Edge Fracture in Mixed Microstructure Steels

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Presentation Outline

• Edge Fracture – Background
• Past Case Studies
• Material Evaluations on Production & Trial Material
  – Edge quality effects
  – Hole expansion testing on current and new grades of AHSS
  – Nano-indentation and microstructure
• Concluding Remarks
Edge Fracture – Background

- Fracture initiating at a trimmed edge, typically not predicted by an FLC
  - A local formability phenomena: an inter-relationship between steel microstructure, damage during trimming, and subsequent edge-stretch during forming.
  - AHSS more susceptible than single phase materials (Low Carbon, HSLAs)
Edge Fracture – Background

- Edge fractures typically occur in the highest edge strain area in the presence of a rough trimmed edge.
  - Typically during drawing or from a stretch flange after a rough die trim
Edge Fracture Case Studies

- Edge fracture instances are not isolated to particular steel suppliers, grades of AHSS, gauge, or coating.
- Case study subset selected to show common root causes and resolutions.

<table>
<thead>
<tr>
<th>Part</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Compartment Rail</td>
<td>DP780/420</td>
</tr>
<tr>
<td>Torque Box</td>
<td>DP980/550</td>
</tr>
<tr>
<td>Rear Rail Inner</td>
<td>DP590/340</td>
</tr>
<tr>
<td>Center Pillar Inner</td>
<td>MP980/700</td>
</tr>
<tr>
<td>Lock Pillar Inner</td>
<td>DP780/420</td>
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<tr>
<td>Hinge Pillar Outer</td>
<td>DP590/340</td>
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<tr>
<td>Front Body Hinge Pillar</td>
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</tr>
<tr>
<td>Sill – U/B #2 CR</td>
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<tr>
<td>Rocker Inner</td>
<td>DP780/420</td>
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<tr>
<td>Front Rocker Inner</td>
<td>DP980/700</td>
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</table>
Multiple Fracture Locations

1. At notch
2. Tab
Front Compartment Rail – CR780T / 420Y (DP)

- Fractures at locations 1 (notch) accounted for 2/3 of initial fractures
- Predominance of fractures on RH only, occurring in the trim die
- Materials within specification, trim clearances OK
- Part nesting (unsupported on trim tool)

7.2% major strain from draw operation
4% thinning
Front Compartment Rail – CR780T / 420Y (DP)

• Fracture Location #2 (occurring in the draw die)
  12.2% major strain

• Several ‘B’ blanks showed splits resulting in scrapped parts

• ‘A’ blanks showed very few or no splits

‘B’ Blank, 17.2% Scrap

‘A’ Blank, 0.8% Scrap
Front Compartment Rail – CR780T / 420Y (DP)

• This design is frequently used for double attached left / right compartment rails (material utilization)

• Significant edge stretch condition during the draw in the ‘horse collar’ area

• Also, thin bypass condition between common trim lines (difficult to support) affected trim quality.
Rear Rail CR590T / 340YDP

- Intermittent edge fracture predominantly on one hand of part.
  - Size and exact location of fractures were variable run-to-run.

“Taco chip” SPLIT
Rear Rail CR590T / 340YDP

- LH vs. RH trim conditions made more robust.
- Trim steel insert maintenance required (sharpening).

Eliminated the secondary blanking operation by adding shear to the cutouts.

Added shear to upper trim steels.

Added more guidance & support to help with flexing.

Adjusted Clearances.
Potential Sources of Poor Trim Quality

• Poor Nesting (Trimming in Air)
• Die Breathing and Flexing
• Die Guidance
• Improper Clearance
  – Typically too tight
  – 13-15% recommended for most AHSS
• Sharpness of Trim Steels
Part with Flanged Hole – DP980T / 550Y

- Part hole expansion is 13%
- Material capability is 12-15%
  - Other material properties within specification
  - Hole Expansion (recently added to qualification approval process in May 2014)
- Design not robust for material capability
- Changed material to high yield ratio CR980T / 700Y-MP-LCE
  - (HER ~ 30%)
- No issues-to-date
Effect of Laser Cut vs. Die Cut Edge Quality

Laser Cut

Die Cut

Water Jet Cut

Laser Cut – Edge Profile

Die Cut – Edge Profile

Water Jet – Edge Profile
Micro-Hardness Edge Profile Comparison

Laser Cut Profile

Water Jet Cut Profile

Die Cut Profile

Burnish
Fracture 1
Fracture 2
DP590 Cut Edge Performance Evaluation

Uniaxial Tension Testing
Modified ASTM E8 Specimens

Engineering Stress (MPa)
Engineering Strain (%)

Die/Laser Cut Edge
Modified ASTM E8 (MB)

ASTM E8 Std. Bar (SB)
Try-out vs. Production Blanks

• Laser cut blanks in try-out material are not a good indicator of potential edge fractures in production with die struck blanks.

• Stamping plants are concerned about receiving dies for secondary try-out when the dies have not stamped die struck blanks in primary try-out.

• Timing of production-intended blanks needs to ensure that delivery occurs before dies are shipped to home line.
Hole Expansion Testing

Variability of hole expansion testing exists due to variation in microstructure within a material, the quality of the sheared hole, and specific testing equipment site-to-site.

- A tool for qualification of material and general understanding of edge stretch performance with an adequate sample size; however, challenges exist for use for lot acceptance testing.

Where:

\[ \text{HER} = \left( \frac{D_f - D_0}{D_0} \right) \times 100 \]
Hole Expansion Testing

- 10 mm hole punching
  - Die clearance 0.2 mm
- Testing per ISO 16630
  - Speed: 0.5 mm/s
  - Testing in hole punch direction
  - Digital data acquisition until thru-thickness crack observed
  - 5 samples per material

Fig. 1. Schematic diagram (a) before and (b) after the hole expansion test.

1 - Sample
2 - Binder
3 - Die
4 - Conical punch
5 - Crack on hole edge
6 - Burr from punching
Hole Expansion Test

- Mechanical properties of select grades for hole expansion testing.
- Current production DP780 and DP980 vs. newer RA-bearing 1180 MPa grades.

<table>
<thead>
<tr>
<th>Type</th>
<th>Coating</th>
<th>Thickness</th>
<th>YS</th>
<th>UTS</th>
<th>UE</th>
<th>TE</th>
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<tbody>
<tr>
<td>TRIP 1180</td>
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<td>916</td>
<td>1289</td>
<td>7.2</td>
<td>14.1</td>
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<tr>
<td>DP980 (550YS)</td>
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<td>643</td>
<td>1014</td>
<td>10.0</td>
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<tr>
<td>DP780</td>
<td>GI</td>
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<td>463</td>
<td>833</td>
<td>12.9</td>
<td>17.0</td>
</tr>
</tbody>
</table>
Hole Expansion Testing

- Newer high strength 1180 MPa grades showing >= HER vs. more conventional DP steels and less sensitivity to edge condition.
- New grades need balance of global and local formability for most applications.
Nano-Indentation Evaluation – DP780

- Nano-indentation testing was performed to determine constituent hardness distributions in mixed microstructure DP780 steel.
- Two production samples were acquired representing two steel sources.
  - Under similar blanking and stamping conditions, one steel exhibited edge fracture while the other did not.
- Samples were ground/polished using standard metallurgical techniques and finish-polished with colloidal silica.
MTS Nanoindenter XP was used.

- Testing was performed at room temperature with a Berkovich tip
- Displacement control was used to indent to 100 nm maximum depth
- 12 x 12 array of indents was placed on each specimen, spaced 2 µm apart
- Resulting hardness was averaged over a 60-90 nm depth to remove any surface abnormalities
Microstructure

0.2% YS: 489 MPa
UTS: 886 MPa
UE: 11.5%
TE: 17.8%

0.2% YS: 492 MPa
UTS: 851 MPa
UE: 11.8%
TE: 19.9%

Edge Fractures

No Fractures

ND

RD

TD

20 μm
Summary

• Edge fracture susceptibility is influenced by a variety of related factors: blank edge condition, material, part design / forming (strain distribution) / trimming process.

• A balance of global and local formability performance is required for most cold-stamped parts and shall be considered in steel development.
  – Uniform, fine-grained structure required
  – Reduced hardness differential between constituents

• An industry-wide test is needed for material lot acceptance to predict edge fracture susceptibility
  – Performance not predicted by standard tensile testing
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Thank You for Your Attention!

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