

GREAT DESIGNS IN **STEEL**

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

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ACKNOWLEDGEMENT

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

Yu-Wei Wang, Sobhan Nazari, John Markryginnis, Jimmy Zhang, Feng Zhu, Sajan George, Scott Stevens, Jun Hu, Erik Anderson, Kevin Ward, Steve Walls Jr

Issac Luther, Dawn Stubleski (TWB Company)

Greatly appreciate the support from Cleveland-Cliffs Inc.

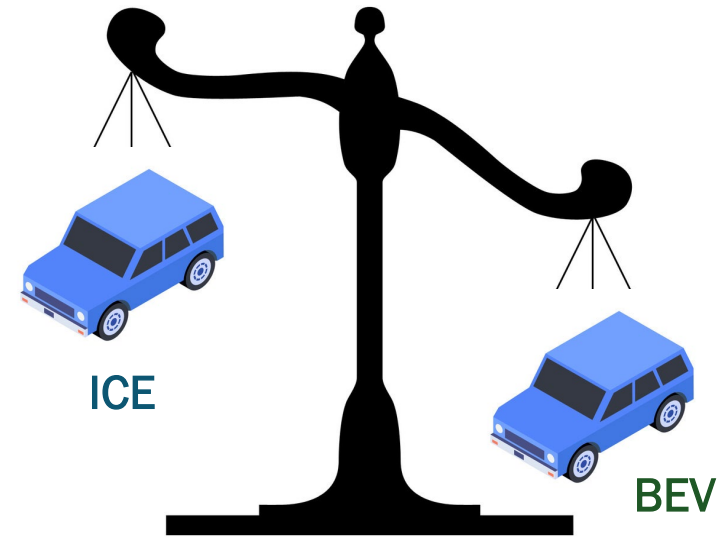


AGENDA

- **BACKGROUND**
- **C-STAR™ DESIGN DETAILS**
- **TEST RESULTS**
- **CORRELATION AND C-STAR™ ADVANTAGES**
- **MANUFACTURABILITY**
- **SUMMARY AND FUTURE ACTIVITIES**

BACKGROUND

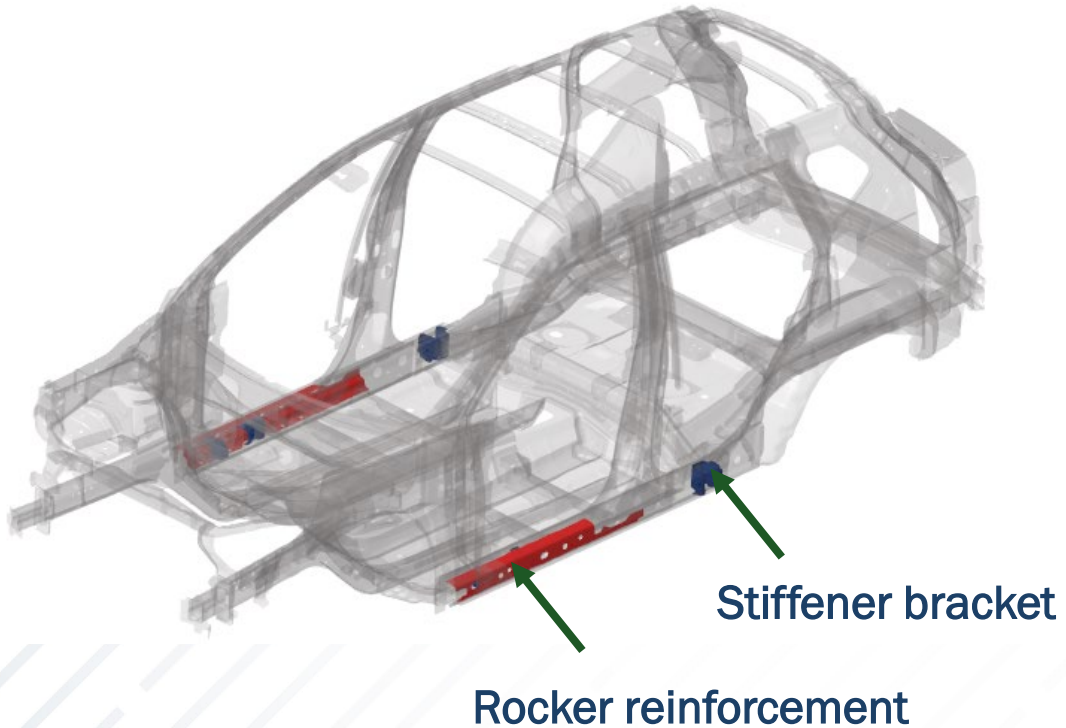
- Battery protection becomes more and more important.
- For curb weight, BEVs (battery electric vehicle) are roughly 20% heavier than similar size of ICEs (internal combustion engine) vehicles¹.
- One of the biggest challenges is to protect the battery enclosure under severe side impact load.



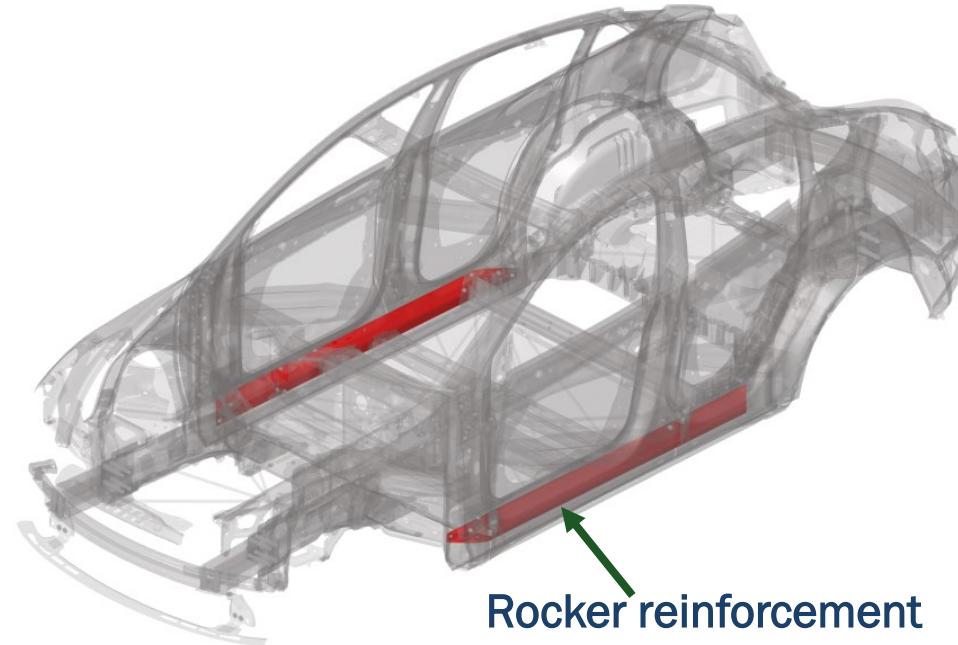
SOURCE: NHTSA-NCAP

BACKGROUND

ICE



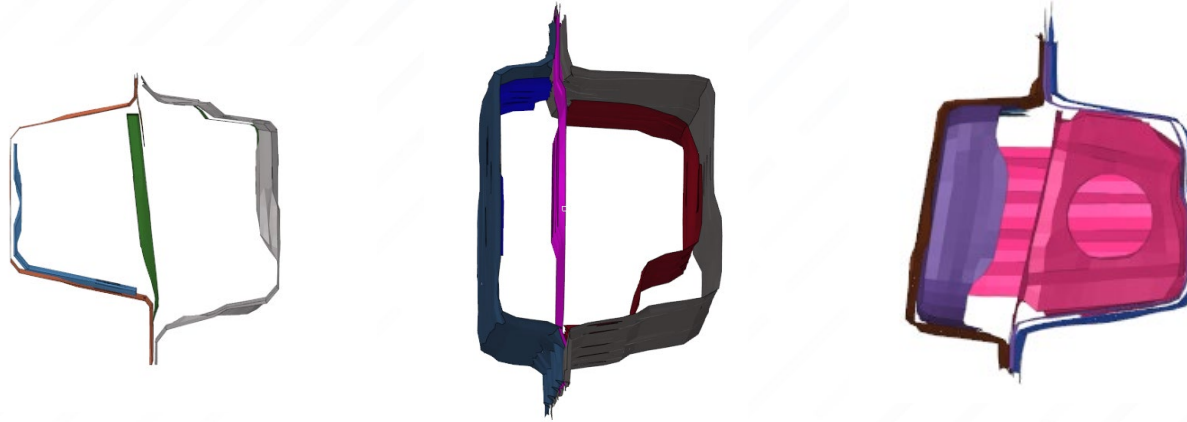
BEV



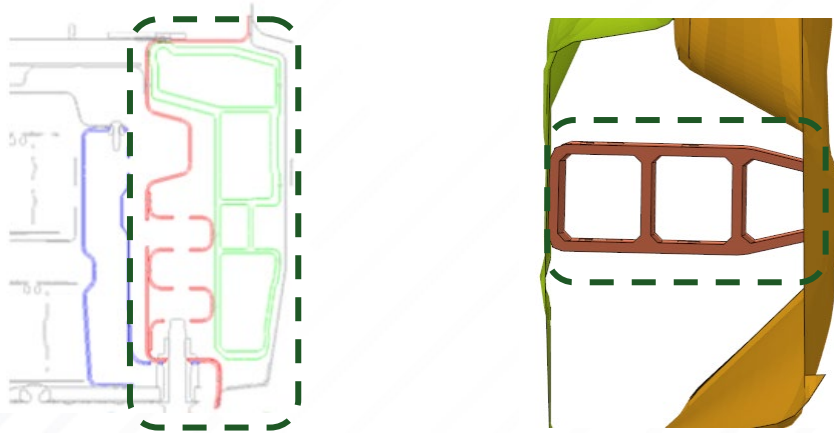
- Rocker reinforcement of BEVs covers more area longitudinally than ICE vehicles.
- The function of it is mainly considered as battery side load protection.

BACKGROUND

ICE



BEV



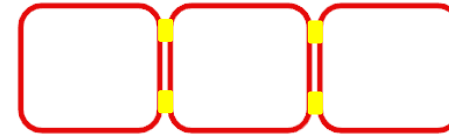
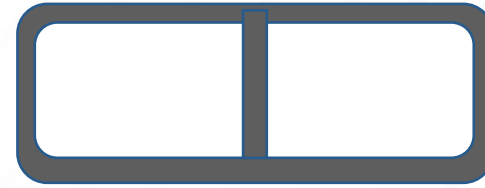
- Compared with ICE, more material distributed laterally in BEVs rocker reinforcement is beneficial for energy absorption and intrusion protection.

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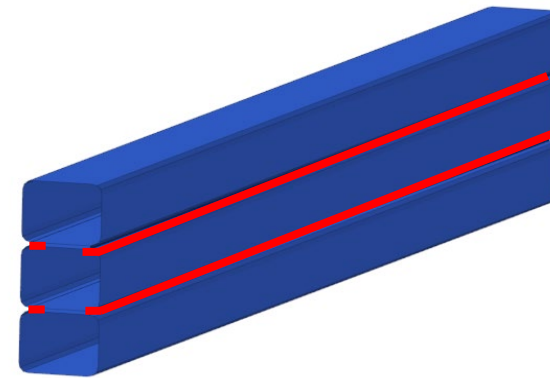
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- CAE RESULTS AND CORRELATION
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C-STAR™ DESIGN DETAILS

- 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

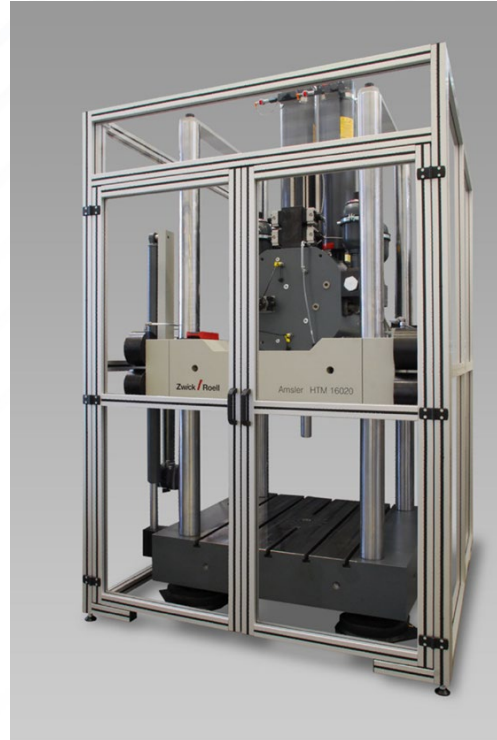


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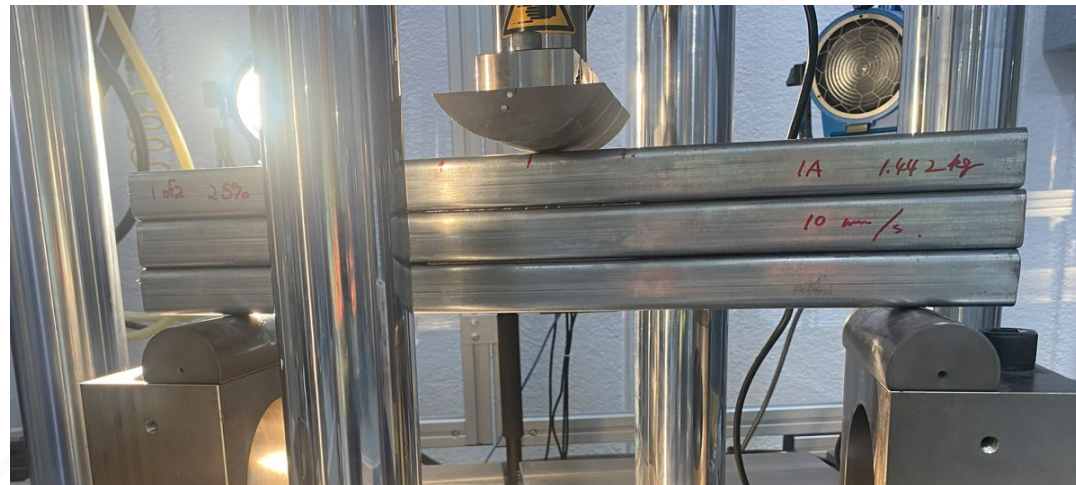
TEST SET UP

- 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

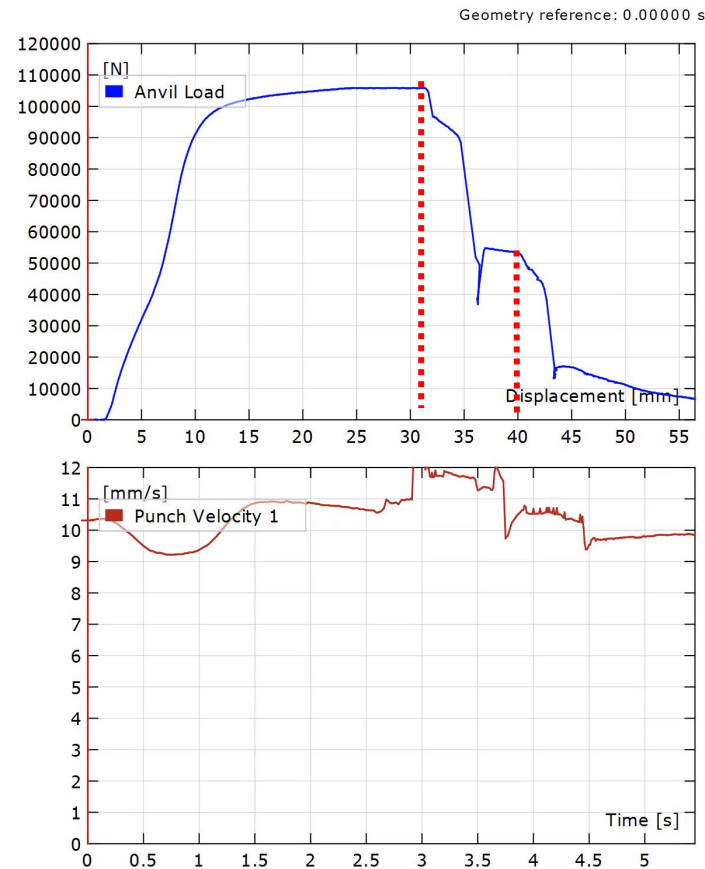
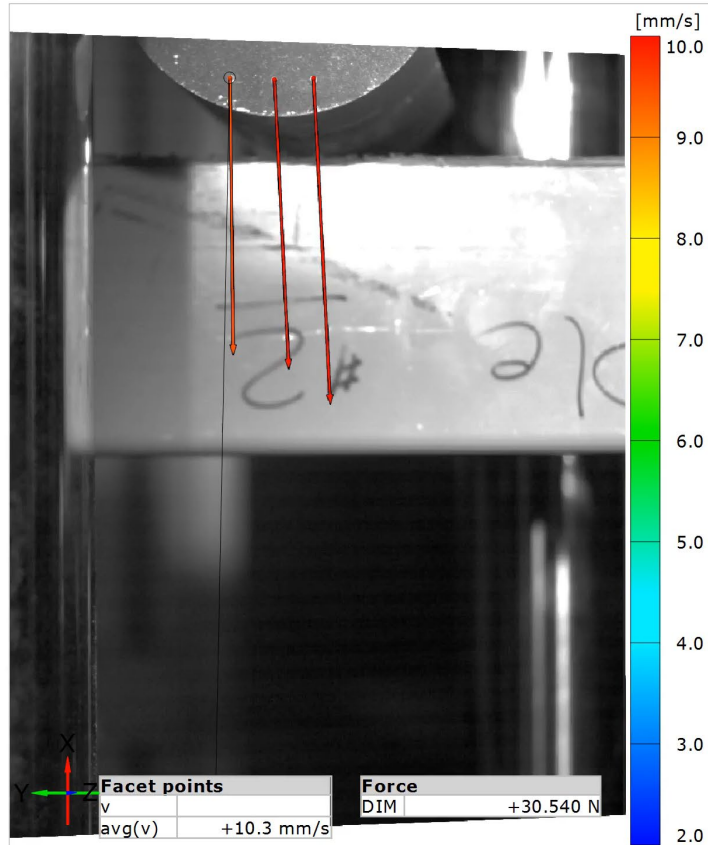
- 0.001~20m/s loading rate
- 160kN nominal force
- Tensile, axial crush, three-point bending capability
- 300mm effective piston stroke



TEST RESULTS - 2 CHAMBERS ALUMINUM

OEM Aluminum Extrusion 3-Point-Bending at 10mm/s

0.00000 s

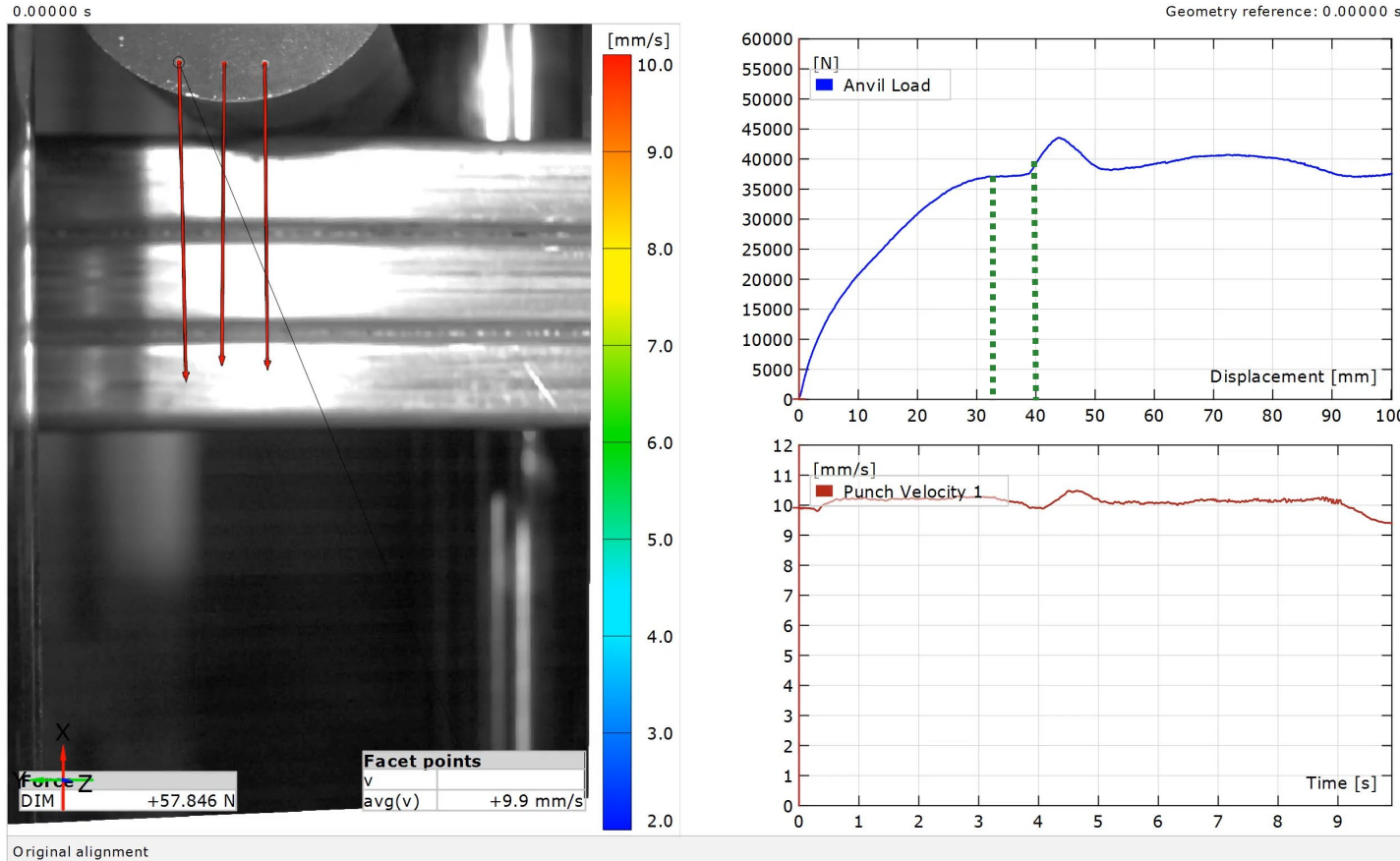


- Aluminum part is 4.6mm thick with 6000 series grade, 2.0kg.
- Aluminum 2 chambers sample; 107kN peak force.
- Catastrophic failure after reaching peak load.



TEST RESULTS – C-STAR™

FORMTUBE® 800 3-Point-Bending at 10mm/s



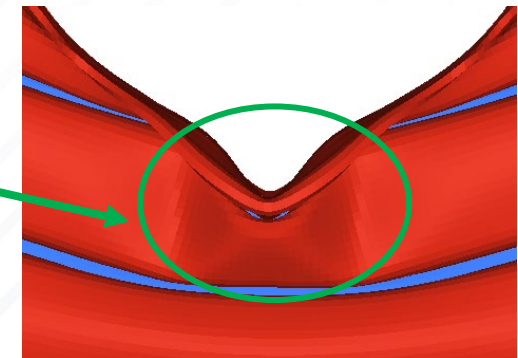
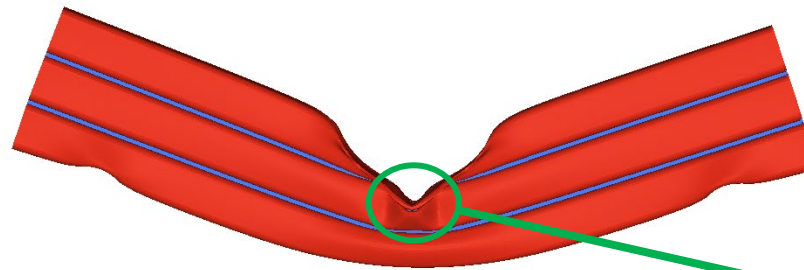
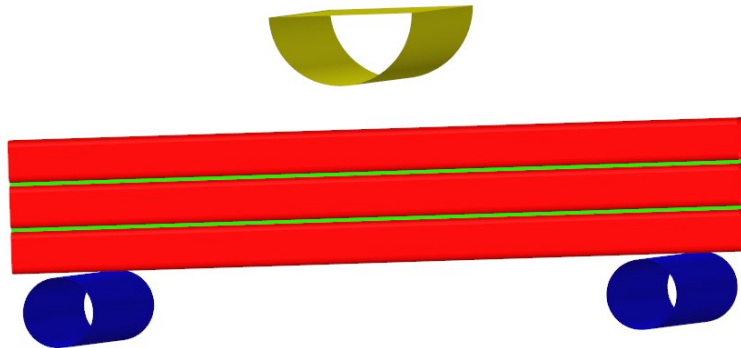
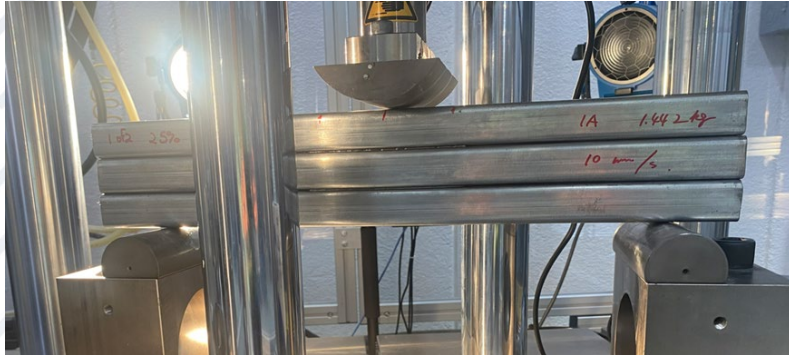
- FORMTUBE® 800 tubes, 1.2mm, 1.4kg.
- C-STAR™; 45kN peak force.
- Stable load displacement curve after peak force. The structure can still maintain high level load.



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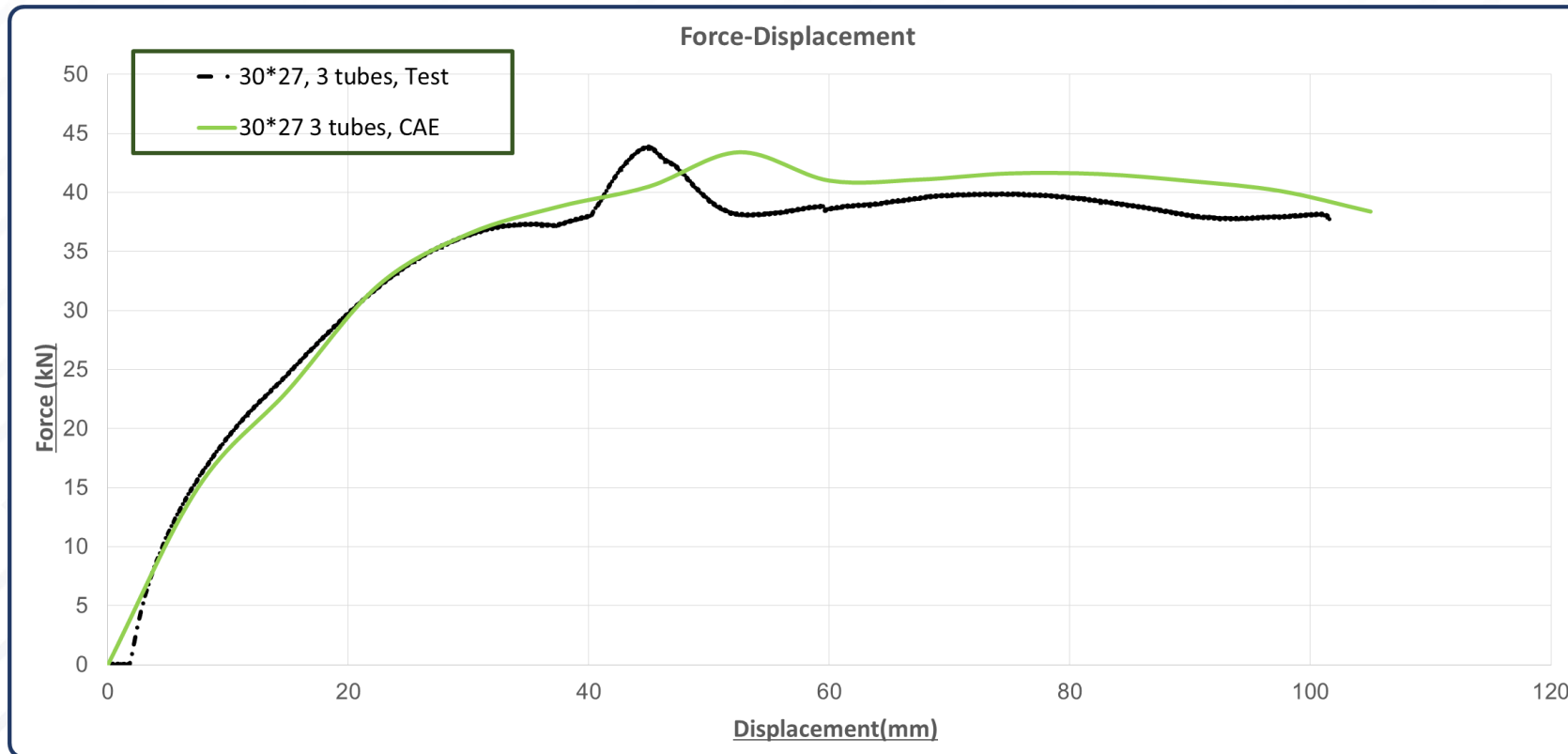
TEST VS CAE CORRELATION



- CAE model shows a well captured plastic deformation area.

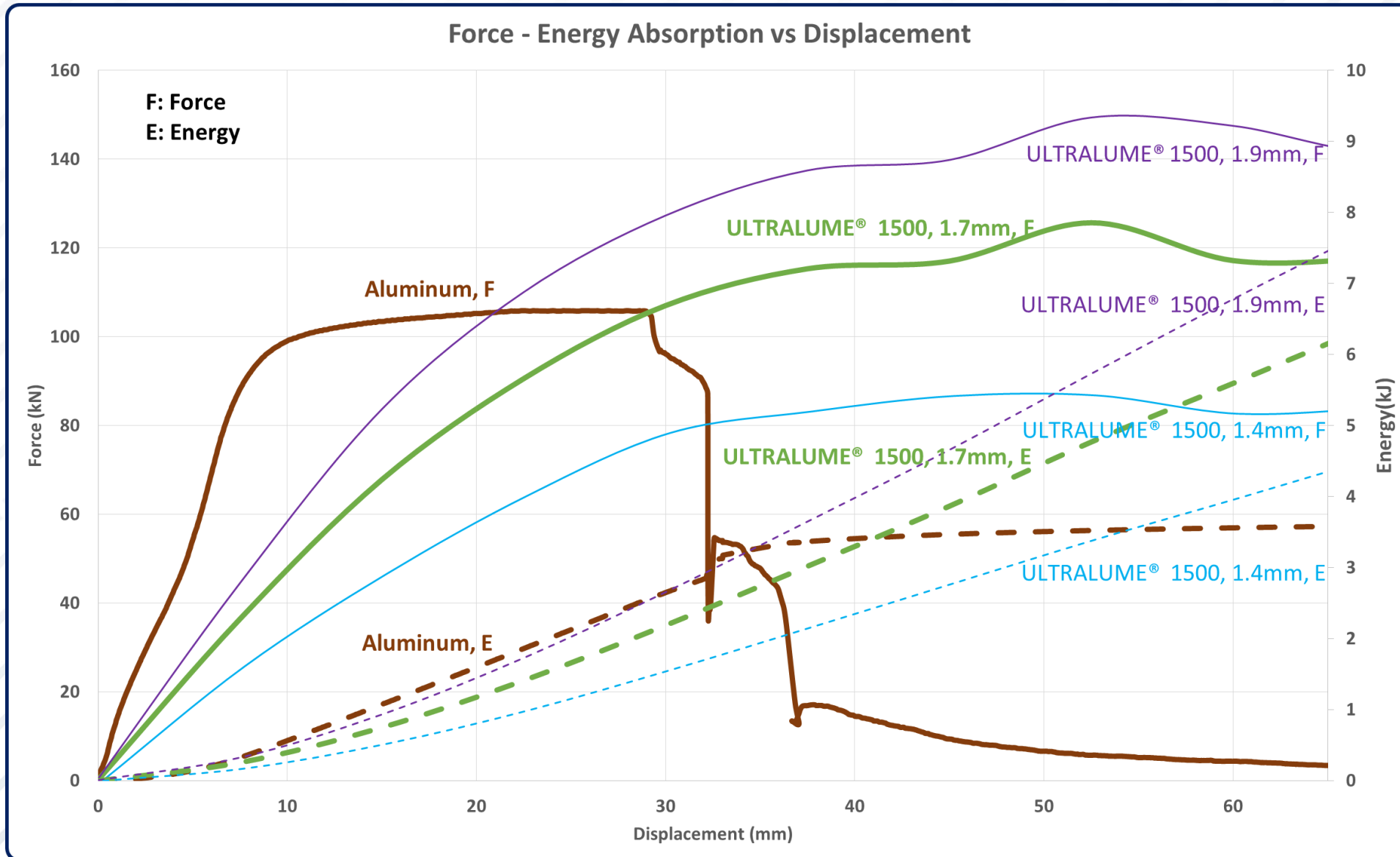
TEST VS CAE CORRELATION

FORMTUBE®800 Correlation



- CAE model establishes a good correlation with physical test.

C-STAR™ ADVANTAGES



C-STAR™ ADVANTAGES

	Weight	Peak Force	Energy equivalent point
Aluminum Baseline	2.0kg	107kN	
C-STAR™ ULTRALUME®1500, 1.4mm	1.7kg (-15%)	87kN (-19%)	55mm
C-STAR™ ULTRALUME®1500, 1.7mm	2.0kg (+0%)	125kN (+17%)	42mm
C-STAR™ ULTRALUME®1500, 1.9mm	2.3kg (+15%)	149kN (+40%)	34mm

- 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.

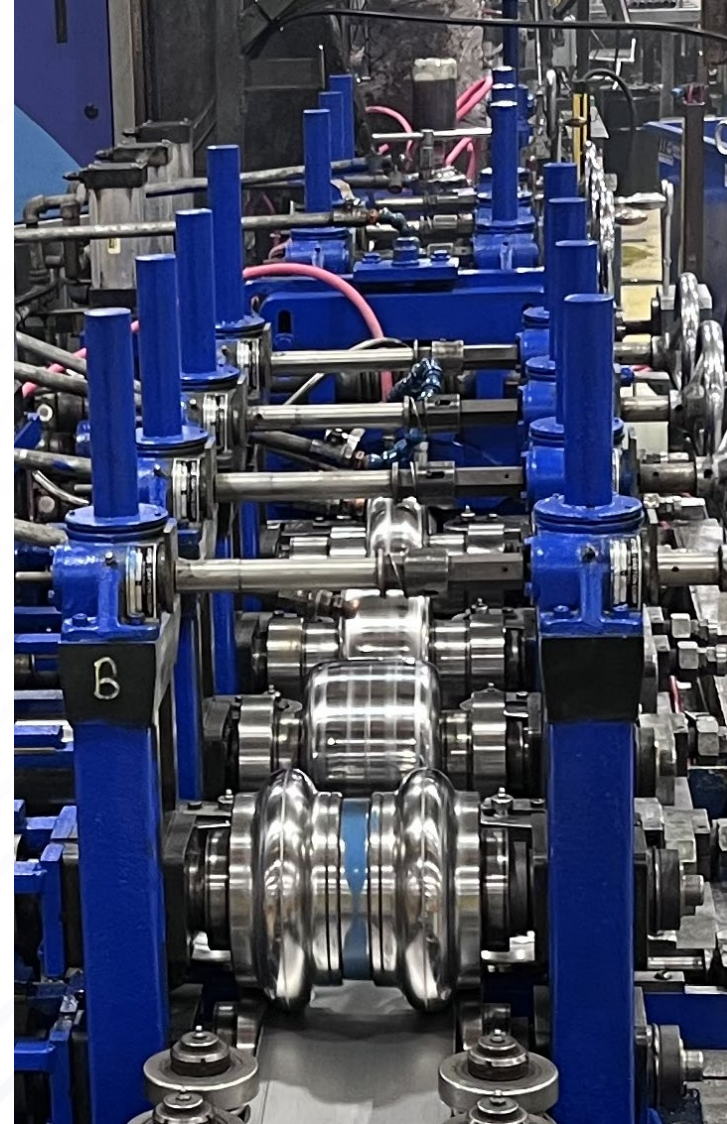
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MANUFACTURABILITY – TUBE

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

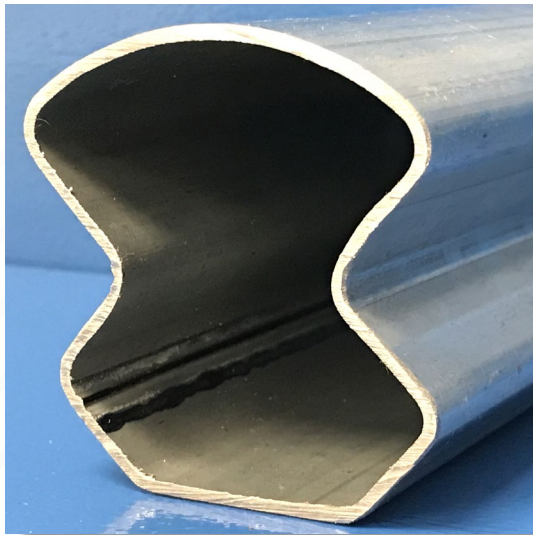
ULTRALUME® PHS
 1.6 mm thick
 175 mm perimeter
 35:1 D/t ratio

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

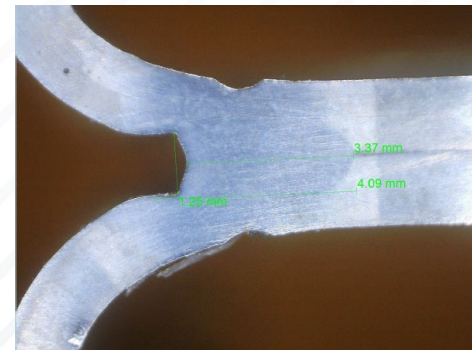
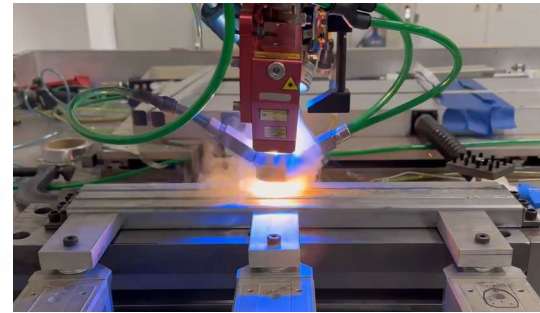
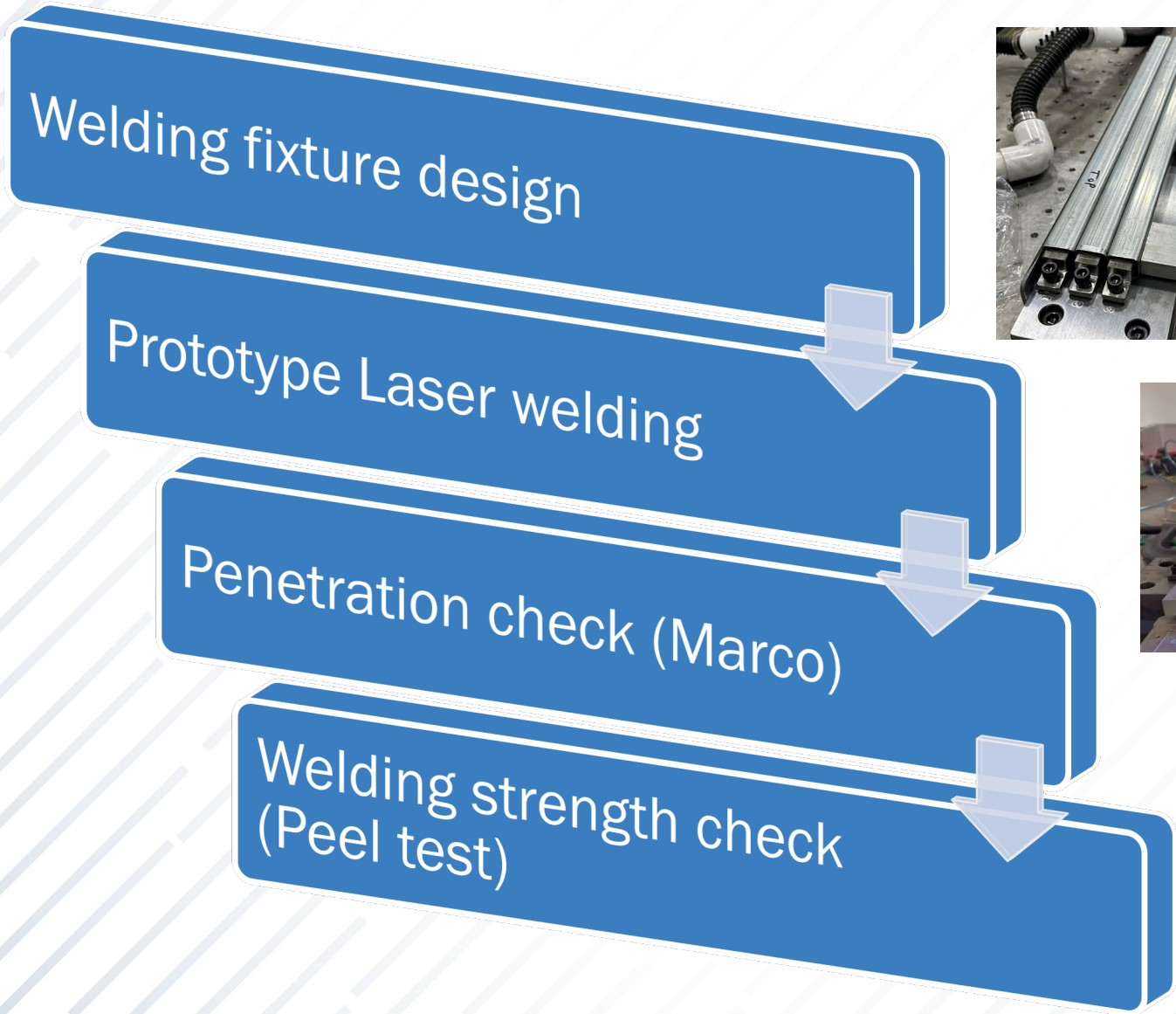
DP 980
 1 mm thick
 200 mm perimeter
 100:1 D/t ratio

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

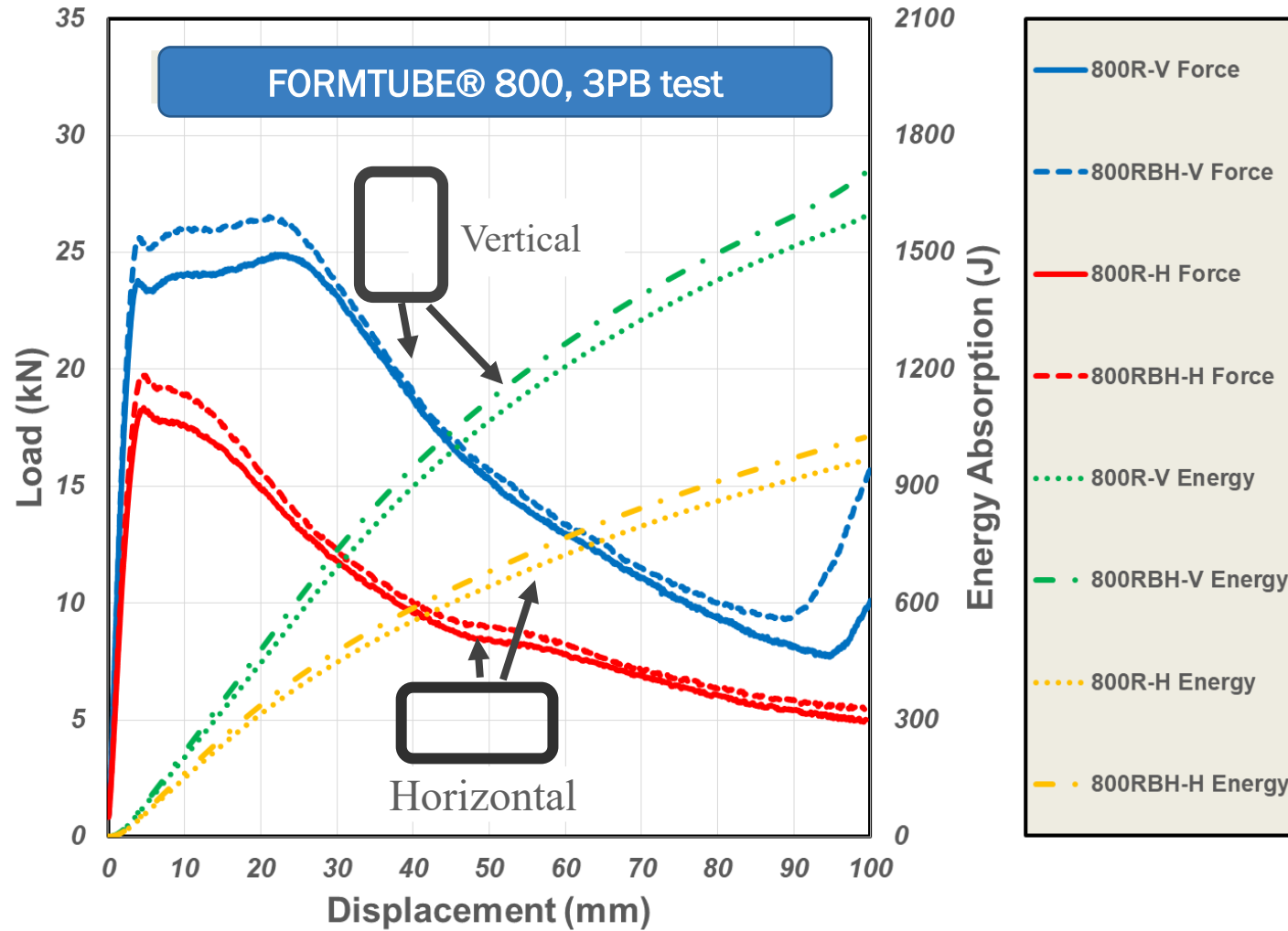


Capability to leverage AHSS grades for lightweighting applications

MANUFACTURABILITY – WELDING



BH (BAKE HARDEN) IMPACT



- Bake harden effect has a 6% improvement on peak force for this FORMTUBE®800 tube.

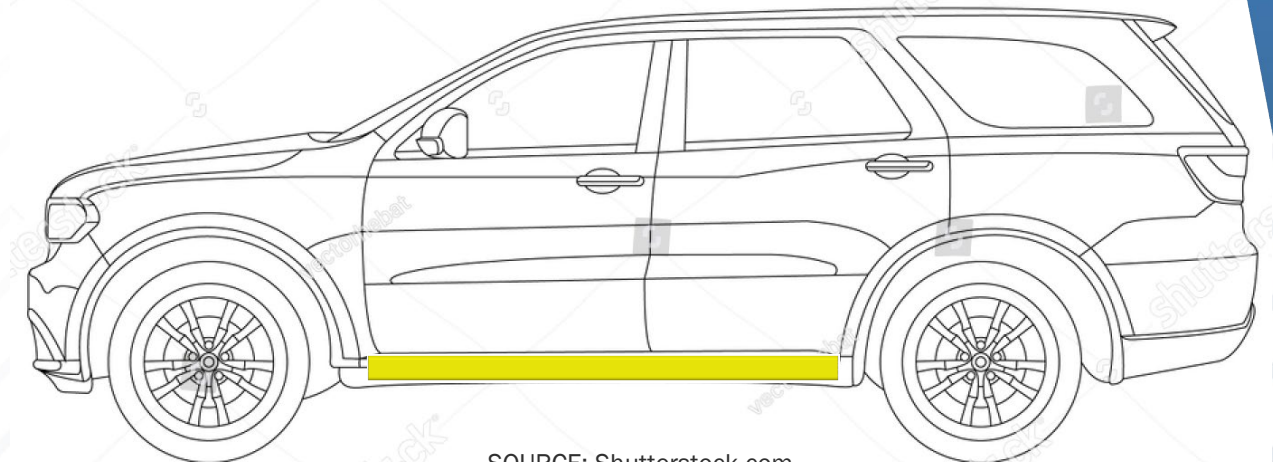
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SUMMARY AND FUTURE ACTIVITIES

Summary:

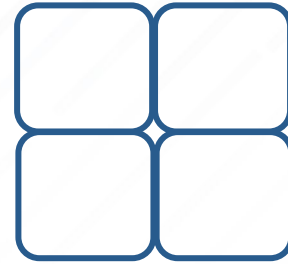
- With similar mass, C-STAR™ outperforms aluminum baseline on:
 - Peak force.
 - Energy absorption at certain space.
- C-STAR™ is a sustainable, versatile and highly scalable product with cost and manufacturability efficiency.
- Being the largest flat-rolled steel company in NA, Cleveland-Cliffs provides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



SUMMARY AND FUTURE ACTIVITIES

Future activities:

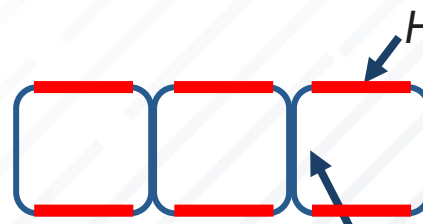
- Investigation of different tube configurations: combinations of grade, gauge and geometry.
- Performance evaluation at sub-assembly level
- Mechanical joining methods assessment, such as bolting, riveting, etc.
- Other applications in the vehicle body structure



Different configurations



Different gauge/grade combinations



Tailored blank tubes

FOR MORE INFORMATION

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