Product Design Considerations for AHSS
Displaying Lower Formability Limits
in Stamping - With Sheared Edge
Stretching

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INTRODUCTION

• Occasional premature fracture is observed in the stretched edge conditions and during bending or bending under tension while stamping some advanced high strength steel (AHSS) components.

• Affecting factors are: Stress state, edge condition/quality, shearing process, previous deformation history, volume content and shape of hard phase, carbon level, micro-cleanliness, homogeneity of the structure.

• Conventional forming limit curve (FLC) may not always predict these failures.

• Today’s lecture will be dedicated to the failure occurring during shared edge stretching.
## TYPICAL PROPERTIES OF TESTED MATERIALS

<table>
<thead>
<tr>
<th>Grade</th>
<th>YS (MPa)</th>
<th>UTS (MPa)</th>
<th>UE (%)</th>
<th>TE (%)</th>
<th>n-value</th>
<th>r-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDGA 50 XK</td>
<td>406</td>
<td>488</td>
<td>16</td>
<td>26.2</td>
<td>0.159</td>
<td>1.11</td>
</tr>
<tr>
<td>HDGA 590R</td>
<td>416</td>
<td>621</td>
<td>15</td>
<td>23.7</td>
<td>0.147</td>
<td>1.22</td>
</tr>
<tr>
<td>HDGA DP590</td>
<td>387</td>
<td>607</td>
<td>16</td>
<td>25.5</td>
<td>0.156</td>
<td>1.07</td>
</tr>
<tr>
<td>HDGA DP780**</td>
<td>533</td>
<td>819</td>
<td>12</td>
<td>18.1</td>
<td>0.127</td>
<td>0.86</td>
</tr>
<tr>
<td>HDGA DP980**</td>
<td>543</td>
<td>985</td>
<td>10</td>
<td>15.0</td>
<td>0.120</td>
<td>0.69</td>
</tr>
<tr>
<td>HDGA TRIP780</td>
<td>435</td>
<td>782</td>
<td>19</td>
<td>22.8</td>
<td>0.191</td>
<td>0.87</td>
</tr>
<tr>
<td>HR SF590*</td>
<td>562</td>
<td>635</td>
<td>14</td>
<td>25.4</td>
<td>0.134</td>
<td>0.90</td>
</tr>
<tr>
<td>HR DP590</td>
<td>389</td>
<td>638</td>
<td>13</td>
<td>26.1</td>
<td>0.128</td>
<td>-</td>
</tr>
<tr>
<td>HR 590R*</td>
<td>487</td>
<td>608</td>
<td>16</td>
<td>29.7</td>
<td>0.145</td>
<td>0.94</td>
</tr>
</tbody>
</table>

*) 3.2mm

**) Calculated for (7%-11%
DP780: n = 0.194 (4%-6%)
DP980: n = 0.179 (4%-6%)
Comparison of Stress-Strain Curves, Tested As Delivered, L-dir.

- DP780
- 50XK
- T780
- 590R
- DP980
- DP590
HOLE EXPANSION RATIO - DEFINITION

• In the present work the JFS T1001-1996 standard was followed: This standard specifies a method of determining the hole expansion ratio in sheet steels with a thickness in a range of 1.2 mm to 6.0 mm inclusive.

• Hole expansion is defined as the amount of expansion obtained in a circular punch hole of a test piece, when a conical punch is forced in the hole until any of cracks in the hole edge extends all through the test piece thickness;

• Numerically it is expressed as the ratio of the final hole diameter at fracture through thickness to the original hole diameter, as defined by the following equation:
  - \( l = \frac{(D_h - D_o)}{D_o} \times 100 \)
  - \( l \): Hole expansion ratio (%)
  - \( D_o \): Original hole diameter (\( D_o = 10 \text{mm} \))
  - \( D_h \): Hole Diameter after fracture (mm)

In addition a spherical punch have been used for comparative study
- Olsen tester, 50 mm die,
- Special fixture to align sample with the die and punch
- Variable punch geometry
- 1.4 mm material thickness

- Laser cutting parameters:
  - Focal length: 127 mm
  - Speed 1,800 mm/min
PUNCHED/CUT HOLES’ QUALITY

50XK, 1.4mm
Rollover, % of thickness
6.3% 9.1% 13.5% 18.9%

590R, 1.4mm
Rollover, % of thickness
4.8% 7.6% 11.7% 17.2%

DP590, 1.4mm
Rollover, % of thickness
5.5% 8.3% 13.8% 17.9%

DP780, 1.4mm
Rollover, % of thickness
4.4% 5.9% 10.5% 14.0%

Clearance, % of thickness (Laser)
1.1% 6.4% 13.5% 20.8%
### PUNCHED/CUT HOLES’ QUALITY, Cont’d

<table>
<thead>
<tr>
<th>Material</th>
<th>DP980, 1.4mm</th>
<th>Rollover, % of thickness</th>
<th>T780, 1.4mm</th>
<th>Rollover, % of thickness</th>
<th>Clearance, % of thickness (Laser)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>4.2%</td>
<td>4.1%</td>
<td>1.1%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>7.0%</td>
<td>8.1%</td>
<td>6.4%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.1%</td>
<td>11.5%</td>
<td>13.5%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>13.9%</td>
<td>16.2%</td>
<td>20.8%</td>
<td></td>
</tr>
</tbody>
</table>

- **Rollover, % of thickness:** Values represent the percentage of material that has rolled over during the punching or cutting process.
- **Clearance, % of thickness (Laser):** This indicates the clearance achieved during the laser cutting process, expressed as a percentage of the material's thickness.
LOCAL PROPERTIES OF SPECIMENS

DP 780, Laser cut

50XK, Laser cut

DP780A, 1.4 mm, Micro-hardness Profile

50XK, 1.4 mm, Micro-hardness Profile
LOCAL PROPERTIES OF SPECIMENS

DP 780, 13.5% Clearance

50XK, 13.5% Clearance

50XK, 13.5% Clearance
INFLUENCE OF EDGE QUALITY ON HOLE EXPANSION

50XK, 1.4mm

\[ \lambda = 81.0\% \]  \[ \lambda = 77.0\% \]  \[ \lambda = 87.3\% \]  \[ \lambda = 106.2\% \]

590R, 1.4mm

\[ \lambda = 38.9\% \]  \[ \lambda = 29.2\% \]  \[ \lambda = 47.6\% \]  \[ \lambda = 55.5\% \]

1.1\%  \[ 6.4\% \]  \[ 13.5\% \]  \[ 20.8\% \]
INFLUENCE OF EDGE QUALITY ON HOLE EXPANSION, Cont’d

HSLA 50ksi \( \lambda = 84\% \)

590R \( \lambda = 29.2\% \)

DP590 \( \lambda = 33.8\% \)

t = 1.4mm  Clearance = 6.4%, Conical Punch
## INFLUENCE OF EDGE QUALITY ON HOLE EXPANSION, Cont’d

### DP590, 1.4mm

<table>
<thead>
<tr>
<th>λ</th>
<th>1.1%</th>
<th>6.4%</th>
<th>13.5%</th>
<th>20.8%</th>
</tr>
</thead>
</table>

### DP780, 1.4mm

<table>
<thead>
<tr>
<th>λ</th>
<th>16.2%</th>
<th>15.2%</th>
<th>15.7%</th>
<th>17.9%</th>
</tr>
</thead>
</table>
INFLUENCE OF EDGE QUALITY ON HOLE EXPANSION, Cont’d

Clearance = 6.4%
Conical Punch

<table>
<thead>
<tr>
<th>Steel Grade</th>
<th>λ</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP590</td>
<td>33.8%</td>
</tr>
<tr>
<td>DP780</td>
<td>19.0%</td>
</tr>
<tr>
<td>DP980</td>
<td>7.7%</td>
</tr>
<tr>
<td>T780</td>
<td>20.8%</td>
</tr>
</tbody>
</table>

t = 1.4mm
INFLUENCE OF EDGE QUALITY ON HOLE EXPANSION, Cont’d

DP980, 1.4mm

\[ \lambda = 4.3\% \]
\[ \lambda = 7.7\% \]
\[ \lambda = 7.9\% \]
\[ \lambda = 9.1\% \]

T780, 1.4mm

\[ \lambda = 16.1\% \]
\[ \lambda = 20.8\% \]
\[ \lambda = 20.4\% \]
\[ 23.2\% \]

1.1\%
6.4\%
13.5\%
20.8\%
Influence of burr orientation and clearance

DP590 - Conical Punch

- Burr Up
- Burr Down

Hole Expansion Ratio vs. Clearance

- Ream
- Laser
- Clearances: 1.1%, 6.4%, 13.6%, 20.7%
HOLE EXPANSION RATIO, Cont’d

Conical Punch, Influence of Edge Finishing

Hole Expansion Ratio

Ream Laser 1.1% 6.4% 13.6% 20.8%

Clearance

50XK 590R DP590 DP780 DP980 T780
Influence of burr orientation and material grade

13.6% Clearance - Conical Punch

- Burr Up
- Burr Down

HOLE EXPANSION RATIO, Cont’d
HOLE EXPANSION RATIO, Cont’d

Clearance = 6.4%
Spherical Punch

DP590
$\lambda = 31.1\%$

DP780
$\lambda = 8.3\%$

DP980
$\lambda = 4.6\%$
Influence of punch geometry and material grade

13.6% Clearance: Material vs. Punch Geometry

- Conical
- Spherical

Hole Expansion Ratio

Steel:
- 50XK
- 590R
- DP590
- T780
- DP780
- DP980

HOLE EXPANSION RATIO, Cont’d
Example 1: Commercial DP780
Using laser for cutting the edge to improve its stretch performance

<table>
<thead>
<tr>
<th>Material</th>
<th>Edge Preparation</th>
<th>HER, %</th>
<th>Change, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP780</td>
<td>Shearing, Cl. = 12%</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>DP780</td>
<td>Laser + Deburring</td>
<td>33</td>
<td>+ 83%</td>
</tr>
<tr>
<td>DP780</td>
<td>Laser</td>
<td>40</td>
<td>+ 120%</td>
</tr>
</tbody>
</table>

Example 2: Commercial DP780
Using alternative steel design approaches results in improved stretch-ability (local-formability) but typically results in higher yield strengths (higher YS/TS ratio) therefore existing specifications for Dual Phase steel may not apply.

<table>
<thead>
<tr>
<th>Material</th>
<th>YS/TS</th>
<th>HER, %</th>
<th>Change, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP780</td>
<td>0.65</td>
<td>18</td>
<td>-</td>
</tr>
<tr>
<td>Experimental DP780</td>
<td>0.75</td>
<td>38</td>
<td>110</td>
</tr>
</tbody>
</table>
Example 3: DP590
Using SF material for components with critical stretch-ability requirements

<table>
<thead>
<tr>
<th>Material</th>
<th>Edge Preparation</th>
<th>HER, %</th>
<th>Change, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR DP590</td>
<td>Shearing, Cl. = 12%</td>
<td>36</td>
<td>-</td>
</tr>
<tr>
<td>HR 590R</td>
<td>Shearing, Cl. = 12%</td>
<td>63</td>
<td>+ 76%</td>
</tr>
<tr>
<td>HR SF590</td>
<td>Shearing, Cl. = 12%</td>
<td>101</td>
<td>+ 182%</td>
</tr>
</tbody>
</table>
Example 4: Any commercial Dual Phase Steel
Improved product design to eliminate excessive edge stretching
CONCLUDING REMARKS

- 8% - 10% die clearance is commonly used as the optimum for edge stretch-ability, however some of the steels tested thus far at the U. S. Steel the clearance above 15% showed improved edge stretch ability (780T being the exception)

- Presented results were obtained for good quality punching tools. Impact of production tools deterioration on blank edge stretch-ability is subject to testing

- Commercial DP780 and DP980 steels demonstrates near-constant hole expansion ratio’s as the die clearances were increased
Both DP780 and DP980 tested steels can be optimized for enhanced edge stretch-ability (i.e. local formability), however this may increase YS/TS ratio and lower global formability.

Laser cut edge commonly used at the try-out stage displays superior stretch-ability for AHSS steels. Replacing laser with conventional blanking would lead to significantly lower edge stretch-ability.

Hole expansion limits for various AHSS materials are directly applicable for FEM-based numerical prediction of sheared edge failure in automotive parts stamping.
REFERENCES


4. Shi M. F., Chen X., Stretch Flange-ability Limits of Advanced High Strength Steels, SAE 2007-01-1693
Thank you
Any questions?