Prediction and Reduction of Edge Cracking in Forming Advanced High Strength Steels

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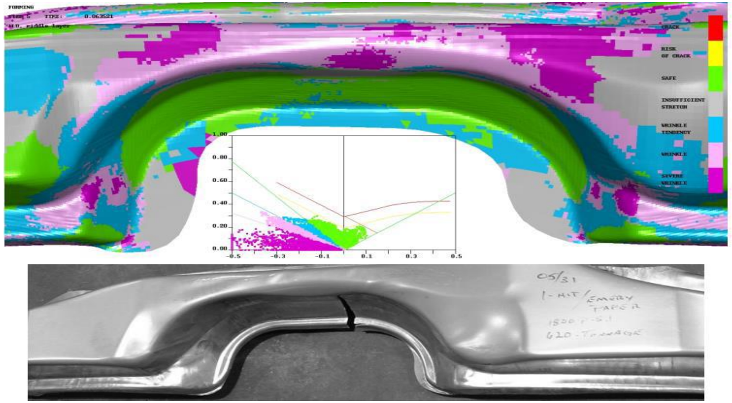
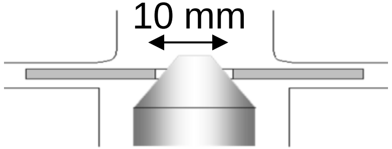
Introduction

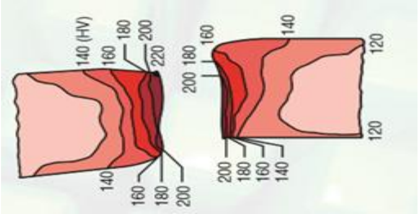
- Edge cracking more frequently occurs in stamping advanced high strength steels (AHSS) than other ductile steels and aluminum alloys.
- Major drivers are:
  - Reduced local ductility (i.e. residual stress and poor edge quality) during blanking or punching operations
  - Inadequate clearance between the trim die and punch
  - Worn out trim tool or die.
- Difficult to reliably evaluate edge cracking as well as to accurately predict. ***Technical Gap!***



Discrepancy between FEA and Stamping
(Chen and Zhou, 2008)



HER Test



Hardness (HV)

Strategy for Prediction of Edge Cracking

Step 1:
Obtain a consistent edge quality

Step 2:
Simple experimental method and accurate measurement for edge cracking

Step 3:
Prediction of Edge Cracking in Stamping Simulations

Conventional methodology

Punching the hole with various equipment and clearances → Hole expansion testing with a 10-mm hole → Compare the thinning value between simulation and exp. measurement

Newly developed methodology

Punching the hole with the dedicated tooling with control of the clearance → Hole expansion testing with a larger hole/half specimen dome test → Use the developed failure criteria from experiments to predict edge cracking

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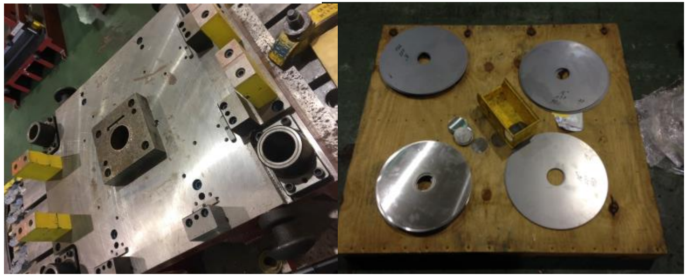
DESIGN OF THE NEW HOLE EXPANSION TESTING METHOD

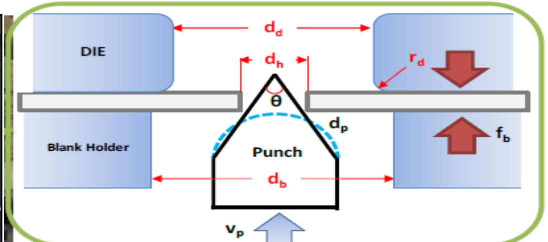
New Testing Method for Edge Cracking

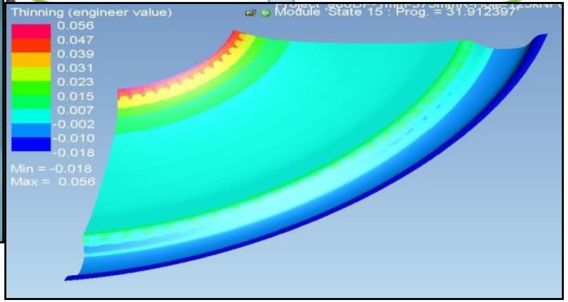
- A new hole expansion ratio (HER) testing method was developed to evaluate edge cracking with AHSS.
- Testing method includes both punching and hole expansion tests.



Hole Punched Samples with the Dedicated Tooling available in KTH

HER Testing Setup at EWI



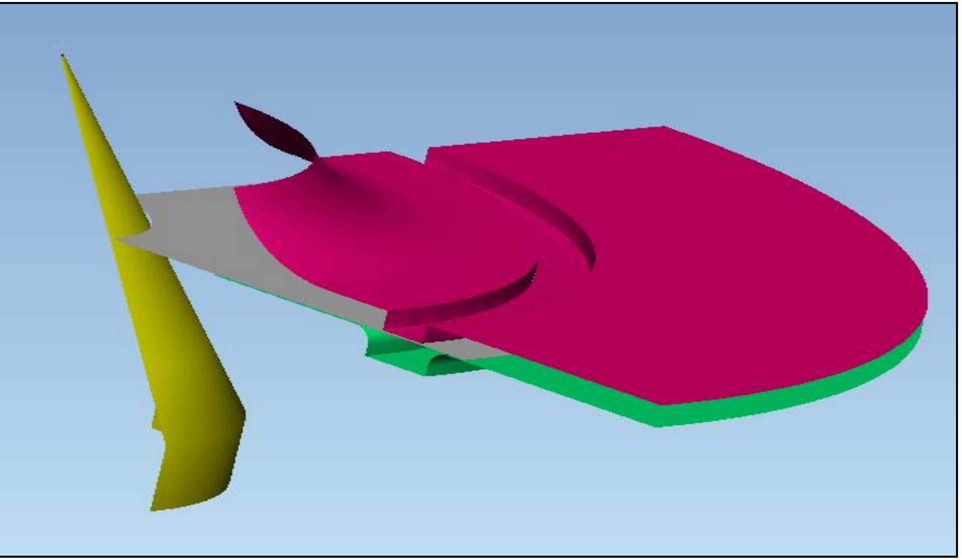


FEA of 3-in. Diameter Hole Expansion

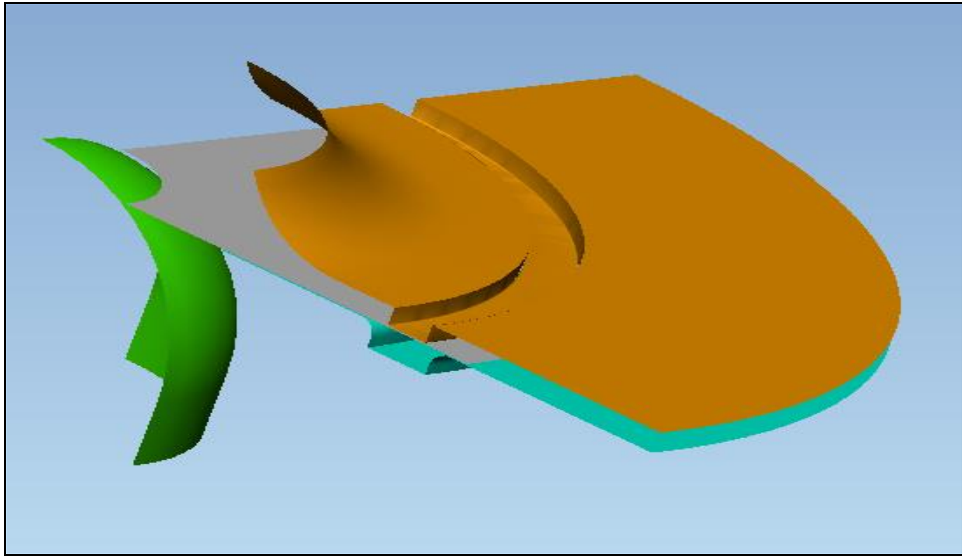
Determination of the Hole Size

- Determination of the more effective hole expansion testing procedure and tooling design that are:
  - Sensitive to the hole-edge quality and material properties
  - Easy to measure or capture edge cracking
  - Capable to obtain consistent test results for the HER.

Finite Element (FE) Simulation Models



Conical Punch HER Test

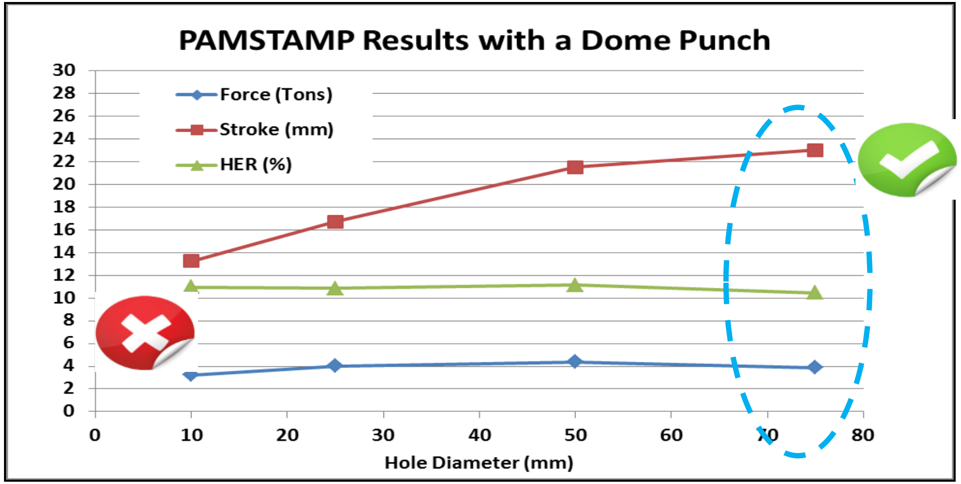


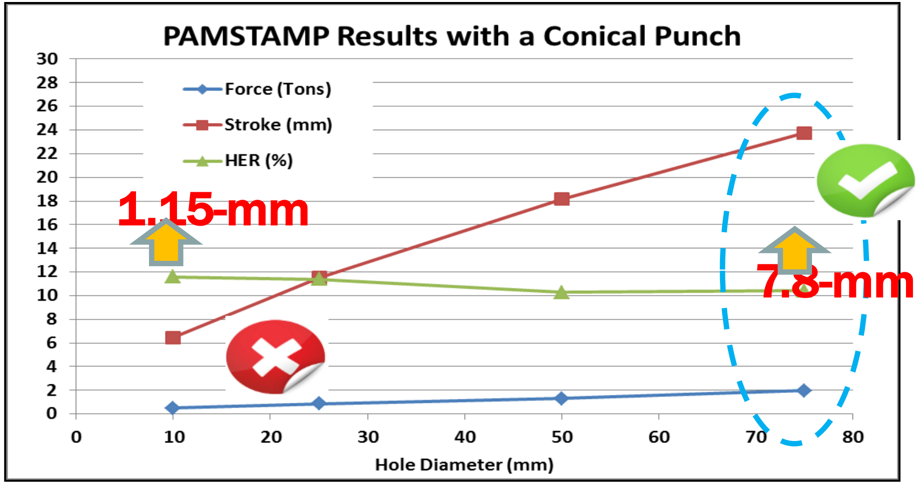
Dome Punch HER Test

The blank model used the shell elements.

Findings in FE Simulations

- Three key variables—force, die stroke, and HER—are compared when maximum thinning reached 6% for DP980.





A 75-mm hole gives a more distinguishable change of the hole diameter and punch stroke than a 10-mm hole.

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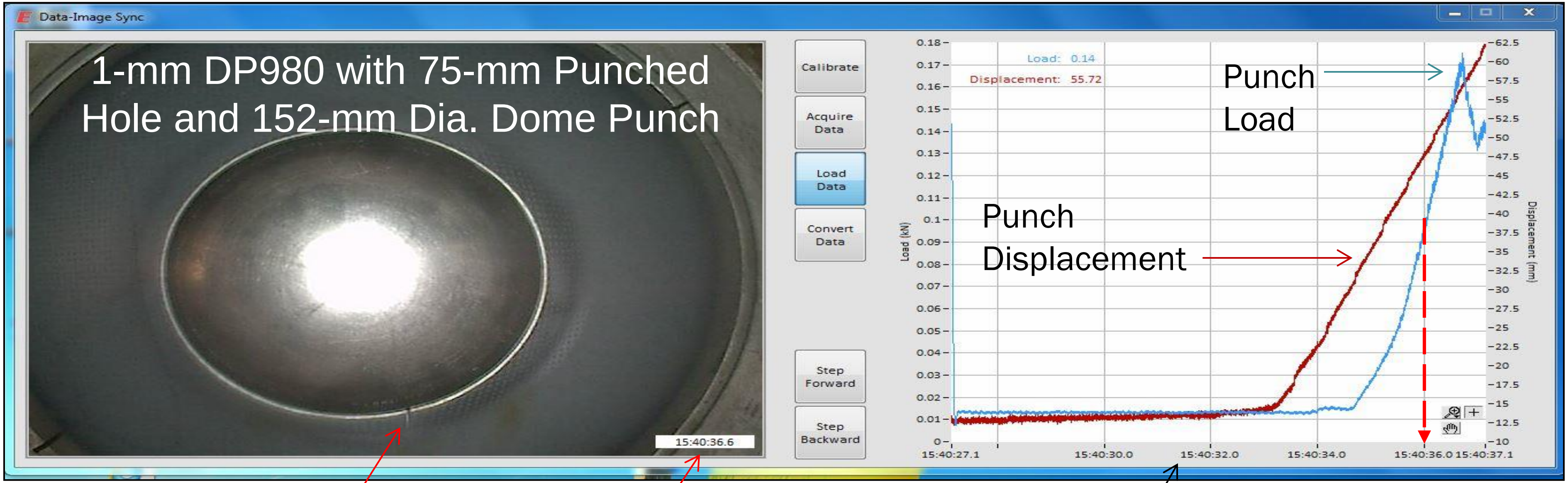
HOLE EXPANSION TESTING WITH VISUAL MONITORING SYSTEM

Synchronized Image, Load, and Displacement



The synchronized system can accurately capture the hole expansion at the crack initiation.

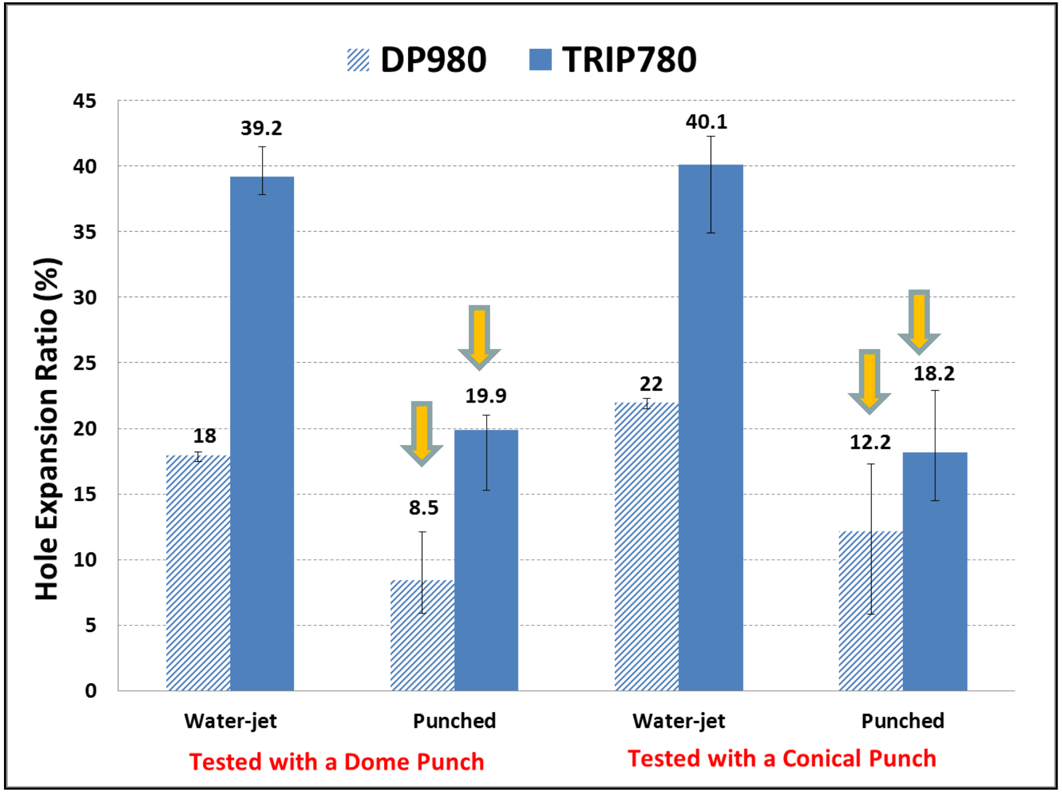
HER Experiment Matrix

Materials	Conical Punch	Dome Punch
TRIP780 (1.4 mm)	Punched hole	Punched hole
	Water-jet cut hole	Water-jet cut hole
DP980 (1.0 mm)	Punched hole	Punched hole
	Water-jet cut hole	Water-jet cut hole

- At least five samples were tested in each condition.
- Hole diameter: 75 mm (≈ 3 in.).

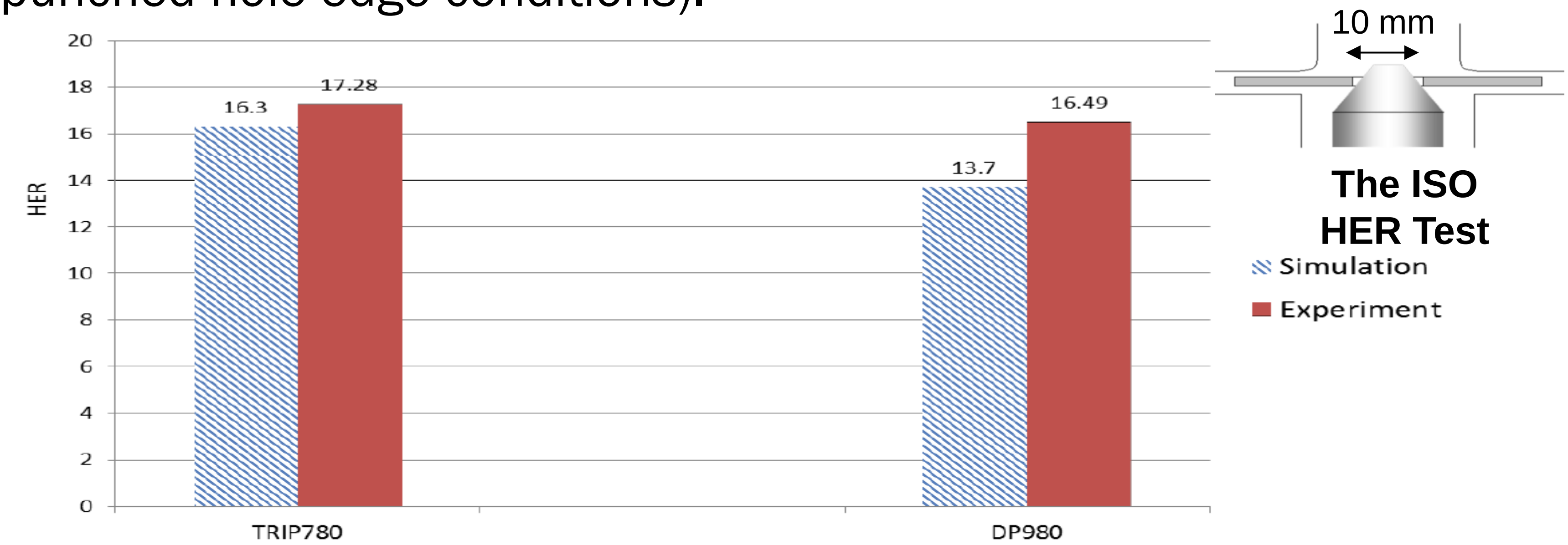
Results of New Hole Expansion Testing

- New hole expansion testing gave up to 11.4% (8.5 mm) difference between DP980 and TRIP780 samples (with the punched hole edge and a dome punch).



Results of the ISO Standard HER Testing

- The ISO standard HER test (with 10-mm hole size) gave only 0.8% (0.8 mm) difference between DP980 and TRIP780 samples (with the punched hole edge conditions).



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Jim Dykeman, Honda R&D

HALF SPECIMEN DOME TEST (HSDT)

HSDT Matrix

Materials	Edge Conditions
TRIP780 (1.4 mm)	5 blanks with the sheared edge
	5 blanks with the water-jet cut edge
DP980 (1 mm)	5 blanks with the sheared edge
	5 blanks with the water-jet cut edge

- A 6-in. diameter dome punch was used by EWI.
- A 4-in. diameter dome punch will be used by Honda.
- The sample size was 8 ×16 in. for EWI and 4 × 8 in. for Honda.

Tested Specimens with Cracks

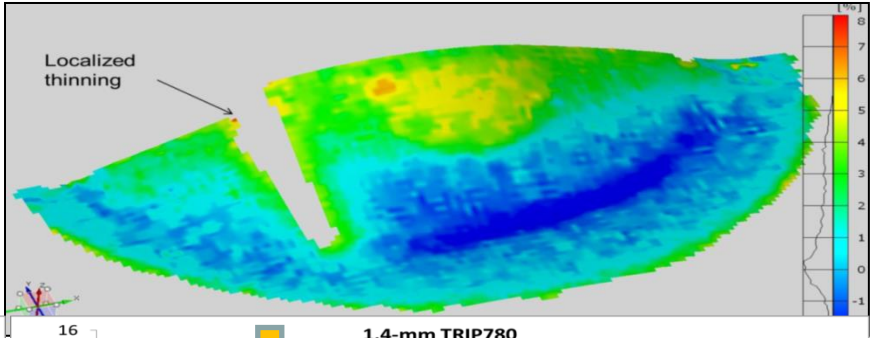
1.0-mm DP980 with the Sheared Edge

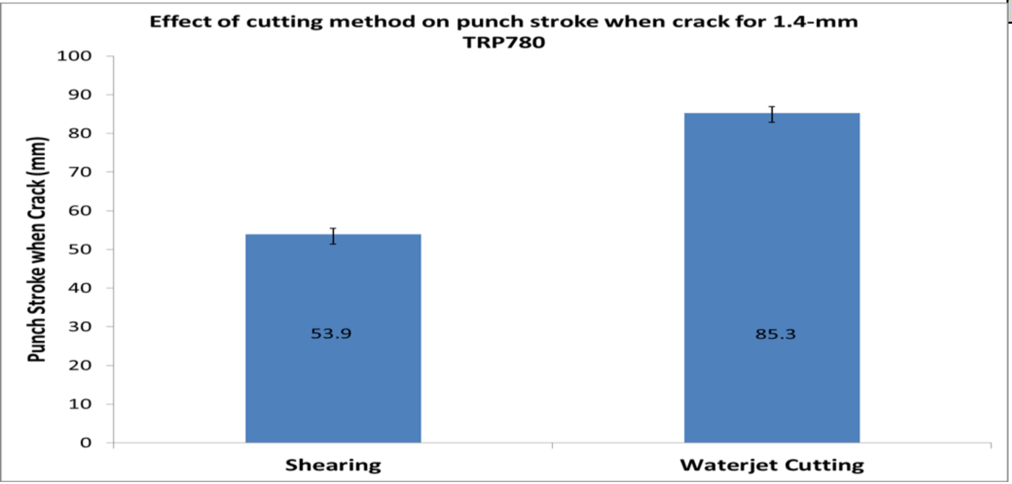
1.0-mm DP980 with the water-jet Cut Edge

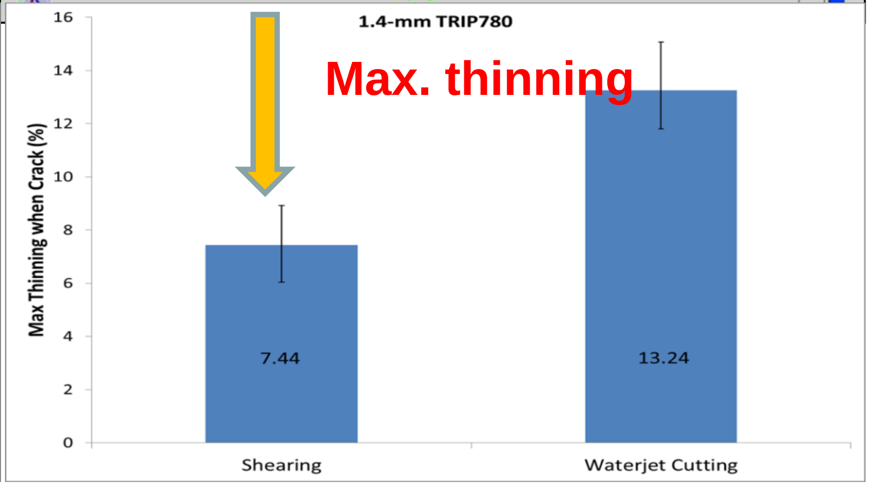
1.4-mm TRIP780 with the Sheared Edge

HSDT Results — TRIP780 (1.4 mm)

- High impact of cutting method on test results.







Comparison of the HSDT Results

- The HSDT results between Honda and EWI showed good correlations.
- EWI used a 6-in. diameter dome punch, and Honda used a 4-in. diameter dome punch.

Max. Thinning (%)	DP980 Sheared	DP980 Water-Jet	TRIP780 Sheared	TRIP780 Water-Jet
EWI	6.42%	9.10%	7.44%	13.24%
Honda	6.46%	11.90%	8.90%	15.18% (no crack)
Error (%)	0.04%	2.8%	1.46%	1.94%

Comparing Different Testing Methods

Criteria	The Standard (ISO HER) Test	3-in. Diameter HER (3D HER) Test	Half-Dome Stretching Test
Sample preparation cost	Medium	Medium high using a dedicated punching tool	Low using a shear machine
Repeatability of testing	Low (with punched hole)	Medium high (with punched hole)	High (with sheared edge)
Measurement accuracy during the test	Low (crack depth of 10~20% of thickness)	High (using a visual monitoring system)	High (using a visual monitoring system)
Additional data	Effects of the tool clearance	Effects of the tool clear	Difficult to control the tool clearance
Applications	Material evaluation in a testing lab	Tooling design and material evaluation in a testing lab	Material evaluation in production

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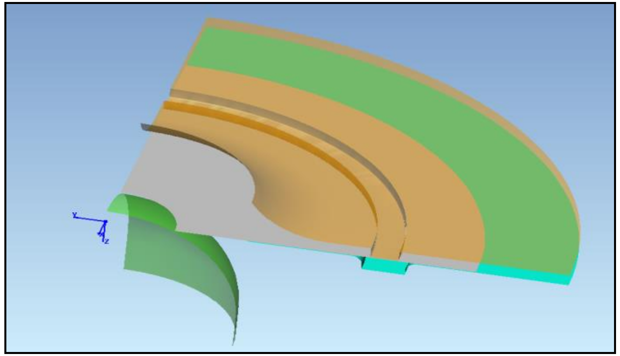
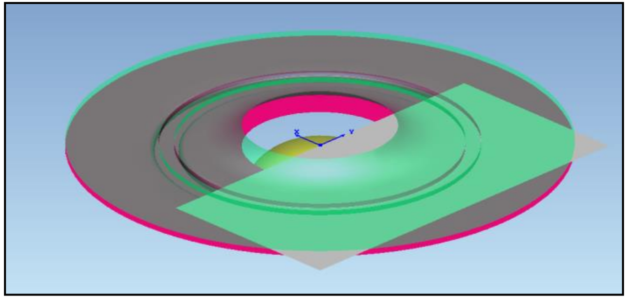
PREDICTION OF EDGE CRACKING

Predictions of Edge Cracking

- EWI evaluated three failure criteria to predict edge cracking that was obtained from the hole expansion and half-dome stretching tests:
  1. Maximum thinning
  2. Maximum principal strain
  3. Modified FLD for edge cracking.
- These failure criteria were applied to FE simulations to predict the edge cracking.

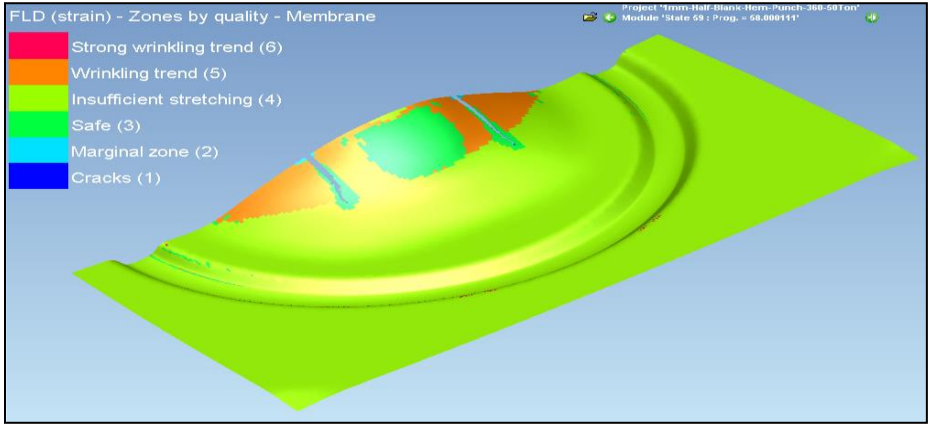


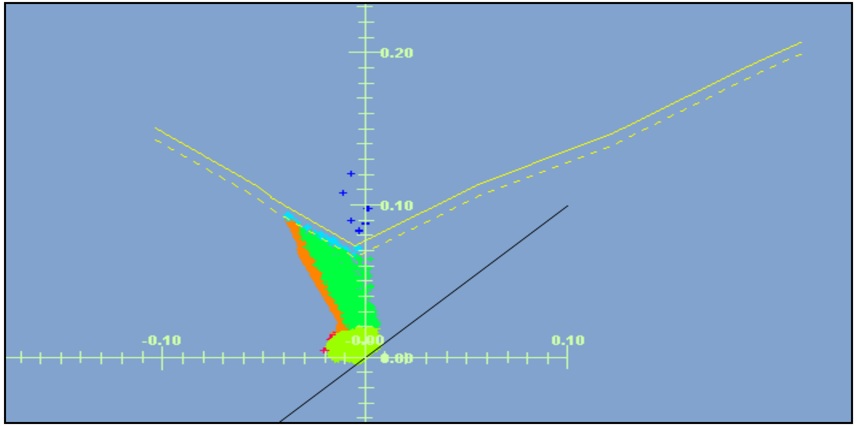
FE Model for Hole Expansion



FE Model for Half Dome

FE Prediction Results





Prediction of Edge Cracking for DP980 with the Sheared Edge

Failure Criteria	FEM Predicted Die Stroke for the Onset of Edge Cracking	Exp. Measured Die Stroke for the Onset of Edge Cracking
Max. thinning	59 mm	52–58 mm
Modified FLD	58 mm	

Comparison of the Maximum Thinning Values

Material/Edge Cond.	Max. Thinning from HDST	Max. Thinning from HER with 3-in. Hole	Max. Thinning for the Necking Failure from Industry Perception
DP980/Sheared edge	5–7 % (Exp.)	4–9% (FEA)	12%
DP980/Water-jet edge	9–12 % (Exp.)	N/A	12%
TRIP780/Sheared edge	7–9 % (Exp.)	7–12% (FEA)	19%
TRIP780/Water-jet edge	12–15% (Exp.)	17–21% (FEA.)	19%

Sheared edges gave about 50% reduction in the maximum thinning compared to the water-jet edges.

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REDUCTION OF EDGE CRACKING WITH INDUSTRIAL FIELD TESTING

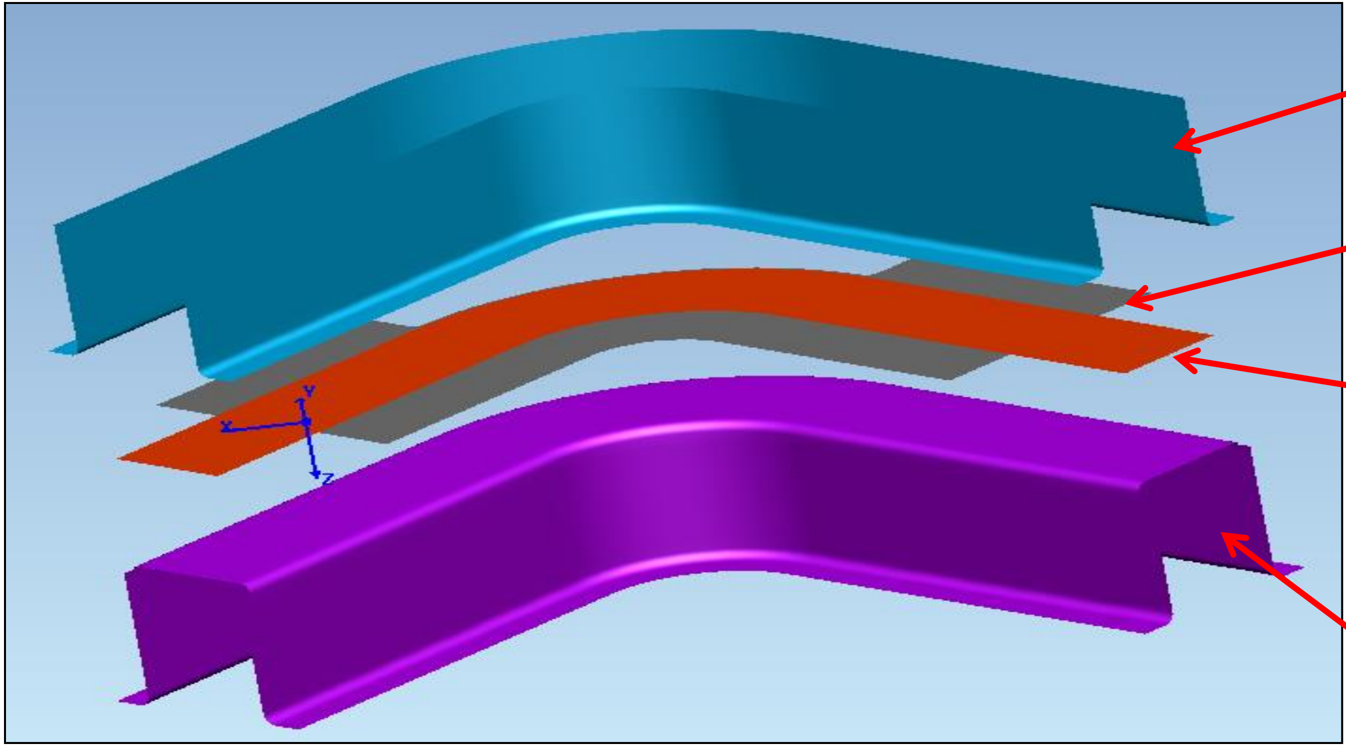
KTH Field Testing for Evaluating the Edge Cracking

TRIP780 (1.4 mm) — Laser Cutting

Shorter to Longer Flanges

30 ° ~ 90 ° Planar Curvature Angle

FE Simulation Model



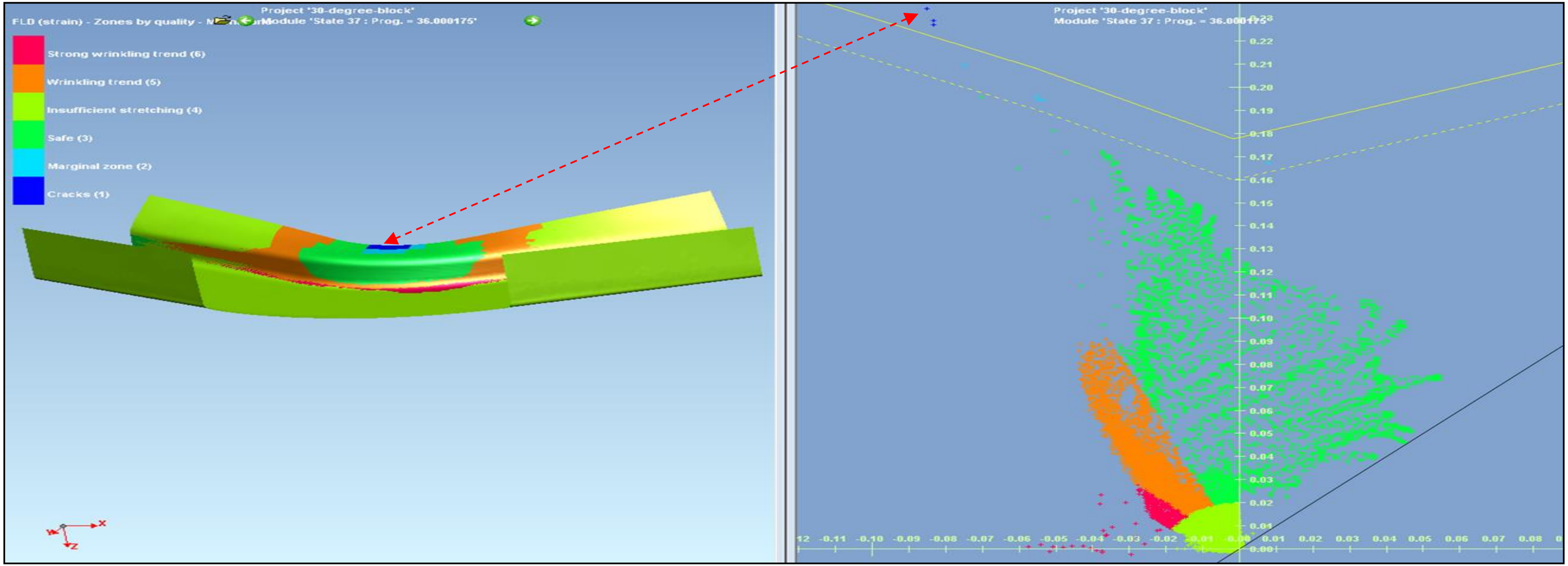
Die

Blank

Blank Holder with 4 Tons

Stationary Punch

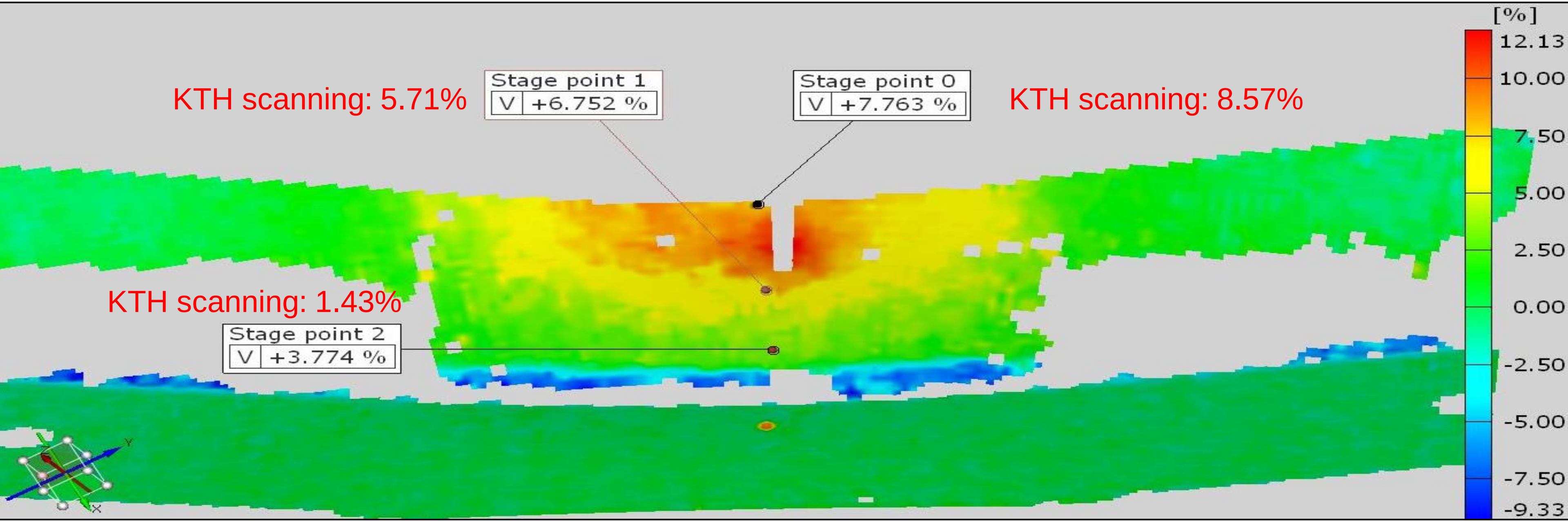
Prediction of Ductile Failure with TRIP780



Simulation results for TRIP780 with 60 Degree Bend Block and 70-mm Flange

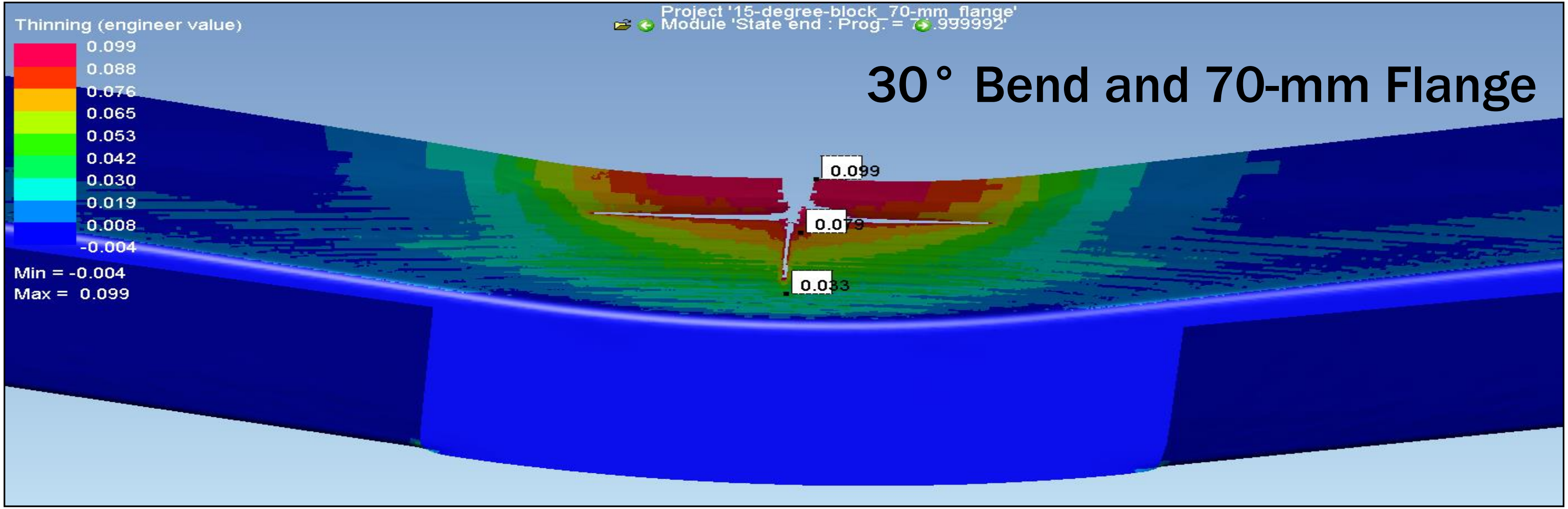
Edge Cracking with TRIP780

30° Bend and 70-mm Flange



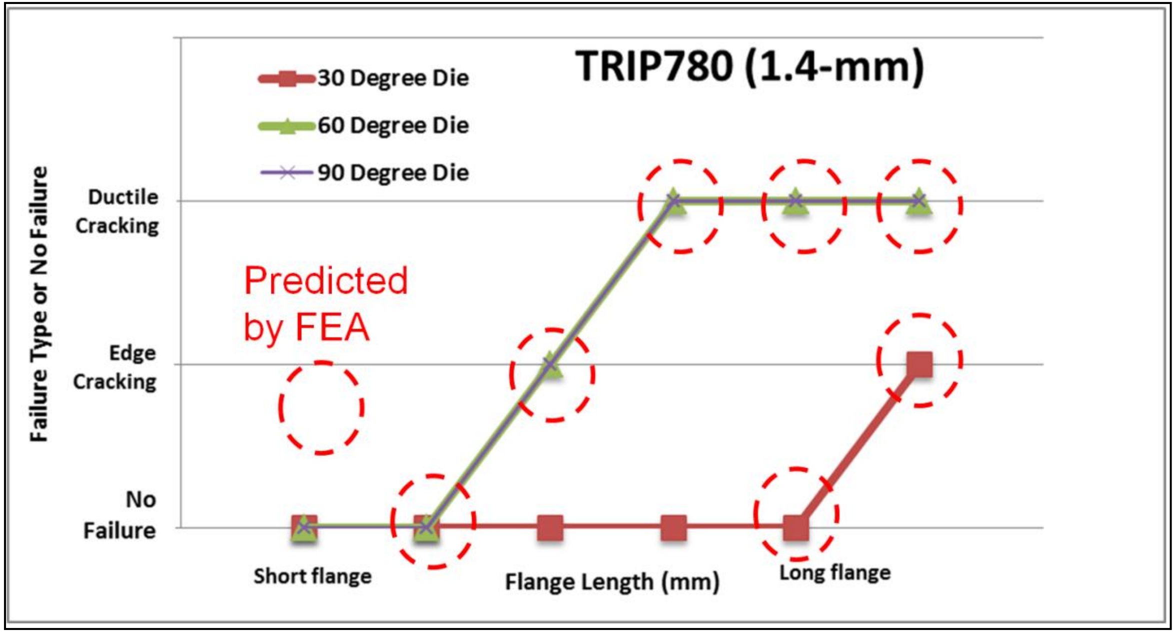
Comparison of the Thinning Data between the ARGUS and Laser Scanning

Prediction of Edge Cracking with TRIP780



Thinning Distribution from Simulation Results with the Failure Criteria (Max. Thinning > 10%)

Findings — TRIP780 (1.4 mm)



- As the flange length increased from 20 to 70 mm, failures occurred, and the failure type changed from edge cracking to ductile cracking.

Conclusions (1/2)

- A 3-in. diameter HER testing showed about 10× distinguishable results of different materials and trimming methods compared to the ISO standard HER testing method (i.e. about 10% vs. less than 1% HER).

- HSDT is a simple testing method to evaluate edge cracking with less effort in preparing the samples and easily comparing the maximum die stroke at the onset of the crack initiation compared to the HER test.

Conclusions (2/2)

- The maximum thinning-based failure criteria is recommended for use in industrial stamping simulations.
- The maximum thinning-based failure criteria reasonably predicted the edge cracking with TRIP780 samples with the KTH die.
- TRIP780 showed the largest change in edge cracking for different trimming conditions (i.e. water-jet vs. shearing).
- TRIP780 and DP980 are susceptible to edge cracking.

Acknowledgements

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HONDA
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EWI Forming Center

KTH PARTS INDUSTRIES INC.

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