Characterization of Thermo-Mechanical Behaviors of Advanced High Strength Steels (AHSS)

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Purpose of Work

- **Ultimate Goals:**
  - Meet DOE goal on weight reduction by promoting more widespread use of Advanced High Strength Steels (AHSS) in vehicle structures.
  - Accelerate development and adoption of AHSS in auto-body structures
- **Objectives:**
  - Develop fundamental understanding and predictive modeling capability to quantify the effects of auto manufacturing processes (forming, welding, paint baking, etc) and in-service conditions on the performance of auto-body structures made of advanced high-strength steels (AHSS)
  - Establish the technical basis to fully realize the advantages of AHSS intensive structures in fuel efficiency and structure crash safety
  - To provide performance data and constitutive models for formed and welded AHSS parts.

Technical Barriers

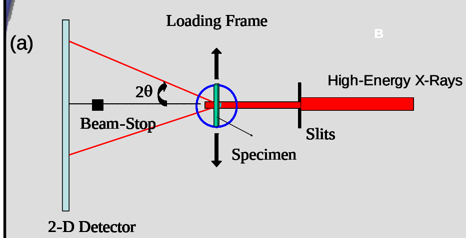
- There exist wide range of grades and types of AHSS and they continue to evolve:
  - The constitutive behaviors for AHSS parts are not available to CAE engineers for rapid prototyping;
  - Lack of quantitative understandings and predictive capabilities on the effects of 2nd phase particles on the overall stress versus strain behaviors of AHSS.
- The behaviors of AHSS parts subject to different thermal and mechanical loading paths (forming and welding) are not fully understood and quantified:
  - Forming induced failure under different loading paths: biaxial stretch, plane strain, stretch bending, etc.
  - Welding induced complex microstructure changes.
- Lack of application guidelines for effective and optimal use of AHSS in auto body structures

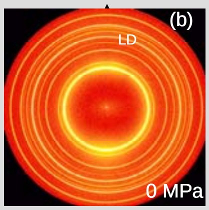
Technical Approach

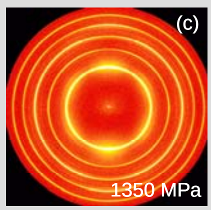
- Forming – PNNL
  - Quantify the base material performance under different loading paths, loading rates and loading temperatures
  - Quantify the effects of loadin mode, rate and temperature on transformation kinetics
  - Evaluate structural performance of formed and welded parts made of AHSS
  - Develop transformation kinetics model and macroscopic constitutive relationships for TRIP steels
  - Develop macroscopic constitutive model to simulate the stress vs. strain behavior of AHSS: TRIP + DP
  - Develop micromechanics model to predict AHSS failure modes under different loadin conditions
- Welding – ORNL
  - Develop a fundamental understanding of microstructure transformation kinetics of AHSS steels during welding
  - Develop integrated thermo-metallurgical-mechanical predictive models for the performance of welded AHSS parts
  - Investigate the weldability of AHSS under various welding processes and parameter conditions applicable to auto production environment
  - Investigate welding techniques for improved AHSS weld performance and benchmark them against the current welding practices for roll-formed and hydro-formed AHSS frame and underbody structure applications
  - Generate weld performance data including static strength, formability impact strength, and fatigue life as function of welding processes and parameters

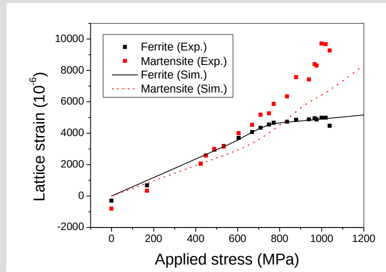
Forming Accomplishment – In-Situ Characterization of Transformation Kinetics and Phase Properties using Synchrotron Source

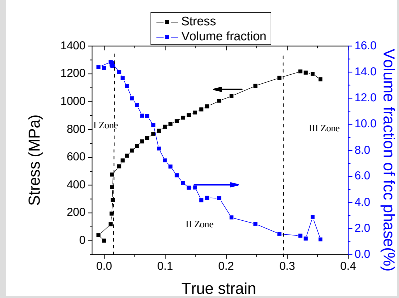
Argonne APS In-Situ HEXRD Measurements to determine individual phase properties





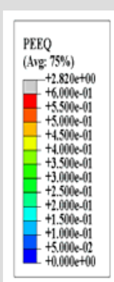


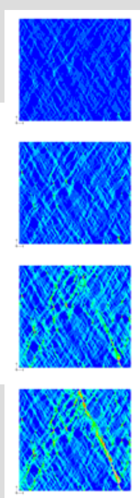


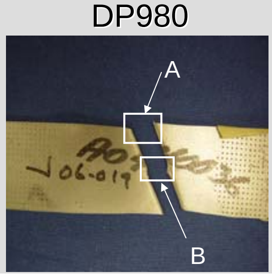


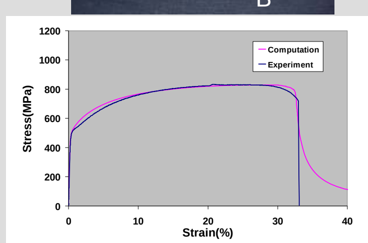
Forming Accomplishment - Failure Mode Prediction for AHSS under Different Loading Conditions

DP980

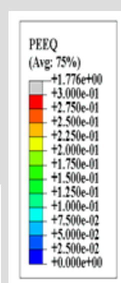


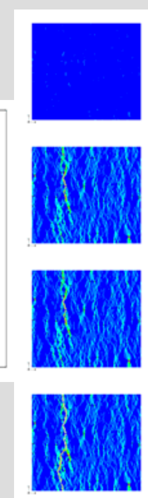






Comparison of predicted/measured stress vs. strain curves





A: sample edge

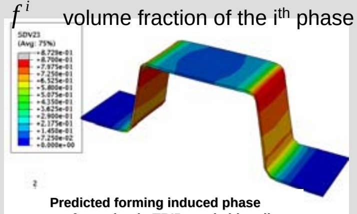
B: sample center

Forming Accomplishment - Integrated Forming Induced Phase Transformation in TRIP Steel Side Rail Crash Simulations

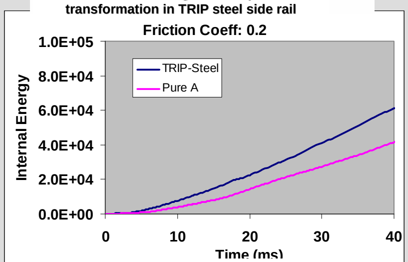
Properties of Multiphase TRIP800

$$\sigma_{ij}^{T800} = f^{Ferrite}\sigma_{ij}^{Ferrite} + f^{Mart}\sigma_{ij}^{Mart} + f^{Aust}\sigma_{ij}^{Aust}$$

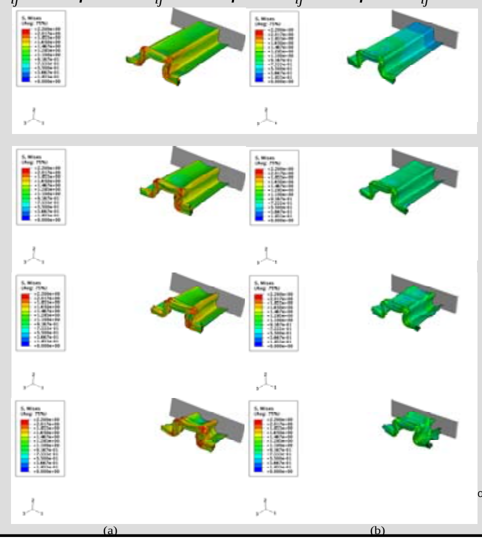
f^i volume fraction of the i[th] phase



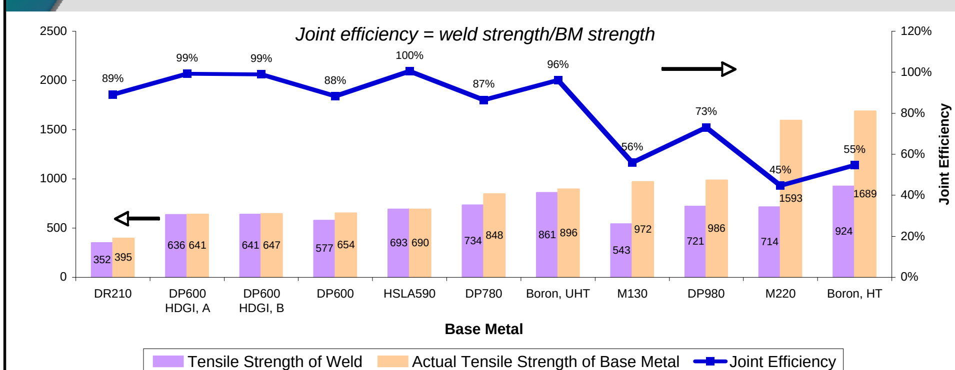
Predicted forming induced phase transformation in TRIP steel side rail



Effects of forming induced Phase transformation in predicted energy absorption of side rail



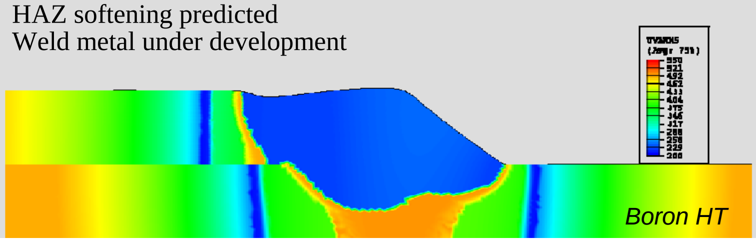
Welding Accomplishment – Correlation between Structural Performance and Microstructural Changes of AHSS welds

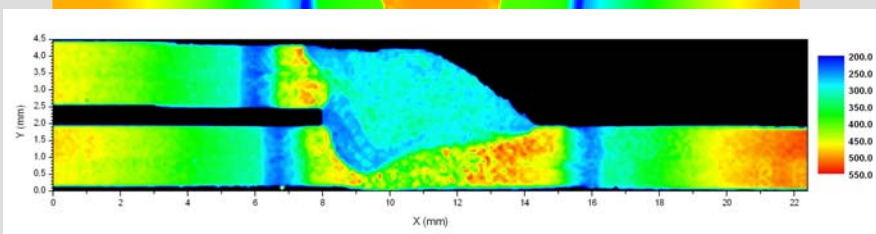


- Cross weld tensile strength generally increases, as base metal strength increases.
- Weld tensile strength of higher grade AHSS is lower than the base metal due to HAZ softening.
- Joint efficiency can be used to quantify the reduced weld strength for design.

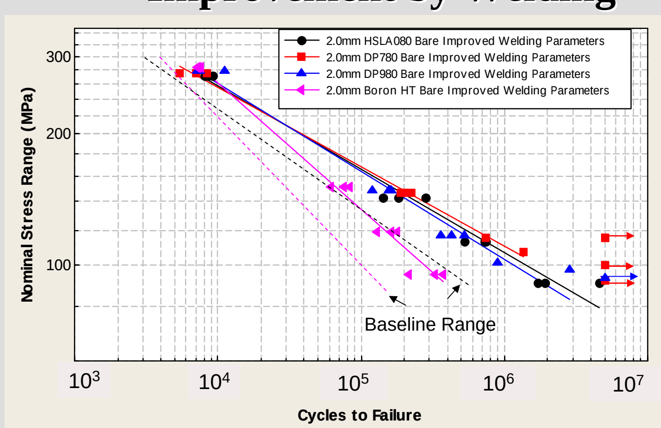
Welding Accomplishment - Integrated Thermal-Metallurgical-Mechanical Modeling of AHSS Welds: Preliminary Results

- HAZ softening predicted
- Weld metal under development





Welding Accomplishment - Fatigue Life Improvement by Welding



- Fatigue life of AHSS welds depend on the steel grade and chemistry
- Considerable Improvement of fatigue life achieved for DP780
  - Over an Order of Magnitude at Low Stress Level
- HAS softening has no influence on weld fatigue life
- Fatigue life prediction for high cycle low stress conditions

Technology Transfer

- Received very strong supports from and maintained close interactions with OEM, steel suppliers and A/SP committees
  - A/SP AHSS Stamping Team
  - Joining Technologies Team
  - A/SP Sheet Steel Fatigue Committee
  - A/SP Lightweight Chassis Structure Team
- Research approach and results have been adopted and further developed by the OEMs and industry consortiums

Activities for Next Fiscal Year

- Forming and base material property predictions of AHSS:
  - Influence of martensite hardness, volume fraction, distribution, shape effects on stress-strain behaviors and failure modes of DP steels
  - Effects of transformation kinetics on stress-strain behaviors and failure modes of TRIP steels
  - Effects of retained austenite shape and volume fraction on fatigue of TRIP steel
- Conduct concept feasibility studies on nano precipitate strengthened steels:
  - Effects of 2nd phase particle size, shape and mechanical properties on the overall steel properties
  - Cost and cycle time for various techniques in introducing nano precipitates
- Welding of AHSS:
  - Complete weld metal microstructure model development
  - Integrate welding process/microstructure model with mechanical performance model
  - Refine weld fatigue life prediction model
  - Predict Phase transformation kinetic in the intercritical region
  - Design guideline and CAE design methodology for welded structure design and prototyping
  - Welding techniques and practices to improve AHSS weld performance

Summary

- Potential for petroleum displacement
  - This project provides the knowledge and modeling tools on AHSS subject to forming and welding such that more AHSS can be used to achieve the DOE vehicle lightweighting goals.
- Research approach
  - A complementary experimental and modeling approach has been used to gain fundamental understandings of AHSS under automotive-related thermal mechanical loadings, i.e., forming and welding.
- Technical Accomplishments
  - On target with project objective and timeline
- Technology transfer
  - Continue close interactions with the OEM and A/SP technical committees to exchange research progress and collaborate on other related projects
- Plans for next year
  - Continue development work in the various technical areas
  - Explore new approaches for GEN III AHSS

Publications and Presentations

1. Predicting Failure Modes and Ductility of Dual Phase Steels Using Plastic Strain Localization, X Sun, WN Liu, KS Choi and MA Khaleel, submitted to *International Journal of Plasticity*, 2008.
2. Influence of Martensite Mechanical Properties on Failure Mode and Ductility of Dual Phase Steels, KS Choi, WN Liu, X Sun and MA Khaleel, submitted to *Materials Science & Engineering A*, 2008.
3. Micromechanical Behavior of Ferrite/Martensite Dual Phase Steels Studied by in-situ High-Energy X-ray Diffraction, ZH Cong, N Jia, X Sun, Y Ren and YD Wang, to be submitted to *Scripta Materialia*, 2008.
4. Load partitioning in multiple-phase TRIP steels investigated by neutron diffraction, S. Cheng, X.-L. Wang, Z.-L. Feng, B. Clausen, H. Choo, P. K Liaw, to be submitted to *Acta Materialia.*
5. Effects of Manufacturing Processes and In-Service Temperature Variations on the Properties of TRIP Steels, X Sun, EV Stephens and MA Khaleel, *SAE 2007 World Congress*. SAE paper no. 2007-01-0793.
6. Weldability and Performance of Advanced High-Strength Steels (AHSS) in Automotive Structure, Z. Feng, J. Chiang, M. Kuo, and C. Jiang, *SAE 2007 World Congress, Detroit, MI.* Invited Panel Presentation
7. Weldability of GMAW Joints of Advanced High Strength Steels. Z. Feng, C. Jiang, M. Kuo and J. Chiang, *Great Designs in Steel 2007*, Livonia, MI AISI.
8. Effect of Phase Transformation on the Tensile Behavior in Transformation-Induced Plasticity (TRIP) Steels Studied by Neutron and Synchrotron X-ray Diffraction", S. Cheng, X.-L. Wang, Z. Feng, H. Choo, Y.D. Wang B. Clausen, J. Almer, P.K. Liaw, *MRS fall meeting*, November 26 - 30, 2007, Boston, MA.
9. Strain Rate and Temperature Dependent Behaviors for Transformation Induced Plasticity (TRIP) Steels, X Sun, EV Stephens and MA Khaleel, in *Mechanics and Mechanisms of Finite Plastic Deformation, Proceedings of the 14th International Symposium on Plasticity and Its Current Applications.* Editors A.S. Khan and B. Farrokh. Jan. 3-8, 2008. Kona, Hawaii. NEAT PRESS, ISBN: 0-0659463-8-X.
10. Application of In-Situ Characterization Methods in Developing the Advanced Numerical Models to Predict the Constitutive Behaviors of TRIP Steels, X Sun, WN Liu, MA Khaleel, ZH Cong, N Jia, YD Wang and PK Liaw, to be presented at *TMS 137th Annual Meeting & Exhibition, March 9-13, 2008.*
11. Texture Development in Transformation-Induced Plasticity (TRIP) Steels Studied by Neutron and X-Ra Diffraction, S Cheng, XL Wang, ZL Feng, YD Wang1, S Vogel, JJ Wall, H Choo, PK Liaw and X Sun, to be presented at *TMS 137th Annual Meeting & Exhibition, March 9-13, 2008.*
12. Modeling of Failure Modes Induced by Plastic Strain Localization in Dual Phase Steels, WN Liu, KS Choi, X Sun and MA Khaleel, to be presented at *SAE 2008 World Congress.*