Dynamic Characterization of Spot Welds for AHSS

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Project ID: LM025

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Overview

Timeline

- Start: Dec, 2006
- End:
  - Phase I: March, 2009
  - Phase II: March, 2013
- Percent complete
  - Phase I: 100%
  - Phase II: 10%

Budget

- Total project funding
  - DOE share: $880K
  - Contractor share: $150K
- Funding received in FY10: $250
- Funding for FY11: $250K (expected in May 2011)

Barriers

- Barriers addressed
  - Efficient optimization of AHSS body structures for light-weighting while meeting crash requirements

Partners

- Interactions/ collaborations
  - GM, Ford, Chrysler, ArcelorMittal Steel, US Steel
- Project lead
  - Oak Ridge National Laboratory

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Project Objectives

- Key technical development
  - A spot weld modeling tool capable of incorporating the behavior of spot weld (strength, failure mode, and deformation rate effects) in advanced crashworthiness CAE, for better utilization of materials in light-weighting efforts
- Key objective/deliverable metrics
  - A new, robust spot weld element and implementation procedure that is practical for automotive crash modelers to use
  - An integrated thermal-electrical-mechanical-metallurgical weld process model to predict the microstructure and property distributions in spot welds
  - Special experiments to determine local material deformation and damage of highly non-uniform weld microstructures
  - Companion property database for impact simulation and analysis
  - Focus on resistance spot weld of advanced high-strength steels (AHSS)

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Relevance

- A primary driver for use of AHSS and other high-strength lightweight materials in BIW is the improvement of crash performance while reducing the weight
- Advanced crashworthiness Computer Aided Engineering (CAE) is an essential tool enabling for safety design and optimization, to accelerate the use of new materials
- As welding is extensively used in auto body structures, the dynamic performance of welded structures is an important consideration in crashworthiness CAE
- The spot weld modeling tool from this project addresses a critical need in higher-level optimization of vehicle light-weighting while meeting crash requirement and cost-effectiveness

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Technology Gap Analysis*

- Consensus
  - The prediction of spot weld failure in FEM crash analysis is generally unsatisfactory, which greatly impedes the overall accuracy of crash analysis of welded structure components
  - Spot welds in AHSS are of particular concern because these welds are subject to both ductile (button pullout) and interfacial failure

- Gap exists in both the fundamental understanding and the practical capability of predicting the failure of spot welded structures in crash
  - Why do welds in AHSS and other light-weight materials exhibit different failure modes, and fail more often under impact?
  - What are the roles of alloy composition and welding parameters in the change in failure mode?
  - What would it take to have crash model adequately handle the deformation and failure of spot welds under impact?
- Past R&D on AHSS spot welds have been largely under static loading conditions. Experience base for various AHSS under high-strain rate conditions is nonexistent or very limited

* *A/SP Strain Rate Characterization Committee report*

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Technology Gap Analysis*

- Impedes the rapid and optimum insertion of AHSS and other lightweight materials in auto body structures.
  - We cannot design components containing AHSS and other lightweight materials, and optimize crash performance using numerical analysis with confidence that weld failures will not occur
  - The weld failures, detected in later stage of new model car development cycle, have frequently resulted in design compromises that can adversely affect weight savings available by using AHSS.
  - Further lightweighting opportunities from optimized use of AHSS and other lightweight materials will not be possible without improved understanding of the phenomena and the development of respective models and CAE tools for crashworthiness analysis.

* A/SP Strain Rate Characterization Committee report

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Project Milestones

Month/Year	Milestone or Go/No-Go Decision
Sep-09	Demonstrate feasibility – initial version of spot weld element ***Phase I Go/No-Go Decision*** *(Completed)*
Sep-09	Transfer initial version of weld model for evaluation *(completed)*
Jul-10	Finalize welding and material testing matrix with input from industry advisory committee *(Completed)*
Sept-10	Complete characterization of the microstructure and microhardness mapping in the RSW zone for three selected AHSS (DP980, TRIP800, and Boron/Martensite) *(Completed)*
Sept-11	Complete microstructure and microhardness characterization of weld population in this project (6 types/grade and coating combinations, 16 combination of thickness and stack configurations) *(On-going)*
Sept-11	Complete integrated weld process/property model development and validation of 6 steel types/grades/coatings consisting of DP980, TRIP800 and Boron/Martensite steel and welding of different steels (weld nugget mixing) *(On-going)*
Sept-11	Beta version of SWE capable of handling HAZ softening *(On-going)*

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Phase II Gantt Chart

Fiscal Year	2010				2011				2012				2013			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Task I: Materials & Coatings																
1.1 Spot Welding of AHSS																
1.2 Weld Characterization																
1.3 RSW Process/Property Modeling																
1.4 SWE for Task 1																
Decision Gate																
Task 2: Thicknesses & Stacks																
2.1 Spot Welding of AHSS																
2.2 Weld Characterization																
2.3 RSW Process/Property Modeling																
2.4 SWE for Task 2																
Decision Gate																
Task 3: Impact Tests																
3.1 Test setup and fixture design																
3.2 Testing of AHSS spot welds																
3.3 AHSS spot welds database																
Decision Gate																
Task 4: Weld Failure Criteria																
4.1 Failure Criteria for AHSS																
4.2 SWE with Failure Criteria																
Decision Gate																
Task 5: Component Tests																
5.1 AHSS Component Impact Testing																
5.2 AHSS Component Modeling																
Decision Gate																
Task 6: SWE Formulation																
6.1 Stand-Alone SWE code																
6.2 Code verification																
6.3 Model transfer to OEM codes																
Decision Gate																

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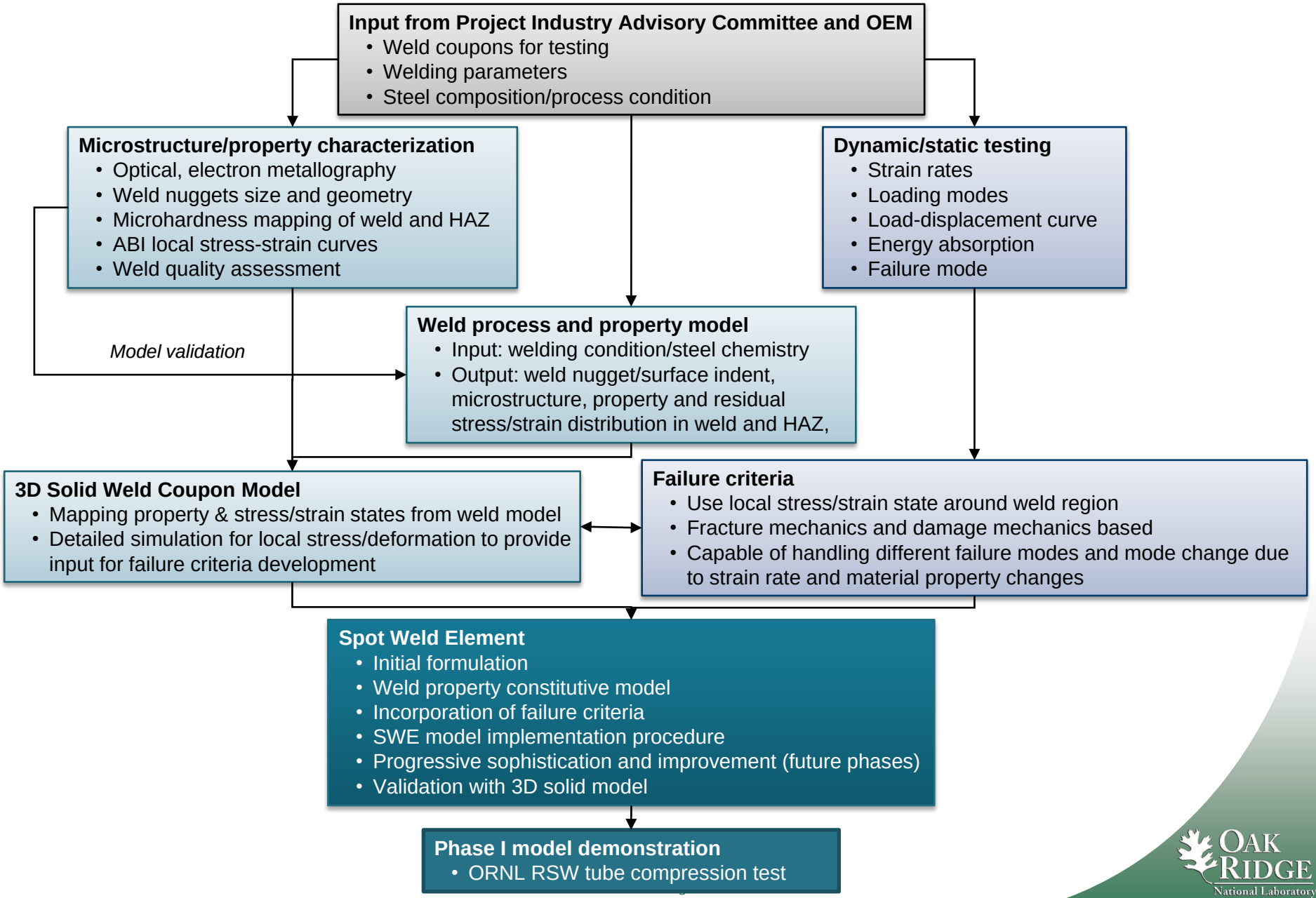
Technical Approach



Progress/Accomplishments (Phase I)

- Successfully completed the concept feasibility development of a new spot weld simulation model for advanced crashworthiness CAE
- Developed an initial version of SWE
  - Capable of handling weld geometry and weld property gradient
  - Capable of predicting different fracture modes and fracture load limit experimentally observed in impact tests
- Developed an initial version of integrated electrical-thermal-mechanical-metallurgical resistance spot weld model
  - Capable of predicting weld geometry, microstructure and microhardness distributions
  - Friendly user input interface for welding parameters, sheet thickness and steel chemistry
- Generated baseline spot weld impact test data
  - Characterization of effects of impact speeds and loading modes;
  - Web-based database for user-friendly interactive data analysis and retrieval.

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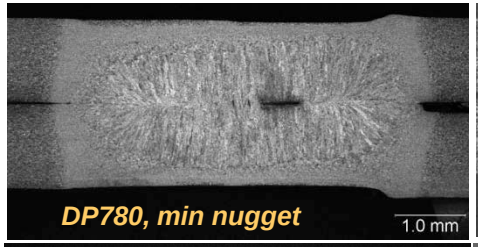
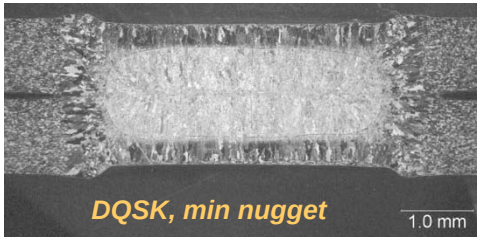
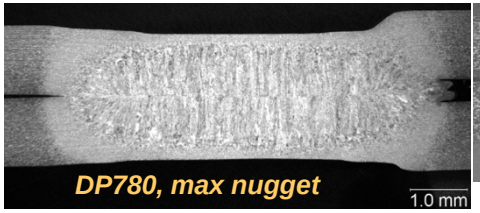
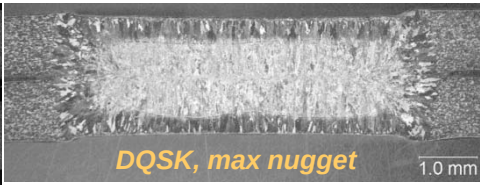
Phase I Accomplishment: Weld Microstructure/Property Modeling & Characterization

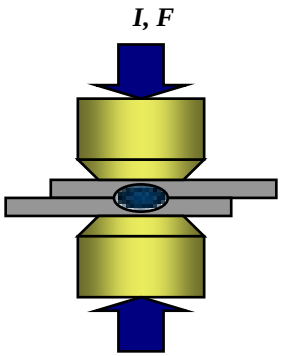
- Weld property gradients are determined and compared among different steels
- Weld size and other geometric attributes including defects are correlated to steel grade and welding conditions
- An incrementally coupled electric-thermal-mechanical-metallurgical model is being developed and under validation

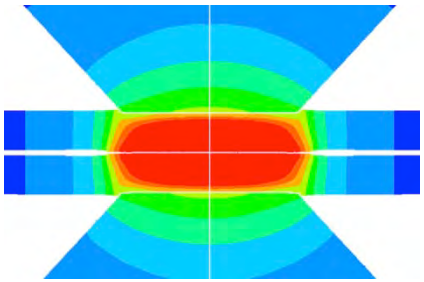




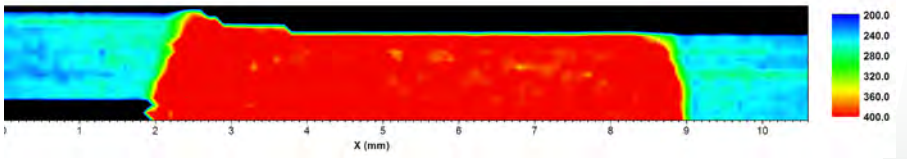




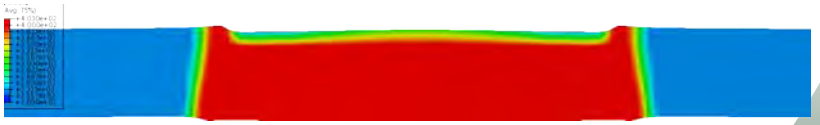




DP780



Hardness mapping measurement



Model prediction

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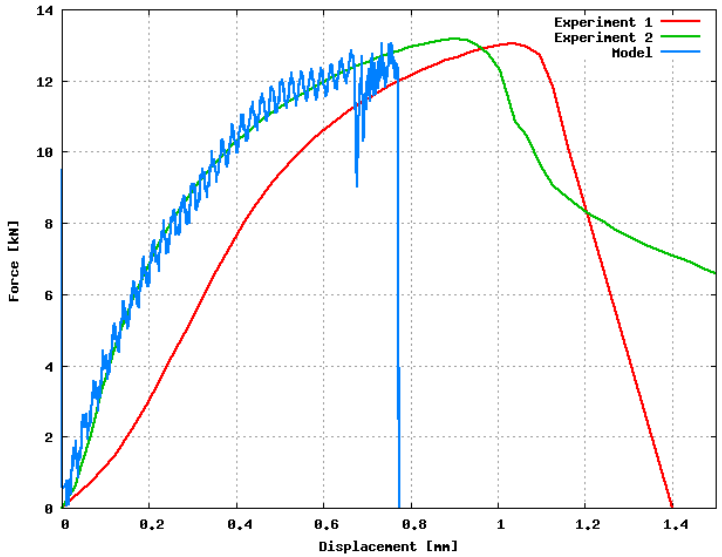
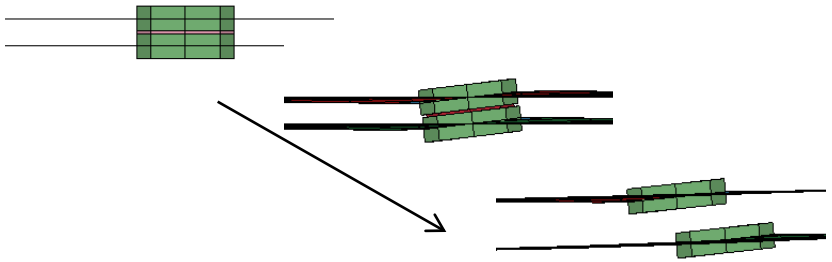
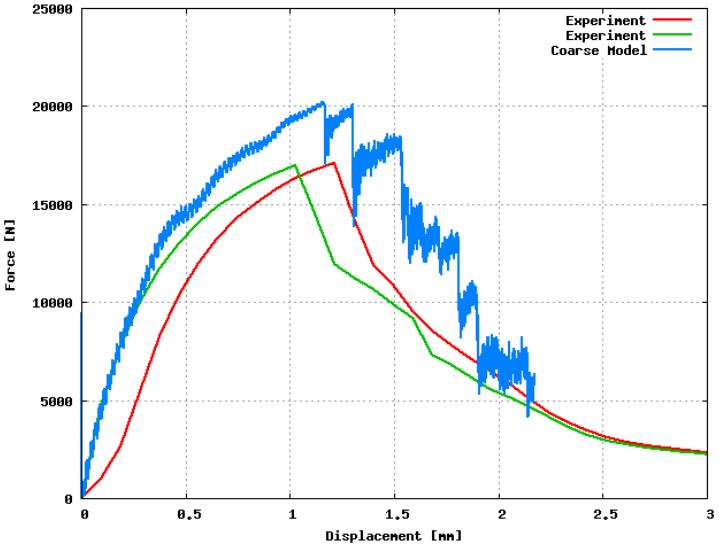
Phase I Accomplishments: SWE Simulation of Impact Test

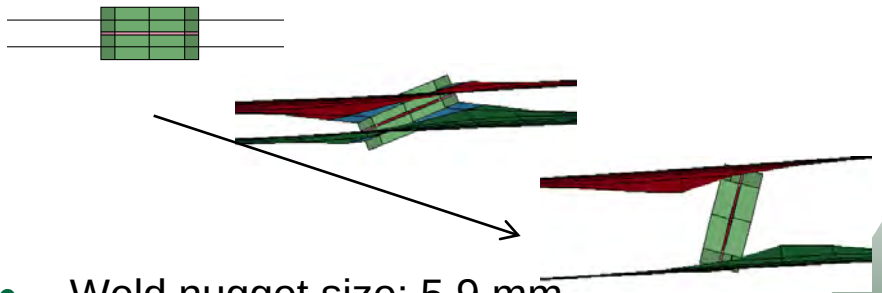
- Our model captures reasonably well the experimentally observed deformation behavior and failure modes





- Weld nugget size: 4.3mm
- Interfacial failure mode





- Weld nugget size: 5.9 mm
- Button pullout failure mode

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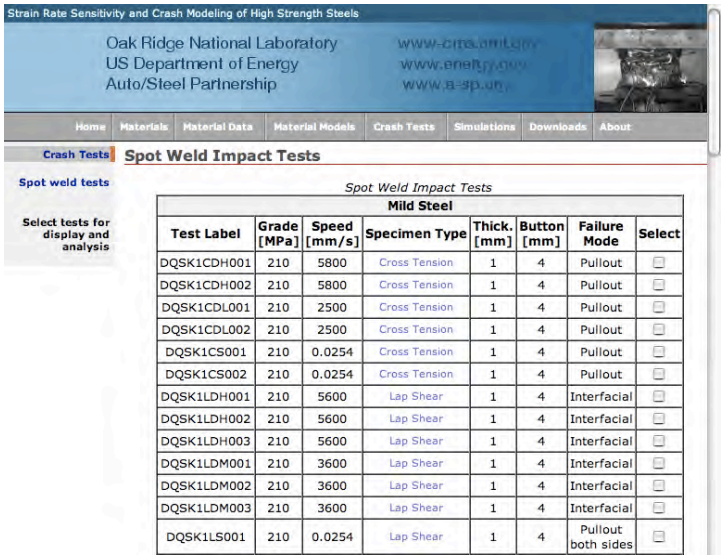
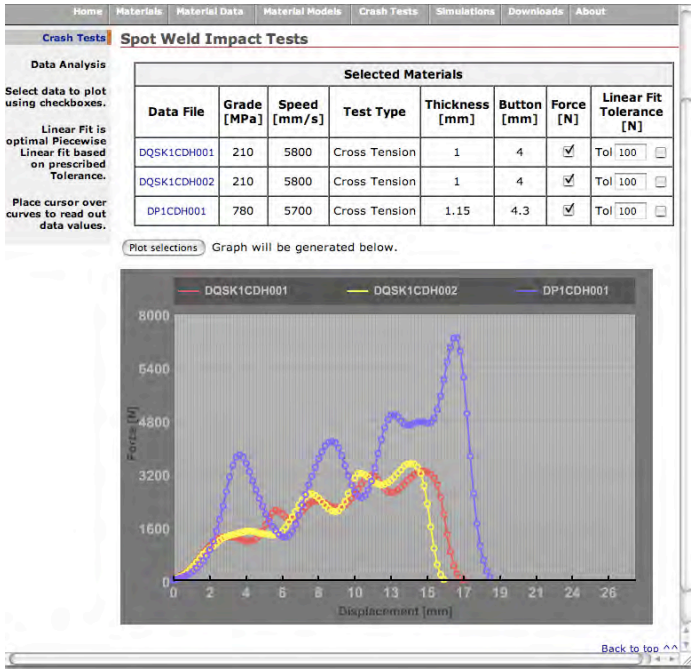
Phase II Accomplishment: Web-based testing data retrieval & dissemination

- Web-based test data collection and retrieval
- Two steel grades, three weld nugget sizes, five loading modes, loading speeds up to 13 mph
- Failure mode and strength correlated to the weld attributes such as weld size and loading rate





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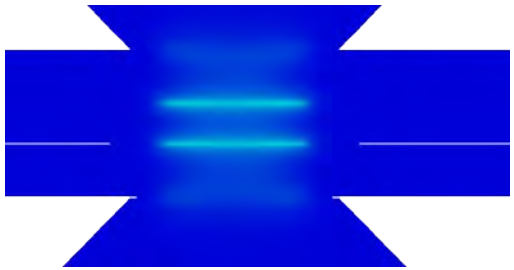
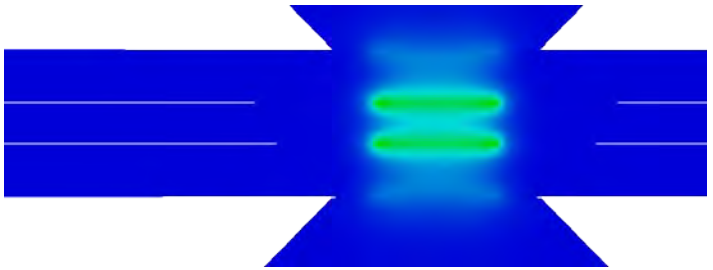
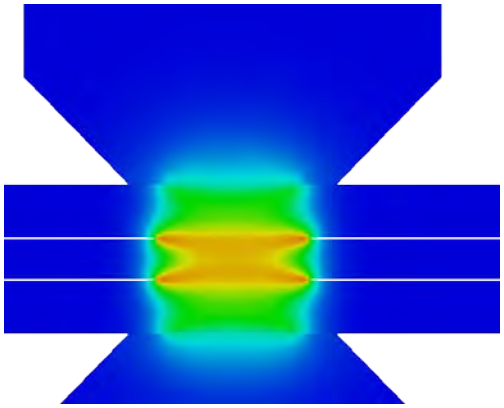
Phase II Accomplishment: Extended weld process model to 3T stack-up weld (DP600 steel)



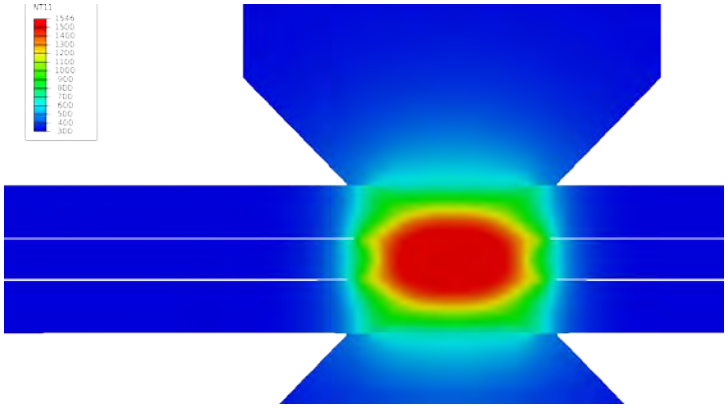
After 1 welding cycle (0.0167sec)



After 2.5 welding cycle (0.0417 sec)



After 4.5 welding cycle (0.075 sec)



After 9 welding cycle (0.15 sec)

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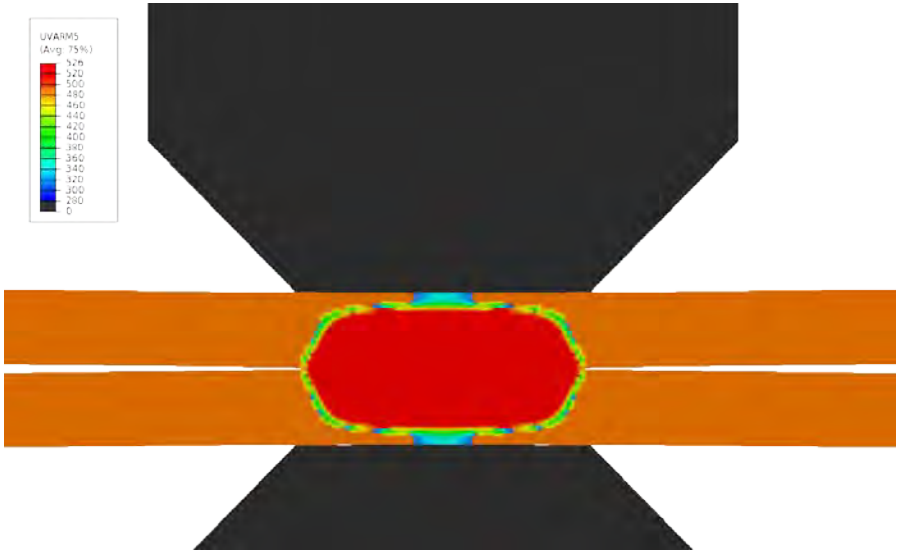
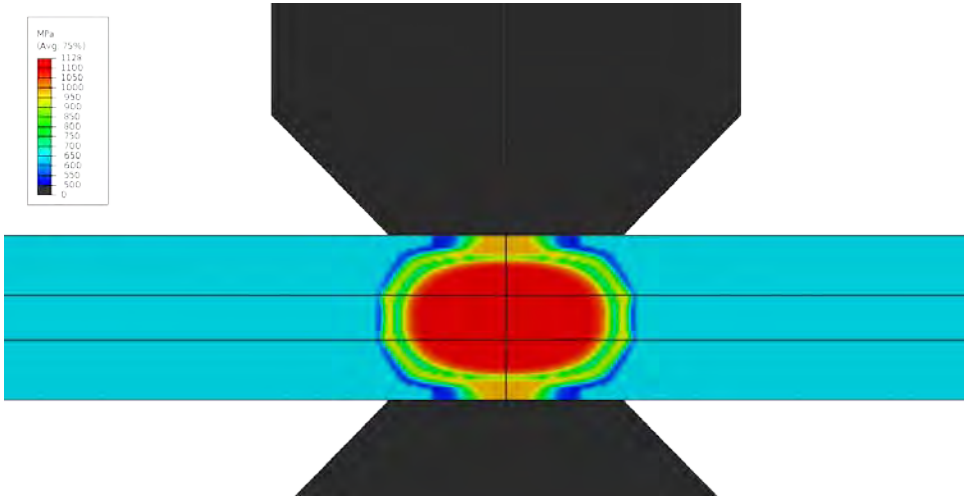
Phase II Accomplishment: Prediction of Property Distributions



Microhardness Distribution
HAZ Softening in 2T Boron steel



Tensile Strength Distribution
3T DP600 steel

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Accomplishment: Prediction of temperature, stress, microstructure by the integrated weld process model

A movie showing the evolution of these properties for a 3T DP steel case

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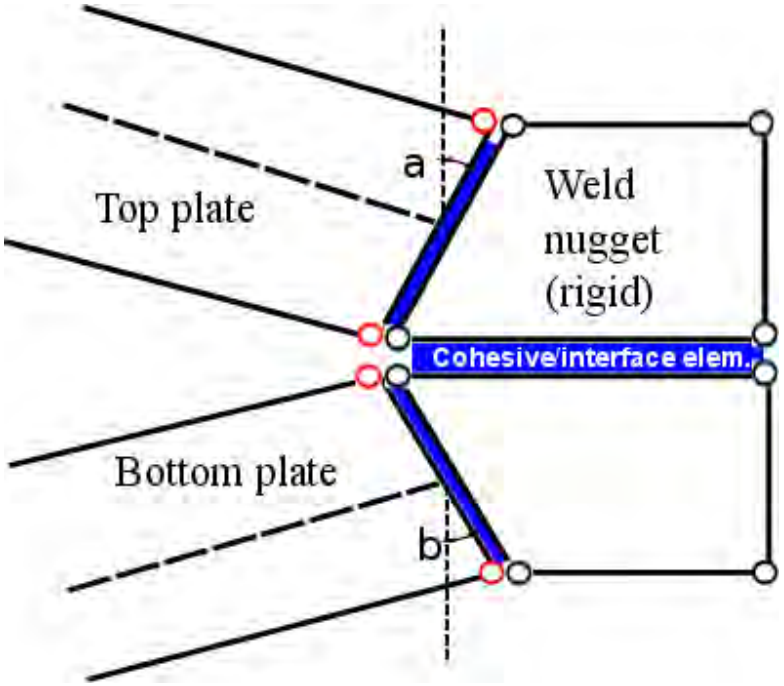
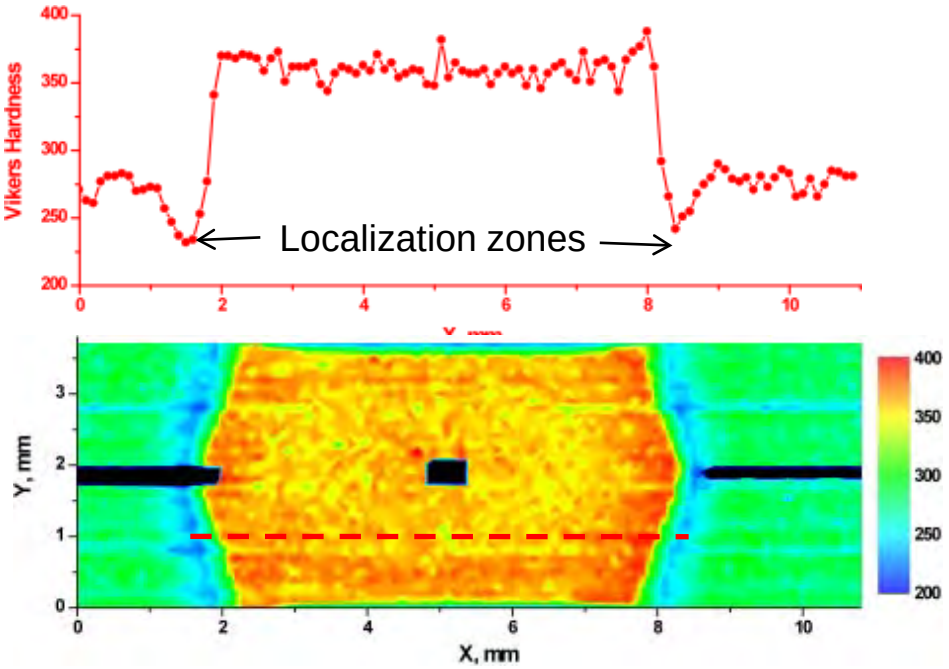
New Formulation for the Mechanical Model

- Simplification of the previous model





- We are working on a new formulation that combines thick shell elements and cohesive (interface) elements

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Accomplishment: Technology Transfer and Industry Collaboration

- Initial version of integrated weld process model has been licensed and transferred to industry
- Web-based crash experimental data base for use by the OEM and suppliers
- Strong support and close interactions with OEM, steel suppliers and A/SP committees
  - Project advisory committee consists of members of Chrysler, Ford, GM, ArcelorMittal and US Steel
  - A/SP financial support in Phase I welding and testing
  - Industry cost-sharing in Phase II welding and testing

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Future Work

- FY2011
  - Complete microstructure and microhardness characterization of weld population planed
  - Validate integrated weld process/property model with 6 steel types/grades/coatings
  - Beta version of SWE model capable of handling HAS softening
- FY2012
  - Extend to different surface coating conditions, different material combinations, different thickness combinations, edge weld, 3-stacks etc
  - Failure criteria evaluation and development
    - Different failure mode including the effect of HAZ softening
  - Validation on coupon and component tests
  - Technology transfer/licensing of spot weld simulation code (beta version)

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Summary

- Successfully completed the Phase I concept feasibility development of a new spot weld simulation model for advanced crashworthiness CAE
- Initial versions of SWE and integrated electrical-thermal-mechanical-metallurgical spot weld model have been developed
  - Licensed to industry
- Baseline impact test data has been collected
  - Effects of impact speeds and loading modes
  - Web-based data management for interactive data analysis and retrieval

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