during necking and fracture.
- Actual measured curves can be used potentially for FEA simulation without extrapolation.
- 6 DP, TRIP and HSLA quasi-static cases complete.
- High strain rate cases complete.

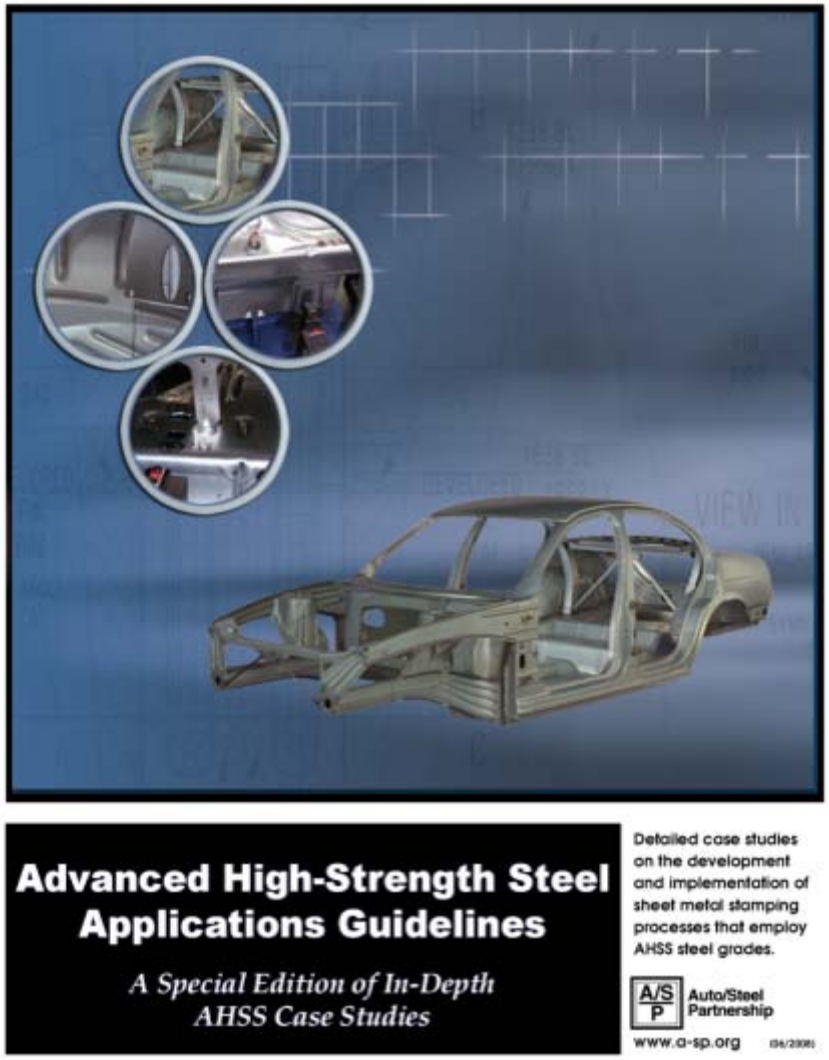


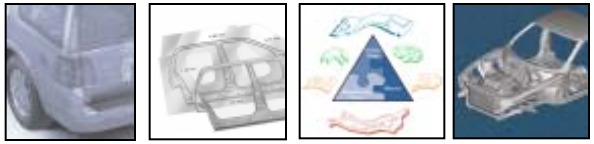




AHSS APPLICATIONS GUIDELINES

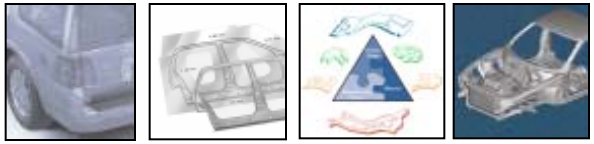
- Advanced High-Strength Steel Applications Guidelines document updated January 2010 (12 Case Studies, hard copy and electronic).





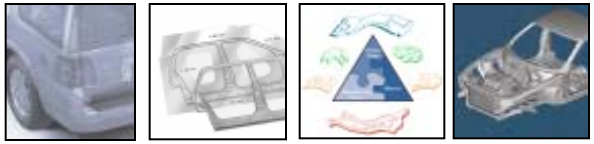
TECHNOLOGY TRANSFER

- Shear Fracture Project Technical Review Meetings – included project PIs, A/SP Forming Team members, other interested member company engineers.
  - Sept. 10, 2008 (included other DOE investigators)
  - April 2, 2009
  - Nov. 11, 2009 (final project review)



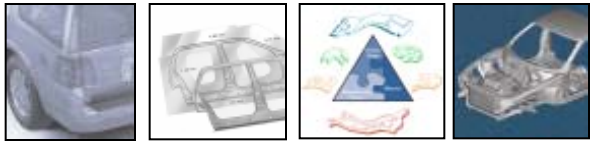
TECHNOLOGY TRANSFER

- Presentations:
  - "Edge Fracture of Dual Phase Steel in Hole Expansion" – MS&T 2008, Pittsburgh, PA (Wayne State University)
  - "Failure Analysis of Advanced High-Strength Steels (AHSS) in Stretch Bending" – Great Designs In Steel 2009, Livonia, MI (EWi/SFTC/Ohio State University)



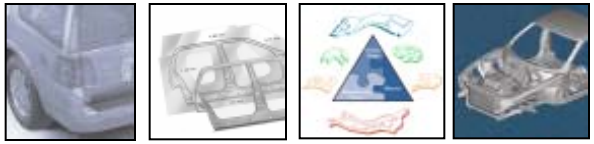
TECHNOLOGY TRANSFER

- Technical Papers - IDDRG 2009, Golden, CO:
  - "Failure Analysis of Advanced High-Strength Steels (AHSS) During Draw Bending" – (EWi/Ohio State University)
  - Accurate Constitutive Equation For Dual-Phase Steels (Ohio State University)
  - "Sheet Metal Shearing And Edge Characterization Of Dual-Phase Steels" (Wayne State University)
- Reports – Distributed to Team Members:
  - "Developing A Spreadsheet For Predicting Limit Strain In Stretching A Sheared Edge" (B. S. Levy & C. Van Tyne)



FUTURE PLANS

- Edge fracture work continuing into 2011.
- 3rd Generation Advanced High-Strength Steel forming trials are on the horizon.



Fatigue of Advanced High-Strength Steel

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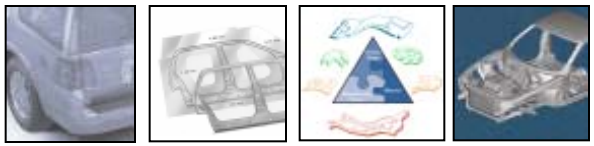


OVERVIEW

Timeline

- Start – 10/2001
- End – 09/2010
- 90% Complete

Budget

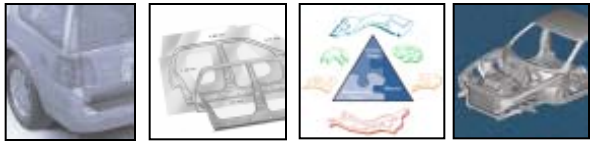
- Total Project Funding
  - DOE - $553K
  - Cost Share - $445K
- Funding for FY09
  - DOE - $23K
- Funding for FY10
  - DOE - $70K

Barriers

- Lack of fatigue data for AHSS base materials and joints

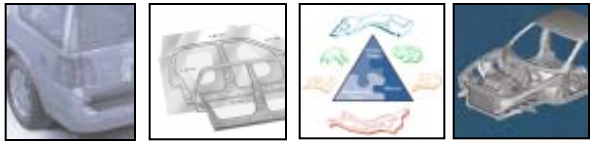
Partners

- University of Michigan
- Roman Engineering Services



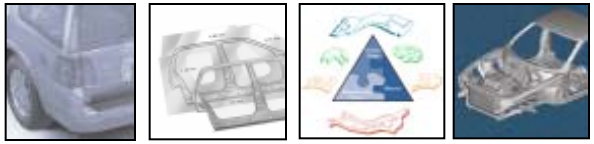
PROJECT GOALS

- 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.



PHASE 1A and PHASE 1B TESTS

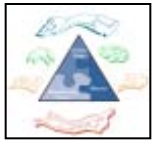
Phase 1A

- **Material combinations**
  - DP590 GA-DP590 GA
  - SAE1008 HR-SAE1008 HR
  - HSLA 420 HR-HSLA 420 HR
  - DP600 HR-DP600 HR
  - BORON-BORON
  - DQSK GA-DQSK GA
  - TRIP780 GI-TRIP780 GI
  - DP780 GI-DP780 GI
  - DP590 GA – SAE1008 HR
  - DP600 HR-SAE1008 HR
  - TRIP780 GI-SAE1008 HR
- **Specimen geometries**
  - Single lap shear
  - Double lap shear
  - Butt weld
  - Start-Stop
  - Perch mount

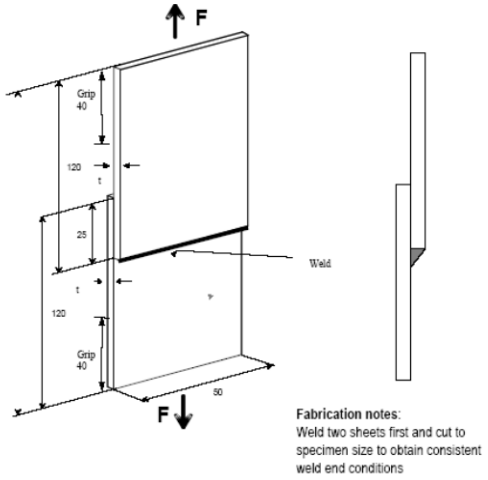
Phase 1B

- **Material combinations**
  - HSLA420 HR-HSLA 420 HR
  - DP590 GA-DP590 GA
  - BORON-BORON
  - DP780 GI-DP780 GI
  - BORON-HSLA 420 HR
- **Specimen geometries**
  - Single lap shear
  - Double lap shear
  - Start-Stop

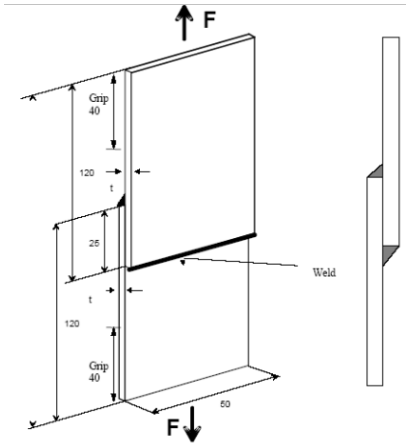




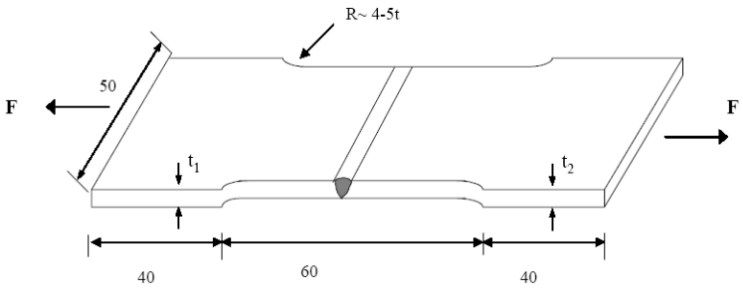

WELD FATIGUE TEST COUPONS



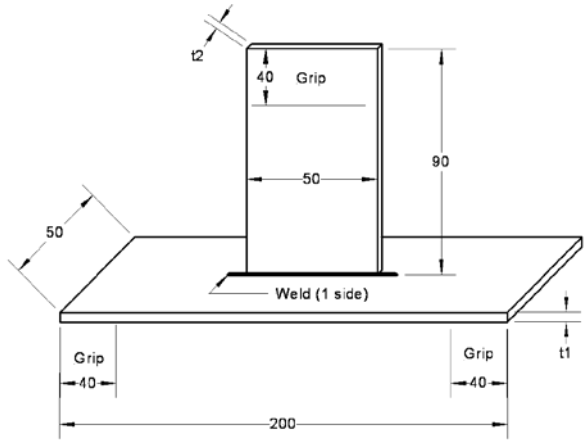
Single Lap Shear test specimen



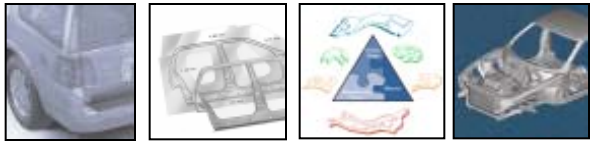
Double Lap Shear Test specimen



Butt Weld Test specimen

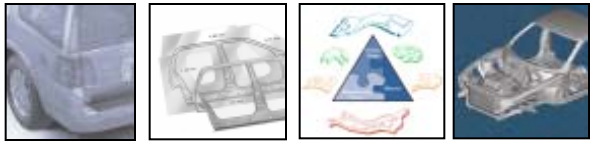


Perch Mount Test specimen



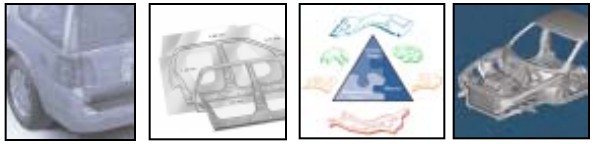
ACCOMPLISHMENTS IN FY2010

- Completed Phase 1A of the GMAW weld fatigue test program.
- Began Phase 1B of the GMAW weld fatigue test program.
- Began work on a variability study to identify sources of test results variation and key geometric parameters of weld specimens from both Phase 1A and Phase 1B fatigue test programs.



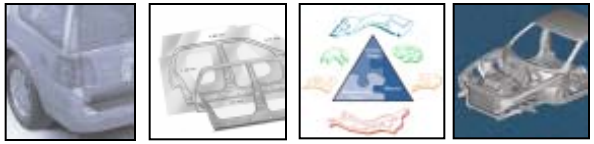
TECHNOLOGY TRANSFER

- SAE paper on variability of weld geometry on spot weld fatigue – April 2009 (accepted for publication in SAE Transactions Journal).
- SAE paper on effect of weld process on variability of weld geometry on MIG welded joints – April 2009.
- SAE presentation and paper on weld fatigue of MIG welded joints – April 2010.



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.
- Complete project by September 2010, no current plans for additional work.



Strain Rate Characterization

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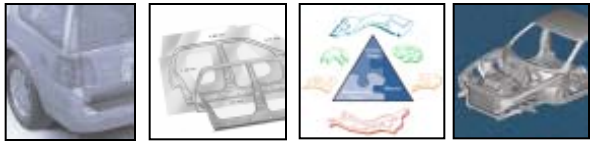


OVERVIEW

Timeline

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

Budget

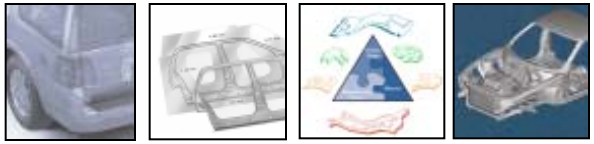
- Total Project Funding
  - DOE - $406K
  - Cost Share - $261K
- Funding for FY08
  - DOE - $91K
- Funding for FY09
  - DOE – $34K

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.

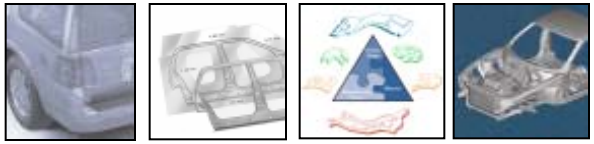
Partners

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

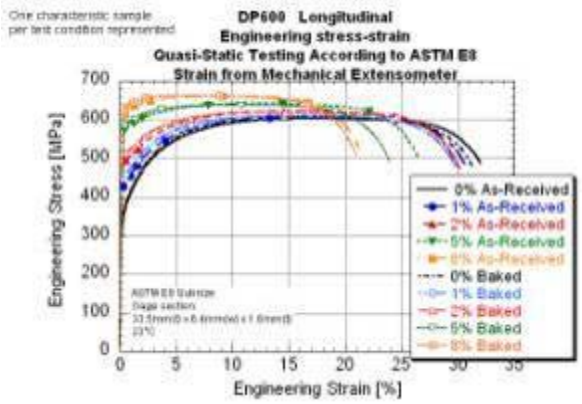


PROJECT GOALS

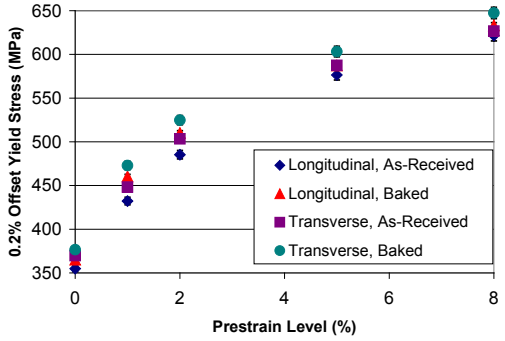
- Develop new experimental setups for characterization of the strain rate sensitivity of AHSS and characterize the materials.
- Develop a new, robust spot weld finite element formulation for modeling the spot weld separation and failure mode as a function of impact, welding conditions and materials.
- Develop experiments to characterize the bake hardening effect of DP steels at high strain rates.

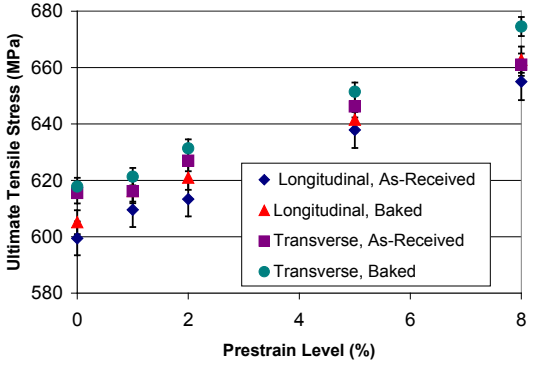


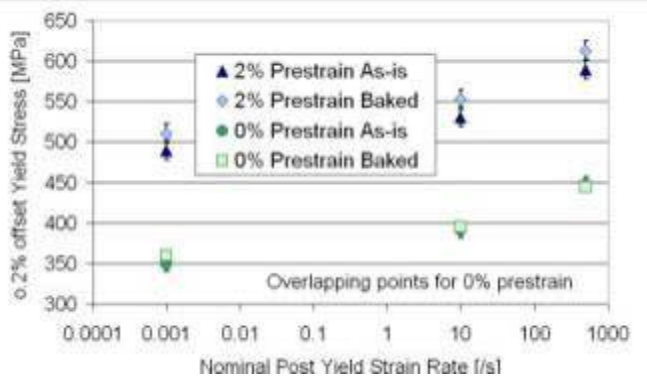
BAKE-HARDENING EFFECT of DP600

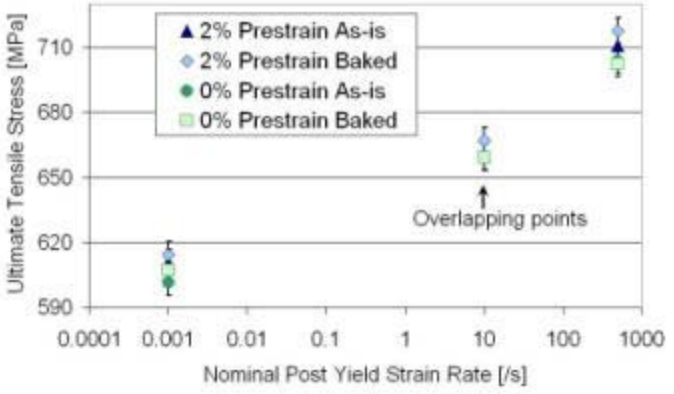


- The most significant improvements in YS and UTS came from pre-strain and increased rate.
- Baking after pre-strain tends to improve (1.8 – 6.5%) YS in DP600 across rates.
- The effect of baking after pre-strain overshadowed by material variability for DP780 – Bake-Hardening effect is not significant.







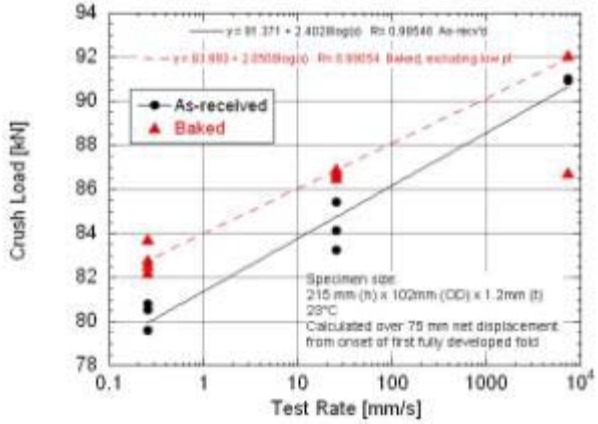


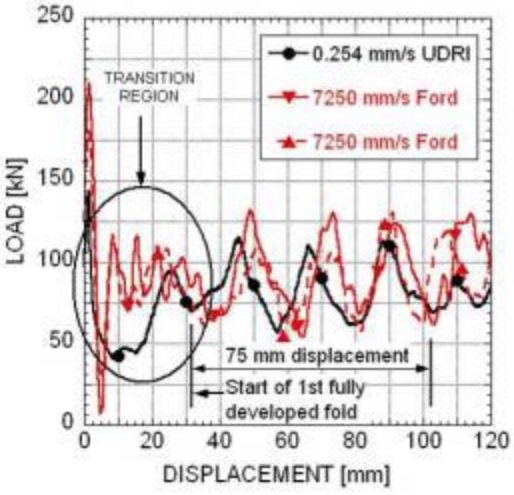
University of Dayton Research Institute

DP780 TUBE CRUSH RESULTS

Effect of Bake-Hardening

- Hydroformed Tubes saw ~3% improvement in average crush load and energy absorbed after baking.

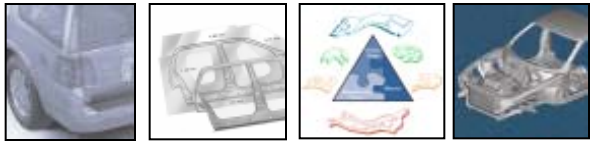






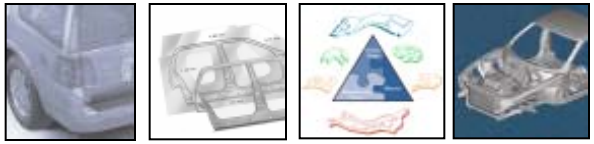

LIST of the RECENT PUBLICATIONS

1. S. Simunovic, P. Nukala, J. Fekete, D. Meuleman & M. Milititsky; “Modeling of Strain Rate Effects in Automotive Impact”; SAE World Congress, 2009, Detroit, MI, SAE Paper: 2003-01-1383
2. S. Simunovic, J.M. 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, J.M. 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, J.M. 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. 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 & X. Chen; “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.
- Future direction of weld modeling is under discussion.
- Project completed February 2009.



Advanced High-Strength Steel Joining

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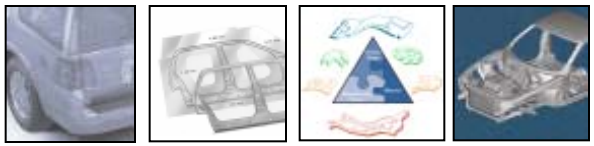


OVERVIEW

Timeline

- Start – 10/2001
- End – 09/2010
- 85% Complete

Budget

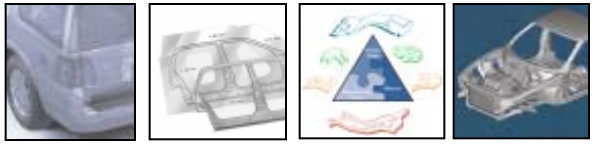
- Total Project Funding
  - DOE - $1,357K
  - Cost Share - $780K
- Funding for FY09
  - DOE - $190K
- Funding for FY10
  - DOE - $264K

Barriers

- Understanding forming characteristics of AHSS.

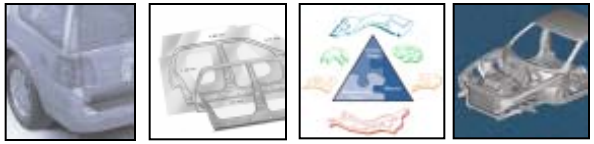
Partners

- AET Integration Inc.
- EWi/Ohio State University
- Roman Engineering Services



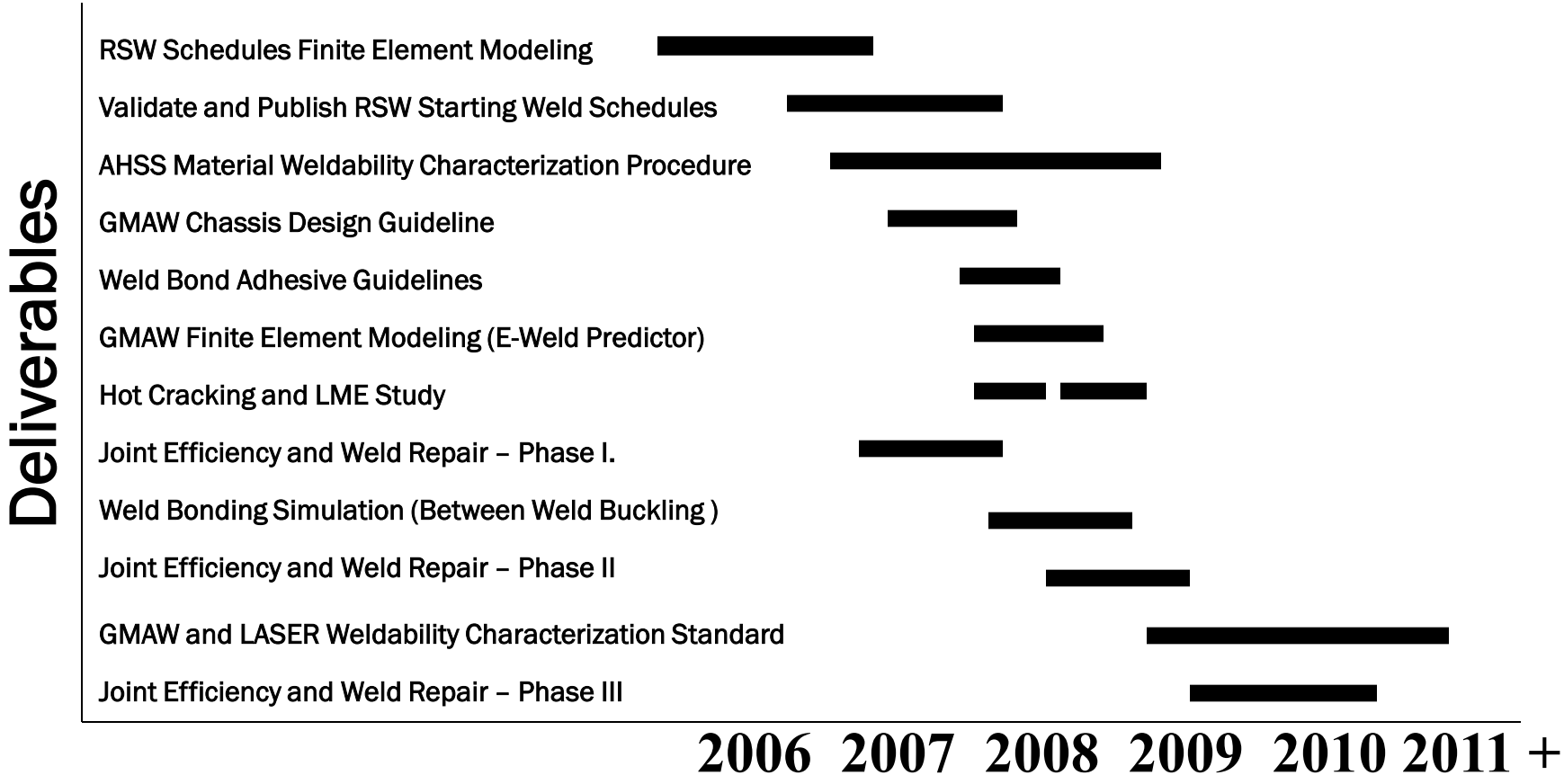
PROJECT GOALS

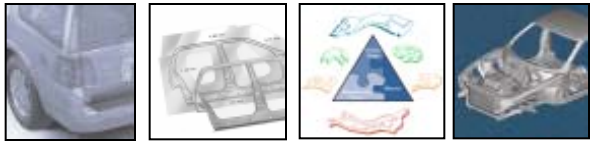
- Provide welding and joining expertise to support A/SP project teams in developing lightweight automotive body structures.
- Supplement the existing welding and joining technical knowledge with applied research to facilitate an increased use of AHSS.
- Utilize A/SP research data to prepare industry weldability and weld quality acceptance standards.



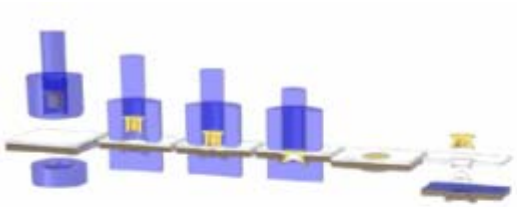
PROJECT TIMELINE

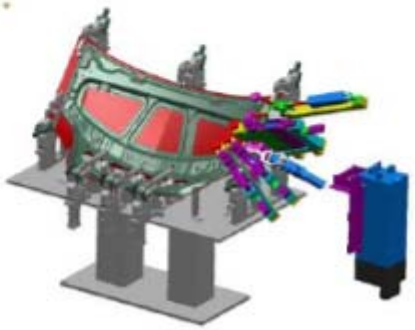
- Resistance Spot Welding Team originally formed in 2000.
- Project Team scope and name revised in 2002 to reflect Joining Technologies rather than just resistance spot welding.

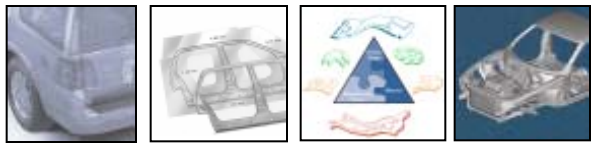




JOINT EFFICIENCY PROJECT APPROACH

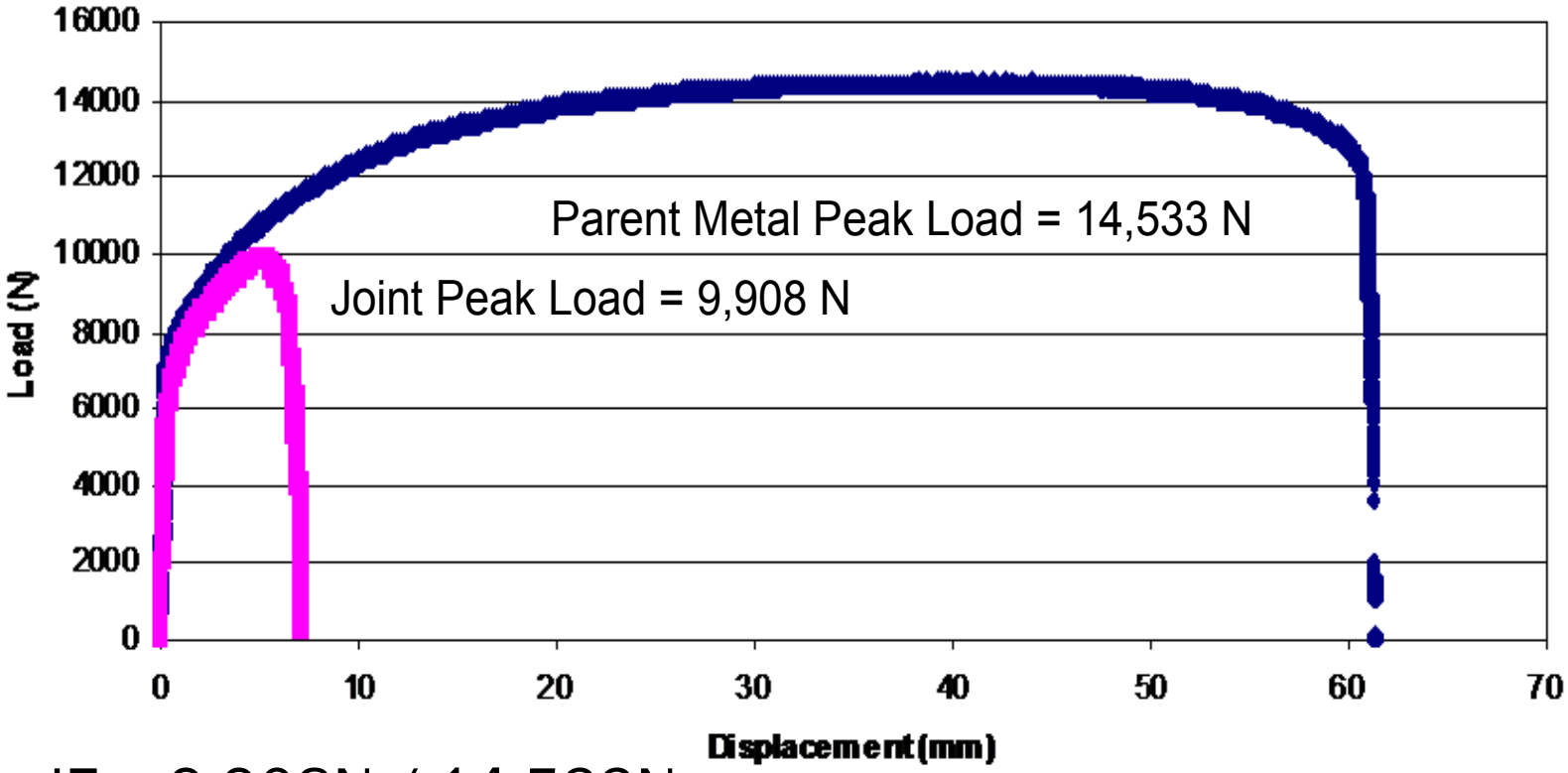






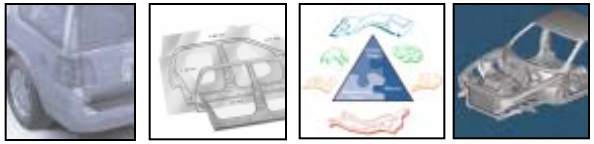
JOINT EFFICIENCY PROJECT APPROACH

- Joint efficiency was calculated as the peak load of the joint divided by the peak load of the parent metal.

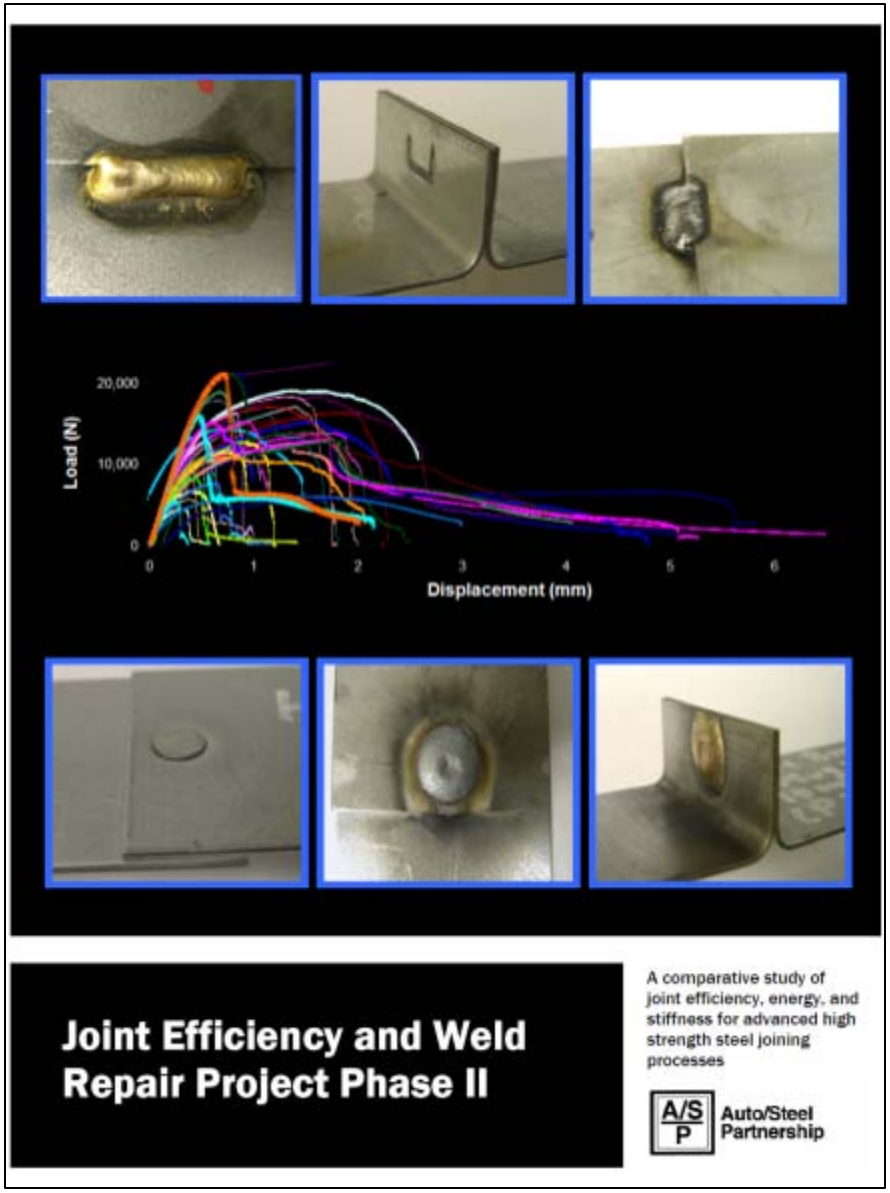


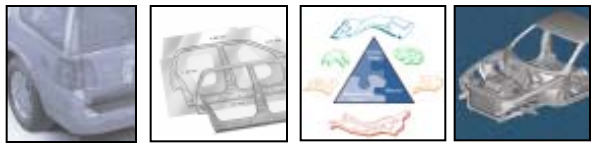
JE = 9,908N / 14,533N

JE = 68%



PROJECT RESULTS

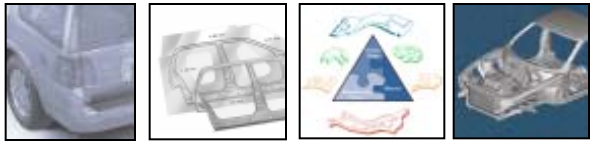




JOINT EFFICIENCY PROJECT APPROACH

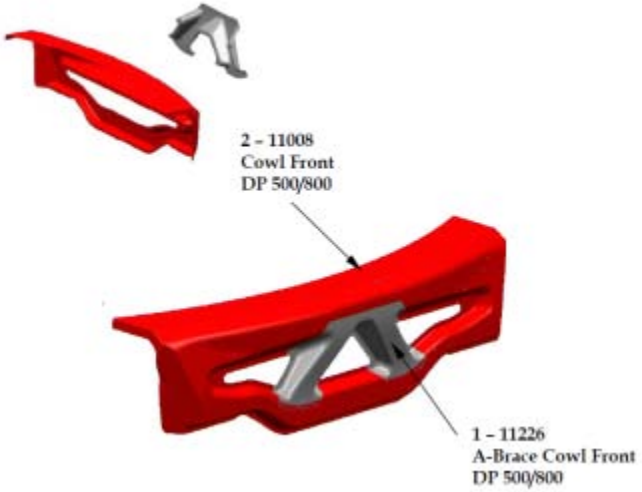
Material	Coupon Configuration	Joining Process	Peak Load (N)	Joint Efficiency	Normalized Energy	Normalized Stiffness
DP780						
	LS					
		Arc Braze (25mm lap fillet) LS	11,339	29.0%	0.5%	77.8%
		GMAW (AWS D8.8M - 25mm fillet) LS	19,562	50.0%	1.8%	86.7%
		Laser (25mm lap) LS	20,633	52.8%	2.9%	88.7%
		Laser Braze (25mm lap fillet) LS	8,075	20.7%	0.2%	81.6%
Mild Steel						
	LS					
		Arc Braze (25mm lap fillet) LS	7,855	54.0%	3.1%	77.0%
		GMAW (AWS D8.8M - 25mm fillet) LS	9,908	68.2%	7.9%	81.3%
		Laser (25mm lap) LS	10,139	69.8%	9.8%	83.0%
		Laser Braze (25mm lap fillet) LS	6,657	45.8%	1.0%	73.0%

- Allows the user to display metrics by selecting processes, materials, and joint configurations.
- Provides quick reference and comparisons of all test data.
- Included in the member tool kit.
- Phase 2 (58 processes evaluated).

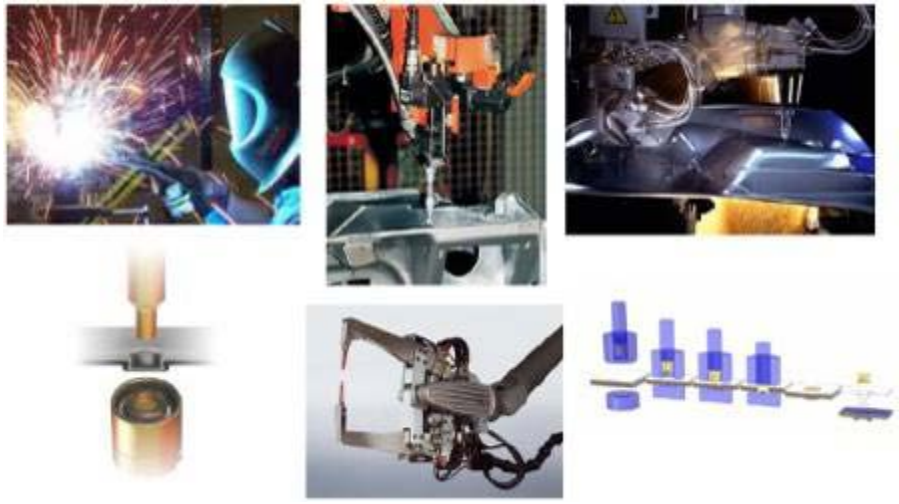


JOINT EFFICIENCY PHASE 3

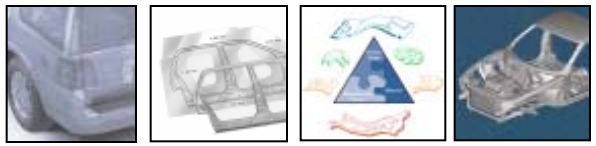
- Develop a computer application to allow automotive OEMs and suppliers the ability to compare the manufacturing costs of various automotive welding and joining processes to support process selection decisions.
- Review and compare technical information for competing joining technologies obtained from Phase 1 and Phase 2 Joint Efficiency Projects along with process cost information.



Component Example: Assembly Cowl Front from Future Generation Passenger Compartment Project

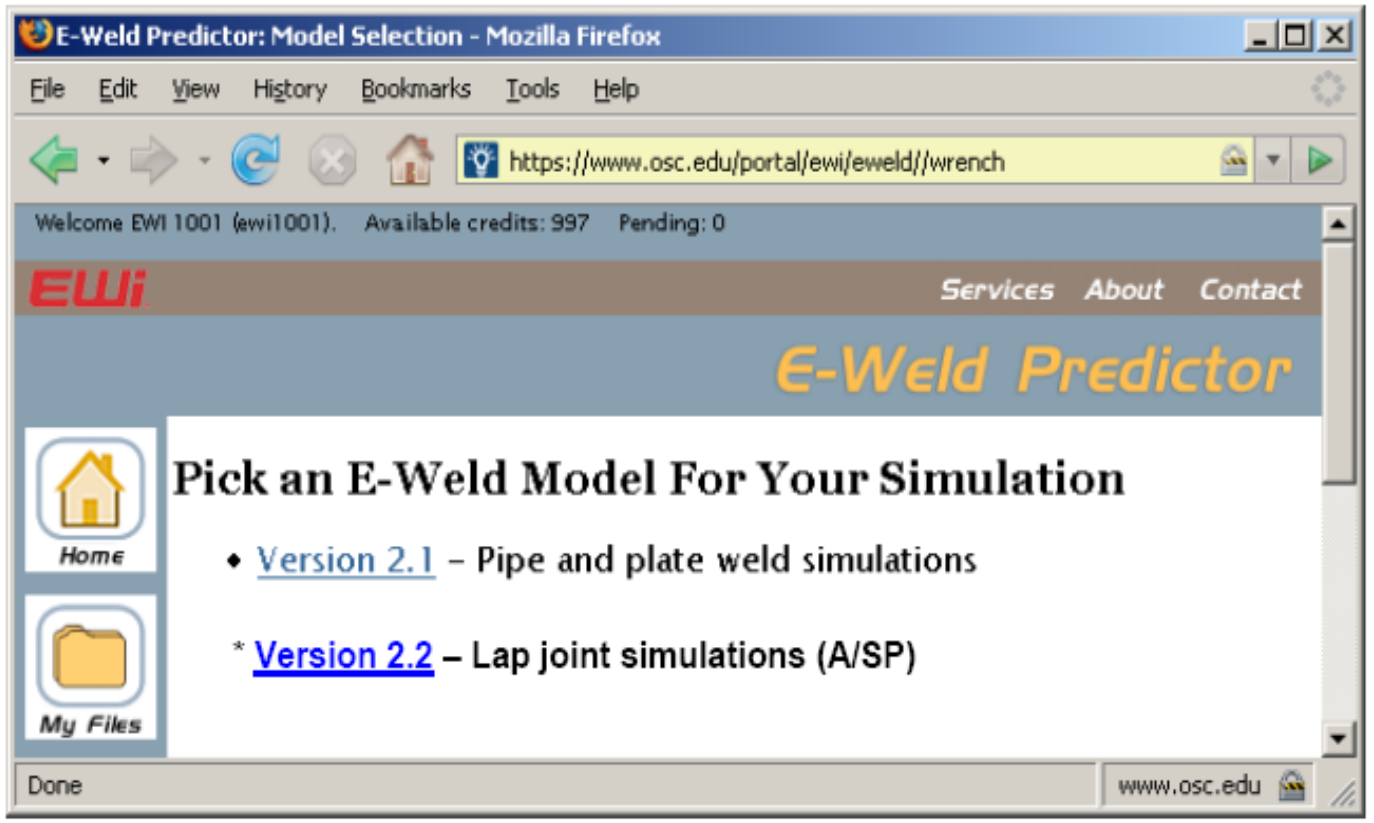


Competing Joining Technologies

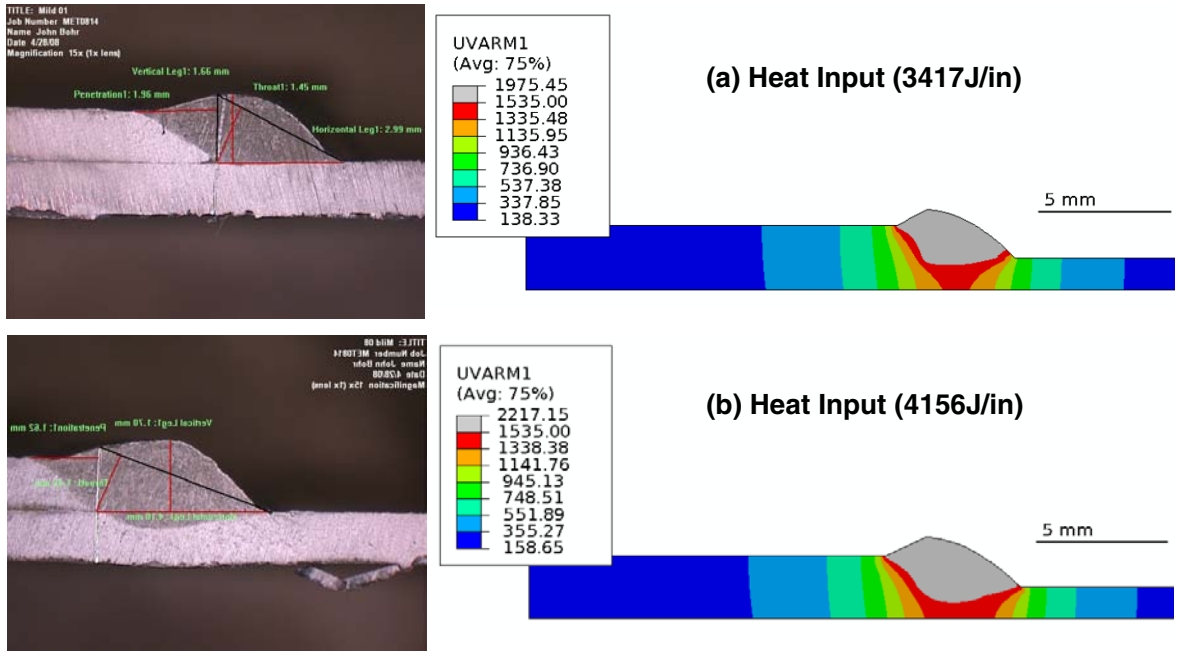


E-WELD PREDICTOR PROJECT RESULTS

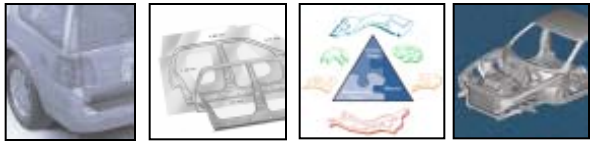
- Develop a demonstration web-portal on typical automotive gas metal arc welding (GMAW) lap-joints.
- Validate the FEA predicted results with experimental results on typical automotive GMAW lap-joints.



- Good agreement between experimental results and predicted leg lengths.
- Under predicted penetration.

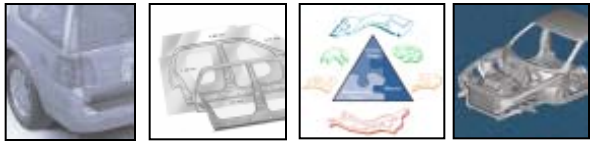


Factors affecting the prediction accuracy included issues with thermal material properties for AHSS and the amount of model calibrations.



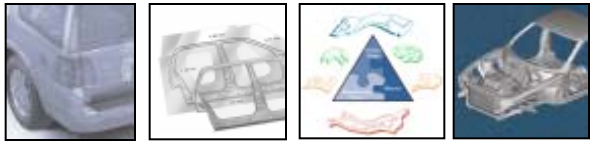
ACCOMPLISHMENTS in FY2010

- Completed Phase II of a comprehensive study on joint efficiency.
- Created and published results of a Between Spot Weld Buckling Project:
  - Influence of weld pitch
  - Influence of structural adhesive
- Supported development of an automotive industry AHSS resistance spot weld material characterization (AWS D8.9M:200X).
- Created and published Weld Bond Adhesive Guidelines.
- Created and published Starting Resistance Spot Weld Schedules.



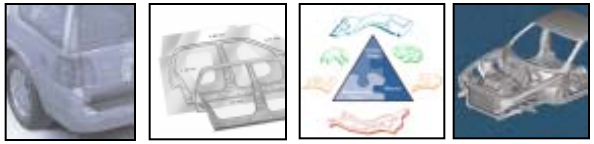
TECHNOLOGY TRANSFER

- Presentations and exhibit:
  - Great Designs in Steel (May 2009).
  - International Auto Body Congress (November 2009).
  - AWS Fabtech (November 2009).
  - Sheet Metal Welding Conference (May 2010).
- Members Only
  - Joint Efficiency Phase 2 Members Only toolkit (CD).
- Public
  - Joint Efficiency Phase 2 Project Results (CD).
  - Liquid Metal Embrittlement and Hot Cracking Sensitivity Project Results (CD).



SUMMARY

- Project to be completed by September 2010.
- Potential future project work being developed under ASP310 Joining Strategy Steering Committee.



2010+ A/SP PROJECT PORTFOLIO

Lightweighting

- Benchmarking
- Lightweight Front Suspension
- Lightweight Fuel Tanks

Enabling

- Advanced High-Strength Steel Stamping
- 3rd Generation of AHSS (NSF)
- Precision Flow Form
- Nonlinear Strain Path
- Stamping Tooling Optimization
- Mapping Forming Simulation Results to Crash Models
- Manufacturing of Thin Gauge AHSS & UHSS for Body & Chassis Parts
- 3rd Generation AHSS Manufacturing Trials

On-Going

- Technology Transfer

Indicates new projects 2010

Indicates anticipated projects 2010 & beyond