Application of Advanced High Strength Steels In Roof Strength Design

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• Motivation of Project.
• Review of Advanced High Strength Steel.
• General Design Approach.
• Final Performance & Lessons Learned.
Motivation of Project

• New FMVSS 216 requirement.
  – Current FMVSS 216 requirement:
    • Initial 5” intrusion.
    • Withstand a 1-1/2 time vehicle gross weight or 5000 lbs.

  – Proposed FMVSS 216 requirement.
    • Prevent structural intrusion that touches the head of a seated 50th percentile male dummy.
    • Withstand a 2-1/2 time vehicle gross weight.
Motivation of Project (Cont.)

• Benefits of AHSS:
  – Improve energy absorption for front Crash (ASP/LWFN).
  – Improve the occupant protection in Side Impact. (ASP/FGPC).
• Objective:
  – Improve the FMVSS 216 roof crush of a light duty truck from 1.5X to 2.5X GVW with AHSS and innovative design.

• Performance targets – 5” roof crush resistance (CAE).
  – Current – 1.5X GVW - 12,700 lbs.
  – Future – 2.5X GVW - 21,000 lbs.
• Weight targets.
  – To the extent possible, weight neutral to baseline light duty truck.
Overview of AHSS

- AHSS are composed of ferrite and other non-equilibrium transformation phases such as bainite, martensite, or retained austenite.

- AHSS includes:
  - Dual Phase (DP).
  - TRansformation-Induced Plasticity (TRIP).
  - Complex Phase (CP).
  - Martensite.
Dual Phase Steel

- Contains the soft ferrite phase with dispersed islands of a hard martensite phase.
- Exhibit low yield-to-tensile ratio, high initial work hardening.
- Has excellent balance of strength and formability.
Application of Dual Phase Steel

• DP500
  – Generally used for exposed outer body panels. The excellent formability, high work hardening, and bake hardening behavior, permitting designers to reduce gauge or improve performance where appropriate.

• DP600
  – Suitable for body structure and chassis frame application. It is often used in medium strength body structure parts that require both good formability and high crash energy absorption, such as front and rear longitudinal rails.
• DP780
  – Frequently used in body structure applications requiring high yield strength and adequate formability, such as passenger safety cage components limited by buckling or transverse bending.

• DP980
  – Used in bumpers, door beam and under body structure parts by either stamping or rollforming.
AHSS and Energy Absorption

![Graph showing the relationship between UTS at 10^{-3}/s, MPa and E_{10\%}, J/mm^3. The graph includes data points for Strain Rate 100/s and Strain Rate 500/s.]
AHSS and Maximum Bending Capacity

Theoretical Value based on perfect rigid plastic model

Boron Steel

Maximum Moment*

0 200 400 600 800 1000 1200

Yield Stress

DP600/HSLA350

DP500/BH280

M130

DP780

DP980

TRIP78

DQSK

DR210

www.autosteel.org
Crack Effect on Bending Capacity
Crack During Crash

Example of crack during the crash.

www.autosteel.org
AHSS Design Approach

Sensitivity Study
Design process
Performance evolution

Meet Target

Final Optimization of Gauge
Final Manufacturability Evaluation
Stop

Yes
No
Key components were identified by buckling location:
- A-Pillar
- C-Pillar
- Front Header (Inner & Outer)
- Rear Header
- Roof Rail (Inner & Outer)
- Cowl Side Inner
- Roof Bow
To seek the design direction, the sensitivity study was performance.
  - Gauge
  - Grade

Methodology.
  - Independently substituting

Sensitivity.
  - Improvement of roof strength for grade improvement of roof strength divided by mass penalty for gauge.
## Sensitivity Design Domain

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Study Domain</th>
<th>Normalized Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Study Domain</td>
</tr>
<tr>
<td></td>
<td>Grade</td>
<td>Gauge (mm)</td>
</tr>
<tr>
<td>Rear Header</td>
<td>DQSK</td>
<td>DP600</td>
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<tr>
<td>Front Header Inner</td>
<td>HSLA350</td>
<td>DP980</td>
</tr>
<tr>
<td>Front Header Outer</td>
<td>HSLA350</td>
<td>DP980</td>
</tr>
<tr>
<td>C-Pillar</td>
<td>DR210</td>
<td>DP780</td>
</tr>
<tr>
<td>Roof Bow</td>
<td>DR210</td>
<td>M130</td>
</tr>
<tr>
<td>Roof Rail Otr Frt</td>
<td>BH280</td>
<td>DP980</td>
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<tr>
<td>Roof Rail Otr RR</td>
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<td>DP980</td>
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<tr>
<td>Roof Rail Inner</td>
<td>BH280</td>
<td>DP980</td>
</tr>
<tr>
<td>A-Pillar</td>
<td>DR210</td>
<td>DP980</td>
</tr>
</tbody>
</table>

N/A = contribution to roof crush strength was not significant.
Gauge Sensitivity (1st Iteration)

UPDATE PROPOSAL DESIGN
Time: 0

Front Header: 0.62
C-Pillar: 0.14
Roof Rail: 1.0
A-Pillar: 0.13
Material Sensitivity (1st Iteration)

Front Header: 0.05
C-Pillar: 0.44
Roof Bow: 0.13
Roof Rail: 0.67
A-Pillar: 1.0
Add new Reinf 1.0 mm DP780 to DP590 A-Pillar Inner

Design change to LWB and add local stiff beads

Rollformed Rear Header, 0.8 mm DP980

Rollformed Roof Rail, 1.2 mm DP780

Rollformed Roof Bow 0.7 mm DP980

Design Change to LWB

Add new Reinf 1.0 mm DP780 to DP590 A-Pillar Inner
Example of Design Modification

Hole removed in new Design  Added new Stiff Beads

1.2 mmDP780

0.9 mmDP780
Example of New Local Reinforcement

View A

View B
Roof Rail Outer RR

Original Design

C-Pillar

Reinforcement Design at C-Pillar Upper

C-Pillar Double Reinf

Reinforcement Design
Performance Evaluation

AHSS Design: Meet new Federal regulation

OEM Design: Meet existing Federal Regulation

5” Displacement

Force (N)

Displacement (mm)
### Performance & Weight Comparison

<table>
<thead>
<tr>
<th></th>
<th>Δ Mass (lbs)</th>
<th>Performance (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>-</td>
<td>12,750</td>
</tr>
<tr>
<td><strong>Conventional approach</strong></td>
<td>42.0</td>
<td>20,000</td>
</tr>
<tr>
<td><strong>AHSS only</strong></td>
<td>13.0</td>
<td>21,000</td>
</tr>
</tbody>
</table>
Critical parts verified feasible to form using AutoForm Incremental Forming FEA.

Example: FRT HEADER REINF – 1.2 mm DP980
• AHSS is an effective enabler.
  – DP780, TRIP780, DP980 and M900 are good candidates for key roof strength components.

• Material selection.
  – Highest possible strength.
  – Sufficient formability and ductility.
    • Part fabrication feasible.
    • avoid cracking during crash event.
• A holistic approach.
  – Careful selection of steel grades and thickness.
  – Appropriate manufacturing processes.
  – Part geometry modification and new parts designed.
    • Accommodate the formability of the AHSS.
    • Improve the structure performance with minimum weight increase.
Q&A