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

Hyunok Kim\textsuperscript{1*}, Jim Dykeman\textsuperscript{2}, Anoop Samant\textsuperscript{3}, and Cliff Hoschouer\textsuperscript{4}

\textsuperscript{1}EWI Forming Center, \textsuperscript{2}Honda R&D, \textsuperscript{3}KTH Parts, and \textsuperscript{4}Shiloh
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!**
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

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**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
Hyunok Kim, EWI-FC
Anoop Samant, KTH Parts Ind.

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.
• 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.
HOLE EXPANSION TESTING WITH VISUAL MONITORING SYSTEM

Hyunok Kim, EWI-FC
Anoop Samant, KTH Parts Ind.
Cliff Hoschouer, Shiloh
Synchronized Image, Load, and Displacement

The synchronized system can accurately capture the hole expansion at the crack initiation.
### HER Experiment Matrix

<table>
<thead>
<tr>
<th>Materials</th>
<th>Conical Punch</th>
<th>Dome Punch</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRIP780</td>
<td>Punched hole</td>
<td>Punched hole</td>
</tr>
<tr>
<td>(1.4 mm)</td>
<td>Water-jet cut hole</td>
<td>Water-jet cut hole</td>
</tr>
<tr>
<td>DP980</td>
<td>Punched hole</td>
<td>Punched hole</td>
</tr>
<tr>
<td>(1.0 mm)</td>
<td>Water-jet cut hole</td>
<td>Water-jet cut hole</td>
</tr>
</tbody>
</table>

- 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).
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).
Hyunok Kim, EWI-FC
Jim Dykeman, Honda R&D

HALF SPECIMEN DOME TEST (HSDT)
### HSDT Matrix

<table>
<thead>
<tr>
<th>Materials</th>
<th>Edge Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRIP780 (1.4 mm)</td>
<td>5 blanks with the sheared edge</td>
</tr>
<tr>
<td></td>
<td>5 blanks with the water-jet cut edge</td>
</tr>
<tr>
<td>DP980 (1 mm)</td>
<td>5 blanks with the sheared edge</td>
</tr>
<tr>
<td></td>
<td>5 blanks with the water-jet cut edge</td>
</tr>
</tbody>
</table>

- 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.

<table>
<thead>
<tr>
<th>Max. Thinning (%)</th>
<th>DP980 Sheared</th>
<th>DP980 Water-Jet</th>
<th>TRIP780 Sheared</th>
<th>TRIP780 Water-Jet</th>
</tr>
</thead>
<tbody>
<tr>
<td>EWI</td>
<td>6.42%</td>
<td>9.10%</td>
<td>7.44%</td>
<td>13.24%</td>
</tr>
<tr>
<td>Honda</td>
<td>6.46%</td>
<td>11.90%</td>
<td>8.90%</td>
<td>15.18% (no crack)</td>
</tr>
<tr>
<td>Error (%)</td>
<td>0.04%</td>
<td>2.8%</td>
<td>1.46%</td>
<td>1.94%</td>
</tr>
</tbody>
</table>
## Comparing Different Testing Methods

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

Jianhui Shang and Hyunok Kim, EWI-FC
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.
## Prediction of Edge Cracking for DP980 with the Sheared Edge

<table>
<thead>
<tr>
<th>Failure Criteria</th>
<th>FEM Predicted Die Stroke for the Onset of Edge Cracking</th>
<th>Exp. Measured Die Stroke for the Onset of Edge Cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. thinning</td>
<td>59 mm</td>
<td>52–58 mm</td>
</tr>
<tr>
<td>Modified FLD</td>
<td>58 mm</td>
<td></td>
</tr>
</tbody>
</table>
Sheared edges gave about 50% reduction in the maximum thinning compared to the water-jet edges.

<table>
<thead>
<tr>
<th>Material/Edge Cond.</th>
<th>Max. Thinning from HDST</th>
<th>Max. Thinning from HER with 3-in. Hole</th>
<th>Max. Thinning for the Necking Failure from Industry Perception</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP980/Sheared edge</td>
<td>5–7 % (Exp.)</td>
<td>4–9% (FEA)</td>
<td>12%</td>
</tr>
<tr>
<td>DP980/Water-jet edge</td>
<td>9–12 % (Exp.)</td>
<td>N/A</td>
<td>12%</td>
</tr>
<tr>
<td>TRIP780/Sheared edge</td>
<td>7–9 % (Exp.)</td>
<td>7–12% (FEA)</td>
<td>19%</td>
</tr>
<tr>
<td>TRIP780/Water-jet edge</td>
<td>12–15% (Exp.)</td>
<td>17–21% (FEA.)</td>
<td>19%</td>
</tr>
</tbody>
</table>
Anoop Samant, Kevin Casanova, KTH Parts Ind.
Jianhui Shang and Hyunok Kim, EWI-FC

REDUCTION OF EDGE CRACKING WITH INDUSTRIAL FIELD TESTING
KTH Field Testing for Evaluating the Edge Cracking

TRIP780 (1.4 mm) — Laser Cutting

30° ~ 90° Planar Curvature Angle

Shorter to Longer Flanges
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
Comparison of the Thinning Data between the ARGUS and Laser Scanning

KTH scanning: 5.71%

Stage point 1

Stage point 0

KTH scanning: 8.57%

KTH scanning: 1.43%

Stage point 2

30° Bend and 70-mm Flange

Edge Cracking with TRIP780
Prediction of Edge Cracking with TRIP780

30° Bend and 70-mm Flange

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 $10 \times$ 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.
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• Participating organizations:
Hyunok Kim, P.E., Ph.D.
Technical Director
EWI Forming Center
614.688.5239
hkim@ewi.org