Dynamic Characterization of Spot Welds

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This presentation does not contain any proprietary or confidential information
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
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)
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-Three 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.
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