Dynamic Characterization of Spot Welds

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Purpose of Work

- **Key technical development**
  - **A workable modeling tool for incorporating the behavior of spot welds in crash simulations, including strength, failure mode, and deformation rate effects, 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**
  - **The focus on Advanced High Strength Steels (AHSS) in this program is expandable to other light weight materials and joining technologies in future follow-on activities**

Supporting Goals of FreedomCAR

- **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:**
    - **Enable more widespread use of advanced high-strength steels in autobody structure to achieve the 20% vehicle weight-reduction for petroleum displacement**
  - **Long term:**
    - **Provide enabling technology for application in Multi-Material Vehicle for even greater vehicle weight-reduction**
      - **Mg-Al, Mg-Steel, etc.**
      - **High-volume production**
      - **Affordable**
      - **Recyclable**

Barriers

- **Industry Consensus (by A/SP Strain Rate Characterization Team)**
  - **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 very limited or nonexistent**

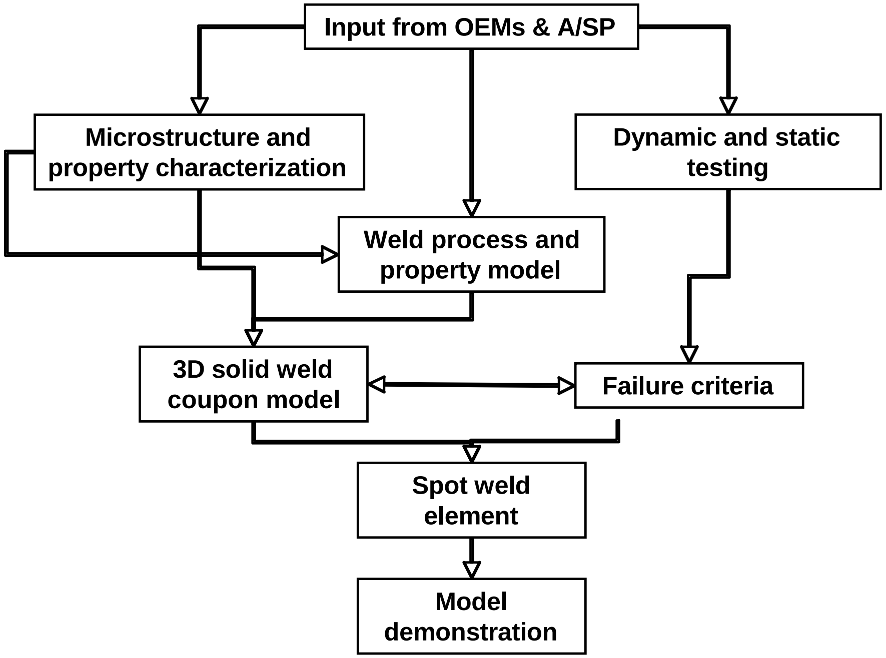
Implications of Current State of Art

- 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

Approach

A Three-Pronged Approach

- A new spot weld element and associated constitutive models
- Modeling and characterization of weld microstructure and property
- Deformation and failure behavior test under dynamic loading conditions

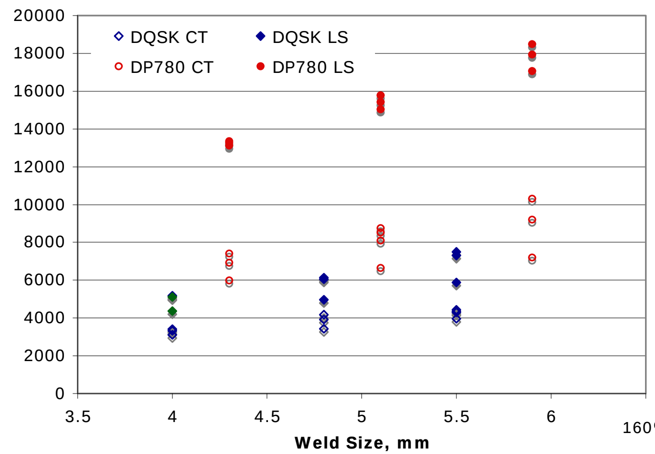


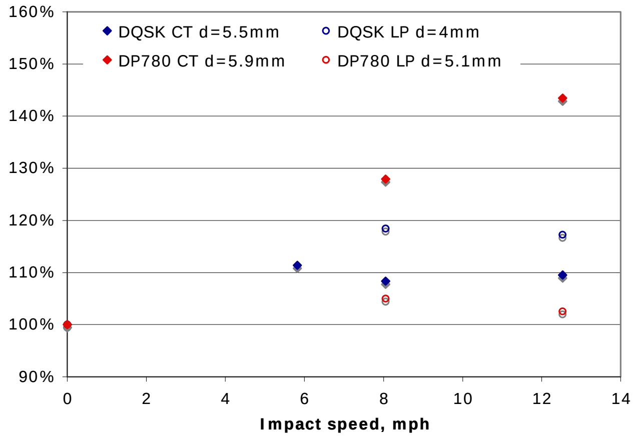
Program Schedule and Gate

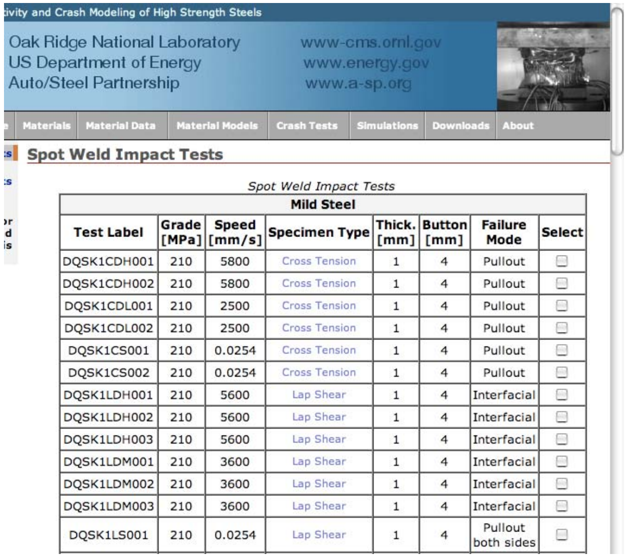
- Phase I (Dec 2006 - May 2008)
  - Initial version of the spot weld element (SWE) and its implementation procedure
  - Companion experimental data set for steel grades, thickness, and welding conditions selected by A/SP and OEMs
  - SWE Model Demonstration
- Decision Gate at End of Phase I
  - Will SWE model work as expected?
- Phase II (24 months)
  - Further refinement/improvement of SWE for other AHSS
  - Expand to other light-weight materials (Al, Mg) and welding processes

Dynamic testing: Progress to date (University of South Carolina)

- **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 loading rate**

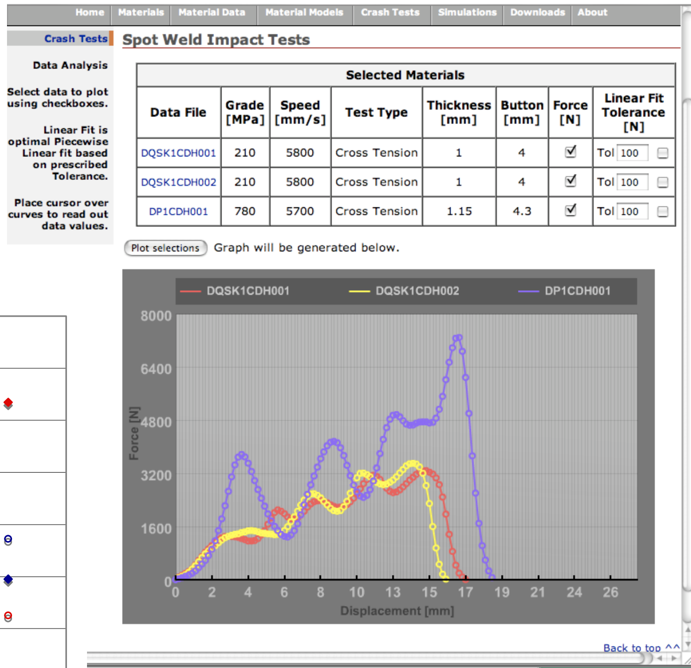






Spot Weld Impact Tests

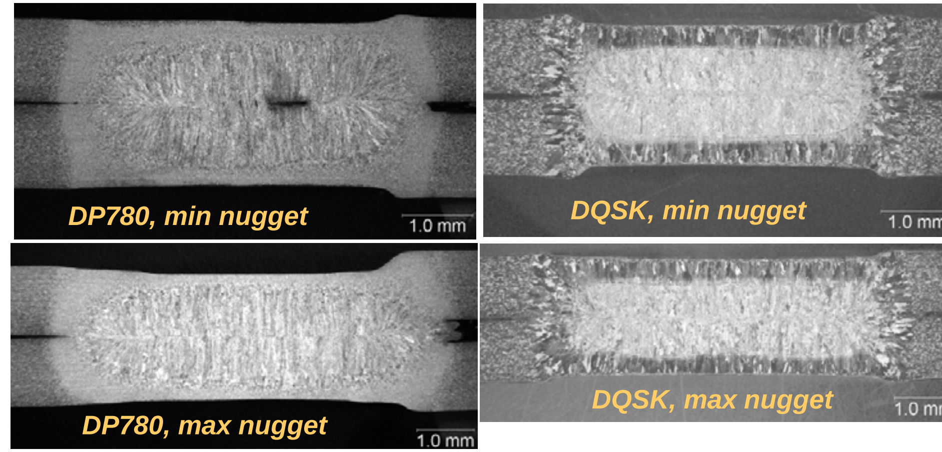
Mild Steel								
Test Label	Grade [MPa]	Speed [mm/s]	Specimen Type	Thick. [mm]	Button [mm]	Failure Mode	Select
DQSK1CDH001	210	5800	Cross Tension	1	4	Pullout	
DQSK1CDH002	210	5800	Cross Tension	1	4	Pullout	
DQSK1CDL001	210	2500	Cross Tension	1	4	Pullout	
DQSK1CDL002	210	2500	Cross Tension	1	4	Pullout	
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	

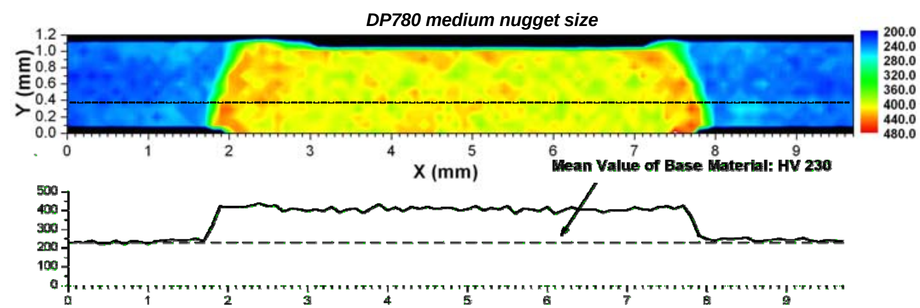


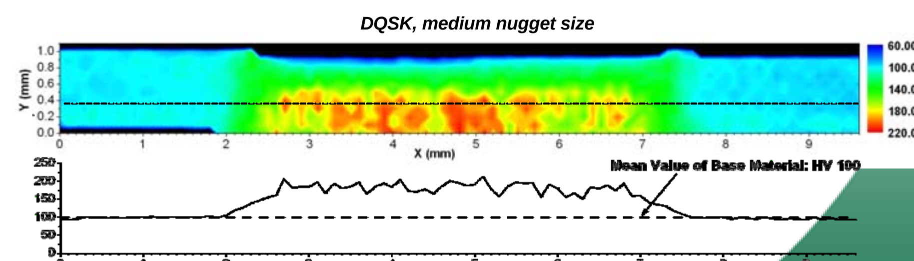
Selected Materials							
Data File	Grade [MPa]	Speed [mm/s]	Test Type	Thickness [mm]	Button [mm]	Force [N]	Linear Fit Tolerance [N]
DQSK1CDH001	210	5800	Cross Tension	1	4	☑	Tol 100
DQSK1CDH002	210	5800	Cross Tension	1	4	☑	Tol 100
DP1CDH001	780	5700	Cross Tension	1.15	4.3	☑	Tol 100

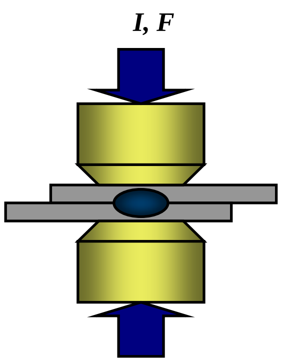
Weld Modeling & Characterization:
Progress to Date (ORNL)

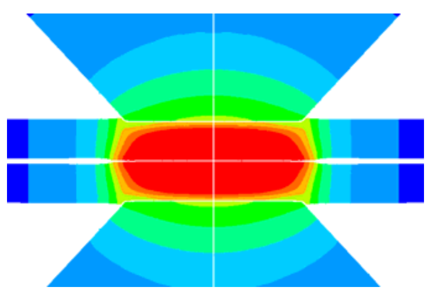
- **Weld property gradients have been determined and compared among different steels**
- **Weld size and other geometric attributes including defects have been correlated to steel grade and welding conditions**
- **An incrementally coupled electric-thermal-mechanical-metallurgical model is being developed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





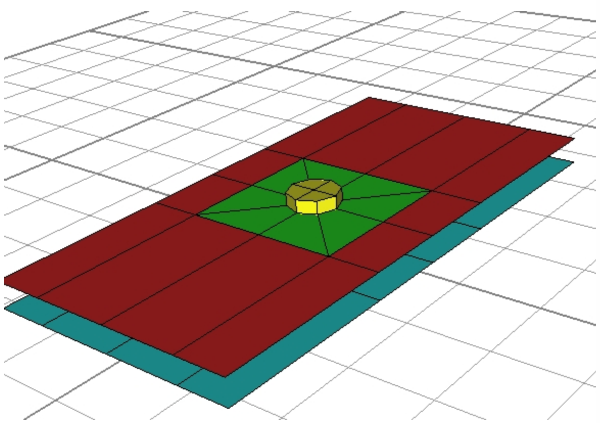


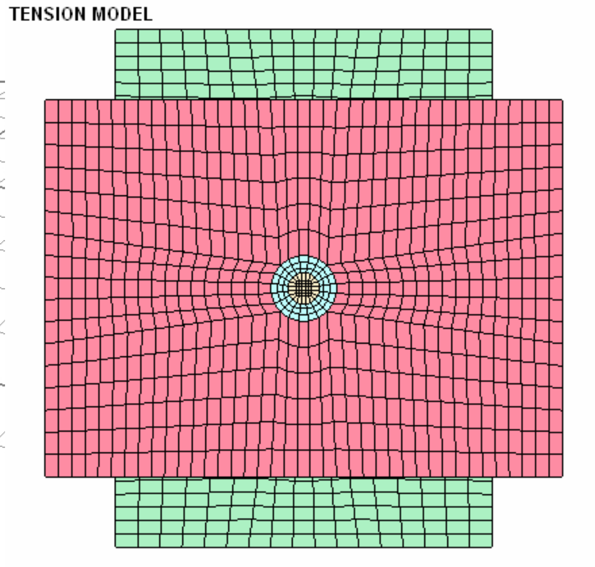


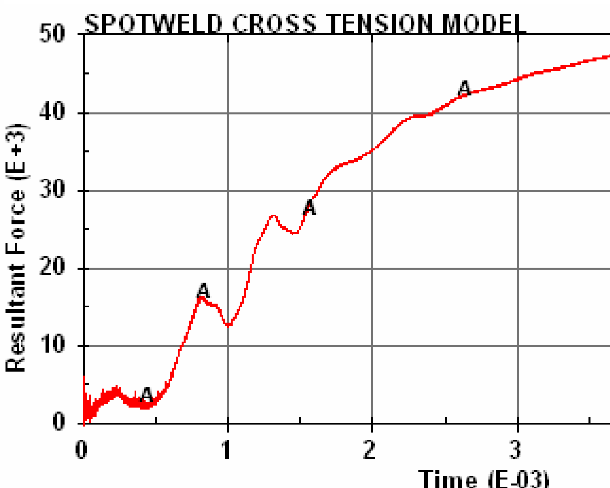


Spot Weld Element:
Progress to date (ORNL)

- **Initial spot weld model formulation is developed**
- **Model can replicate main failure modes and provides stress and strain data at relevant location**
- **Constraints link shell and solid element nodes to reduce computational time**
- **Surrogate model is implemented in LS-DYNA**
- **Sub-models will be added to treat failure**
- **Failure criteria to be considered:**
  - **Ductile damage models**
  - **Fracture (Zhang criteria)**







Cross-tension test simulation

Technology Transfer

- **Demonstration of SWE approach is planned at the end of Phase I (May 2008)**
- **SWE formulation and implementation will be transferred to industry via A/SP Strain Rate Sensitivity Team (a consortium of the Big-Threes and steel companies)**

Activities for Next Fiscal Year

- **Complete the development of SWE**
  - **Incorporating various failure modes**
  - **Verification of SWE with dynamic testing results**
- **Phase II**
  - **Further refinement and improvement of SWE for other AHSS materials, thickness combinations**
  - **Expand to other lightweight materials (Al and Mg) and other welding processes**

Summary

- **The new, robust spot weld crash simulation tool being developed will enable efficient optimization of structures for light-weighting while meeting crash requirement.**
- **Dynamic testing, weld characterization and modeling, and initial development of the spot weld element have been completed**
- **Activities for the next fiscal year will focus on completion of SWE development, verification, and provide an initial version to the industry**

Acknowledgement

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