Hybrid Advanced High-Strength Steel Design Options for Meeting Enhanced Roof Crush Requirements

Mansour Mirdamadi  Blake Zuidema
Mustafa Ahmed     Liang Huang
Alan Robinson     Min Kuo

Dow Automotive  Mittal Steel USA

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Microstructure of dual phase steel

- AHSS are composed of ferrite and other non-equilibrium transformation phases such as bainite, martensite, or retained austenite
- Exhibit low yield-to-tensile ratio, high initial work hardening
- Has excellent balance of strength and formability

AHSS includes

- Dual Phase (DP)
- Transformation-Induced Plasticity (TRIP)
- Complex Phase (CP)
- Martensite
BETAFOAM™ Product Overview

- BETAFOAM is a family of PU foam-based products
  - Two-component iso/polyol system
  - Components react when mixed to form closed cell foam at **room temperature**
- Product portfolio includes
  - Bulk foam products
    - Classical MDI foam formulations
    - Low MDI foam formulations
  - Molded products
    - Structural Foam Insert (SFI)
- Application Fit
  - BIW Engineering – bulk and parts
    - OEM In-plant implementation – post-paint or G/A
    - Pre-OEM plant implementation – Tiers (POA)
  - Chassis Engineering - bulk
    - Engine cradles and suspension cross members - Tiers (POA)
**BETAFOAM Benefits**

- **Potential Application**
  - Performance improvements required but locked or carry-over structural content
  - Performance efficiency required with new structural content or vehicle architecture
  - Enhance / maintain performance w/o growing sections or changing styling theme

**Added mass**

<table>
<thead>
<tr>
<th>Added mass</th>
<th>0.38 kg</th>
<th>0.77 kg</th>
<th>1.15 kg</th>
<th>0.31 kg</th>
</tr>
</thead>
</table>

**Outer Tube:**
- \( d = 50 \text{ mm} \), \( t = 0.9 \text{ mm} \)
- Finish: E-coated and painted
- Tube mass: 571 g
- Foam mass: **352 g**
**Project Objectives**

- **Objectives**
  - To develop an innovative design solution that allows integration of AHSS and BETAFOAM (cavity reinforcement) and BETAMATE (structural bonding) while providing
    - Enhanced roof crush resistance
    - Lightest mass as compared to conventional design approach
    - Optimized for reducing total system cost

- **Hypothesis**
  - AHSS and structural foam offers lighter solutions than what could be achieved by either material individually
Evaluations of BETAFOAM and AHSS

• Objectives
  ➢ To perform quasi-static studies of hollow tube subjected to four-point bending
  ➢ To perform sensitivity studies based on thickness of metal
  ➢ To establish differences in load-deflection response, energy absorption, and mass efficiency (peak load per mass)

• Problem definition
  ➢ 70 mm diameter HSLA steel tube
  ➢ Simply supported at the ends
  ➢ Baseline thickness 2.5 mm (mass: 1.97 kg)
  ➢ Total length: 458 mm
  ➢ Subjected to quasi-static loading

• BETAFOAM evaluation studies
  ➢ BETAFOAM 87100/87124 24 pcf PU foam system
  ➢ Mass: 0.67 kg

• Steel thickness studied
  ➢ 2.5 mm, 2.25 mm, 2.0 mm, 1.75 mm, and 1.5 mm

• Steel grades
  ➢ HSLA 350 and DP780
Enhanced Load Carrying Capability

Assumptions: No steel failure is allowed
Performance, Mass, and Cost Assessment

Cost: material only
Tube length: 16 ft

Normalized Performance, Mass, & Costs

- Force
- Material Costs
- Total Mass
Technical Approach

Evaluate BIW structural response

Sensitivity Studies

Thickness & reinforcements
Steel grades
BETAFOAM treatment
Structural bonding

Evaluate mass and performance efficiency

Develop and evaluate hybrid solution

Achieved targets?

Yes

Seek buy-in

No

Implement

Additional options to be considered
Baseline Performance Assessment

Buckling zones
AHSS Substitution Design

- AHSS substituted into baseline geometry with no up gauge:
  - Peak load 70% of target

- AHSS substituted into baseline geometry, upgauged to achieve close to roof crush requirements
  - Mass penalty 42 lbs

Innovative design is necessary to further improve the performance and mass efficiency of structure
Structural Foam Sensitivity Studies

<table>
<thead>
<tr>
<th>Iterations</th>
<th>Added Mass (kg)</th>
<th>BIW Energy</th>
<th>Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iter 1</td>
<td>0.8</td>
<td>5%</td>
<td>6%</td>
</tr>
<tr>
<td>Iter 2</td>
<td>1.6</td>
<td>11%</td>
<td>10%</td>
</tr>
<tr>
<td>Iter 3</td>
<td>3.1</td>
<td>19%</td>
<td>18%</td>
</tr>
<tr>
<td>Iter 4</td>
<td>4.7</td>
<td>29%</td>
<td>30%</td>
</tr>
<tr>
<td>Iter 5</td>
<td>5.5</td>
<td>28%</td>
<td>38%</td>
</tr>
<tr>
<td>Iter 6</td>
<td>8.9</td>
<td>48%</td>
<td>52%</td>
</tr>
<tr>
<td>Iter 7</td>
<td>6.0</td>
<td>28%</td>
<td>42%</td>
</tr>
</tbody>
</table>

- Structural foam mass is not optimized
- Critical locations
  - A-pillar
  - A-pillar to roof header
  - Mid section of C-pillar
  - C-pillar to roof header
  - Rear header
- New iterations include the content of the previous iteration content
- Innovative design is necessary to further improve the performance and mass efficiency of structure

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Hybrid Design Content

- Redesign the critical components with TWB and roll forming
  - Add A-Pillar reinforcement
  - Roll forming roof rail tube
  - Roll forming roof bow & rear header
  - Redesign cowl side inner

- Apply BETAFOAM in critical locations in AHSS design
  - C-Pillar Upper Area
  - C-Pillar Middle Area
Structural BETAFOAM
Combined Benefits

- Enabler to AHSS in locally reinforcing BIW structure without the need of additional metal reinforcements or material thickness increases

<table>
<thead>
<tr>
<th></th>
<th>Steel Only</th>
<th>AHSS &amp; C-Upper &amp; C-Mid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Bending</td>
<td>34.27</td>
<td>35.32 (+1.05 Hz)</td>
</tr>
<tr>
<td>2nd Bending</td>
<td>37.39</td>
<td>39.05 (+1.66 Hz)</td>
</tr>
<tr>
<td>Match Boxing</td>
<td>40.02</td>
<td>42.24 (+2.22 Hz)</td>
</tr>
</tbody>
</table>

- Acoustic sealing of BIW cavities and improving system level NVH
- Improves BIW, and TBIW static and dynamic stiffness resulting in better ride and handling, and a reduction of acoustic treatment
Comparison of Energy Absorption Characteristics Compared to Baseline

Energy Absorption Significantly Improved

- Baseline
- AHSS without BETAFOAM
- AHSS with BETAFOAM

Comparison of Energy Absorption Characteristics Compared to Baseline

- BIW
- FRONT DOOR
- REAR DOOR
Performance Assessment Summary

- AHSS and structural BETAFOAM offers lighter solutions than what could be achieved by either material alone.
- AHSS w/ BETAFOAM (optimized) provides a 10% cost savings over conventional solution.
- Mass penalty associated with optimized AHSS BETAFOAM solutions +5.3 lbs as compared to +42 lbs using conventional approaches.
- BIW first bending frequency improvement: +1.0 Hz.
- BIW match boxing frequency improvement: +2.0 Hz.
Lessons Learned

• Innovative synergistic design approach recognizing the benefits of AHSS and structural BETAFOAM product attributes are key for achieving performance while minimizing cost & weight

• Hybrid design elements
  ➢ AHSS
    - Roll formed component
    - LWB potential option for optimization
  ➢ Structural BETAFOAM treatment
    - C-Pillar Upper Area
    - C-Pillar Middle Area
    - A-Pillar (optional)

• BETAFOAM provides flexibility in
  ➢ Reduction of sheet metal thickness
  ➢ Elimination of metal reinforcements
  ➢ Locally reinforces sheet metal while providing stiffness continuity across body joints and pillars
  ➢ Fine tuning required chemistry to provide balance between mass, cost, and performance
  ➢ Sealing BIW hollow cavities while providing NVH benefits