Overview of Joining Activities in Lightweighting Materials

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Critical Issues - Joining Lightweighting Materials

- Performance of fusion welds in some Advanced High Strength Steels (AHHSs) is low due to localized changes in microstructure which can impact crash prediction and modeling.
- Magnesium applications can require joining to dissimilar materials which cannot be achieved by fusion welding and calls for solutions to mitigate galvanic corrosion.
- In adhesive bonding, reliable and accurate detection of kissing bond regions must be developed.

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Benefits of New Joining Technologies

- Friction stir welding enables joining of AHHSs without destruction of key microstructural features.
- Sold-state joining technologies like FSW and Ultrasonic Welding can provide a method of joining dissimilar materials
- Robust on-line NDE tools for adhesive joints could expand the use of this technology for both similar and dissimilar materials.

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Lightweight Materials Joining Portfolio

Materials Technologies

- *Dynamic Characterization of Spot Welds in AHHSs (ORNL)*
- *Friction Stir Spot Welding (FSSW) of AHHSs (ORNL + PNNL)*
- *NDE Inspection of Metal to Metal Joints (SNL)*
- Friction Stir and Ultrasonic Solid State Joining of Mg-to-Steel (PNNL + ORNL)
- Friction Bit Joining (ORNL)
- Composite Underbody Attachment to Steel (ORNL)
- On-line Weld NDE and Control with IR Thermography (ORNL)
- <u>FUNDING LEVELS</u>: 2008 ($1,590 K) and 2009 ($1,600 K)

Dynamic Characterization of Spot Welds for AHSSs

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Overview

Timeline

- Start: Dec, 2006
- End:
  - Phase I: March, 2009
  - Phase II: March, 2012
- Percent complete
  - Phase I: 100%
  - Phase II: 0%

Budget

- Total project funding (Phase I)
  - DOE share: $630K
  - Contractor share: $150K
- Funding received in FY08 and FY09
  - Phase I: $290

Barriers

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

Partners

- Interactions/ collaborations
  - University of South Carolina
  - Auto/Steel Partnership Strain Rate Characterization Team
  - GM, Ford, Chrysler, ArcelorMittal Steel, US Steel
- Project lead
  - Oak Ridge National Laboratory

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 metrics
  - A new, robust spot weld element and implementation procedure that is practical for automotive crash modelers to use
  - Companion property database for impact simulation and analysis
  - Resistance spot weld of AHSSs in Phase I, extending to other lightweight materials and joining technologies in future follow-on activities

Supporting Goals of VT's Lightweight Materials Program

- Efficient optimization of structures for light-weighting while meeting crash requirements requires more accurate models that reflect the special properties of the materials needed for light-weighting.
- Near term:
  - Enables widespread use of advanced high-strength steels in autobody structure to achieve the 20% vehicle weight-reduction target for petroleum displacement
- Long term:
  - Enables Multi-Material Vehicle for even further vehicle weight-reduction
    - High-volume production
    - Affordable
    - Recyclable

Technology Barriers

- Industry Consensus (per A/SP and OEMs)
  - 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

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Implications of Current State of Art

- We cannot design components containing AHSS and optimize crash performance using numerical analysis with confidence that weld failures will not occur
- Weld failures detected later, after components are made and tested, frequently result in compromises that adversely affect the 20% weight savings available by using AHSS
- Further light weighting opportunities from optimized use of AHSS and even higher strength steels will not be fully realized without improved tools for analysis

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Milestones

- Phase I Concept Feasibility (Dec 06 – Mar 09) – Completed
  - Initial version of the spot weld element (SWE) and its implementation procedure
  - Companion experimental data set
  - 2 steel grades, multiple weld nugget and quality conditions selected by OEMs
- Decision Gate at End of Phase I – Passed
  - Will SWE model work as expected?
- Phase II Comprehensive R&D – FY2009 - FY2011
  - Further refinement/improvement of SWE for other AHSS and spot weld configurations
  - Expand to other welding processes and/or other light weight materials

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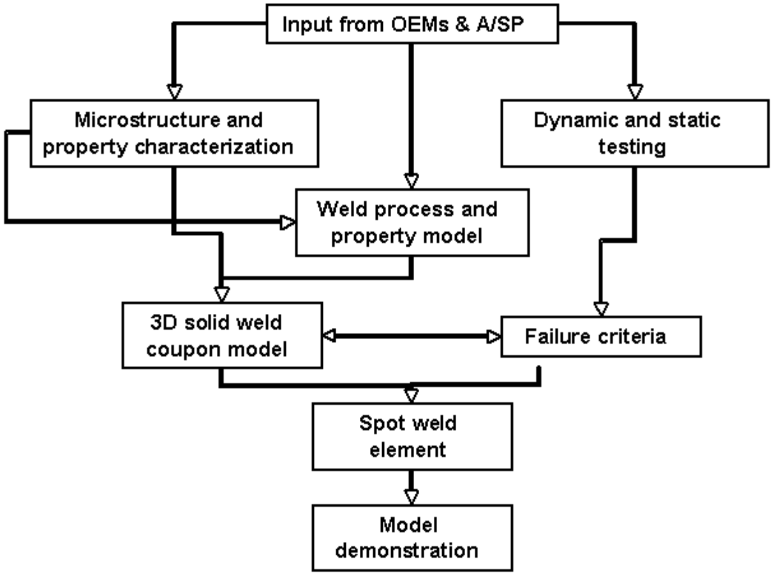
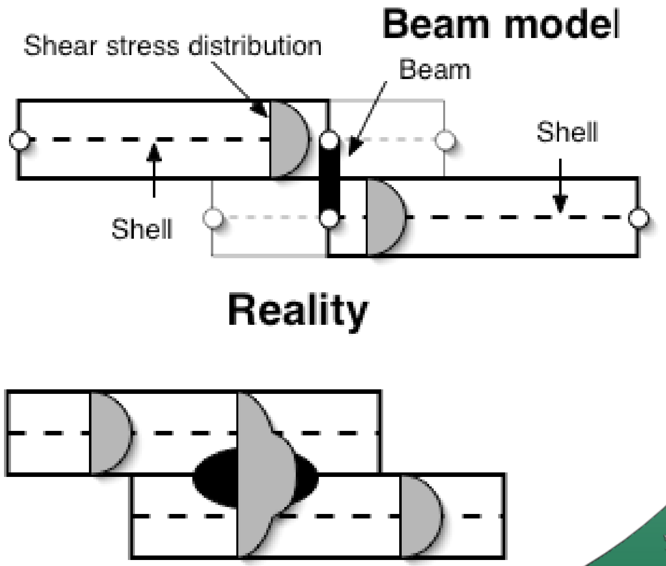
Approach

- A Three-Pronged Approach
  - A new spot weld element (SWE) and associated constitutive models
    - Robust for CAE simulation
    - Weld geometry and microstructure effects
  - Modeling and characterization of weld microstructure and property
    - Weld geometry, microstructure and residual stress simulation for SWE
  - Deformation and failure behavior test under dynamic loading conditions

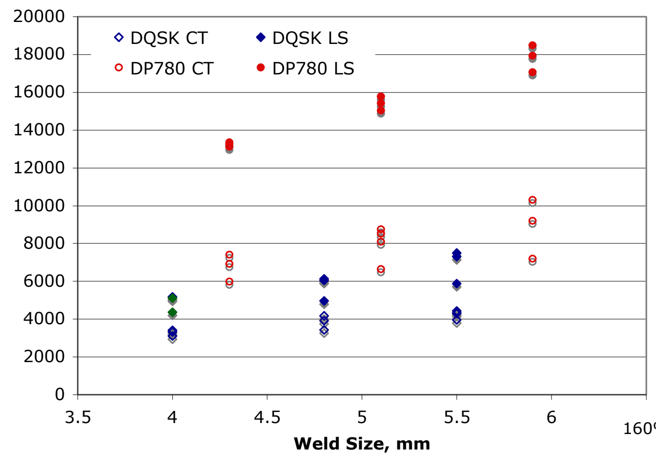


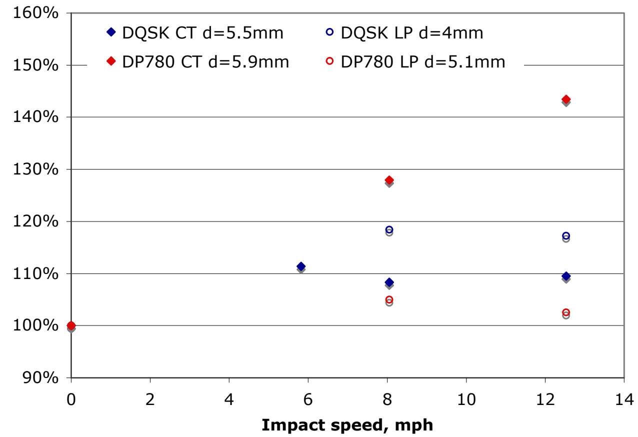
- Limitations of current modeling practice
  - Based on beam element or rigid connection concept
  - Extensive “turning” or experimental fitting was required to work for mild steels
  - The stress and strain distribution inside the weld are not accurately represented, and unable to handle the deformation and failure of AHSS and other “designer’s” materials

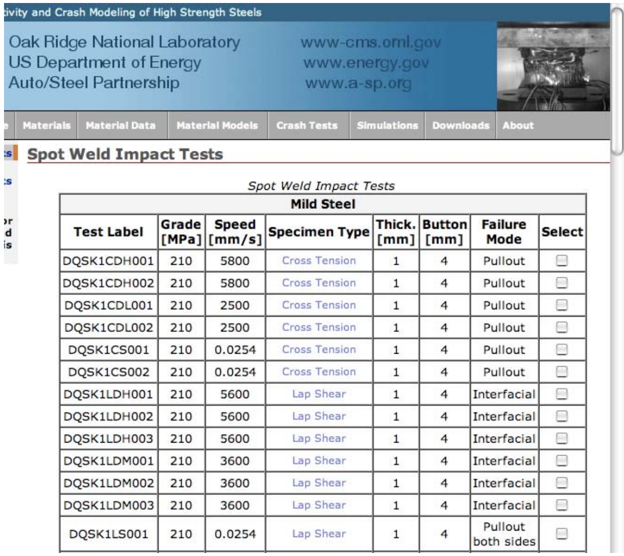


Technical Accomplishment: Dynamic testing

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

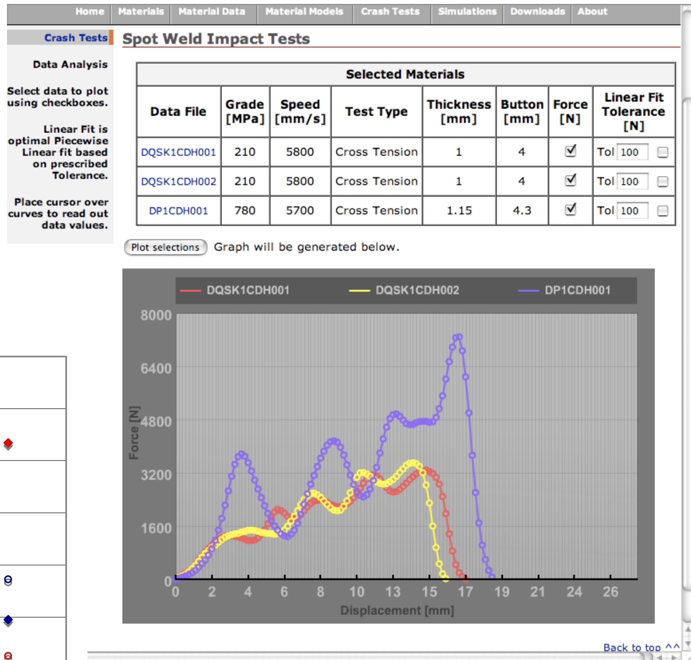






Spot Weld Impact Tests

Test Label	Grade [MPa]	Speed [mm/s]	Specimen Type	Thick. [mm]	Button [mm]	Failure Mode	Select
Mild Steel							
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	

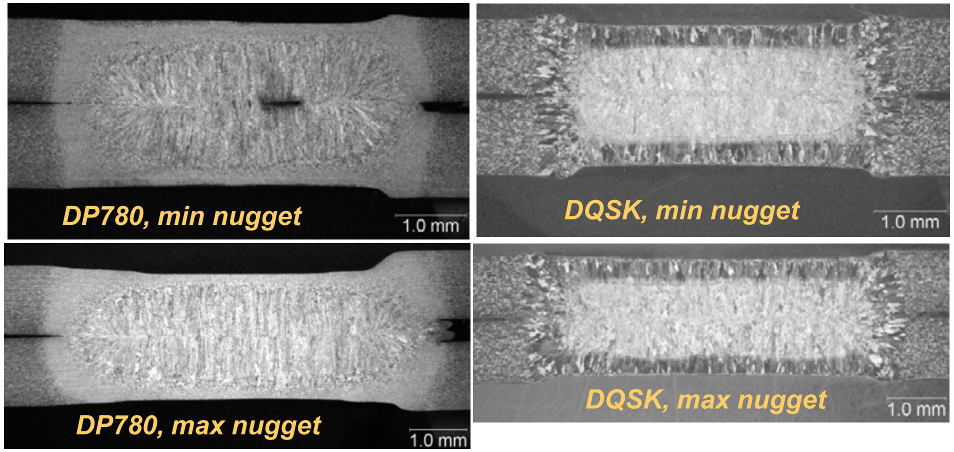


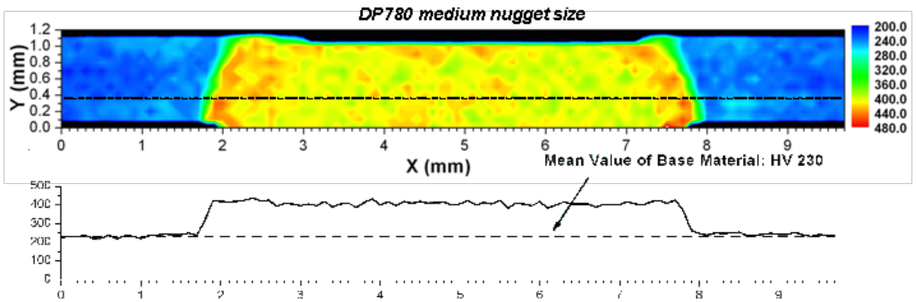
Selected Materials

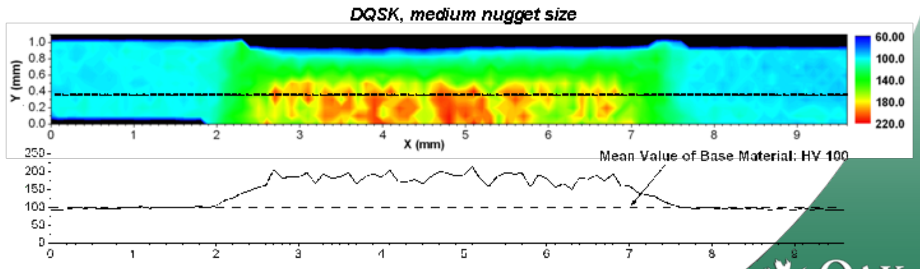
Data File	Grade [MPa]	Speed [mm/s]	Test Type	Thickness [mm]	Button [mm]	Force [N]	Linear Fit Tolerance [N]
DQSK1CDH001	210	5800	Cross Tension	1	4	☑	Tol 100
DQSK1CDH002	210	5800	Cross Tension	1	4	☑	Tol 100
DP1CDH001	780	5700	Cross Tension	1.15	4.3	☑	Tol 100

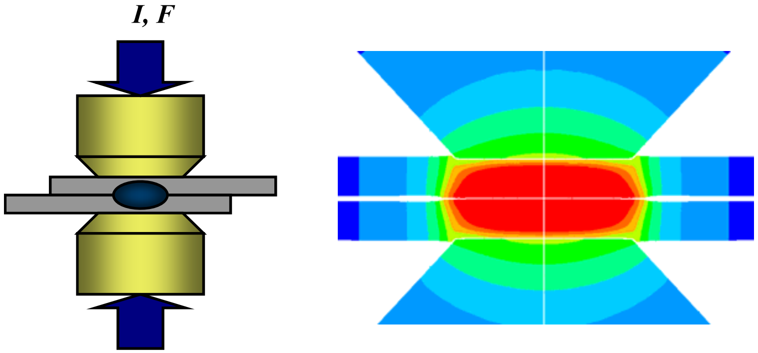
Technical Accomplishment: Weld Microstructure/Property Modeling & Characterization

- 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

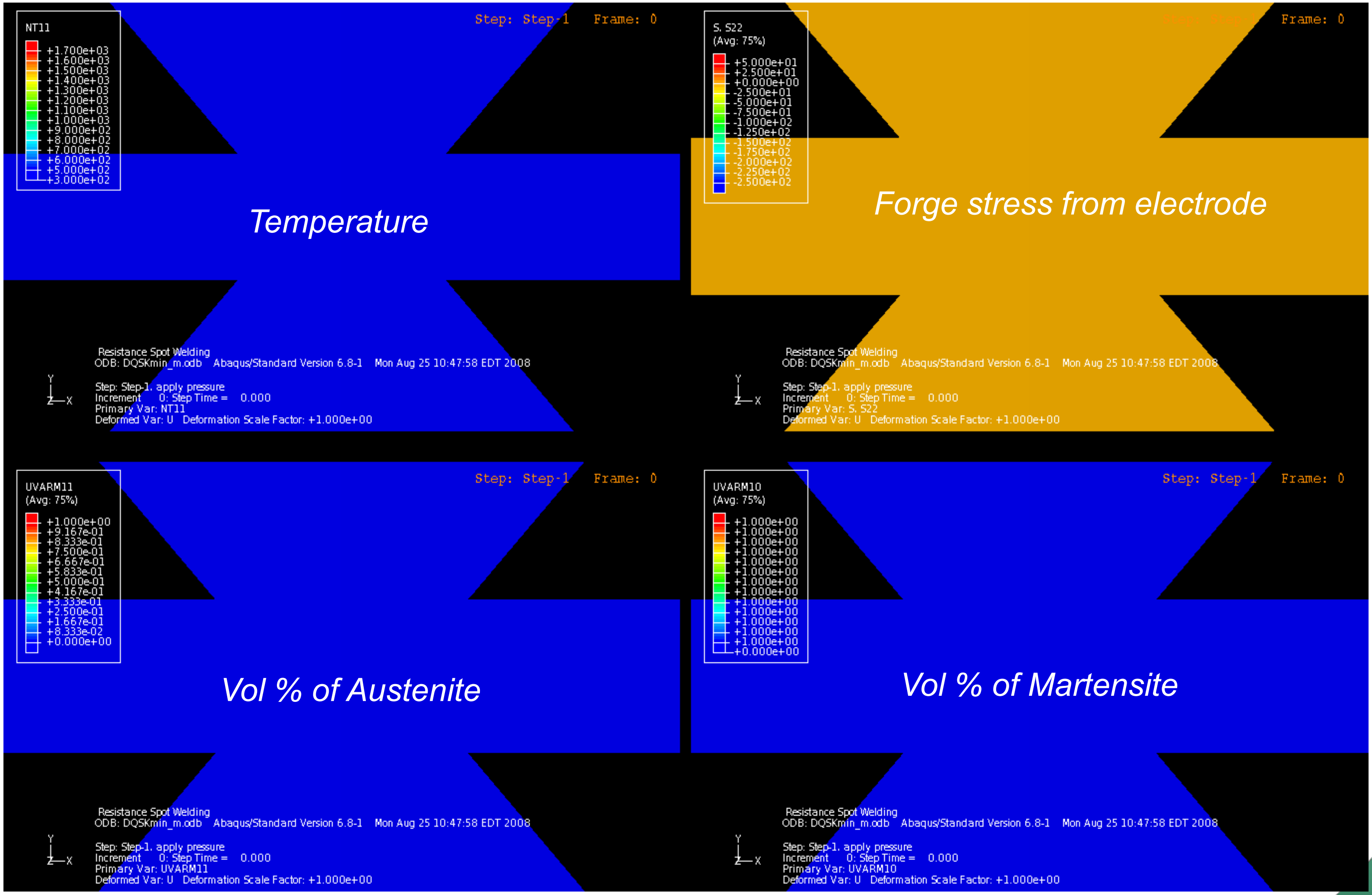








Technical Accomplishment: Integrated electrical-thermal-mechanical-metallurgical model for RSW process



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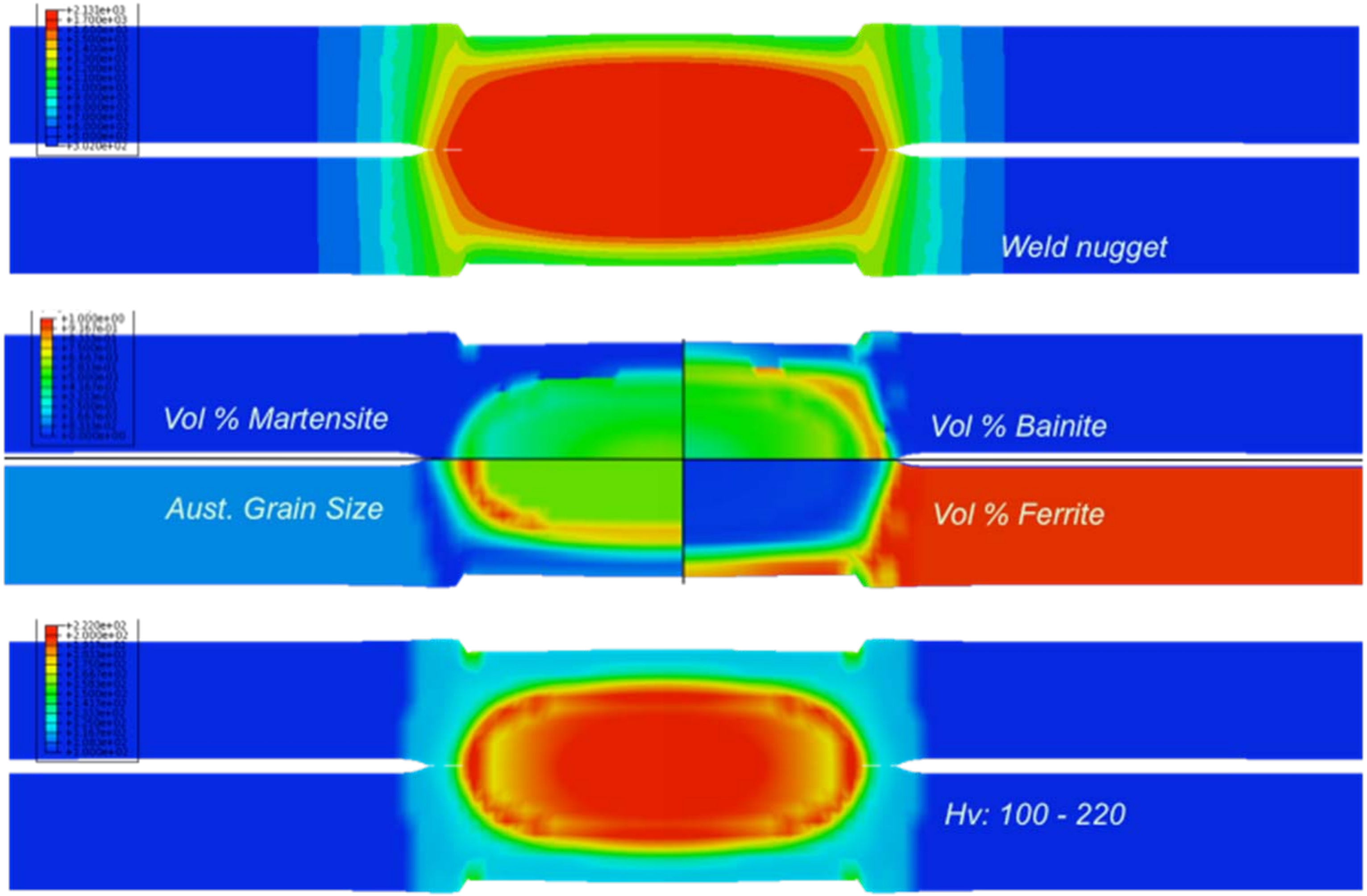
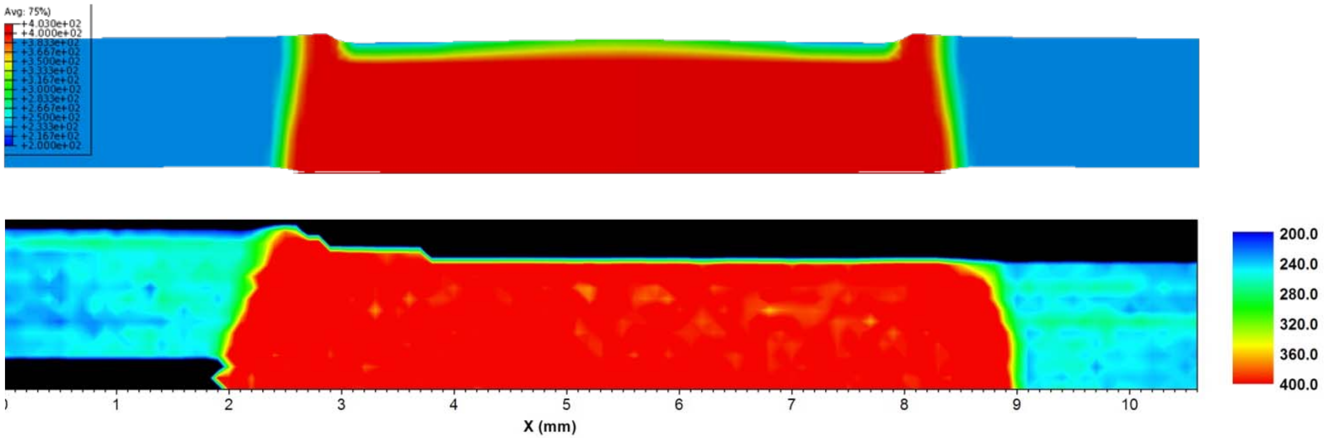
Technical Accomplishment: Prediction of Weld Microstructure and Properties



Technical Accomplishments: Comparison of Microhardness Distribution



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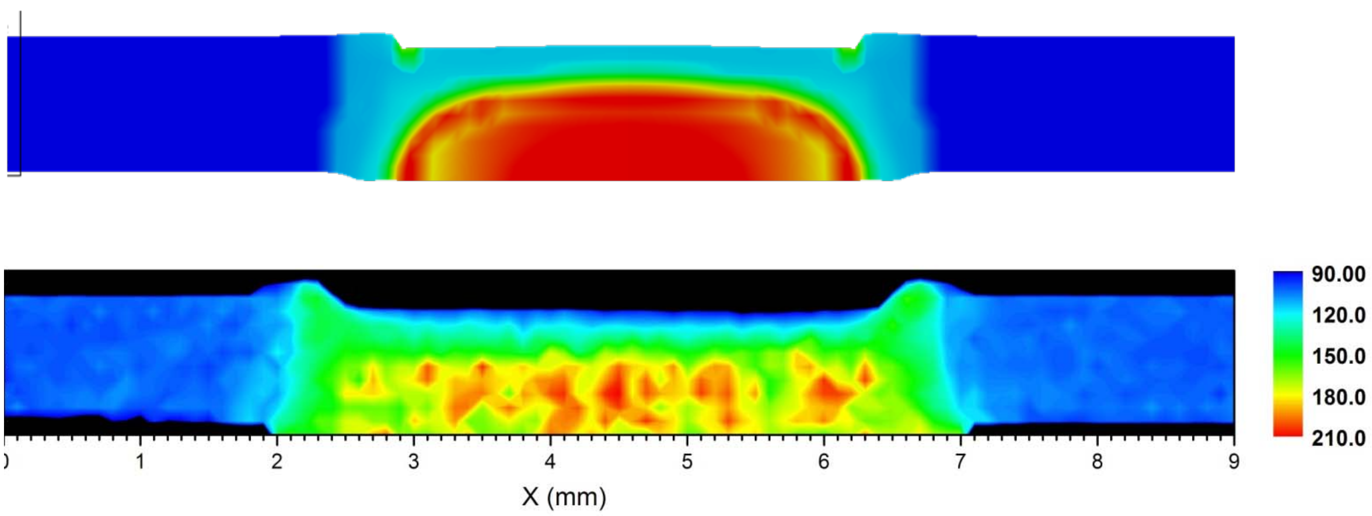
Model prediction

Hardness mapping measurement



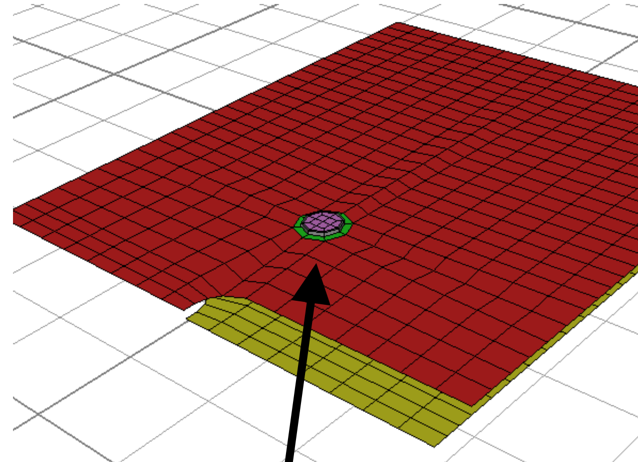
DQSK

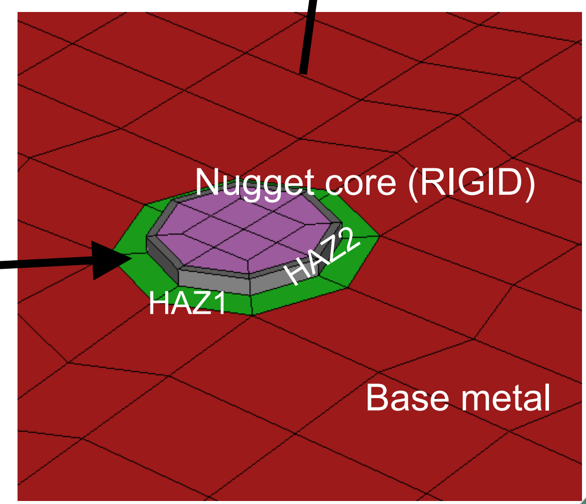
Model prediction

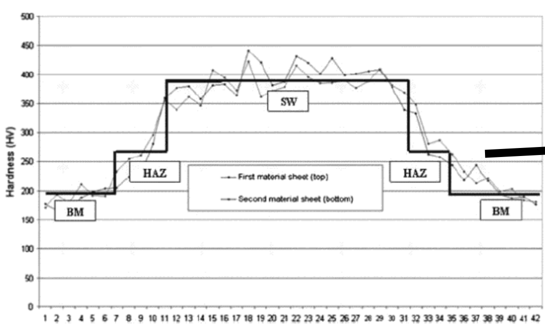
Hardness mapping measurement

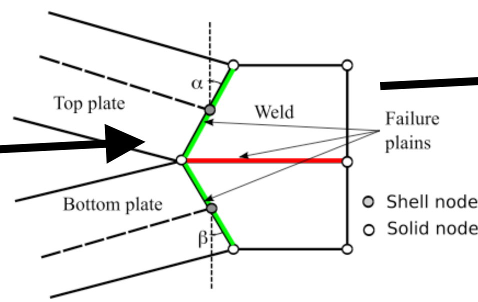
Technical Accomplishments: Spot Weld Element Formulation

- Shell-to-Solid Shell Approach
  - Rigid core for robustness (computational efficiency)
  - Weld properties based on hardness differences from process simulations
- Weld fracture formulation
  - Different failure modes
  - Simple fracture criterion so far



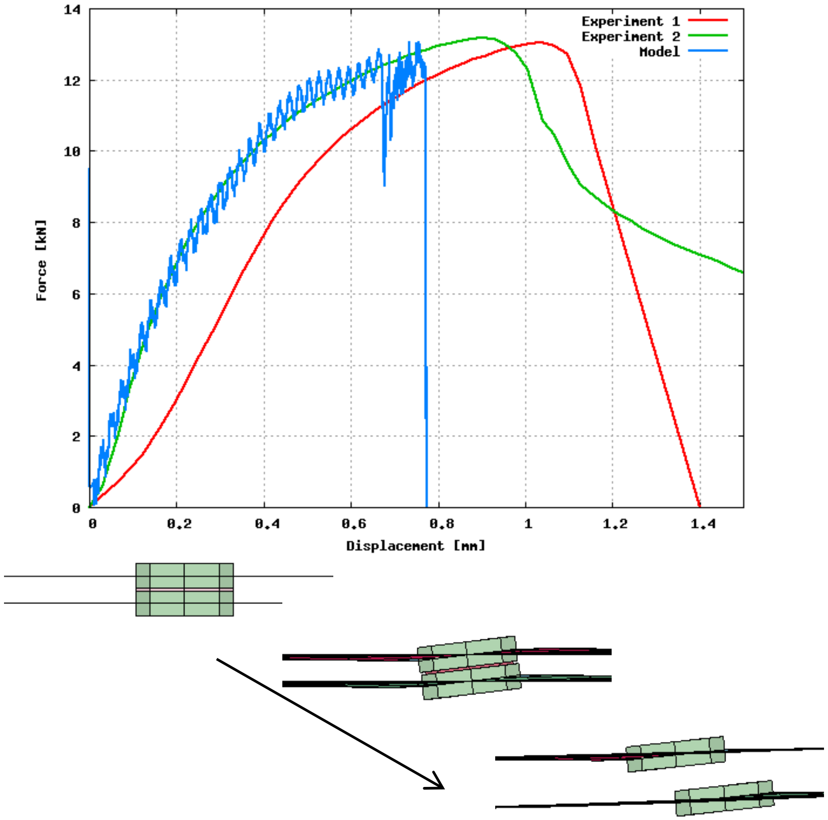




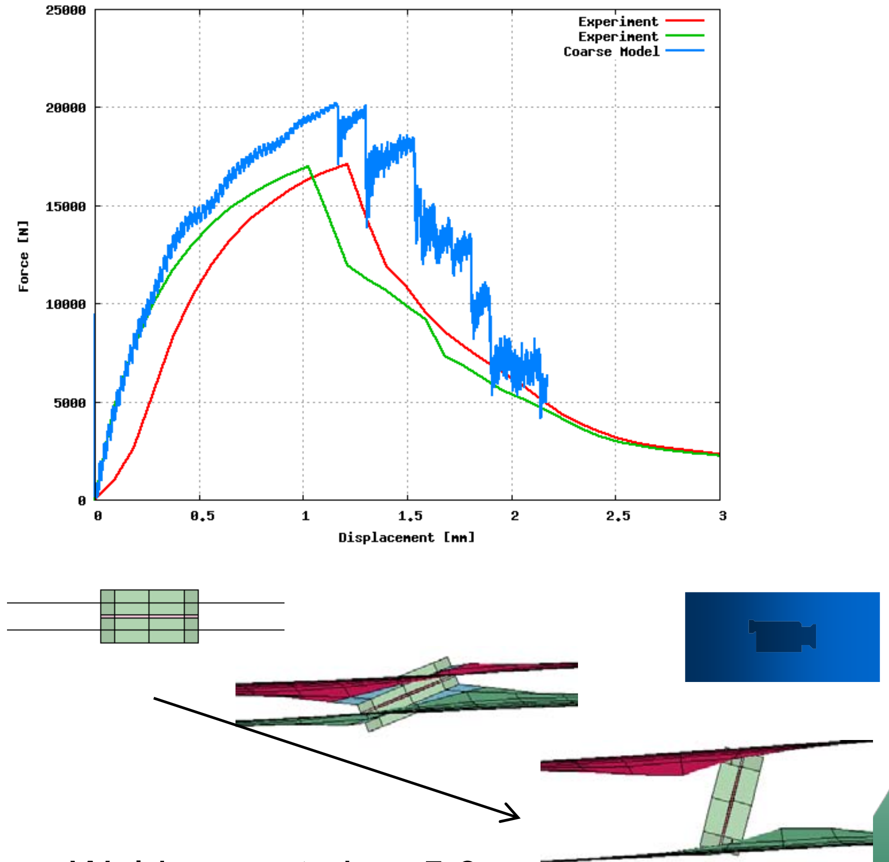


Technical Accomplishments: Simulation of Impact Test

- 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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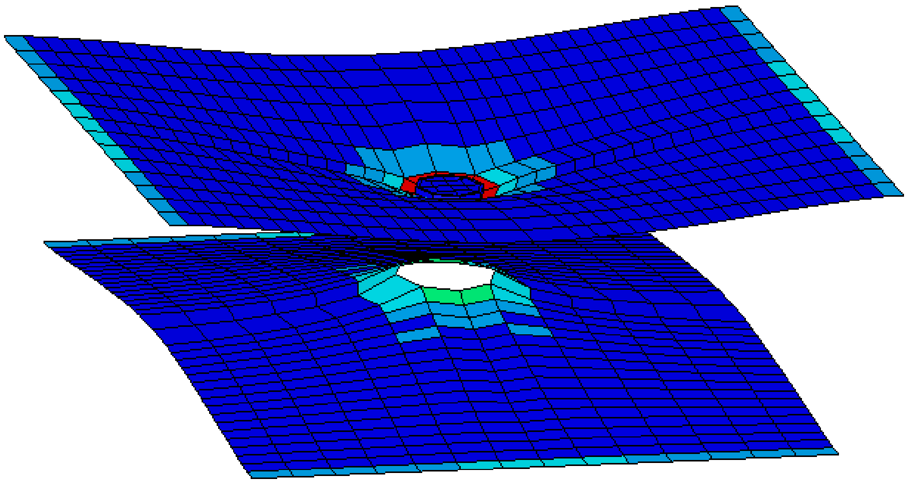
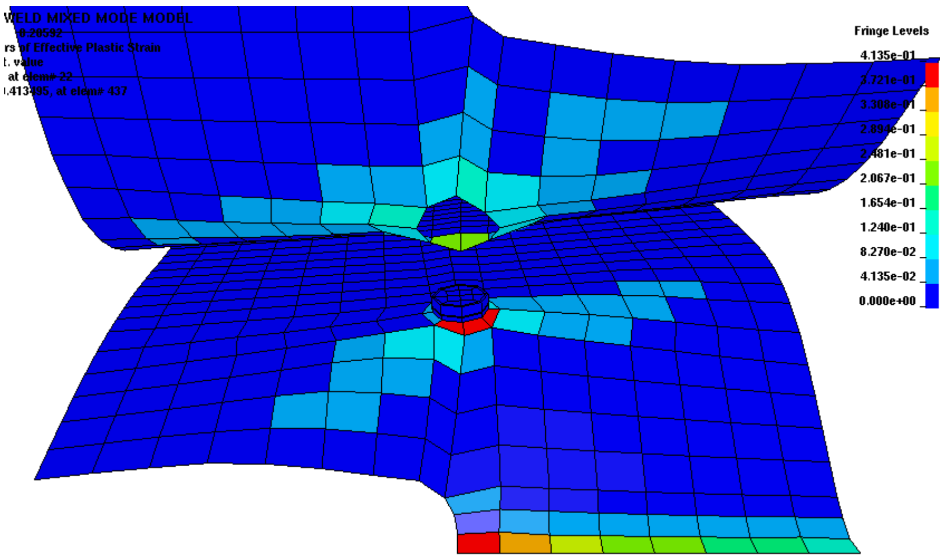
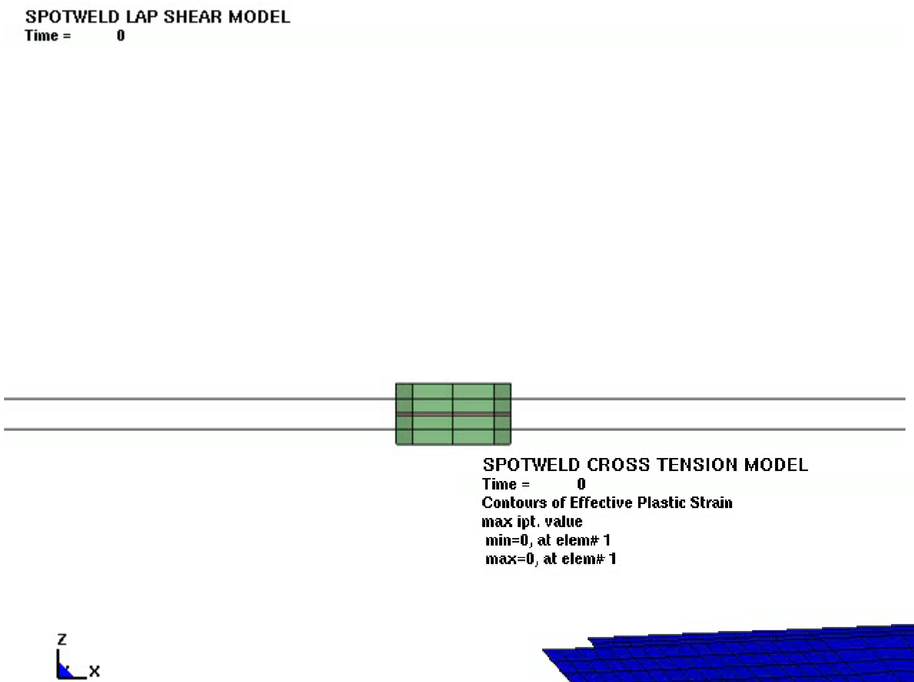
Technical Accomplishments: Simulation of Impact Tests (Cont'd)

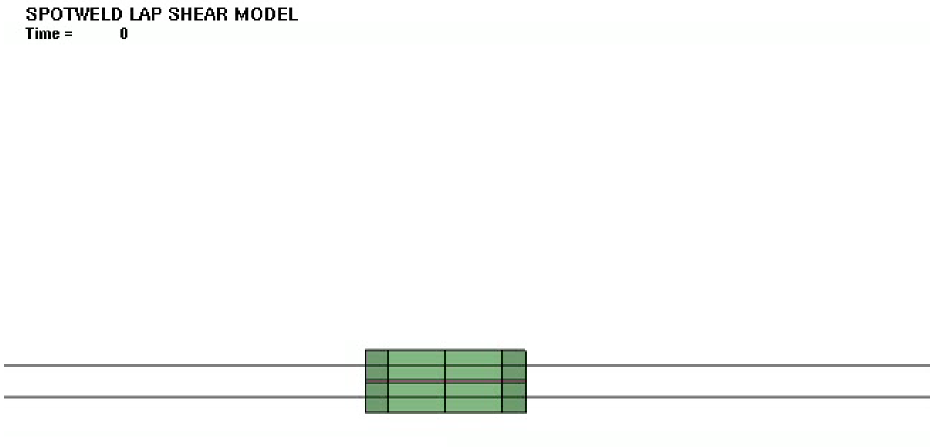


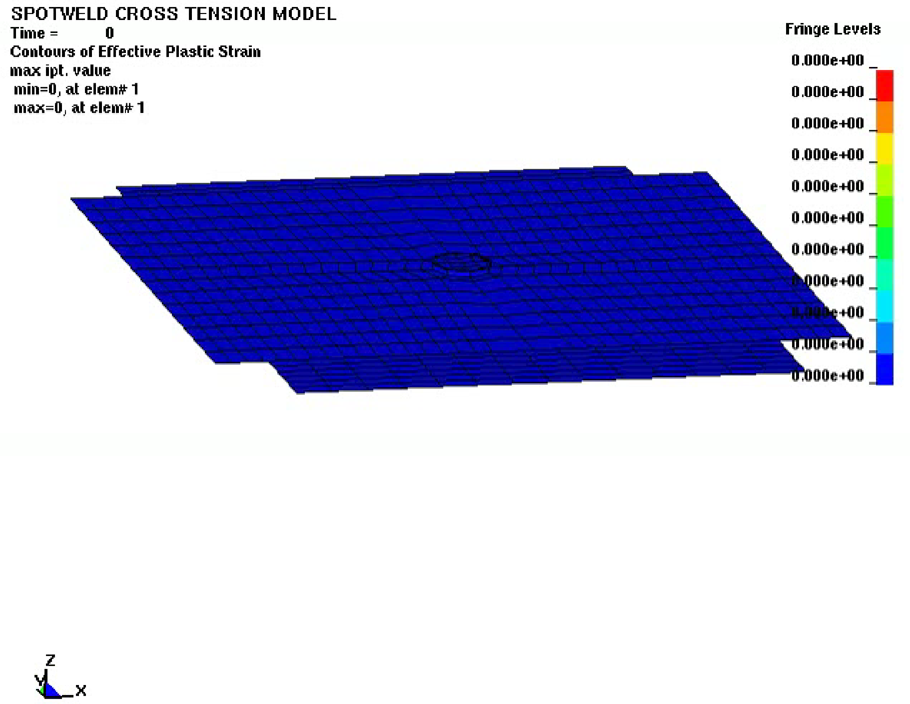


- Cross-tension test. Button pull-out as in experiments
- Mixed loading mode. Button pull-out as in experiments

Technical Accomplishments: SWE Simulations (Animations)







Summary:

- Successfully completed the Phase I concept feasibility development of a new spot weld simulation model for advanced crashworthiness CAE
- Initial version of SWE has been developed
  - Capable of handling weld geometry and property gradient
  - Capable of predicting different fracture modes and load limits observed
  - Computationally robust
  - Potentially eliminating/reducing extensive tests for new spot weld configurations
- Integrated electrical-thermal-mechanical-metallurgical resistance spot weld model have been developed
  - Capable of predicting weld geometry, microstructure and microhardness distributions in AHSS
  - User inputs are basic welding parameters, sheet thickness and steel chemistry
  - CAE friendly
- Baseline impact test data has been collected
  - Effects of impact speeds and loading modes have been characterized
  - Web-based data management for interactive data analysis and retrieval

Future Work (Phase II)

- Phase II will be a more comprehensive R&D
  - Further refinement/improvement for other AHSSs and spot weld configurations (early Phase II)
    - Additional materials, different material combinations, different thickness combinations, edge weld, 3-stacks etc
    - Different failure mode including the effect of HAZ softening
    - Failure criteria evaluation and development
  - Weldbond for AHSSs (mid Phase II)
    - Failure criteria including the adhesive bonding
  - Extend to other materials and joining processes (late Phase II)
    - Joining of steels to other materials (composite, Al, or Mg) – multi-material body structure
    - Friction bit joining, friction stir joining, laser welding
- Maintain close interactions with OEM modelers
  - Selection of welding and testing cases
  - Component level demonstration and validation

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Acknowledgement

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  - Kathy Wang (Chair), Dave Mueleman (GM)
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