NEW STEEL TUBE DESIGN FOR BEV BATTERY ENCLOSURE PROTECTION – C-STAR™ (CLIFFS STEEL TUBE AS REINFORCEMENT)

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I would like to acknowledge the great contributions from our team members:

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Issac Luther, Dawn Stubbleski (TWB Company)

Greatly appreciate the support from Cleveland-Cliffs Inc.
AGENDA

- BACKGROUND
- C-STAR™ DESIGN DETAILS
- TEST RESULTS
- CORRELATION AND C-STAR™ ADVANTAGES
- MANUFACTURABILITY
- SUMMARY AND FUTURE ACTIVITIES
Battery protection becomes more and more important.

For curb weight, BEVs (battery electric vehicle) are roughly 20% heavier than similar size of ICEs (internal combustion engine) vehicles.\(^1\)

One of the biggest challenges is to protect the battery enclosure under severe side impact load.
• Rocker reinforcement of BEVs covers more area longitudinally than ICE vehicles.
• The function of it is mainly considered as battery side load protection.
• Compared with ICE, more material distributed laterally in BEVs rocker reinforcement is beneficial for energy absorption and intrusion protection.
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- CAE RESULTS AND CORRELATION
- MANUFACTURABILITY
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C-STAR™ DESIGN DETAILS

- Long, uniform, hollow design space is ideal for tube design.

- Chamber shapes are effective for energy absorption.

- C-STAR™ are developed and compared with aluminum baseline.

- Laser weld is used to join three tubes together with minimum HAZ (heat affected zone) and around 3x thickness penetration.

Cross section comparison of aluminum baseline and steel tube design.
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TEST SET UP

• Three-point bending is conducted to assess the performance.

• The anvil is speed controlled.

• Force-displacement data is collected and video is recorded by digital image correlation camera.

• Both peak force and energy absorption are evaluated.

Zwick Roell HTM 16020 high speed testing machine
- 0.001~20m/s loading rate
- 160kN nominal force
- Tensile, axial crush, three-point bending capability
- 300mm effective piston stroke
TEST RESULTS – 2 CHAMBERS ALUMINUM

- Aluminum part is 4.6mm thick with 6000 series grade, 2.0kg.
- Aluminum 2 chambers sample; 107kN peak force.
- Catastrophic failure after reaching peak load.
TEST RESULTS – C-STAR™

- FORMTUBE® 800 tubes, 1.2mm, 1.4kg.
- C-STAR™; 45kN peak force.
- Stable load displacement curve after peak force. The structure can still maintain high level load.
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• CAE model shows a well captured plastic deformation area.
CAE model establishes a good correlation with physical test.
C-STAR™ ADVANTAGES

Force - Energy Absorption vs Displacement

F: Force
E: Energy

ULTRALUME® 1500, 1.9mm, F
ULTRALUME® 1500, 1.7mm, E
ULTRALUME® 1500, 1.4mm, F
ULTRALUME® 1500, 1.4mm, E
### C-STAR™ ADVANTAGES

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Peak Force</th>
<th>Energy equivalent point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum Baseline</td>
<td>2.0kg</td>
<td>107kN</td>
<td></td>
</tr>
<tr>
<td>C-STAR™ ULTRALUME®1500, 1.4mm</td>
<td>1.7kg (-15%)</td>
<td>87kN (-19%)</td>
<td>55mm</td>
</tr>
<tr>
<td>C-STAR™ ULTRALUME®1500, 1.7mm</td>
<td>2.0kg (+0%)</td>
<td>125kN (+17%)</td>
<td>42mm</td>
</tr>
<tr>
<td>C-STAR™ ULTRALUME®1500, 1.9mm</td>
<td>2.3kg (+15%)</td>
<td>149kN (+40%)</td>
<td>34mm</td>
</tr>
</tbody>
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- With mass parity, C-STAR™ outperforms aluminum baseline around 17% peak force; more energy after 42mm deformation.
- The larger the EA zone, the greater the benefit for steel design.
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MANUFACTURABILITY – TUBE

Cleveland-Cliffs Tubular Components:

- **Makers of FORMTUBE®**
- Auto Structural/Exhaust - 60% of sales
- Widest product mix in ERW (Electric Resistance Welding) market:
  - Carbon and stainless grades
  - Galvanized, Aluminized, uncoated
  - EDDS (Extra Deep Drawing Steel) through Gen 3 AHSS (Advanced High Strength Steel)
- Un-matched ERW dimensional capability:
  - 0.8 mm minimum thickness
  - 150 mm maximum Diameter
  - 100:1 D/t capability
  - Custom shapes
- Leader in AHSS Tubular solutions
MANUFACTURABILITY – TUBE

ULTRALUME® PHS
1.6 mm thick
175 mm perimeter
35:1 D/t ratio

DP 980
1 mm thick
200 mm perimeter
65:1 D/t ratio

ULTRALUME® PHS
3 mm thick
227 mm perimeter
24:1 D/t ratio

DP 980
1 mm thick
200 mm perimeter
100:1 D/t ratio

NITRONIC 30 1200
0.8 mm thick
130 mm perimeter
50:1 D/t ratio

Capability to leverage AHSS grades for lightweighting applications
MANUFACTURABILITY – WELDING

- Welding fixture design
- Prototype Laser welding
- Penetration check (Marco)
- Welding strength check (Peel test)
Bake harden effect has a 6% improvement on peak force for this FORMTUBE® 800 tube.
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SUMMARY AND FUTURE ACTIVITIES

Summary:
- With similar mass, C-STAR™ outperforms aluminum baseline on:
  o Peak force.
  o Energy absorption at certain space.
- C-STAR™ is a sustainable, versatile and highly scalable product with cost and manufacturability efficiency.
- Being the largest flat-rolled steel company in NA, Cleveland–Cliffs provides a wide range of portfolio to meet customers' specifications.
SUMMARY AND FUTURE ACTIVITIES

Future activities:
- Investigation of different tube configurations: combinations of grade, gauge and geometry.
- Performance evaluation at sub-assembly level
- Mechanical joining methods assessment, such as bolting, riveting, etc.
- Other applications in the vehicle body structure
FOR MORE INFORMATION

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