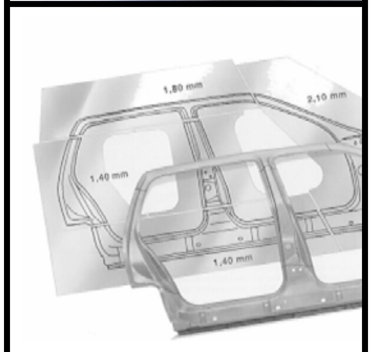
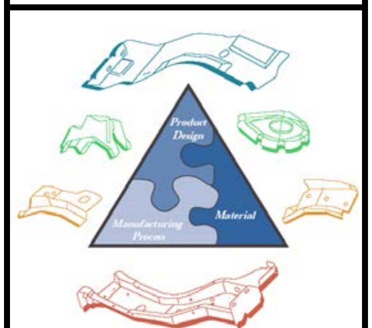
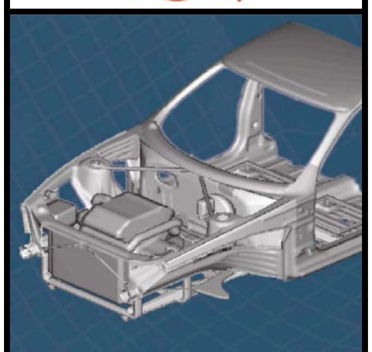






Advanced High-Strength Steel Stamping

ASP-050

Gene Hsiung

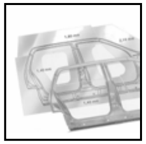
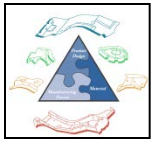
General Motors

May 18th, 2012

Project ID LM063

Auto/Steel Partnership

www.a-sp.org


A/SP AHSS STAMPING OVERVIEW

Timeline

- Start – Oct. 1, 2001
- Finish – Sept. 30, 2011
- 100% complete

Budget

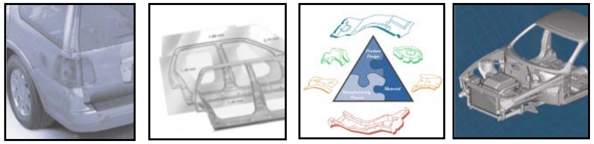
- Total project funding
  - DOE: $2,664K
  - Cost Share: $2,664K
- Funding for FY11
  - $303K
- Funding for FY12
  - $90K

Barriers

- Challenging Material
- Availability of 3G AHSS
- Aging dies

Partners

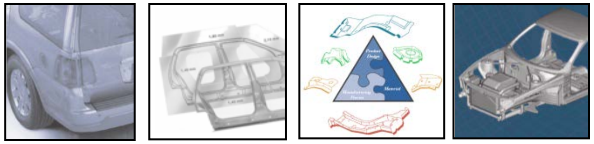
- Project Leaders:
  - Chrysler Group LLC
  - Ford Motor Company
  - General Motors Company
- Interactions/Collaborations
  - 6 steel suppliers
  - Livermore Software Tech.
  - Tranor/Autodie/Fraunhofer USA
  - PNNL
  - Oakland Univ./Wayne State Univ.



OBJECTIVES

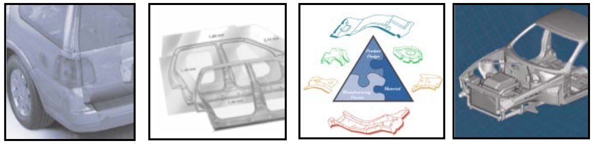
- To support the efforts of the A/SP Lightweight Initiative Projects to achieve cost-effective mass reduction in vehicle systems

- In depth studies of AHSS, including 3rd Generation UHSS, stamping ability and exploring the low cost sustainable stamping process



A/SP AHSS STAMPING APPROACHES

- New AHSS benchmarking
  - Conduct production scale stamping trials and numerical simulations to evaluate the newly developed AHSS
- Edge fracture evaluation
  - Perform lab scale experiments, industrial scale die trials and micro-structure analysis to understand local edge fracture phenomenon on AHSS
- Assess local softening technology
  - Evaluate the feasibility of using local softening technology in AHSS under production environment



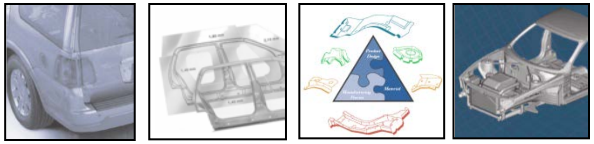
BENCHMARKING APPROACH

Four stamping trials were conducted using three draw dies:

GM P-Pillar
Chrysler B-Pillar
Chrysler Straight Rail

With DP980 and Q&P980 AHSS to

- **Evaluate formability**
- **Evaluate spring-back**



A/SP AHSS STAMPING BENCHMARKING APPROACH

GM B-Pillar Tryout

Key Learning

- DP980 performance varies
- DP980 formability performance in general has been improved continuously
- DP980 with better formability performance has been developed
- Q&P980 performs well
- With proper design, complex parts can be made out of these DP980 Steels

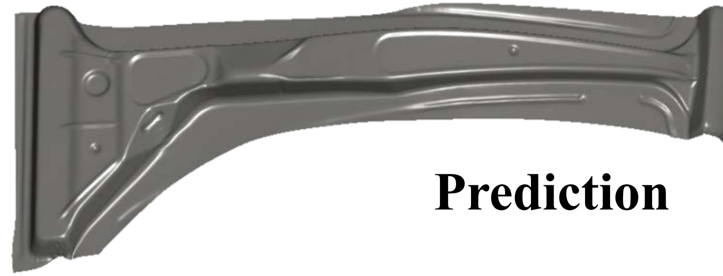
Stamping Trial #1

Material	Supplier	Comments
DP980T/550Y Bare	M - 1	Blanks were 18mm short on narrow end. Formed panel had splits in the bead on the wide end on long side. Necking in the datum boss
DP980T/600Y Bare	M - 2	Some parts were fracture free, some had necking in a bead and on the radius in the area of the roof rail.
MP980T/700Y Bare	M - 3	Part had no splits. Panel was not warm after forming. Galling is not evident.
DP980T/ 550Y GA	M - 5	Severe splits. Panel can not be scanned with these fractures.
DP980 / 700 GI	M - 4	Blank had splits in the bead along the long side of the panel. The datum embosses also had splits
DP980 / DUCRI 680Y	M - 6A	No Splits, No necking. Panels ran clean with little die wear.
DP980 / DUCRI 635Y	M - 6B	No Splits, No necking. Panels ran clean with little die wear.
DP980 / DARI 760Y	M - 6C	No Splits, No necking. Panels ran clean with little die wear.
DP980 /690Y GI	M - 7A	No Splits, No necking. Panels ran clean with little die wear.
DP980 / 670Y CR	M - 7B	No Splits, No necking. Panels ran clean with little die wear. NOTE: When circle grid panel was drawn, splits occurred.

Stamping Trial #2

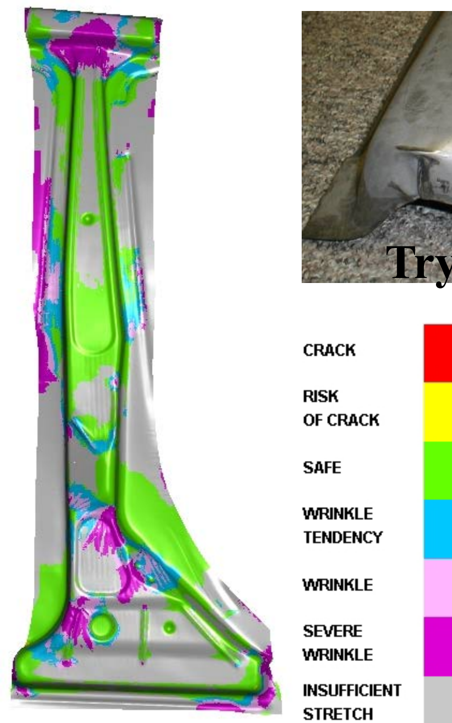
Material	Supplier	Comments
DP980T/550Y Bare	M1 TKS	Necking in the area of the datum boss. No splits Little galling took place
MP980T/700Y Bare	M2 USS	Necking in the area of the datum boss. No Splits. Galling took place. Die had to be polished after each hit.
QP980T/DUCRI 680Y	M3 QP	No necking or splitting. No splits. Little galling two place.

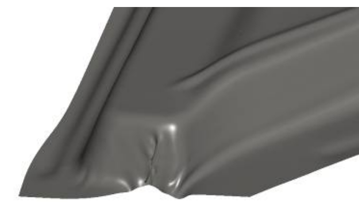
GM B-Pillar Simulation using USS DP 980



Key Learning

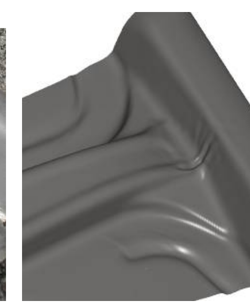
- The formability simulation results correlates with tryout very well
- It's hard to hold the part shape, mainly due to twisting and side wall curl spring-back
- The newly developed material hardening model (Yoshida) is promising, but requires more material testing



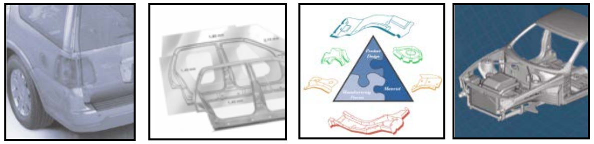


Prediction

Tryout

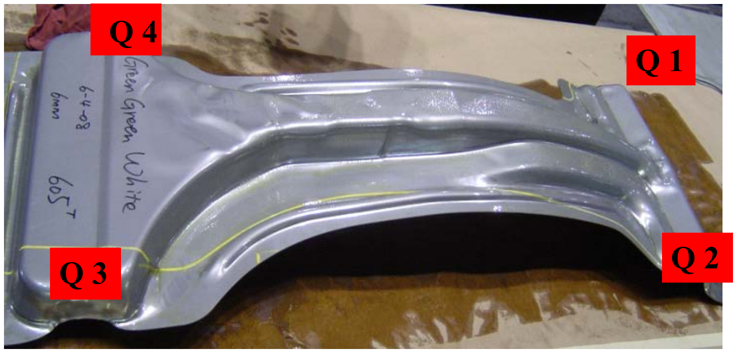


Prediction



A/SP AHSS STAMPING BENCHMARKING APPROACH

Chrysler B-Pillar Tryout



Material	Thickness	YS MPa	UTS MPa	TE %
Bao QP1000	1.23 mm	759	1010	16.5
USS DP980	1.46 mm	652	921	10.3
TKS DP980	1.41 mm	562	936	13.5

seq. number Panel ID	RAM F ton	ram travel bottom to	Tryout condition and observation note
2-TKS-1	789	home	no kiss block, crack on large and small ends, break two pieces, small wrinkle on post top
7-TKS-2	363	6mm to home	both large and small end have **splits**, move large end blank 5mm to even out after draw
8-USS-1	367	6mm to home	no kiss block 16 cylinder , **severe splits**, small end double metal
1-QP-1	645	home	crack on large and small ends, wrinkle on post top, big galling area at corner must be cleaned increase binder pressure to max 24 cylinder from 16 cylinder, take away kiss block
3-QP-2	734	home	crack on large and small ends, wrinkle on post top, galling on flat binder surface, see double metal and edge crack there.
4-QP-3	703	home	add back 2 kiss blocks at large end, still has split and wrinkle there small end also has big split, use 16 cylinder only
5-QP-4	652	home	no kiss block, binder galling tear off a piece of sheet from bead.make a hole on panel,
6-QP-5	336	6mm to home	no kiss block, one big split at corner of large end, wrinkle on post top tear a crack by galling, **small end no split**, buckle inside Po at corner galling can tear in the middle and crack to both end

Key Learning: QP steel shows better formability with more wrinkles (thinner gauge)

EDGE FRACTURE APPROACH

Two lab tests

- **Hole Expansion Test**
- **Pre-Form Coupons Test**

one stamping trial

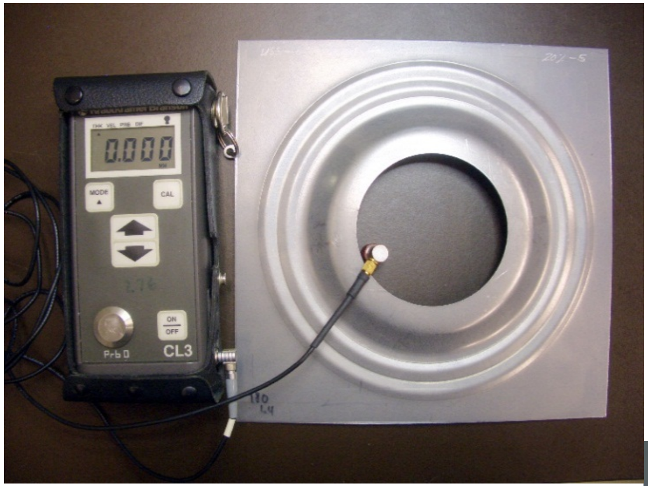
- **Large Cutout Die**

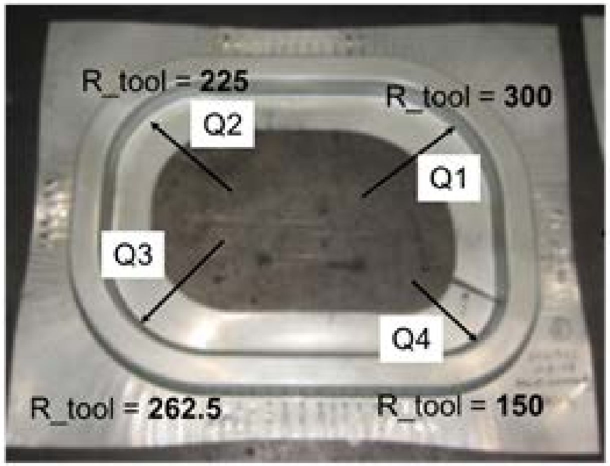
and

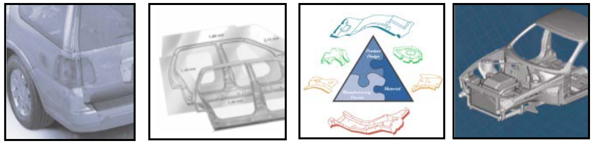
- **Microstructure Study**

were conducted with AHSS including Q&P980 to:

- **Evaluate edge fracture criteria**
- **Evaluate different failure modes**
- **Evaluate pre-form effect**





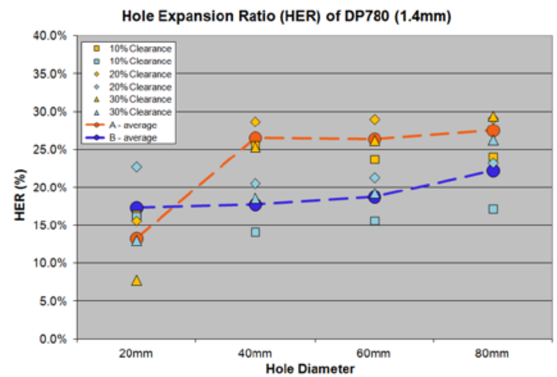


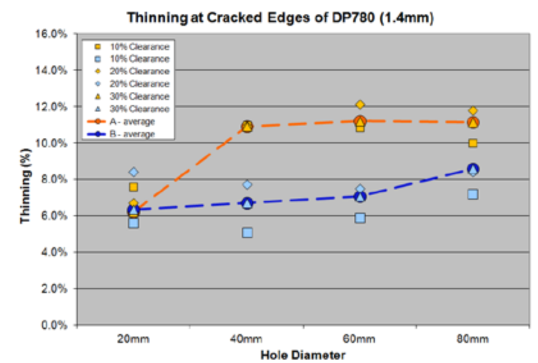
EDGE FRACTURE APPROACH

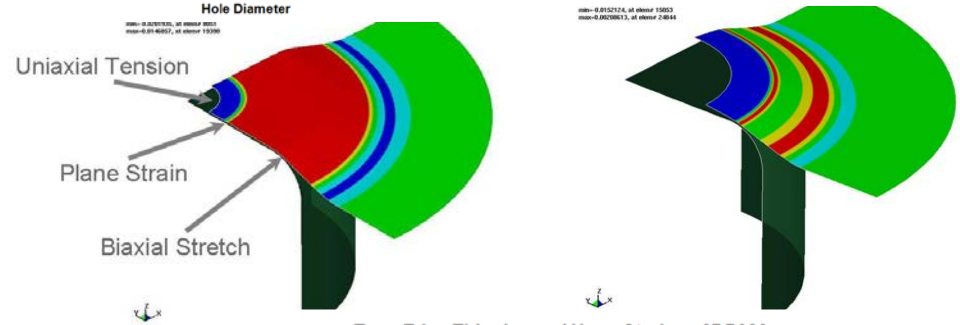
Laboratory Hole Expanding Test

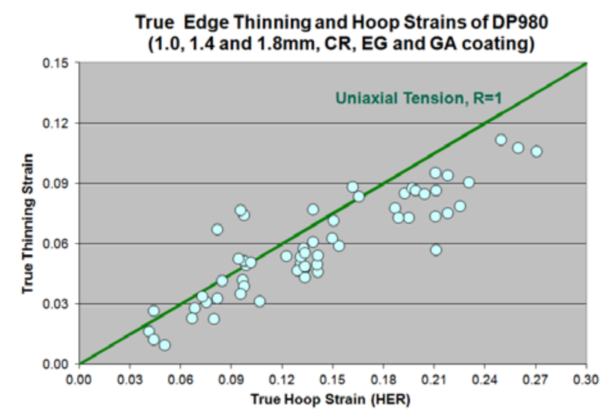
Key Learning

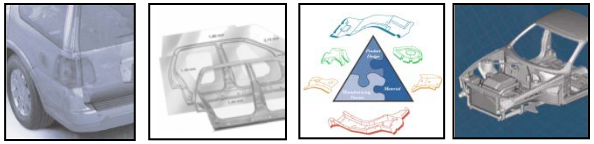
- The hoop (HER) and thinning strains of DP780 and DP980 increase with the hole diameters
- The sheared edge conditions caused by the microstructures of DP780 and DP980 steel can reduce or diminish the increases in HER and edge thinning
- The increases in the edge hoop (HER) and thinning strains are due to the strain gradient determined by the sample geometry and tooling configurations









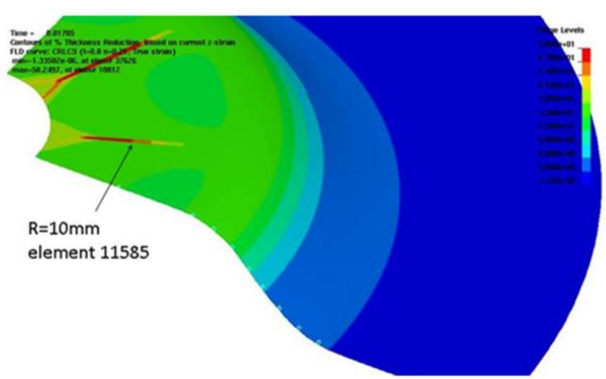


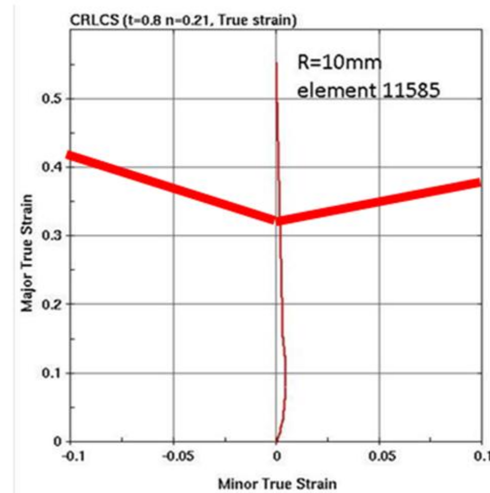
EDGE FRACTURE APPROACH

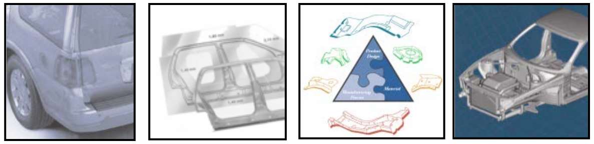
Two Failure Modes

Key Learning

- Edge Fracture: Larger hole samples do not have a sufficient area in biaxial tension to develop a necking type of failure before the edge fractures
- Necking/Split: Change of strain path leads to a failure by necking/split under plane strain condition



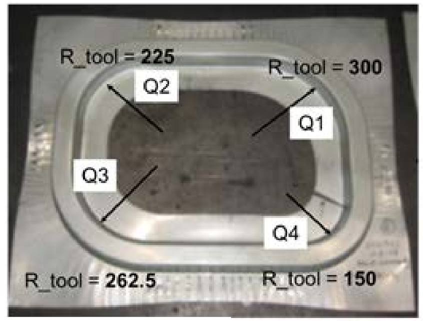


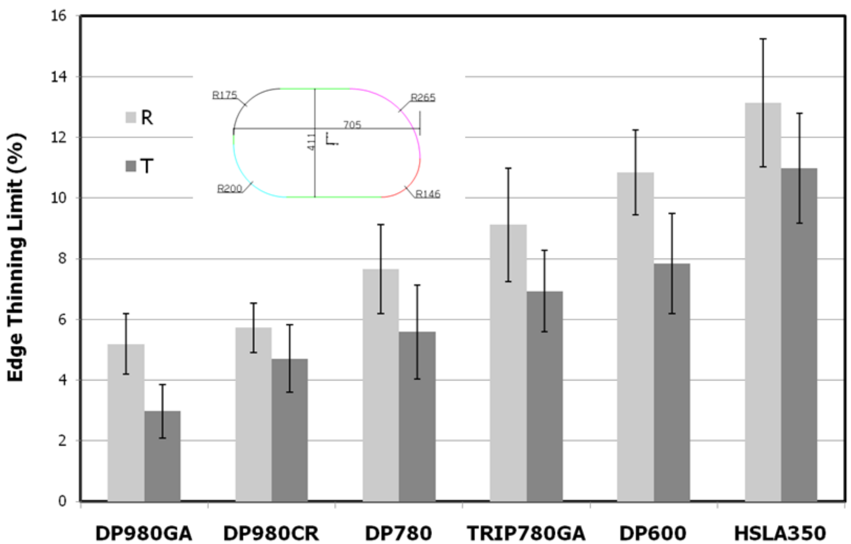


A/SP AHSS STAMPING

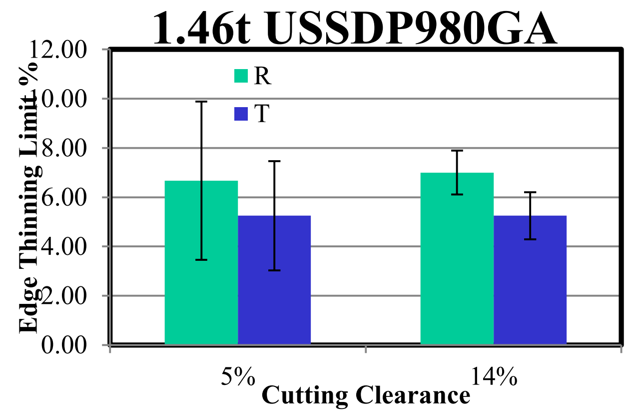
EDGE FRACTURE APPROACH

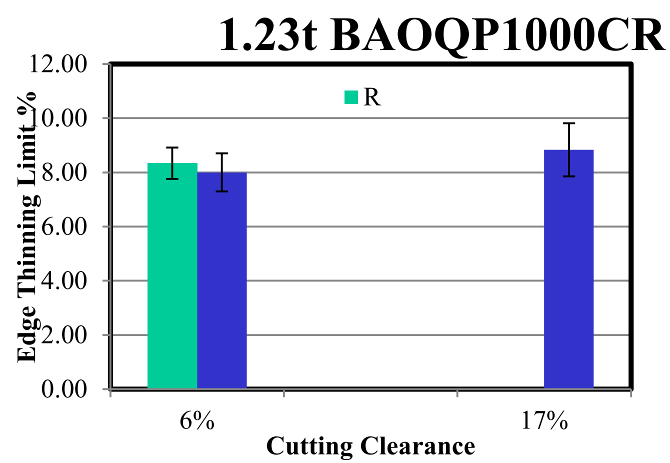
Edge Thinning Limit



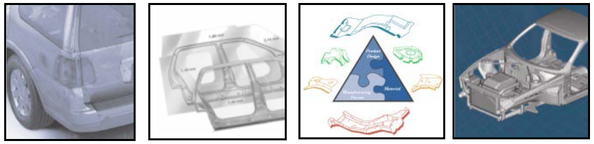


Large cutout stamping trial results





Key Learning: Improved edge stretch thinning limit was noticed on the three DP980 AHSS comparing with the limit found a few years ago

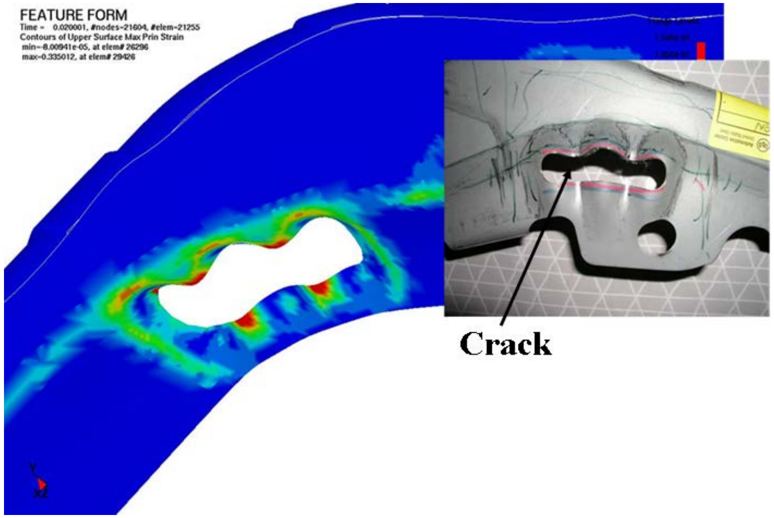


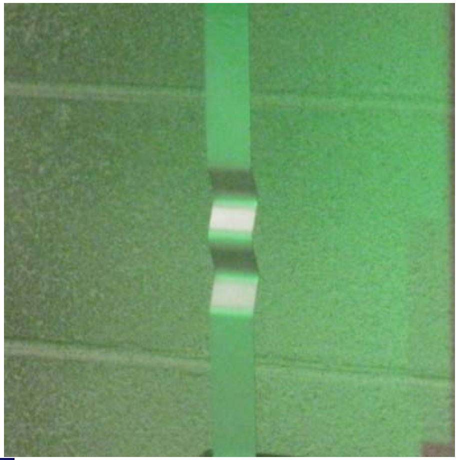
EDGE FRACTURE APPROACH

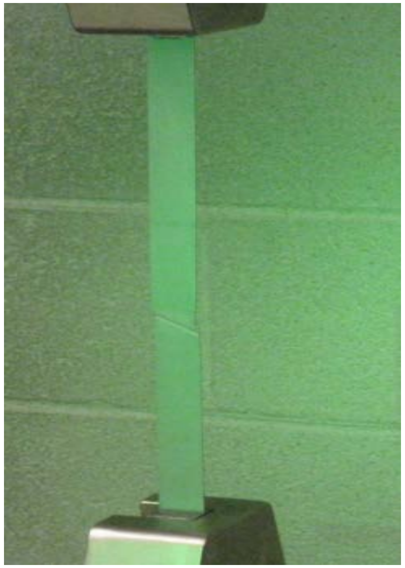
Pre-Form Effect

Key Learning

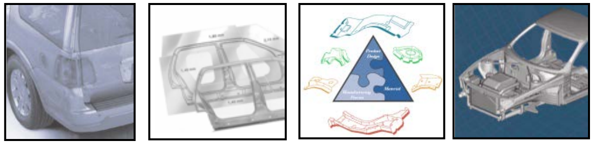
- The pre-form process does not affect the edge stretching ability of DP980, Q&P980 and DP780, but reduces the edge stretching ability of HSLA50 and 590R







Material / direction	Fracture Region (I/O perform) Larger Radius	Fracture Region (I/O perform) Medium Radius	Fracture Region (I/O perform) Smaller Radius
590 R (Rolling)	Inside	Inside	Inside
590 R (Transverse)	Outside	Inside	Inside
DP 780 (Rolling)	Outside	Outside	Inside
DP 780 (Transverse)	Outside	Outside	Outside
DP 980 (Rolling)	Outside	Outside	Outside
DP 980 (Transverse)	Outside	Outside	Outside
DP 980c (Transverse)	Outside	Inside	Inside
HSLA 50 (Rolling)	Inside	Inside	Inside
HSLA 50 (Transverse)	Outside	Outside	Outside
Q&P 980 (Rolling)	Outside	Outside	Outside
Q&P 9780 (Transverse)	Outside	Outside	Outside



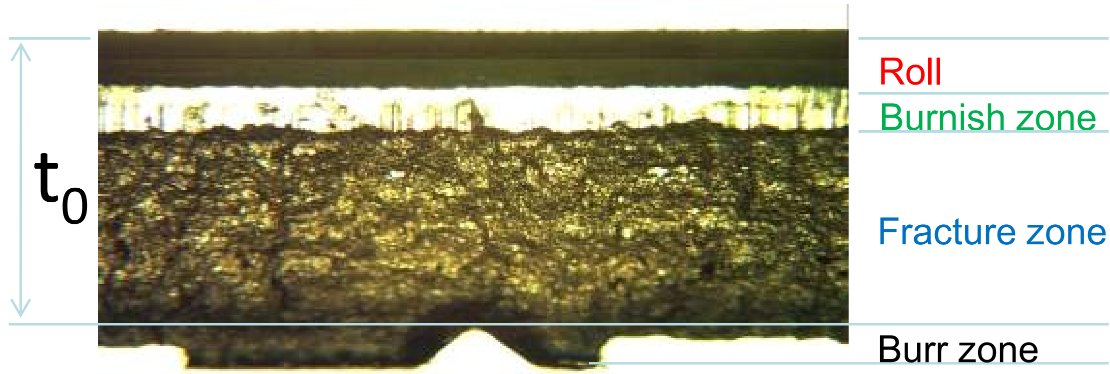
EDGE FRACTURE APPROACH

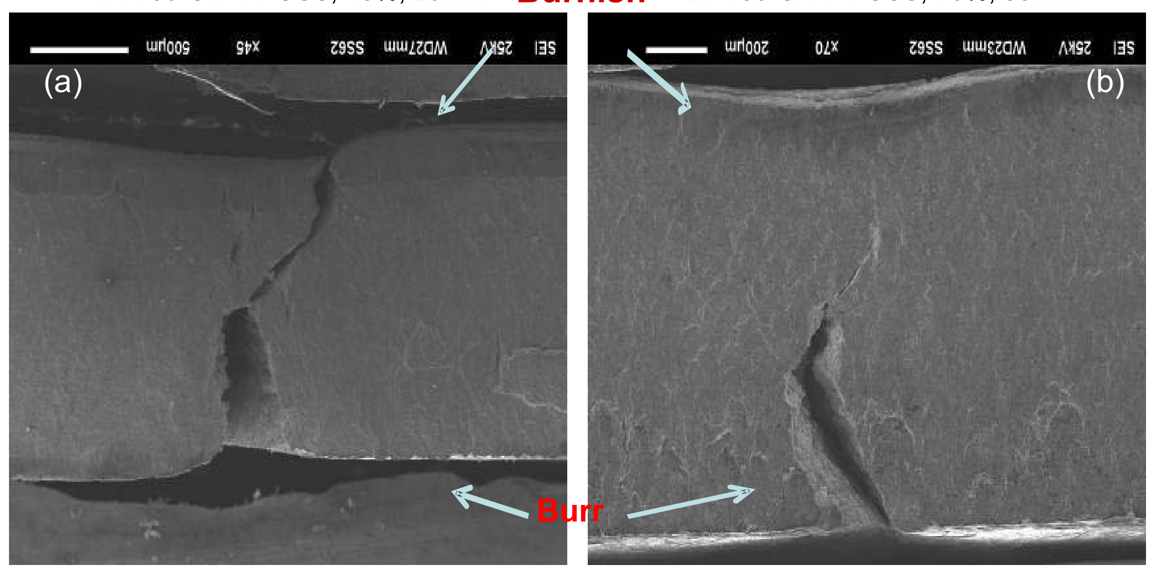
Microstructure Study

Key Learning

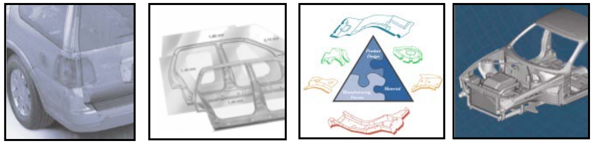
- For small hole diameter, pre-cracks can initiate from both burnish/fracture or fracture/burr areas. However, the dominating pre-crack always comes from fracture/burr area, indicating more damaging from pre-shear.

- For large hole diameter, almost no pre-crack can be found in burnish/fracture area, suggesting the dominating pre-crack initiates from fracture/burr area.





Fracture morphology of sheared edges after hole expansion



LOCAL SOFTENING APPROACH

Seeking potential low cost (vs. hot stamping) blank preparation processes:

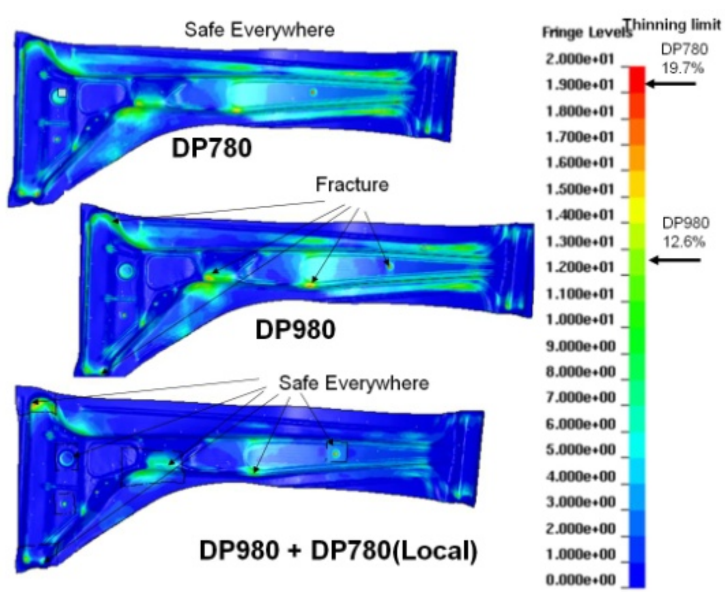
Local Softening technology

using

- **Induction Heating**
- **Laser Heating**

for AHSS (DP980) parts in the following two steps:

- **Lab Development**
- **Real Part Testing**



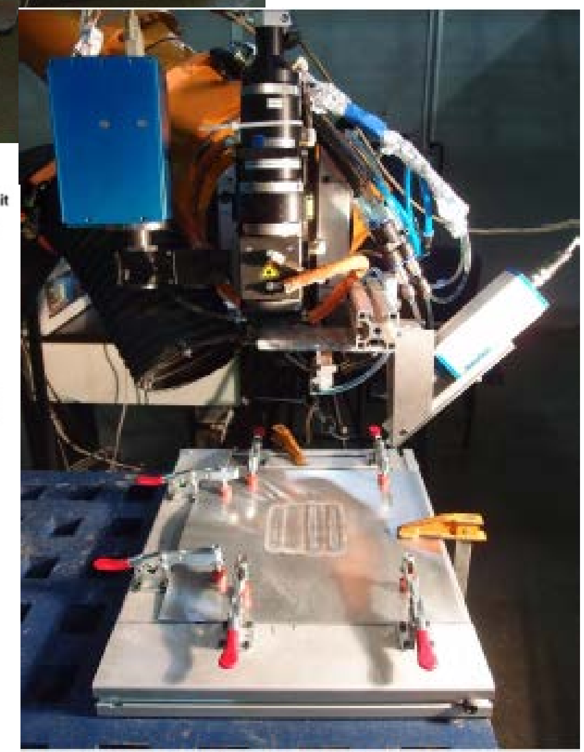
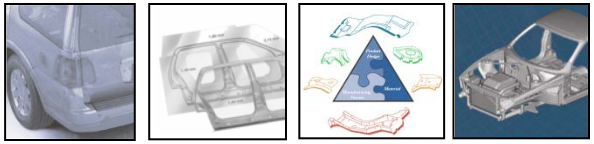
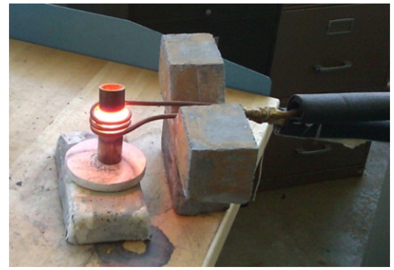


Figure 2: Experimental Setup



LOCAL SOFTENING APPROACH

Induction Lab Development



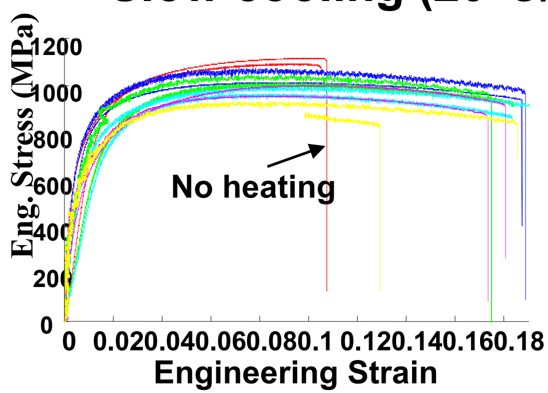
T_{max}

Blue: 800C
Green: 850C
Cyan: 900C
Magenta: 950C
Yellow: 1000C

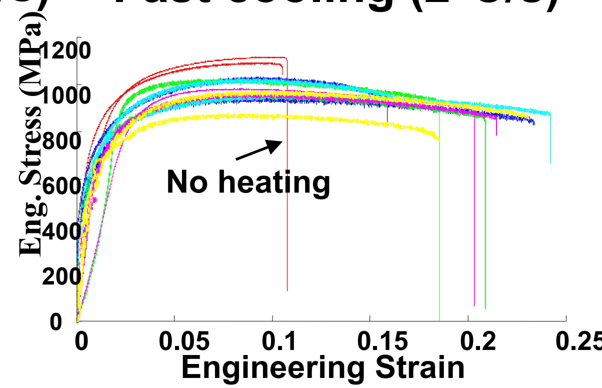
Key Learning

- Induction local heating can be used to reduce the tensile strength and increase the elongation for the tested DP980 sheet steel.
- Critical parameters and their recommended ranges have been investigated. Lower Tmax above austenite transformation temperature and Slow cooling rate (2ºC) give better improvements

- Slow cooling (20ºC/s)



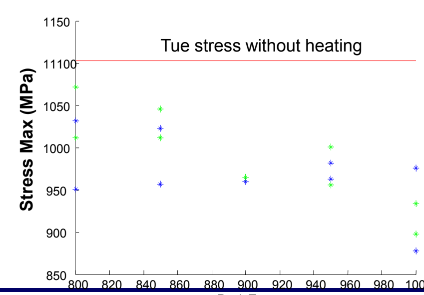
- Fast cooling (2ºC/s)

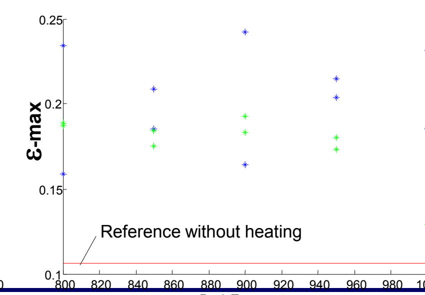


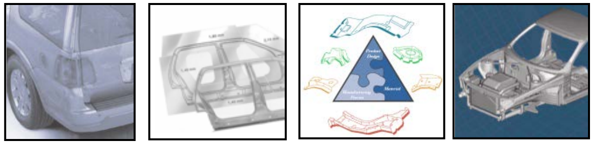
UTS vs. T_{max}

Slow cooling (20ºC/s)
Fast cooling (2ºC/s)

Elongation vs. T_{max}







LOCAL SOFTENING APPROACH

Laser Lab Development

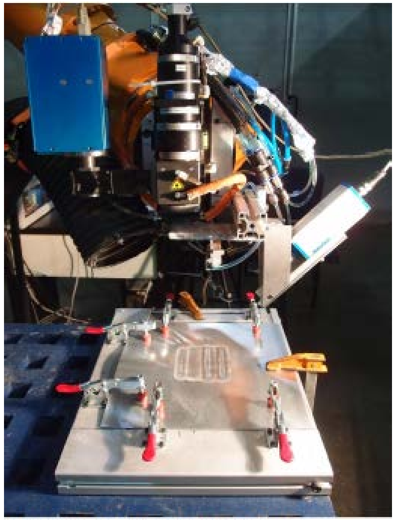
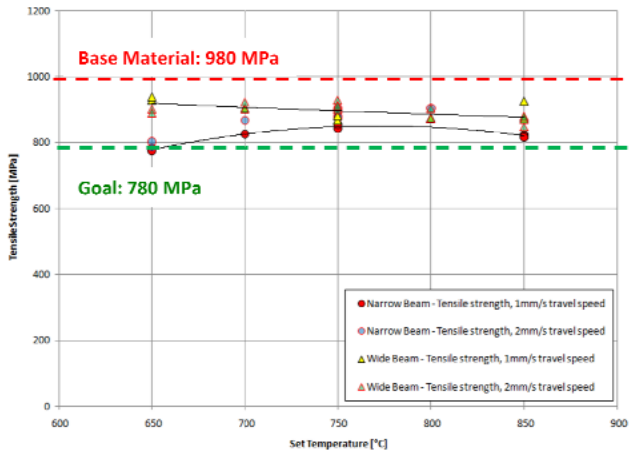
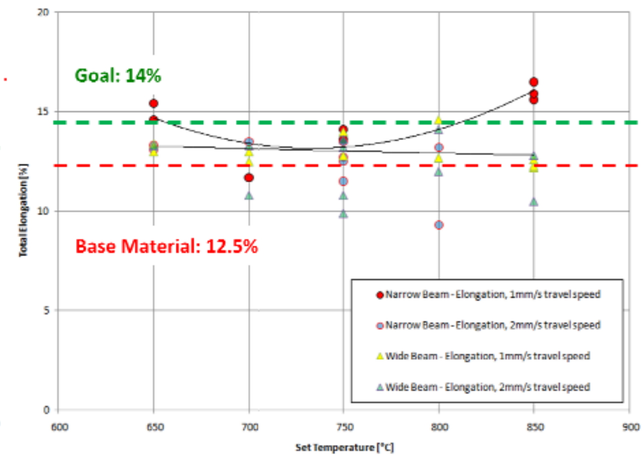
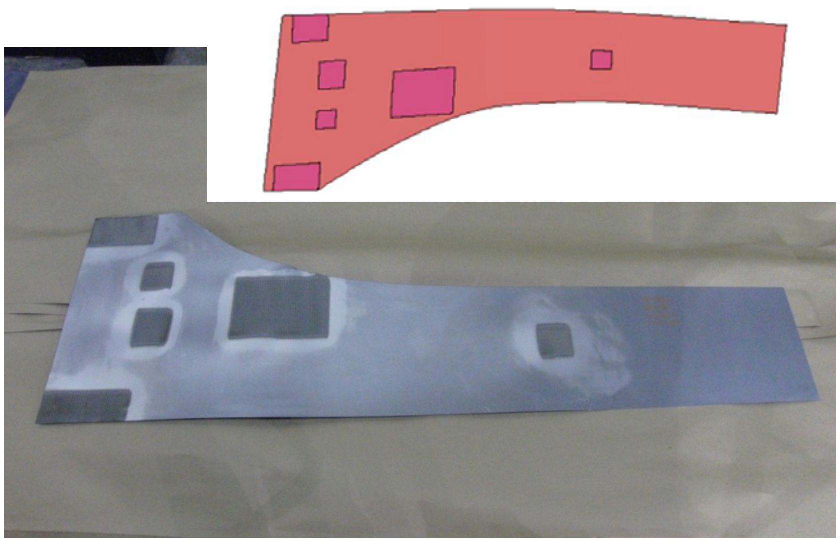


Figure 2: Experimental Setup



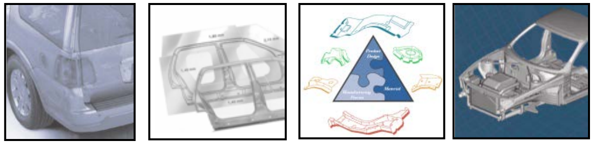


DP980 blank with 6 DP780 areas as "local softened"



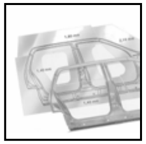
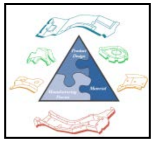
Key Learning

- 20% reduction in yield strength and 10% increase in total elongation was achieved
- A laser softening process can be applied locally to improve the material properties for stamping.



FUTURE WORK

- New AHSS benchmarking
  - GM B-Pillar, Chrysler B-Pillar, Straight rail, Large cutout
- Resolving potential production challenges
  - Local softening technology implementation
  - Pre-form effect on AHSS
  - Die, press-line loads and deflection test
- Simulation software and criteria development
  - Spring-back prediction improvement
  - Tensile-compression test standardization
  - Instantaneous n-value investigation

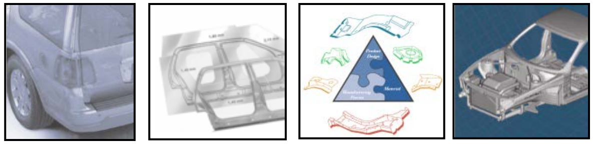

COLLABORATION & TECHNOLOGY TRANSFER

Collaboration

- Chrysler, Ford, GM: Provide production dies for trials and expertise on stamping
- Steel suppliers: Provide new AHSS steels for testing and expertise on metallurgy
- ArcelorMittal: Conduct Hole Expansion Tests
- Livermore Software Technology Co: Develop and implement simulation models in the commercial software LS-DYNA; conduct simulations
- Tranor Industries: Perform GM B-Pillar tryout
- Autodie: Perform Chrysler B-Pillar, Straight Rail, Large Cutout tryouts
- Fraunhofer USA: Local laser softening
- PNNL: Microstructure analysis on AHSS
- Oakland University: Pre-form edge fracture test
- Wayne State University: Microstructure study on edge fracture tests and induction heating test

Technology Transfer

- Great Designs in Steel, May 2011
- NADDRG, May 2011
- SAE, April 2011
- Automotive light-weighting workshop, February 2012
- Project Technical Review Meetings – all member companies



SUMMARY

- The new DP980 material tested performs better than the previous DP980 in formability and edge fracture
- The first 3rd generation AHSS, Q&P980, performs better than DP980 in formability and edge fracture
- Current software technology is capable of predicting formability performance (necking-related) but not accurate for spring-back and fracture related problems for AHSS
- Two failure modes, necking and fracture, on edge fracture have been observed and required more studies
- The pre-form process does not affect the edge stretching ability of New AHSS: DP980 and Q&P980
- Lab test results indicated that it is feasible to apply local softening technology to improve AHSS formability