USAMP AMD 408 – DIE FACE ENGINEERING FOR ADVANCED SHEET MATERIALS

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This presentation does not contain any proprietary or confidential information

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Project Team

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Purpose of Work

Springback Prediction:

- Sheet metal distorts due to elastic recovery when forming stresses caused by tool contacts are removed.

Springback Compensation:

- If we know what shape we want the metal product to be, what shape should the tool surface be?

Shape after removal from stamping press

Observed springback between stamped panel before and after trim.

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Purpose of Work For Light-Weighting

- **State of the art of springback prediction and compensation technology relies too much on experience with mild steel.**

- **Springback is more challenging for AHSS and aluminum alloys due to either higher forming stresses or lower elastic modulus.**

These two factors impede the use of light-weighting metals**.**

Mild steel is the 11th Hour Solution during physical tryout to deal with difficult springback issues

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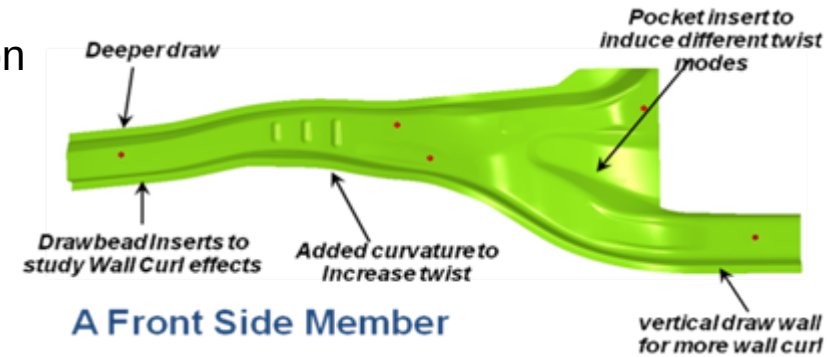
Barriers and Approach To Springback Prediction

- **Challenges**
  - Complex Springback Modes: Side Wall Curl and Twist
  - Rigid Body Motion DoF and Panel Flexibility Complicate Measurement/Correlation Study
- **Solutions**
  - Developed New Part to Exaggerate Springback Challenges
  - New Element Technology, Surface Contact/Continuity, and Material Models

    Work with LSTC (LS-DYNA) to identify technology gaps and evaluate LSTC solutions
  - Improved Registration Methods and Fixture Simulation



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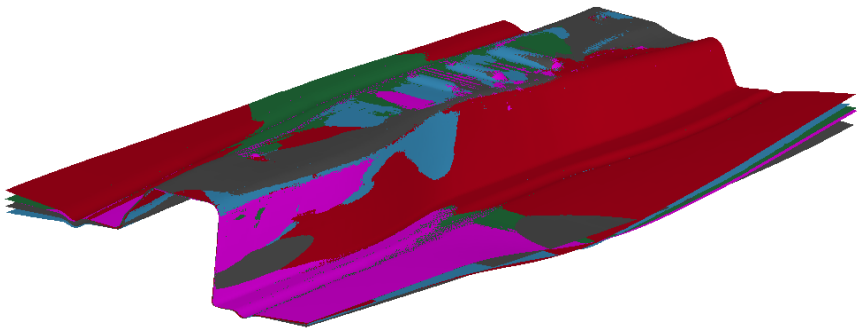
Barriers and Approach To Springback Compensation

- **Challenges**
  - Maintaining Die Surface Continuity and Quality
  - Side Wall Curl and Twist compensation
  - *Variability*



- **Solutions**
  - Define requirements and Conduct Benchmark Study (Think3D,ICEM,Tebis)
  - Combine Springback Minimization with Limited Compensation
  - *Springback Minimization Based on Springback Prediction*

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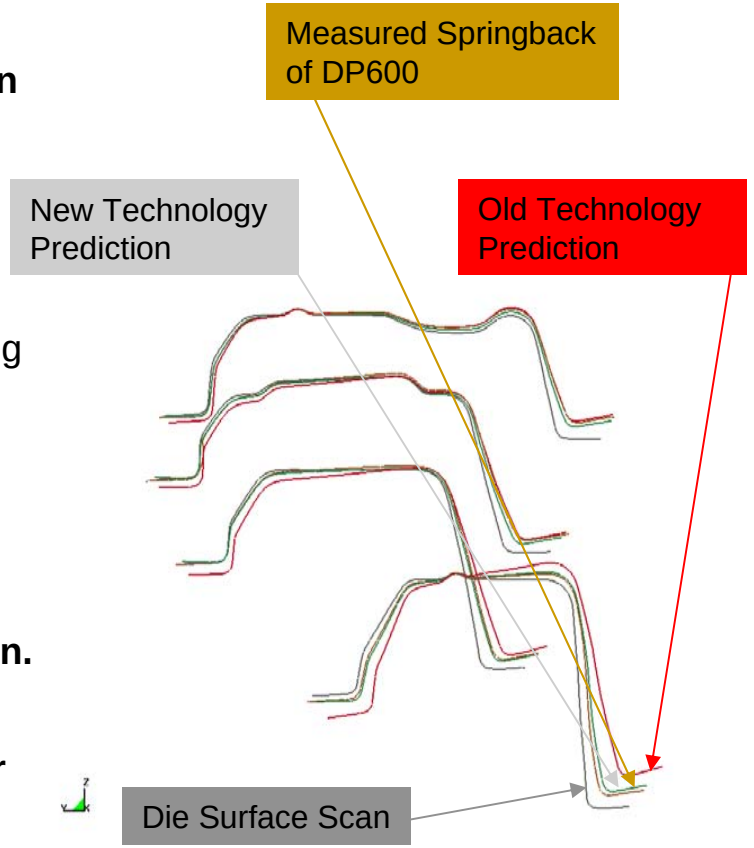
Results: Improvements in Springback Prediction

- ✓ **Worked with LSTC to develop list of developments in which improvement in FEM technology is considered an important factor in the accurate springback.**
- ✓ **Assisted LSTC to implement solutions to these challenges.**
- ✓ **Developed comprehensive experimental database for** 8 light-weighting metals **for calibration of advanced material models.**
- ✓ **Developed Challenging Full-size Part and Common Die Tooling with Exaggerated Springback Challenge.**
- ✓ **Evaluated LSTC improvements for accuracy in springback prediction.**
- ✓ **Developed "Best Practice" of Existing and Improved Technology for Springback Prediction.**



Comparison of predicted and measured springback along critical sections through the Common Die Part formed with the DP600 alloy.

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Validated Tool Compensation Via Springback Prediction

- ✓ **Developed Standard for Surface Quality to be used in Springback Compensation**
- ✓ **Completed Benchmark Study of Existing and Emerging Commercial Springback Compensation Software Solutions**
- ✓ **Completed Pilot Test of Springback Prediction Based on Springback Prediction**

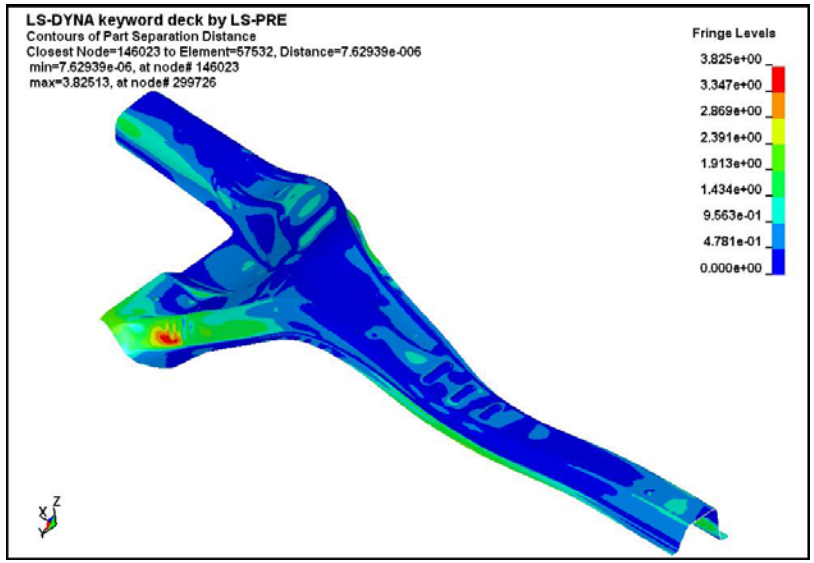
Re-Machined Common Die in Press

Lower Punch and Binder

Upper Cavity

No visible problem was found that may be caused surface morphing

Deviation From Design Intent of Panel Formed With Compensated Die



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Summary

- Substantial improvement in the reliability of springback prediction in draw forming has been achieved for DP600, DP780, TRIP780, and AA 5754-O.
- Improvements made by LSTC will be rolled out in their manuals, training, and support program.
- A “Best Practice” in the process of springback prediction has been developed and is implemented by the die engineering groups at GM, Ford, and Chrysler.
- An extensive database for 8 aluminum and AHSS alloys has been created to calibrate advanced material models for cyclic loading process.
- Commercial Springback Compensation Technology has been benchmarked and standards for surface quality have been developed.
- Springback Compensation Based on Springback Prediction has been demonstrated for DP600 on a specially designed full sized die, modified from a production part to amplify springback issues.
- Papers on the scientific contributions of the project are planned for the Numisheet 2008 Conference, and other forums and publications.
- This project was completed in 4Q 2007 and the final report (of approximately 500 pages) will be available in 1Q 2008.

Plans for Next Year

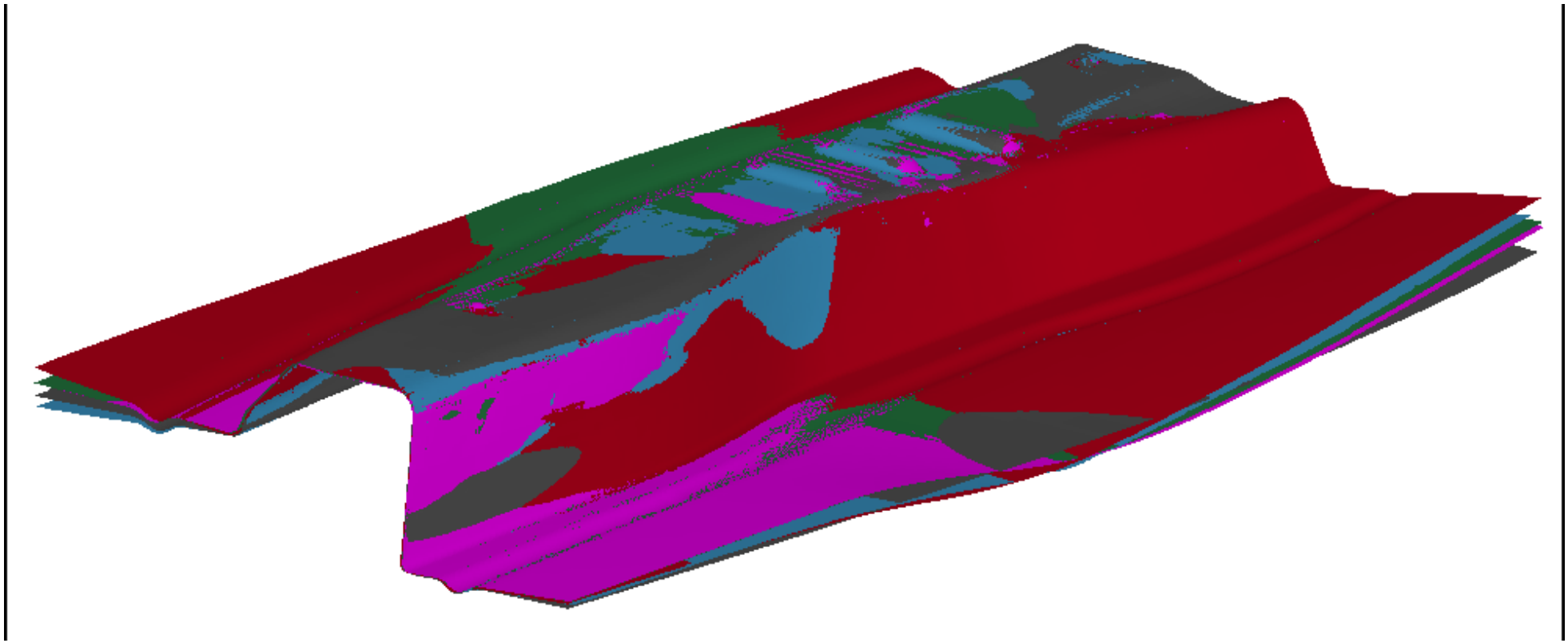
- **There are still significant challenges facing the Virtual Manufacturing Process that are even more difficult for light-weigthing materials.**

- **These challenges include:**

  - Simulation of **Line Die Forming**, which involve non-proportional loading histories that are outside the validated capability of even the most advanced material models available.

  - Simulation of **New Processes**, such as high temperature forming, which is necessary for Boron steels, magnesium, and superplasticity of aluminum, add another dimension to material modeling, as well as an order-of-magnitude increase in material testing and database requirements.

Background Material and Details of Deliverables



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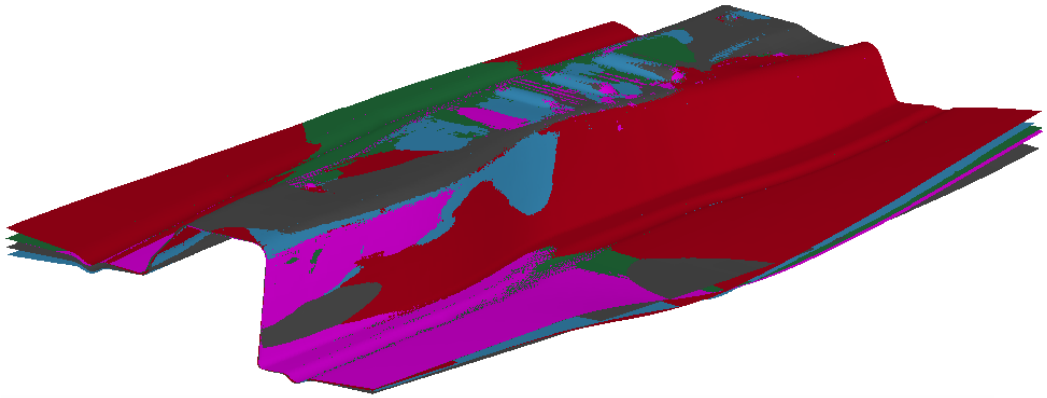
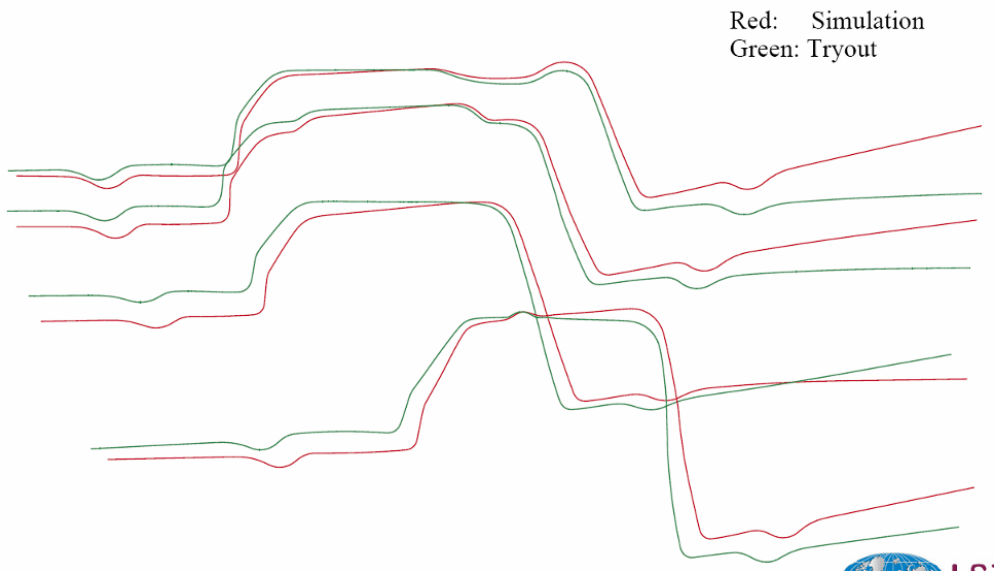
Purpose of Work For Light-Weighting

Springback prediction/compensation is an immature technology that relies heavily on experience with the use of conventional mild steels.

More than 70% of physical tryout costs are due to springback compensation.

Due to the lower elastic modulus for aluminum and the higher forming stresses for HS steels, springback is significantly higher than it is for mild steels and more challenging.





Prior State of the Art

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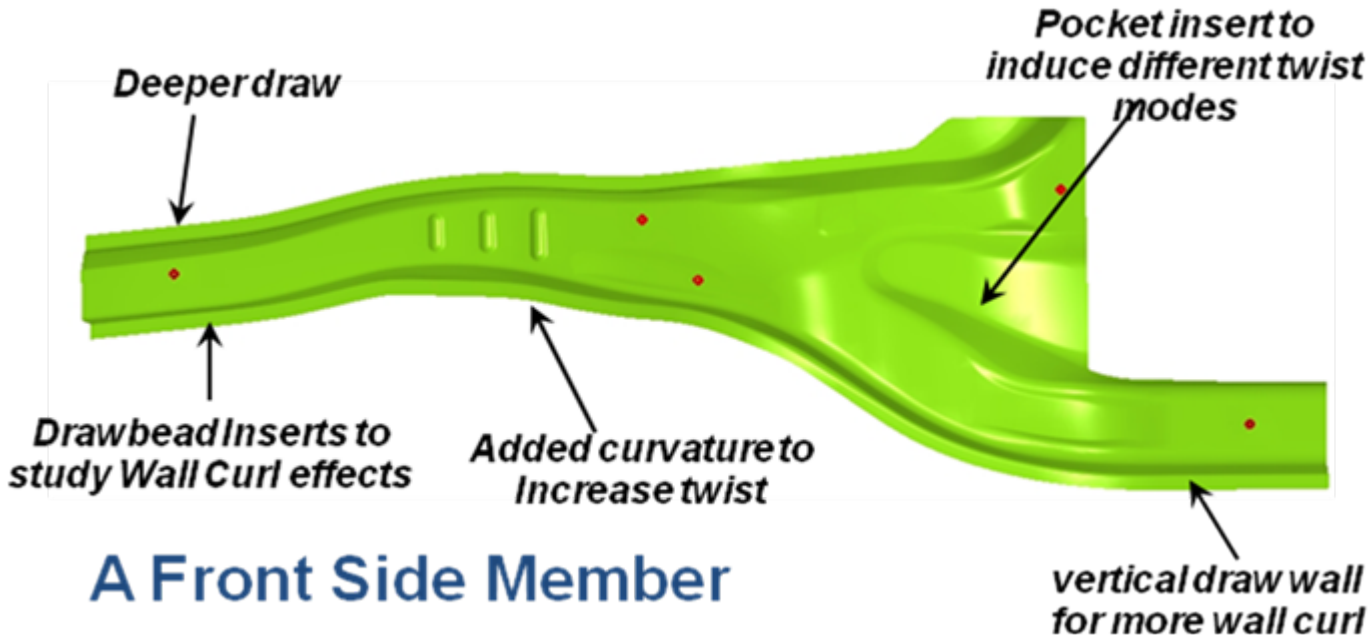
Development of the "Common Die" Tool to Exaggerate Springback Challenges

- **Y-Shape Rail Based on a Ford Production Part**
- **Modified to contains features of interest to all OEM's**
- **Additional surface morphing involving twist to increase surface complexity**



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Major Technical Obstacles to Accurate Springback Prediction

- Cyclic loading has a significant impact on forming stresses
  - **Conventional material models are not reliable for cyclic loading of anisotropic metals.**
- Sharp tool radii are responsible for generating most of the forming stresses
  - **Conventional Contact Algorithms require too many elements on sharp tool radii leading to prohibitively costly simulations.**
- Normal (through-thickness) stresses are significant for high t/R conditions
  - **Shell Elements do not consider non-zero normal stresses.**
  - **Solid Elements are tool expensive for most production forming simulations**

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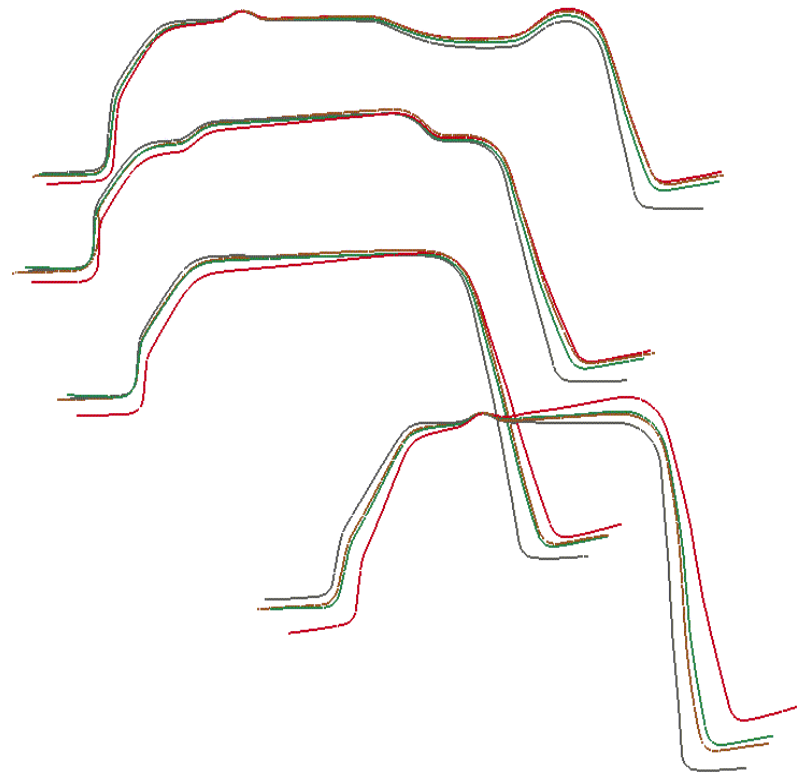
Improved Material Models

Implemented/Validated/and Evaluated New Models for Improved Springback

Identified the F. Yoshida Model to be best in class for Aluminum

Modified the Yoshida Model to improve description of work hardening of AHSS alloys



Comparison of predicted and measured springback along critical sections through the Common Die Part formed with the DP600 alloy

LEGEND

Grey	–	Die Face Surface Scan	Brown	–	Formed and Trimmed Product Scan Data
Red	–	Predicted Springback Using Old Material Model	Green	–	Predicted Springback Using Modified Yoshida Model

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Improved Material Models Require a New & Larger Database

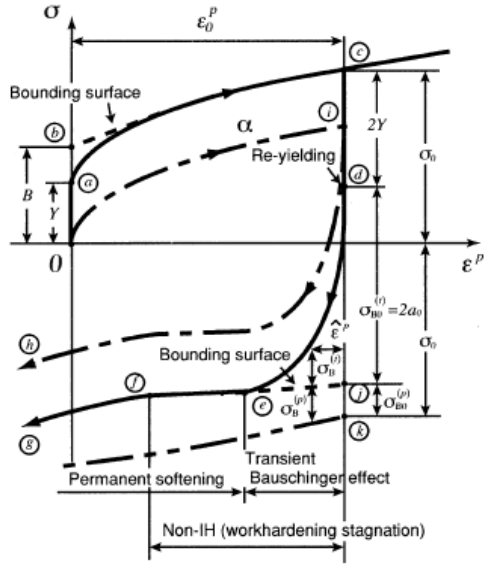
Developed database, test matrix, and calibration procedures for advanced models for 8 aluminum and AHSS alloys. Test data include:

1) conventional uniaxial tension tests

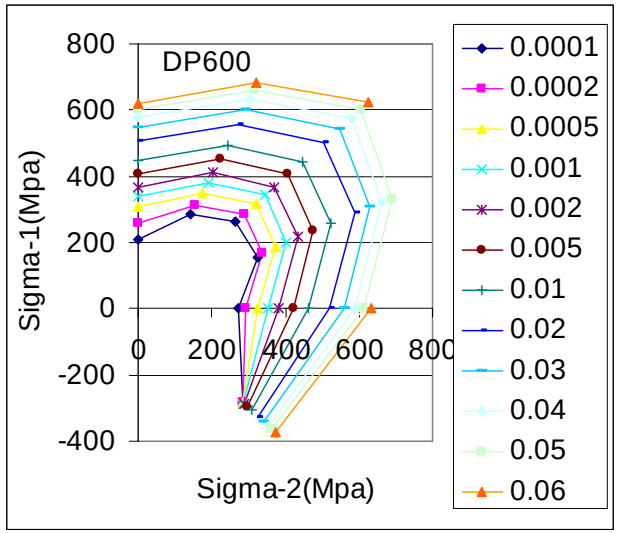
2) compression, tension, and shear loading

3) single and multi-cycle loading with several strain increments

4) biaxial stress loading tests



Typical cyclic stress-strain response that requires advanced material models



Anisotropic evolution of yield surface shape with plastic strain

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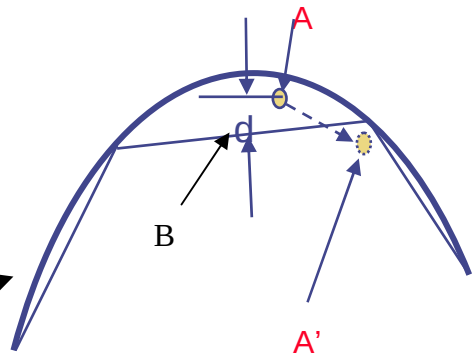
Improved Surface Contact/Continuity

Areas of high curvature generate most of the forming stresses and therefore play a dominant role in springback

Conventional Surface Contact Algorithms require too many elements is areas of high curvature leading to high costs to obtain accurate springback results

A Smooth Contact Algorithm **reduces number of elements without sacrificing accuracy**



Example:

Prediction of the springback angle for channel draw typically requires more than 4-10 elements on the die radius to obtain a converged solution.

# of Elements	1	2	4	10
Springback Angle (deg)	19.9	21.2	20.8	21.5

The new Smooth Contact Algorithm is found to overcome this convergence problem with a course mesh (with only about a 20% increase in cost compared to conventional contact).

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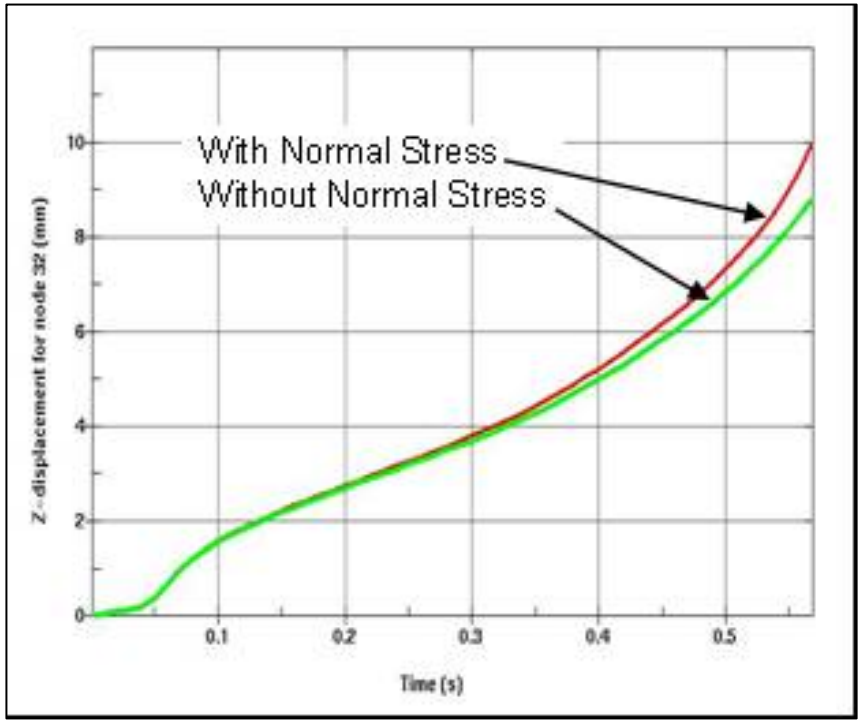
Normal Stresses Are Significant when t/R is Large

A special Shell Element **was developed by LSTC that computes the normal stress from the calculated normal surface contact pressure of associated nodes and factors its value in the constitutive relations.**



The effect on deformation was noticeable, but was considered by the team to NOT be as significant as it was anticipated.

The new Shell Element is not adopted in the recommended "best practice", with an exception perhaps in extreme cases for thick metals or very sharp radii.

Developed Requirements for Surface Compensation

Primary Manufacturing Challenges for Surface Compensation

- Creation of undesirable die surface conditions:

  eg. Backdrafts & oscillations

- Magnification of surface gaps and slope discontinuities

  beyond NC quality

- Inordinate increase in surface data file size

- Excessive manual repair to remedy surface issues

Solution

- Developed Manufacturing Requirements for Die Compensation
- Obtained Buy-In of Standards from Compensation Software Vendors
- Evaluated Performance of Compensation Software Vendors

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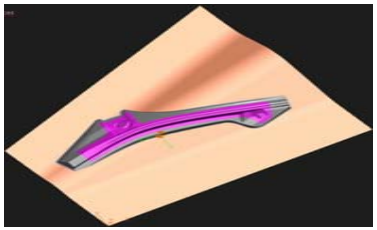
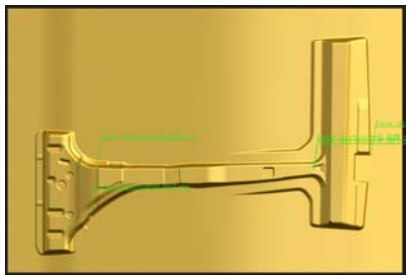
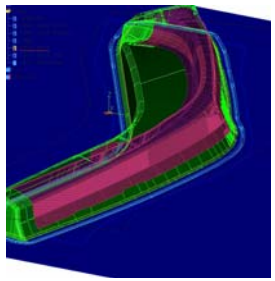
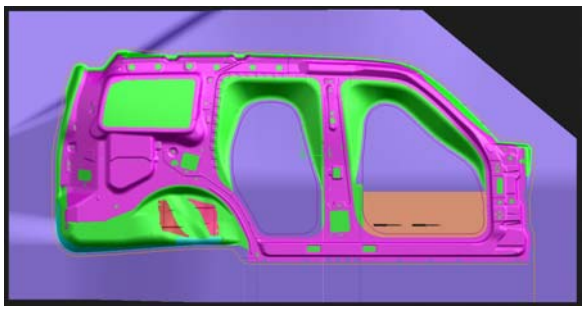
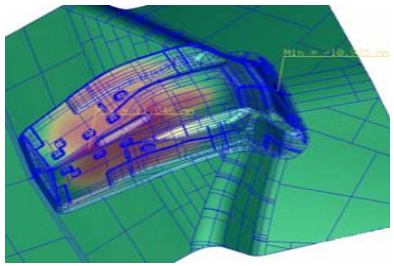
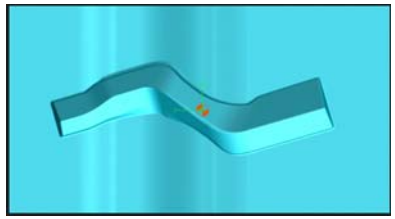
Evaluation of Surface Compensation Standards

Benchmark of Springback Compensation Technology Software

- Participating vendors (Tebis, Think3D, and ICEM), others invited
- Selected 6 automotive products providing complete design intent surfaces and the data for the expected springback in each case

- No vendor satisfied all requirements of the standard
- Tebis software was found to be leading the state of the art

Outstanding issue is the amount of manual repair required

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Evaluation of Surface Compensation Technology

Benchmarking Compensation Technology -> Validation

- The benchmark served to establish the capability of commercial software to be able to morph surfaces to meet NC machine quality requirements
- A final step is to **evaluate the efficacy** of the virtual springback prediction & compensation technologies as a system, on a production tool for an automotive application.

Tebis Compensation Solution Evaluated On Common Die Tool

- Predict springback of DP600 using new prediction technology
- Supply die compensation data based on springback result to Tebis
- Repair (manually) the Tebis compensated die surface math data
- Recut tool, assess tool surface quality, and stamp DP600 panels
- Compare the surface of the trimmed part to the design intent

Evaluation of Surface Compensation Technology

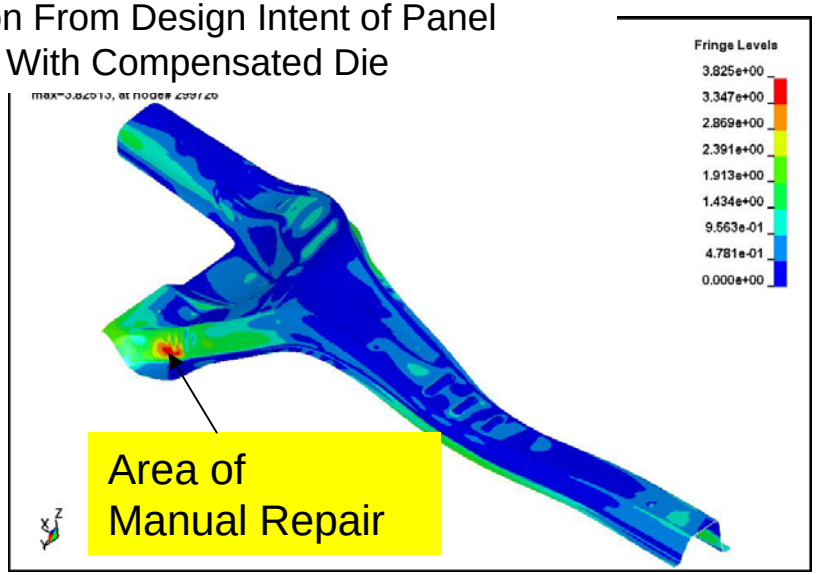
Re-Machined Common Die in Press

Lower Punch and Binder

Upper Cavity

No visible problem was found that may be caused surface morphing

Deviation From Design Intent of Panel Formed With Compensated Die



- Surface quality after manual repair was acceptable for production
- The new product, formed from the compensated tool, was in most areas within 0.5 mm of design intent (shown in blue)

- Design intent **was not achieved** in a few areas (where repairs were required to improve surface quality) --- it was later discovered that these manual modifications to the surface data were made in error due to the neglect of the springback compensation requirements
- **This outcome illustrates one of the reasons it is desired to minimize the amount of manual repair --- it's not just the labor & time costs of the repair.**

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