

AHSS Stamping Project – A/SP 050

Nonlinear Strain Paths Project – A/SP 061

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Ford Motor Company
May 12th, 2011

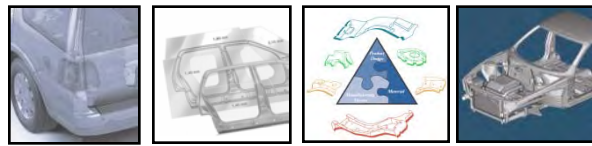
Project ID #LM041



Auto/Steel
Partnership

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Timeline

- Start – 10/2001
- End – 09/2011

Budget

- Total project funding
 - DOE – \$2,461K
- Funding for FY11
 - DOE – \$394K

Barriers

- challenging material
- Availability of 3G AHSS

Partners

- Wayne State University
- Oakland University
- PNNL

Objectives

- To support the efforts of the A/SP Lightweight Initiative Projects to achieve cost-effective mass reduction in vehicle systems
- All work has been directed towards implementing AHSS into the vehicle architecture and study in the following areas:
 - Process simulation
 - Springback Control
 - Fracture

Process Simulation -DP980 Formability

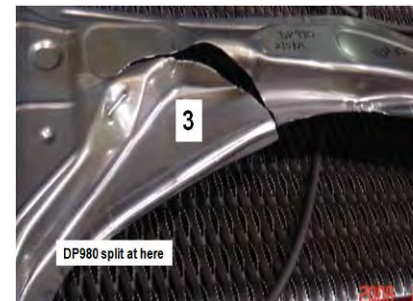
- Motivation
 - Unknown production capabilities for producing complex parts (e.g. B-Pillars) reliably with steel at 980MPa and above by low-cost, low-energy conventional stamping
- Task
 - Ten different DP980 from different suppliers, domestic and foreign



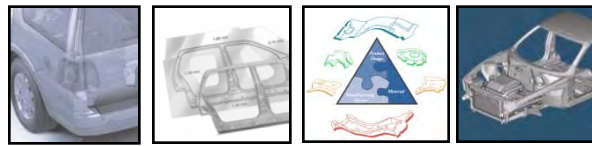
DP780, Draw panel



TRIP700, Draw panel



Low Carbon DP980 CR



- DP980 formability assessment
 - Not all the DP980s are the same, some are more formable than others
 - Test results provide validation data for numerical simulation to improve formability and springback predictability
- Feasibility study of local softening technologies
 - Tensile testing results show that the DP980 tensile behavior was softened after heating with ambient cooling

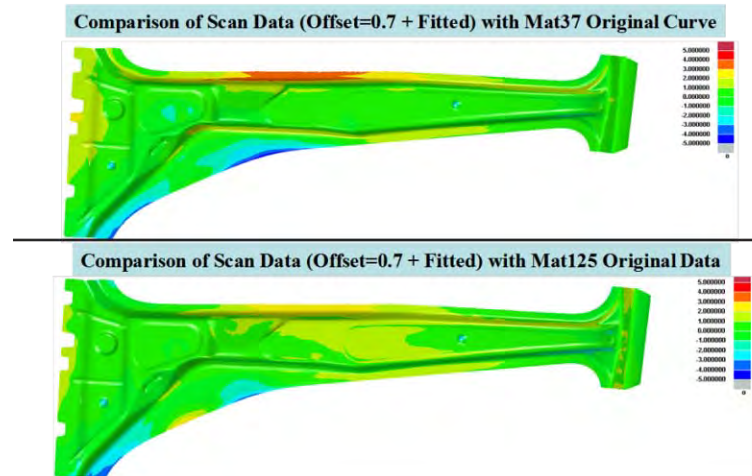
Springback Control Approach

- Motivation

- Can USAMP-developed compensation software package be used to predict compensated surface for DP780?

- Task

- Validate springback control by cutting die to the compensated surface and run parts using B-pillar die
- Parts were measured and compared to the nominal CAD data



Shape Deviation of FE Simulation from Measured Real Panel

Springback Control Accomplishments

- Validation of the USAMP-developed compensation software
 - Overall, in most critical areas, the shapes predicted by simulation correlate well with the real panel shape, except the areas on some portions of the flange.
- Evaluation on LS-DYNA material models
 - Two types of material models in simulation were evaluated. Better result was found by using MAT125

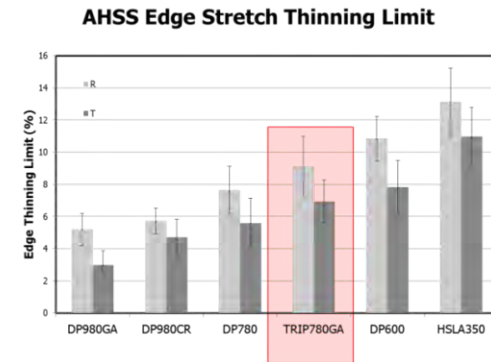
Fracture Approach - Edge Cracking

- Stretched-edge fracture is one of the critical issues in application of AHSS
- Criteria appear to be different for larger radius cut-out features compared to smaller radius cut-out features
- The criteria obtained from standard hole expansion testing is not useful for stamping with larger scale holes



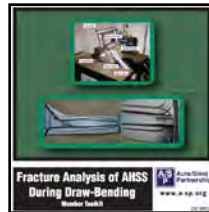
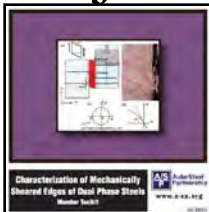
Fracture Accomplishments

- Plane strain fracture
 - Some AHSS materials (50KSI & TRIP780) show significant orientation dependency on their fracture strain
 - More studies are needed
- Edge cracking
 - The edge fracture criteria for large size cut-out has been developed and implemented
 - The sheared edge thinning limit increased with reducing tensile strength
 - The edge thinning stretched along the rolling direction is higher than that along the transverse direction
- Microstructure study
 - The directions of burr affect numbers of micro-cracks on the sheared-edges
 - Study will be continued until September 2011



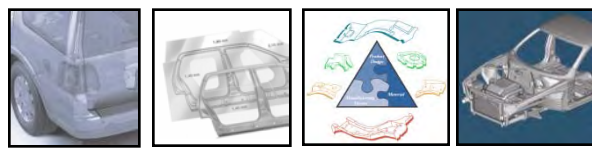
Collaboration & Technology Transfer

- Partners
 - Wayne State University – Edge cracking study
 - Oakland University – Fracture study
 - PNNL – Multi-phase material microstructure fracture study
- Technology Transfer:
 - Great Designs in Steel, May 2010
 - NADDRG, May 2010
 - SAE, April 2010
 - AHSS Fracture Symposium, August 2010
 - Project Technical Review Meetings – all member companies



Future Work

- Conduct a gap assessment into the accuracy of current predictive tools on stamping ultra high-strength steel (UHSS) (980MPa and above) in the following areas:
 - (1) Accuracy of forming and springback simulation
 - (2) Formability
 - (3) Fracture behavior
 - (4) Forming tonnage
 - (5) Die structural integrity
 - (6) Advanced manufacturing method - Local softening techniques
- Define follow-on project as appropriate to close gaps identified



- Not all the DP980s are the same, some are more formable than others
- It is feasible to perform local softening to improve formability
- USAMP-developed compensation software package is effective in predicting compensated surface for DP780
- The edge fracture criteria for large size cut-out has been developed and implemented

Timeline

- Start – Oct. 1, 2009
- Finish - Sept. 30, 2011
- 70% Complete

Barriers

- Predictive modeling tools
- Tooling and prototyping
- Performance

Budget

- Total project funding
 - \$1,399k (DOE: \$700K/Cost Share \$699k)
- Funding received in FY10:
 - \$236k (DOE: \$101K/Cost Share \$135k)
- Funding for FY11:
 - \$1,163k (DOE: \$ 598k / Cost Share \$565k)

Partners

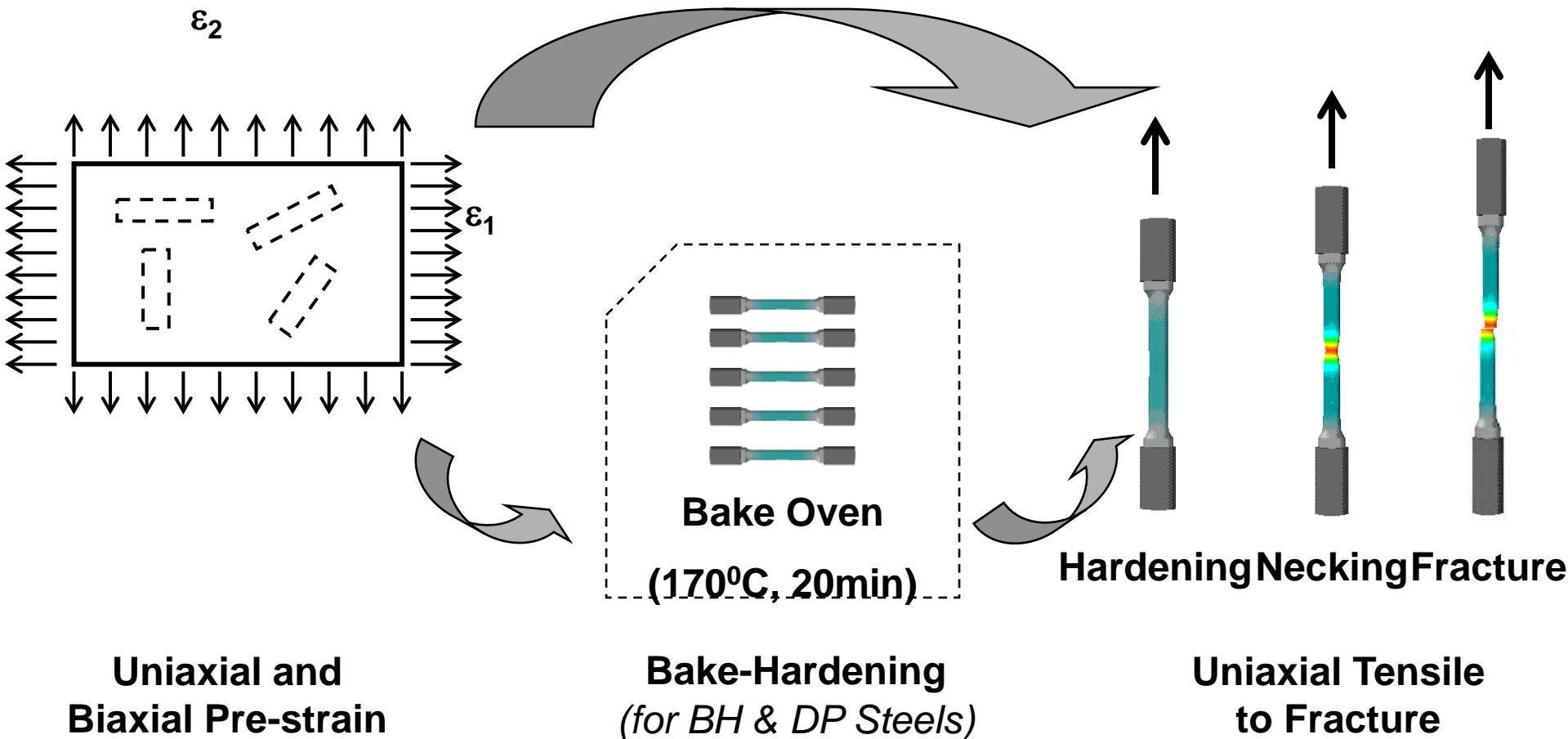
- Project Leads:
 - Chrysler Group LLC
 - Ford Motor Company
 - General Motors Company
- Interactions/ collaborations:
 - ArcelorMittal / US Steel
 - Livermore Software Technology Co.
 - SuperiorCam
 - NIST
 - Oakland Univ. / Wayne State Univ. / MIT / Tokyo Univ. of A&T

Objectives

- Deliver a comprehensive set of experimental data and associated predictive models for the Advanced High-Strength Steels (AHSS) under nonlinear strain path deformations.
- The models include constitutive behavior, forming limit and fracture criteria for stamping/hydroforming simulations and vehicle crashworthiness simulations.
- The project will
 - Enable efficient vehicle design for more weight reduction opportunities to take advantage of the rapid hardening behavior of AHSS;
 - enable the acceleration of AHSS usage by reducing the cost and time for AHSS manufacturing.

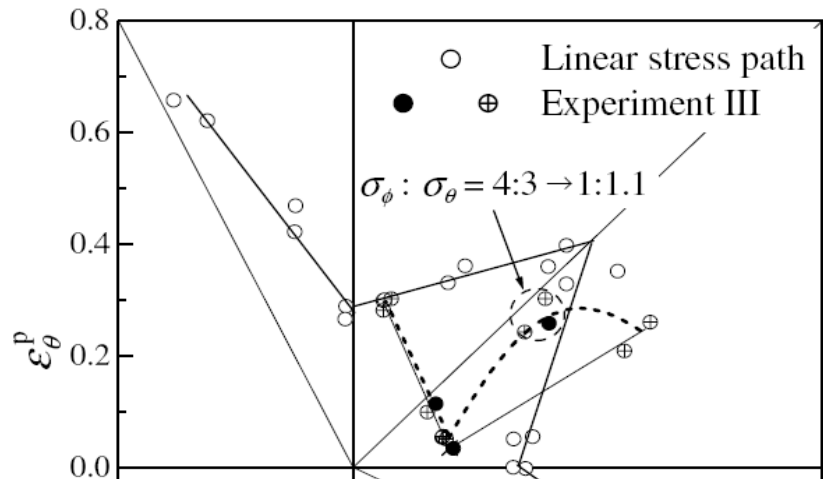
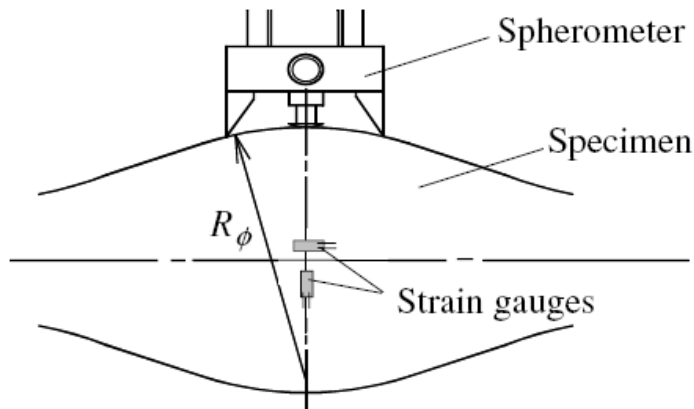
Approach/Strategy – Discontinuous Loading

- ❑ *Transient hardening and bake-hardening under uni-axial / equi-biaxial strain path changes.*

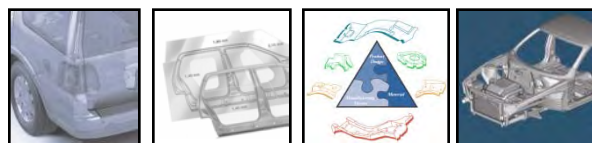


Approach/Strategy – Continuous Loading

- ❑ *Transient hardening and forming limits under general biaxial strain path changes.*
- ❑ *Adaptive control of axial loading vs. pressure to achieve desired change of strain paths.*
- ❑ *Allows path change without unloading.*
- ❑ *Calculation of stresses from applied loads.*



Courtesy of Yoshida & Kuwabara,
Tokyo University of Agriculture and Technology



Approach/Strategy – Fracture Modeling

1. Solid-Element Fracture Model

Develop, validate, and implement a physics-based Fracture Model applicable to FEA simulation using solid elements that can predict the effect of the trim process on the trim edge condition and predict the subsequent formability of the trimmed edge

2. Fast Shell-Element Fracture Model

Develop a fast, simple Fracture Model that can be reliably used in simulations of trim and subsequent formability based on FEA simulation using shell elements

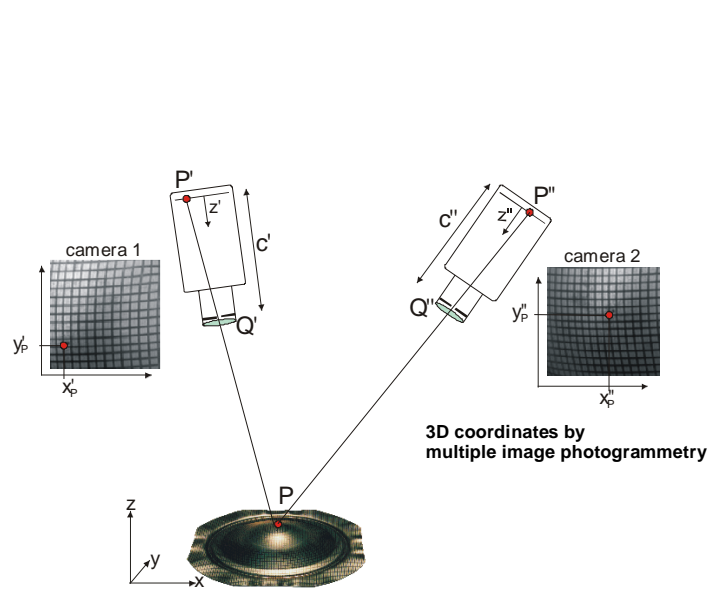
3. Foundation for the Next Generation Fracture Model(s)

Lay a foundation for development of more advanced fracture model(s) to include consideration of material anisotropy, strain-rate, temperature, and more complex deformation histories, including combined manufacturing and product performance

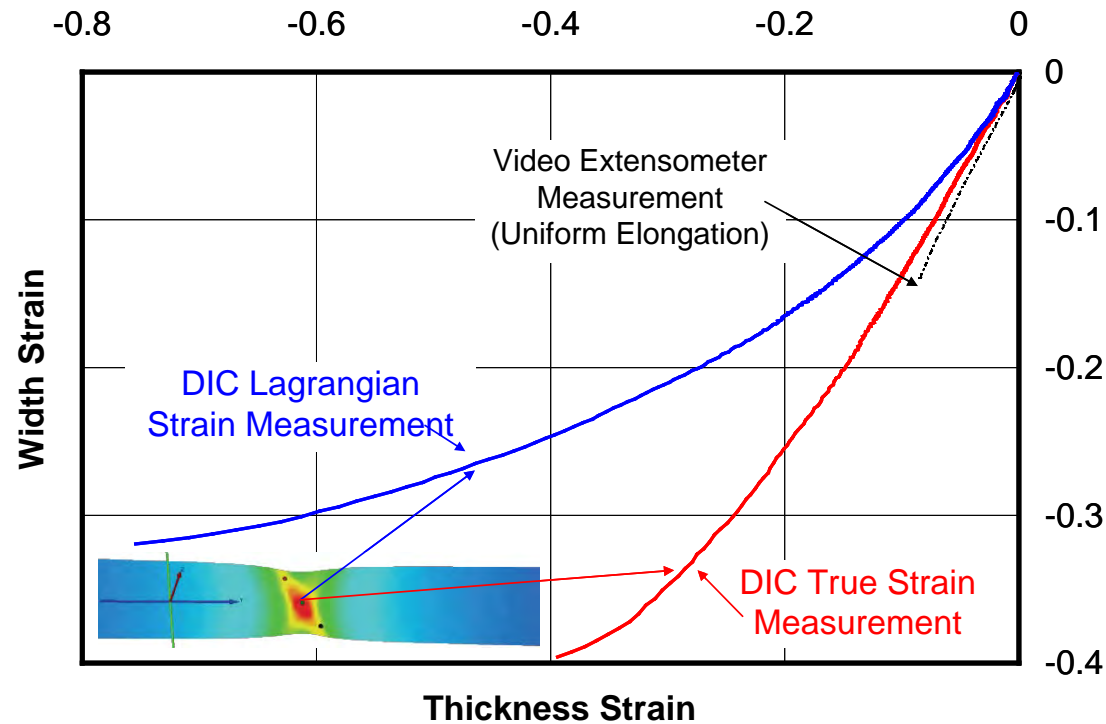
Technical Accomplishments

FY10 Accomplishments:

- Completed temperature-dependent strain testing of 6 grades of AHSS
- Completed Uni-axial Transient Hardening Tests using DIC (800+ tests)



3D Digital Image Correlation & Tracking

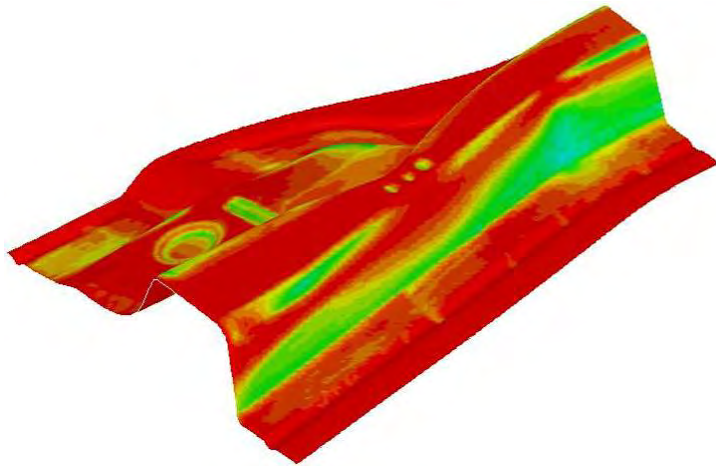


DIC Strain Processing & Evaluation

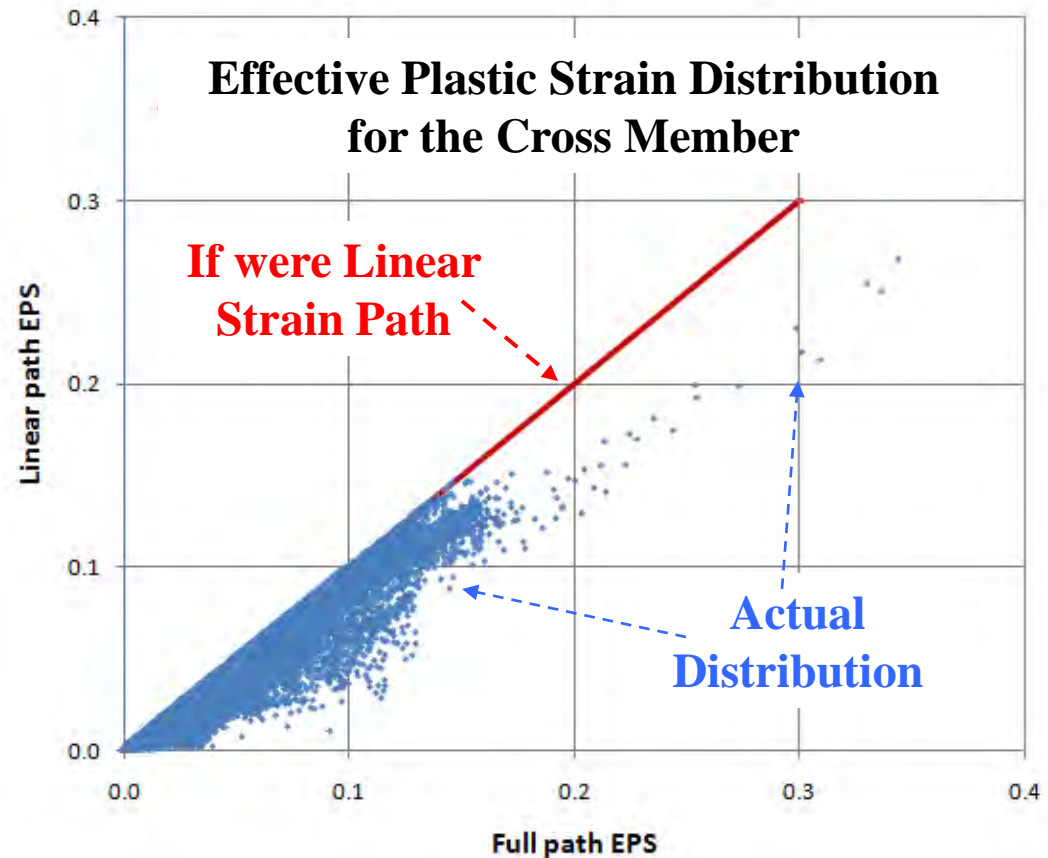
Technical Accomplishments

FY10 Accomplishments:

- Developed Strain-Path Independent Forming Limit Criteria



A DP600 Cross Member



Partners:

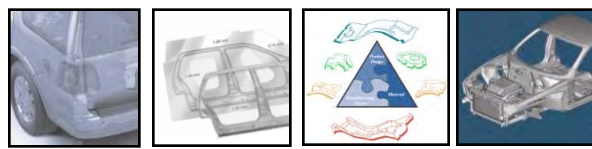
- ArcelorMittal (Industry – Prime; within VT): provide sheet steels for testing; uni-axial pre-straining; expertise on metallurgy and behavior.
- US Steel (Industry – Prime; within VT): provide sheet steels for testing; bake-hardening; expertise on metallurgy and behavior.
- Livermore Software Technology Co (Industry – Prime; outside VT): develop and implement simulation models in the commercial software LS-DYNA; conduct simulations for tooling design.
- SuperiorCam (Industry – Sub; outside VT): tooling design and fabrication.
- Oakland University (Academic – Sub ; outside VT): DIC tests and analysis.
- Wayne State University (Academic – Sub ; outside VT): temperature-dependent tests and analysis.
- MIT (Academic – Sub; outside VT): fracture modeling
- Tokyo University of A & T (Academic – Sub ; outside VT): transient hardening tests under biaxial continuous strain changes.
- NIST Center for Metal Forming (Federal laboratory – Sub ; outside VT): expertise and guidance on materials and test standards.

FY11:

- Achieve Milestone #3 (in May 2011): Establish a comprehensive database of biaxial transient hardening and forming limit behavior under continuous strain path change conditions.
- Achieve Milestone #4 (in July 2011): Validate forming limit behavior under continuous strain path change conditions in production tooling.
- Achieve Milestone #5 (in Sept 2011); Develop, implement and validate transient hardening, path-independent forming limit and fracture models for stamping and crash simulations within production software LS-DYNA.

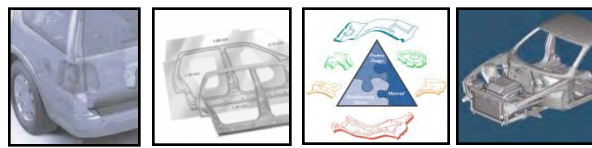
Beyond FY11:

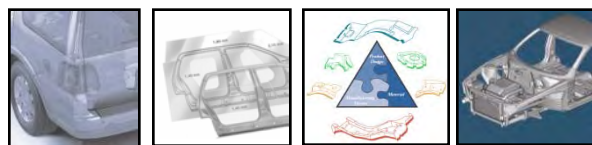
- Project funding ends Sept. 2011.
- Transfer developed technologies to automotive OEMs (Chrysler, Ford and GM) and AISI companies (ArcelorMittal, US Steel, etc.)
- Continue to develop application procedures and guidelines within Auto/Steel Partnership and transfer to member companies.
- Work to improve simulation models based on production feedback.



Summary

- This is an enabling project for more aggressive vehicle weight reduction opportunities by taking advantage of the rapid hardening behavior of AHSS; it will enable the acceleration of AHSS usage by reducing the cost and time for AHSS manufacturing.
- Sheet metal continues to deform and change mechanical properties throughout the manufacturing processes (hardening and thinning from stamping/hydroforming, microstructure change from welding, bake-hardening from paint shop). However design & engineering practices based on current CAE models ignore such deformation history, resulting in over-design and added weight.
- The project aims to deliver a comprehensive set of experimental data and associated predictive models for the Advanced High-Strength Steels (AHSS) under nonlinear strain path deformations. The models include constitutive behavior, forming limit and fracture criteria for stamping/hydroforming simulations and vehicle crashworthiness simulations.
- Significant accomplishments have been achieved in FY10 and are on target to achieve FY11 milestones.





Technical Back-Up Slides

Process Simulation – Feasibility of Local Softening

- Motivation

- Seeking potential lower cost (vs. hot stamping) process for cold stamping of parts with 1000MPa or higher

- Task

- Conducting local heating on DP980 sheet tensile coupons using induction heating method

- Local Patch Softening Technology

- Lab study results: improved formability
 - Potential low cost production process for cold stamping of parts with 1000MPa or higher strength, utilizing OEM's stamping plant's capacity, and manufacturing energy saving (vs. hot stamping)

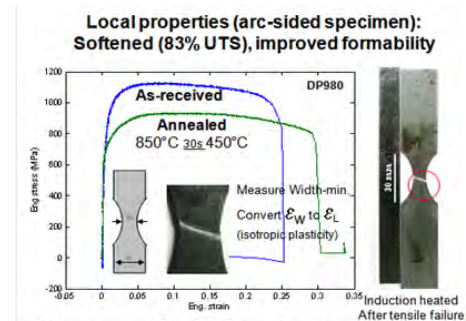


Fig. 9. Oxidation scale in the DLHT-A condition



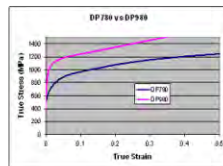
Fig. 13. Tensile Flow Curves

Figures are copied from Paper of Enhancing Dual Phase Steel Formability by Diode laser Heat Treatment by **Capello, Edoardo; Previtali, Barbara**; Politecnico di Milano, Dipartimento di Meccanica, Milan, Italy, Journal of Laser Applications, vol. 21, issue 1, p. 1, 2009

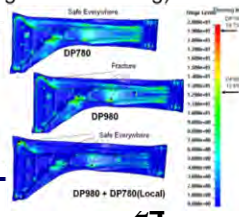


One slide from DP980 softening feasibility study by A/SP Stamping Team jointed with WSU

- Simulation with an assumed sheet properties (including local softening)



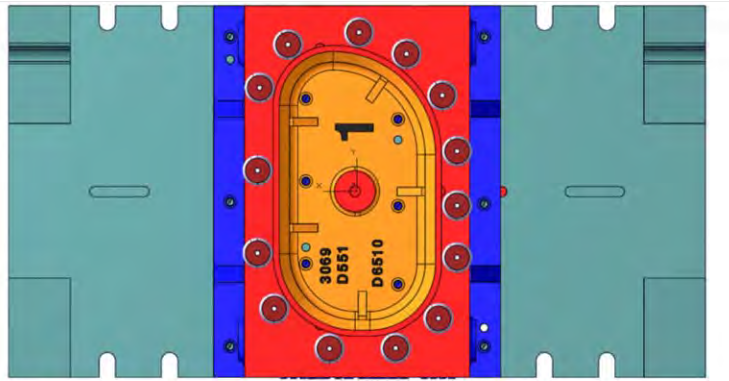
DP980 blank with 6 DP780 areas as "local softened"



Fracture – Edge Cracking, Large Cutout

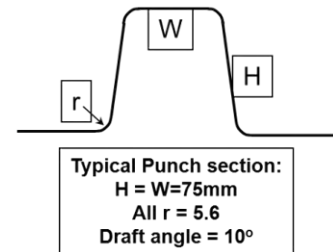
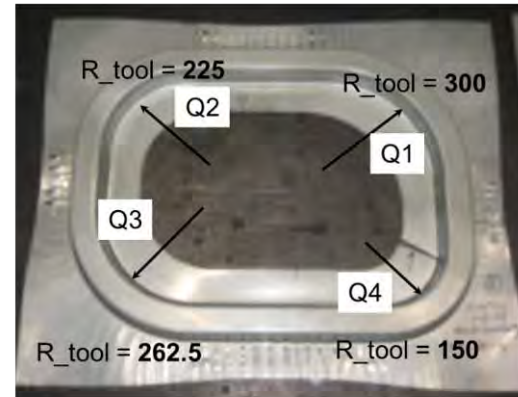
- Motivation: Develop edge fracture criterion for large radius stretched features
- Task:
 - Sets of Chrysler LLC Edge-Cracking Experimental Dies were used
 - Thinning and edge fracture has been characterized and correlated with process conditions

Blanking Die Design:



14 Polyurethane Spring:
OD = 60 mm, ID = 14 mm, Compress 20 mm, Total holding force = 22.4 ton

Forming Die Design:



Baseline sheet thickness $T_0=1.47\text{mm}$

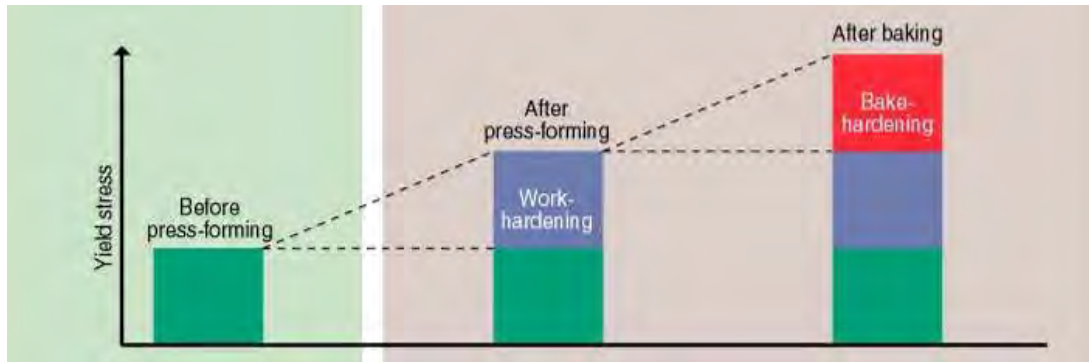
Draw die binder force: 1200psi, 16cylinders

Cutting clearance 5%, 10%, 15%, 20% & 25%

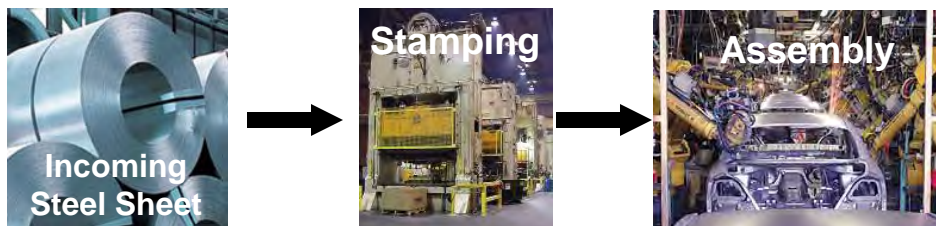


Background

- Sheet metal continues to deform and change mechanical properties throughout the manufacturing processes (hardening and thinning from stamping/hydroforming, microstructure change from welding, bake-hardening from paint shop).
- The steel on your vehicle is not the same steel from the steel mill!



Real-World Crash

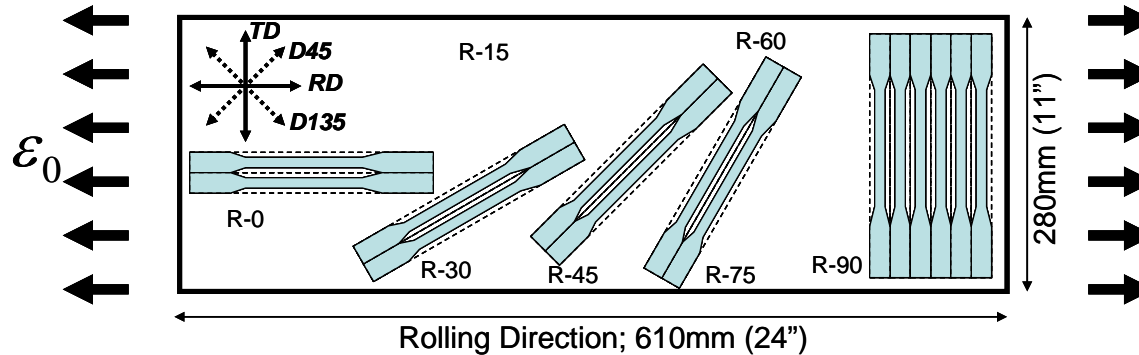


**The steel on your vehicle
is not the same steel
from the steel mill!**

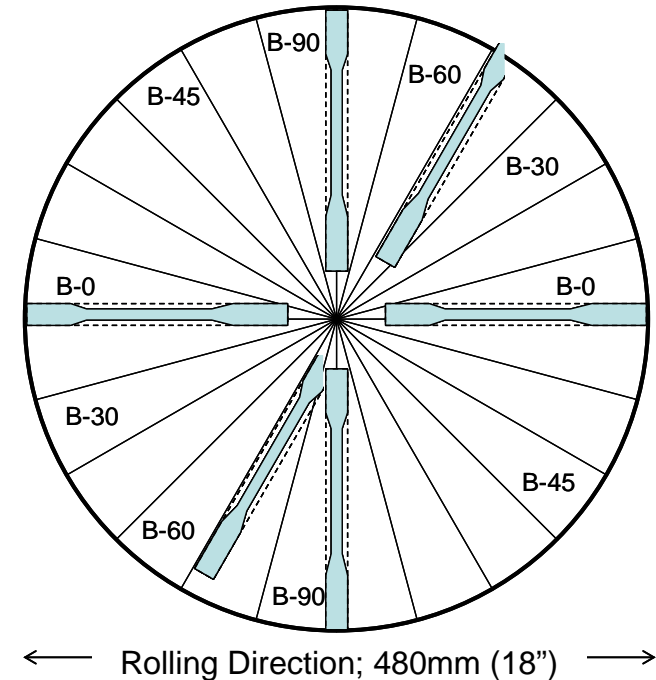
Approach/Strategy – Test Plan

Transient Hardening & Bake-Hardening (A total of 882 tests):

- **6 Steel Grades:** DDQ, BH210, DP600, DP780, TRIP780, DP980
- **3 Pre-strain Orientations:** Rolling, Transverse, Diagonal directions
- **7 Pre-strain Levels:** uniaxial 0%, 5%, 10%, 15%, 20%; Equibiaxial: 5%, 10%
- **7 Subsequent Tensile Orientation** (relative to pre-straining orientation): 0° , 15° , 30° , 45° , 60° , 75° , 90° .



Uni-axial Pre-strain Pattern



Equi-biaxial Pre-strain Pattern