A Comprehensive Study of Hole Punching for AHSS

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1. AK Steel Corporation
2. FCA USA LLC
3. General Motor Company
Acknowledgements

The work discussed in this presentation was partially supported by the A/SP Stamping Team using funds from the Auto/Steel Partnership.
Outline

- Introduction
- Experimental Procedure
  - Tool Setup
  - Experiment Variables and Materials
- Results and Discussion
  - Punching Force Studies
  - Dimensional Studies
  - Tool Protections
  - Cutting Edge Qualities
- FEA Simulations
- Summary & Future works

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Introduction

Hole Punching on AHSS

- Punching Force Reduction
- Dimensional Accuracy
- Tool Protection
- Edge Quality

*Image source: Stamping Journal, March, 2014*
Experimental Variables

- Sample size: 254mm × 254mm
- Punch rate: 10 mm/s
- Punch shapes: flat, conical, rooftop
- Punch tipping angle: 7°

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness (mm)</th>
<th>Nominal Punch Clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP 1180</td>
<td>1.20</td>
<td>6.0%, 12.0%, 20.0%</td>
</tr>
<tr>
<td>DP 980</td>
<td>1.16</td>
<td>6.2%, 12.5%, 20.8%</td>
</tr>
<tr>
<td>DP 590</td>
<td>1.31</td>
<td>6.4%, 12.8%, 21.4%</td>
</tr>
<tr>
<td>DDS</td>
<td>1.38</td>
<td>6.1%, 12.2%, 20.3%</td>
</tr>
</tbody>
</table>
# Material Properties

<table>
<thead>
<tr>
<th>Material</th>
<th>Yield Strength (MPa)</th>
<th>Tensile Strength (MPa)</th>
<th>Uniform Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP1180 (1.20mm)</td>
<td>1002.20</td>
<td>1269.35</td>
<td>5.40</td>
</tr>
<tr>
<td>DP980 (1.16mm)</td>
<td>703.52</td>
<td>1038.99</td>
<td>7.16</td>
</tr>
<tr>
<td>DP590 (1.31mm)</td>
<td>451.06</td>
<td>675.05</td>
<td>16.45</td>
</tr>
<tr>
<td>DDS (1.38mm)</td>
<td>162.85</td>
<td>311.23</td>
<td>24.71</td>
</tr>
</tbody>
</table>

![Stress-Strain Curve](image)

### Stress vs Strain

- **DP1180**
- **DP980**
- **DP590**
- **DDS**
Punching Force History

- Conical shaped punch induces large deformation within the cutting area.
- The punch load is quite uniform due to gradual shearing process, similar to scissor cutting for the rooftop punch.

![Graph showing Punch Load vs Stroke for different types of punches](image1.png)

**Material deformation induced by conical/rooftop punch**

**Rooftop Punch Shearing Process**
Averaged Maximum Punch Load

- For all cases, the maximum punch load decreases as cutting clearance increases, but the difference is trivial (about 3 to 4%).
- The rooftop punch leads to significant force reduction and it is more effective on AHSS.
The hole punching force coefficient can be calculated as

\[ K = \frac{P}{\text{UTS} \cdot \pi D \cdot t} \]

- **UTS (MPa):** ultimate tensile strength
- **P (N):** hole punch force
- **D (mm):** hole diameter
- **t (mm):** material thickness

This definition is similar to the shear strength index. More dependencies are considered during the evaluation.
Hole Punching Force Coefficient

- The hole punching force coefficient is negatively correlated to the material strength.
- Mild steel → 1.0; AHSS: 0.7 ~ 0.8
Dimensional Study of Punched Hole

- Dimensional accuracy of punched holes is important in the sheet metal forming.
- Dimensional measurements were repeated for three times for each punch configurations (punch shape, material, and cutting clearance).

*Yang, G. et al, SAE 2016*
Hole Discrepancies

- Conical shape leads to an uniform enlargement for diameter due to the stress release and consequent spring back.
- The holes punched with rooftop shape exhibited oval shape with minor axis along the ridge direction.

**Punched Hole Diameter (mm)**

<table>
<thead>
<tr>
<th>Material</th>
<th>6% Cutting Clearance</th>
<th>12% Cutting Clearance</th>
<th>20% Cutting Clearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP1180</td>
<td>60.1</td>
<td>60.4</td>
<td>60.2</td>
</tr>
<tr>
<td>DP980</td>
<td>60.1</td>
<td>60.4</td>
<td>60.2</td>
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<td>DDS</td>
<td>60.1</td>
<td>60.4</td>
<td>60.2</td>
</tr>
</tbody>
</table>

**Ridge Direction**
- 6% Cutting Clearance
- 12% Cutting Clearance
- 20% Cutting Clearance

**Transverse Direction**
- 6% Cutting Clearance
- 12% Cutting Clearance
- 20% Cutting Clearance
Tool Protections: Snap-through Load

- Snap-through load, i.e. reverse tonnage, leads to severe press machine damage.
- Rooftop punch can provide an effective solution for press machine protection and noise reduction.
Tool Protection From Enlarged Hole

Flat Punch

- Piercing
  - Abrasive Friction
- Punch Pushing
  - Abrasive Friction
- Pulling Back
  - Abrasive Friction

Conical Punch

- Piercing
  - Abrasive Friction
- Punch Pushing
  - Abrasive Friction
- Pulling Back
  - Abrasive Friction

Enlarged Hole
Cutting Edge Quality

- The cutting surface was examined using optical microscope with 200X magnification.
In-plane hole expansion tests were conducted to evaluate the edge damage due to the punch geometry during the punching stage.

The conical shaped tool can produce a punched hole with higher edge stretchability, while rooftop punch results in the most severe edge damage.
FEA Model

- Mixed-Voce-Swift model
  \[ \bar{\sigma} = \alpha [K(\bar{\varepsilon}^p + \varepsilon_0)^n] + (1 - \alpha) [\sigma_l - (\sigma_l - \sigma_0) \exp(-\bar{\varepsilon}^p/\eta)] \]

- All-strain Based Modified Mohr-Coulomb (eMMC) Fracture Model

* Test data is provided by WSU through ASP Fracture Project
Punching Process Simulation

**Flat Punch**
- Stress Concentration
- Crack Initiation
- Spring back
- Induced Gap

**Conical Punch**
Punching Process Simulation

0 degree shearing angle

Material deflection before cutting

Maximum Punch Load
<table>
<thead>
<tr>
<th>Flat Punch</th>
<th>Conical Punch</th>
<th>Rooftop Punch</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Effect; Force Coefficient:0.7~1</td>
<td>No Effect; Force Coefficient:0.7~1</td>
<td>Significant reduction (56%<del>80%); Force Coefficient:0.15</del>0.4</td>
</tr>
<tr>
<td>No Effect; Force Coefficient:0.15~0.4</td>
<td>Uniformly enlarged diameter; could be compensated</td>
<td>Oval shape with minor axis along the rooftop ridge</td>
</tr>
<tr>
<td>Accurate</td>
<td>Oval shape with minor axis along the rooftop ridge</td>
<td></td>
</tr>
<tr>
<td>Large snap-through load; Multiple abrasive wearing;</td>
<td>Large snap-through load; Reduced abrasive wearing;</td>
<td>Significantly reduced snap-through load;</td>
</tr>
<tr>
<td>Inconsistent edge surface condition</td>
<td>Smooth and Consistent Edge Surface</td>
<td>Localized material deformation; Inconsistent edge surface at small clearance</td>
</tr>
</tbody>
</table>
Future Studies

• In-plane hole expansion tests will be continued to study the sheared edge damage mechanism.
• A numerical damage model will be developed to simulate the edge cracking.
• The punch shape and geometry will be optimized to achieve the goals of load reduction and dimensional accuracy.
Thank you!

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