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 loading 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 loading 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

(a) Loading Frame

(b) Specimen

(c) 3-D Detector

**Forming Accomplishment – Failure Mode Prediction for AHSS under Different Loading Conditions**

DP980

A: sample edge

B: sample center

Comparison of predicted/measured stress vs. strain curves

OAK RIDGE NATIONAL LABORATORY
Forming Accomplishment - Integrated Forming Induced Phase Transformation in TRIP Steel Side Rail Crash Simulations

Properties of Multiphase TRIP800

\[ \sigma_{ij}^{\text{TRIP800}} = f_{\text{Ferrite}} \sigma_{ij}^{\text{Ferrite}} + f_{\text{Mart}} \sigma_{ij}^{\text{Mart}} + f_{\text{Aust}} \sigma_{ij}^{\text{Aust}} \]

- Predicted forming induced phase transformation in TRIP steel side rail
- Friction Coeff: 0.2
- 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.

**Joint Efficiency** = weld strength/BM strength
Welding Accomplishment - Integrated Thermal-Metallurgical-Mechanical Modeling of AHSS Welds: Preliminary Results

- HAZ softening predicted
- Weld metal under development

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

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.
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.