Stretch Flangeability of DP490

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Background

- Split of stretched flanges was encountered when DP490 was used to replace BH210 for door outer panels
- Need of a guideline for stretch flanging of DP490 material
One Current Approach

- Limit strain generated from lab hole expansion test was used to assess the flangeability of DP490
• The effect of product geometry on limit strain was considered
Issues with Lab Test

• The effect of stress state on forming of stretch flanging was not neglected

Samples with Incremental Punch Travels

The stress state in flange area changes with the stretch and warpage of sheet metal during forming process until it is ironed out by fully closed dies.
New Simulative Flange Test

- To determine the material stretch flangeability with critical flange height under various testing conditions

- Testing parameters
  - Material: strength, thickness
  - Geometry: flange radius, include angle
  - Process: prestrain, trim die clearance
  - Not included: trim angle, surface curvature in trimming & flanging
### Experiment Setup

- Tests of four DP490 and one BH210 steels

<table>
<thead>
<tr>
<th>Steel ID</th>
<th>Serial #</th>
<th>Coating</th>
<th>Gauge (mm)</th>
<th>0.2 % YS (MPa)</th>
<th>UTS (MPa)</th>
<th>UE (%)</th>
<th>TE (%)</th>
<th>n bar (10%-UE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OOO</td>
<td>DP490</td>
<td>GA</td>
<td>0.66</td>
<td>326.4</td>
<td>588.3</td>
<td>16.1</td>
<td>25.0</td>
<td>0.158</td>
</tr>
<tr>
<td>OOR</td>
<td>DP490</td>
<td>GA</td>
<td>0.70</td>
<td>312.9</td>
<td>546.6</td>
<td>17.7</td>
<td>26.4</td>
<td>0.174</td>
</tr>
<tr>
<td>ORR</td>
<td>DP490</td>
<td>EG</td>
<td>0.73</td>
<td>328.9</td>
<td>538.2</td>
<td>18.3</td>
<td>27.6</td>
<td>0.175</td>
</tr>
<tr>
<td>ORB</td>
<td>DP490</td>
<td>GA</td>
<td>0.79</td>
<td>362.3</td>
<td>535.0</td>
<td>15.7</td>
<td>25.5</td>
<td>0.149</td>
</tr>
<tr>
<td>PPP</td>
<td>BH210</td>
<td>EG</td>
<td>0.79</td>
<td>231.1</td>
<td>360.4</td>
<td>19.2</td>
<td>36.0</td>
<td>0.174</td>
</tr>
</tbody>
</table>

- Over 3,000 samples made for 332 testing conditions

<table>
<thead>
<tr>
<th>Category</th>
<th>Experiment Parameters</th>
<th>Parameter</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Strength (MPa)</td>
<td>535</td>
<td>538</td>
</tr>
<tr>
<td></td>
<td>Thickness (mm)</td>
<td>0.79</td>
<td>0.73</td>
</tr>
<tr>
<td>Geometry</td>
<td>Flange Radius (mm)</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Include Angle (ö)</td>
<td>100</td>
<td>110</td>
</tr>
<tr>
<td>Process</td>
<td>Prestrain (%)</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Trim Clearance (% of t)</td>
<td>8.0</td>
<td>20.0</td>
</tr>
</tbody>
</table>
Tooling & Equipment of Test

- All tests were done with the trim and flange die made of tool materials same as production dies.

Upper Trim Steel

Lower Trim Steel

Trial Press

Lower V-shape Flanging Steel
All stretch flanging samples were inspected with the magnified glass according to the following criteria:

- **Satisfactory** (No crack)
- **Marginal** (No thru thickness crack)
- **Not Satisfactory** (Thru thickness crack)
• **General trend in stretch flanging of DP490**

![Graph showing flange height vs thickness and UTS](image)

- **Material properties**: stretched flange height (h) increased with thickness and decreased with the strength of steel.
- **Product geometry**: h improved with bigger flange radius and include angle.
- **Process parameters**: h reduced with larger prestrain and trim clearance.
- **Significant differences in h** were found for DP490 and BH210, respectively.
Results - Influential Factors

• The influential factors were identified with a DOE study and statistical analysis

- Four product and process parameters examined
  - A: Trim clearance (sheared edge quality effect)
  - B: Flange radius
  - C: Include angle
  - D: Prestrain level

- Two levels in the parameter change (max. and min.)
  - Trim clearance: 0.002” & 0.008” (8%~30% of thickness)
  - Flange radius: 10-mm & 20-mm
  - Include angle: 110° & 155°
  - Prestrain level: 0% & 8%
The results showed that the **flange radius** is the most influential factor on stretch flange height \((h)\) and followed by **include angle**, **trim clearance** and **prestrain**.

The main factors (product and process parameters) are more important than their interactions. It is feasible to adjust the individual parameter to improve the stretch flange height \((h)\).
Microstructures of DP490

• Microstructures of DP490

Summary of Microstructures

<table>
<thead>
<tr>
<th>Sample ID</th>
<th>% 2nd Phase</th>
<th>Microstructure Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>OOO</td>
<td>22.1</td>
<td>mostly martensite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Multiple centerline banding</td>
</tr>
<tr>
<td>ORR</td>
<td>22.0</td>
<td>very fine, mostly bainite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>An obvious centerline banding</td>
</tr>
<tr>
<td>ORB</td>
<td>20.2</td>
<td>mostly bainite, some martensite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Minimal banding</td>
</tr>
<tr>
<td>OOR</td>
<td>18.6</td>
<td>mixture of bainite/martensite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Almost no banding</td>
</tr>
</tbody>
</table>
Microstructures vs. Stretch Flangeability

- The percentage and composition (martensite and/or bainite) of the second phase of a DP490 steel seems important.
- The existence of banding structure appears to have a negative effect on DP490 flangeability.
A multiple variable linear regression analysis for critical flange height $h_c$ was conducted using SAS for all testing results (four DP490 and one BH210 materials).

Equation:

$$h_c = a_0 + a_1 \sigma_T + a_2 R + a_3 \Delta t + a_4 \theta + a_5 e_{pre}.$$  

- $\sigma_T$: Tensile strength (MPa)
- $\Delta t$: Trim clearance (% of thickness)
- $R$: Flange radius (mm)
- $\theta$: Include angle (degree)
- $e_{pre}$: Prestrain (numbers in decimal)

The metal thickness was not included because of its correlation with trim clearance.
The doable stretch flange height of DP490 for all product geometry is about 1.5mm on the basis of experiment results.
Example of Design Guideline

- A hypothetical case of a door outer panel with features of different stretch flange radius and inclusion angle.
Example of Design Guideline

Flangeable Product Geometry for A Hypothetical Door
(UTS=556MPa, Δt=20%, Prestrain = 8%)

Flange Radius (mm)

Include Angle (degree)

H = 3mm

Doable Flanges

Undoable Flanges
The stretch flangeability of DP490 was studied with a new simulative flanging test

- The critical stretch flange height $h_c$ was determined experimentally under different material, geometry and process conditions
- The influential factors affecting the stretch flangeability of DP490 were identified
- The relationship between the microstructures of DP490 and the stretch flangeability was examined
- A useful multiple variable linear regression model for the panel design of DP490 material was established on the basis of experiment results