Localized Buckling Solutions for Thin-Gauge UHSS Bumper Beams

Detroit Engineered Products (DEP)
Madhu Jampala
Avineet Ponde
Scope

• Use of UHSS to down gauge production bumper beams for maximum mass savings.
• Address localized buckling issues and achieve greater mass savings with geometry optimization.

3 Different Bumper Systems Evaluated:

• Roll-formed Bumper
• Hot-stamped Bumper
• Hot-formed Bumper (ACCRA)
Optimization Process

- Input – CAD/STL/FE
- FE Model Creation
- 3 Point Bending Test
- IIHS Low Speed Impact
- Parameterization
  - DEP - Meshworks
- DOE
- Optimization
- Final Optimized Design
ROLL FORMED BUMPER
**Bill Of Materials – Baseline**

**Roll Formed Production Bumper Baseline System – FEA Model**

<table>
<thead>
<tr>
<th>Part NO.</th>
<th>Component Name</th>
<th>Component Thickness (mm)</th>
<th>Yield Stress (Mpa)</th>
<th>Mass (Kgs)</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Crush Can</td>
<td>1.5</td>
<td>358.5</td>
<td>0.80</td>
<td>CR340</td>
</tr>
<tr>
<td>2</td>
<td>Crush Can Back Plate</td>
<td>3.9</td>
<td>358.5</td>
<td>0.81</td>
<td>CR340</td>
</tr>
<tr>
<td>3</td>
<td>Bumper Back Plate 1</td>
<td>2.5</td>
<td>358.5</td>
<td>0.25</td>
<td>CR340</td>
</tr>
<tr>
<td>4</td>
<td>Bumper Back Plate 2</td>
<td>2</td>
<td>358.5</td>
<td>0.48</td>
<td>CR340</td>
</tr>
<tr>
<td>5</td>
<td>Clip</td>
<td>1</td>
<td>507</td>
<td>0.02</td>
<td>DP780</td>
</tr>
<tr>
<td>6</td>
<td>Bumper Beam</td>
<td>1.2</td>
<td>507</td>
<td>3.22</td>
<td>DP780</td>
</tr>
<tr>
<td>7</td>
<td>MIG Weld</td>
<td></td>
<td></td>
<td>0.29</td>
<td>Spot weld Mat</td>
</tr>
</tbody>
</table>

Vehicle Mass= 1558 Kg  Beam Span = 1205 mm  System Mass = 5.87 Kg
### 3 – Point Bending Results

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>DP780</th>
<th>DP1180</th>
<th>MS1300</th>
<th>MS1500</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>7.2</td>
<td>12</td>
<td>13.3</td>
<td>14.9</td>
</tr>
<tr>
<td>1.15</td>
<td>10.7</td>
<td>11.6</td>
<td>13.2</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>9</td>
<td>9.8</td>
<td>11.1</td>
<td></td>
</tr>
<tr>
<td>1.05</td>
<td>8.5</td>
<td>9.3</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td>8.7</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>0.95</td>
<td>7.4</td>
<td>8.2</td>
<td>9.1</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>6.6</td>
<td>7.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.85</td>
<td>5.2</td>
<td>5.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Bumper Beam Mass**

- 3.27 Kg
- 2.59 Kg
- 2.45 Kg

**Mass Savings**

- 0.68 Kg
- 0.82 Kg

*The gauge for which the bumper beam performance is matched to the Baseline performance lies between 0.85mm to 0.9mm*
IIHS Curved Barrier Results (10 km/hr)

DP 780 Baseline - 1.2 mm
- Local Buckling
- Peak force = 15.4 KN

MS1300 - 0.9 mm
- Local Buckling
- Peak force = 16.2 KN
Geometry Optimization

Bottom Bead 1

Parametric FE Model - Meshworks

Top Bead 1

Bottom Bead 2

Top Bead 2

Central Bead Hinge
Dimple Study

6-Rows Dimples

Dimples Diameter = 5mm
Dimples Depth = 1mm
Dimples Pitch = 20mm

Dimples Diameter = 7.5mm
Dimples Depth = 2mm
Dimples Pitch = 35mm

Dimples Diameter = 10mm
Dimples Depth = 2.5mm
Dimples Pitch = 50mm

4-Rows Dimples

Dimples Diameter = 12.5 mm
Dimples Depth = 3mm
Dimples Pitch = 65mm

Dimples Diameter = 12.5 & 15mm
Dimples Depth = 3 & 3.5mm
Dimples Pitch = 80mm

Dimples Diameter = 12.5 & 17.5mm
Dimples Depth = 3 & 4mm
Dimples Pitch = 95mm

Dimples Diameter = 12.5 & 20mm
Dimples Depth = 3 & 4.5mm
Dimples Pitch = 110mm

Dimples Diameter = 12.5 mm
Dimples Depth = 3mm
Dimples Pitch = 65mm
Optimization Setup

• Optimization carried out for the IIHS Curved Barrier
• Design Variables – 25
  – Bead Shape Parameters - 17
  – Dimples Shape Parameters - 4
  – Gauge Parameters - 2
  – MAT Parameters - 2
• DOE Matrix Generated 222 designs
• Response surface created and optimized for the below scenarios
  – Minimize Mass and Maximize 1st peak Bumper Force
  – Zero Local Buckling Distance
Optimized Design

Optimized Beam
0.8 mm MS1500
Mass: 2.28 Kg (-29%)

Peak force = 15.4KN
IIHS Curved Barrier Comparison

Baseline – DP780

Baseline

Peak force = 15.4 KN

Optimized Design – MS1500

Optimized

Peak force = 15.4KN
Design Variable Sensitivity

Most Influence: Top Bead Height & Width

Least Influence: Bottom Bead Hinge & Width
# IIHS Curved Barrier Results Summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Baseline - DP780</th>
<th>Optimized Design - MS1500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bumper Beam 1st Peak Force (kN)</td>
<td>15.4</td>
<td>15.4</td>
</tr>
<tr>
<td>Bumper Beam Thickness (mm)</td>
<td>1.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Local Buckling Distance (mm)</td>
<td>47</td>
<td>3.4</td>
</tr>
<tr>
<td>Back Plate Distance (mm)</td>
<td>127.7</td>
<td>125.4</td>
</tr>
<tr>
<td>Bumper Beam Mass (Kg)</td>
<td>3.22</td>
<td>2.28 (-29%)</td>
</tr>
<tr>
<td>Total Mass (Kg)</td>
<td>5.87</td>
<td>4.95 (-16%)</td>
</tr>
</tbody>
</table>
Conclusions

- A lightweight bumper beam was achieved with 29% mass savings and no localized buckling.
- 19% of the mass savings was due to MS1500 material and the other 10% was from geometry optimization.
- Dimples helped reduce mass but did not solve localized buckling issue.
- The design parameters with the largest influence on improving localized buckling were top bead height and width.
- The design parameters with the least influence on improving localized buckling were bottom bead hinge and width.
HOT-STAMPED BUMPER
Bill of Materials - Baseline

Hot-Stamped Production Bumper Baseline System – FEA Model

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Component Name</th>
<th>Component Thickness (mm)</th>
<th>Yield Stress (MPa)</th>
<th>MASS (Kg)</th>
<th>MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Crush Can</td>
<td>1.5</td>
<td>408</td>
<td>0.85</td>
<td>DP590</td>
</tr>
<tr>
<td>2</td>
<td>Crush Can Back Plate</td>
<td>2.5</td>
<td>408</td>
<td>0.69</td>
<td>HSLA340</td>
</tr>
<tr>
<td>3</td>
<td>Bumper Back Plate</td>
<td>1.5</td>
<td>408</td>
<td>1.01</td>
<td>DP590</td>
</tr>
<tr>
<td>4</td>
<td>Bumper Beam</td>
<td>1.5</td>
<td>962</td>
<td>2.32</td>
<td>PHS1300</td>
</tr>
<tr>
<td>5</td>
<td>MIG Weld</td>
<td></td>
<td></td>
<td>0.13</td>
<td>Weld Mat</td>
</tr>
</tbody>
</table>

Vehicle Mass = 906 Kg          Beam Spam = 1166 mm          System Mass = 5.00 Kg
# 3-Point Bending Results

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>Bumper Beam</th>
<th>Back Plate</th>
<th>PHS 1300</th>
<th>PHS 1900</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>1.5</td>
<td><strong>14.28</strong></td>
<td>18.29</td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td>1.3</td>
<td>16.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td>1.2</td>
<td>16.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>1.4</td>
<td>14.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>1.3</td>
<td>14.56</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>1.2</td>
<td>14.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>1.1</td>
<td>14.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>1.0</td>
<td><strong>14.26</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Bumper Beam Mass | 4.08 | 3.31 |

| Mass Savings | **0.77 kg (-19%)** |
IIHS Curved Barrier (10 km/hr)

**Baseline - PHS1300**
- Bumper: 1.5 mm
- Back Plate: 1.5 mm
- Mass: 3.33 Kg
- Peak force: 14.0 kN

**PHS1900**
- Bumper: 1.5 mm
- Back Plate: 1.0 mm
- Mass: 2.69 Kg
- Peak force: 13.8 kN
Geometry Optimization

- Bottom Bead Height
- Top Bead Height
- Middle Bead Width
- Middle Bead Height
- Back Plate Beads

Parametric FE Model - Meshworks
Optimization Setup

- Optimization carried out for the IIHS Curved Barrier
- Design variables – 52
  - Shape Parameters - 25
  - Gauge Parameters - 26
  - TRB Parameter - 1
- DOE Matrix Generated 277 Designs
- Response surface created and optimized for the below scenarios
  - Minimize Mass and Maximize 1st Peak Bumper Force
  - Zero Local Buckling Distance
Optimized Design

Peak force = 14.7 kN

Optimized Beam
Beam: 1.2 mm PHS1900
Back Plate: 0.7 mm DP980
Mass: 2.21 kg (-33%)

*Back-plate material upgraded to DP 980
*Bumper flanges eliminated for mass-savings
IIHS Curved Barrier Comparison

Baseline – PHS1300

Optimized Design – PHS1900

Baseline

Peak force = 14.0 kN

Optimized

Peak force = 14.7 kN
• The boxed areas of the beam need to be strong and hence higher gauges need to be used in these areas
**Design Variable Sensitivity**

### Shape Variable Sensitivity

1. Middle Bead Width & Back Plate Beads are the most influencing shape variables.
2. Bottom Bead Height Parameters may not give positive results.

**Most Influence:** Middle bead width and back-plate beads

**Least Influence:** Bottom Bead Height

*** Blue – Positive Effect (increase in value will give better performance)

*** RED – Negative Effect (increase in value may decrease in performance)
## IIHS Curved Barrier Results Summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Baseline - PHS1300</th>
<th>Optimized Design - PHS1900</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bumper Beam 1st Peak (kN)</td>
<td>14.0</td>
<td>14.7</td>
</tr>
<tr>
<td>Bumper Beam &amp; Back Plate Thickness (mm)</td>
<td>1.5 / 1.5</td>
<td>1.2 / 0.7</td>
</tr>
<tr>
<td>Bumper Beam Mass (kg)</td>
<td>3.33</td>
<td>2.21 (-33%)</td>
</tr>
<tr>
<td>Total Mass (kg)</td>
<td>5.00</td>
<td>3.87 (-23%)</td>
</tr>
</tbody>
</table>
Conclusions

- A lightweight bumper beam was achieved with 33% mass savings and no localized buckling.

- 19% of this mass savings was due to PHS1900 material and the other 14% was from geometry optimization.

- Using TRB resulted in an additional 4% mass savings for the bumper beam. However, this was not judged high enough to justify additional processing cost.

- The design parameters with the largest influence on improving localized buckling were middle bead width and back – plate beads.

- The design parameter with the least influence on improving localized buckling was bottom bead height.
HOT-FORMED BUMPER
(ACCRA™)
Bill of Materials – Baseline

Hot Formed Production Bumper Baseline System – FEA Model

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Component Name</th>
<th>Thickness (mm)</th>
<th>Yield Stress (MPa)</th>
<th>Mass (Kg)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Back Plate</td>
<td>2.0</td>
<td>358</td>
<td>0.92</td>
<td>CR340</td>
</tr>
<tr>
<td>3</td>
<td>Bumper</td>
<td>1.2</td>
<td>962</td>
<td>4.59</td>
<td>PHS1500</td>
</tr>
<tr>
<td>4</td>
<td>Spot &amp; MIG Weld</td>
<td></td>
<td></td>
<td>0.002</td>
<td>Weld Mat</td>
</tr>
</tbody>
</table>

Vehicle Mass = 1678 Kg  
Beam Spam = 1105 mm  
System Mass = 5.51 Kg
## 3 – Point Bending Results

<table>
<thead>
<tr>
<th>Thickness (mm)</th>
<th>Peak Force (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bumper Beam</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>33.02</td>
</tr>
<tr>
<td>1.15</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>1.05</td>
<td></td>
</tr>
<tr>
<td>Bumper Beam Mass</td>
<td>4.96</td>
</tr>
<tr>
<td>Mass Savings</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- Bumper Beam Mass: 4.96 kN for PHS 1500, 4.34 kN for PHS 1900.
- Mass Savings: 12.5%.
IIHS Curved Barrier (10 km/hr)

PHS1300 Baseline – 1.2 mm

PHS1900 – 1.05 mm

Peak force = 140.0 kN

Peak Force = 154.0 kN
Geometry Optimization

Top_Bead_Height_1  Bottom_Bead_Height_1  Top_Bead_Width_1  Bottom_Bead_Width_1  Center_Bead_width_Parameter

Parametric FE Model - Meshworks

Taper_Parameter_2  Taper_Parameter_1  Center_Uniform_Section  Back_Bead  Hinge_Parameter

Steel Matters Demand Nothing Less www.autosteel.org
Optimization Setup

• Optimization carried out for the IIHS Curved Barrier
• Design variables – 15
  – Shape Parameters -14
  – Gauge Parameters - 1
• DOE Matrix Generated 81 Designs
• Response surface created and optimized for the below scenarios
  – Minimize Mass and Maximize 1st Peak Bumper Force
  – Zero Local Buckling Distance
Optimized Design

End Section  Center Section

94 mm  107 mm
54 mm  57.8 mm

Optimized Beam
0.95 mm PHS1900
Mass: 3.53 Kg (-23%)
IIHS Curved Barrier

Baseline – PHS1300

Optimized Design – PHS1900

Baseline

Peak Force = 140 kN

Optimized Design

Peak Force = 147 kN
Design Variable Sensitivity

Shape Variable Sensitivity

Most Influence

- Top Bead Height
- Back Bead
- Taper Parameter
- Bottom Bead Width 1
- Hinge Parameter

Least Influence
## IIHS Curved Barrier Results Summary

<table>
<thead>
<tr>
<th>Description</th>
<th>Baseline - PHS1300</th>
<th>Optimized Design - PHS1900</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bumper Beam 1st Peak (kN)</td>
<td>140</td>
<td>147</td>
</tr>
<tr>
<td>Bumper Beam Thickness (mm)</td>
<td>1.2</td>
<td>0.95</td>
</tr>
<tr>
<td>Bumper Beam Mass (kg)</td>
<td>4.59</td>
<td>3.53 (-23%)</td>
</tr>
<tr>
<td>Total Mass (kg)</td>
<td>5.51</td>
<td>4.48 (-19%)</td>
</tr>
</tbody>
</table>
Conclusions

- A lightweight bumper beam was achieved with 23% mass savings and no localized buckling.

- 12% of this mass savings was due to PHS1900 material and the other 11% was from geometry optimization.

- The design parameters with the largest influence on improving localized buckling were top bead height, back bead and taper.

- The design parameters with the least influence on improving localized buckling were hinge parameter and bottom bead width.
Mass Summary

- Mass savings after optimizing the 3 bumper beams for IIHS curved barrier are below:

<table>
<thead>
<tr>
<th>Bumper Beam Design</th>
<th>Baseline Beam</th>
<th>Optimized Beam</th>
<th>Percent Mass Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll - Formed</td>
<td>Material: DP 780</td>
<td>Material: MS 1500</td>
<td>Total = 29 %</td>
</tr>
<tr>
<td></td>
<td>Gauge = 1.2 mm</td>
<td>Gauge = 0.8 mm</td>
<td>Grade Effect</td>
</tr>
<tr>
<td></td>
<td>Mass = 3.22 kg</td>
<td>Mass = 2.28 kg</td>
<td>19</td>
</tr>
<tr>
<td>Hot - Stamped</td>
<td>Material: PHS 1300 (beam)</td>
<td>Material: PHS 1900 (beam)</td>
<td>Total = 33 %</td>
</tr>
<tr>
<td></td>
<td>DP590 (back plate)</td>
<td>DP 980 (back plate)</td>
<td>Grade Effect</td>
</tr>
<tr>
<td></td>
<td>Bumper Beam Gauge = 1.5mm Back Plate Gauge = 1.5 mm</td>
<td>Bumper Beam = 1.2 mm Back Plate Gauge = 0.7 mm</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Mass = 3.33 kg</td>
<td>Mass = 2.21 kg</td>
<td></td>
</tr>
<tr>
<td>Hot - Formed</td>
<td>Material: PHS 1300</td>
<td>Material: PHS 1900</td>
<td>Total = 23 %</td>
</tr>
<tr>
<td></td>
<td>Gauge = 1.2 mm</td>
<td>Gauge = 0.95 mm</td>
<td>Grade Effect</td>
</tr>
<tr>
<td></td>
<td>Mass = 4.59 kg</td>
<td>Mass = 3.53 kg</td>
<td>12</td>
</tr>
</tbody>
</table>
Presentations will be available May 18 at www.autosteel.org

Great Designs in Steel is Sponsored by: