GDIS

Advanced Steel Tubular Solution for Rocker Area

HYUNDAI MOTOR GROUP
HYUNDAI AMERICA TECHNICAL CENTER, INC.

CLIFFS

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1. **Hyundai America Technical Center, Inc.**
2. **Cleveland-Cliffs Inc.**

Agenda

Background

Enhanced side protection is necessary for BEV compared to ICE

Design Details

Produce the most balanced design after multiple iterations.

Virtual Design Validations

- Component level CAE assessments
- Vehicle level CAE assessments

Prototype Build

- Tube making
- Heat treatment and laser joining

Physical Component Test

Modified three-point bending component level tests

Summary and Future Work

Vehicle level crash test

Background

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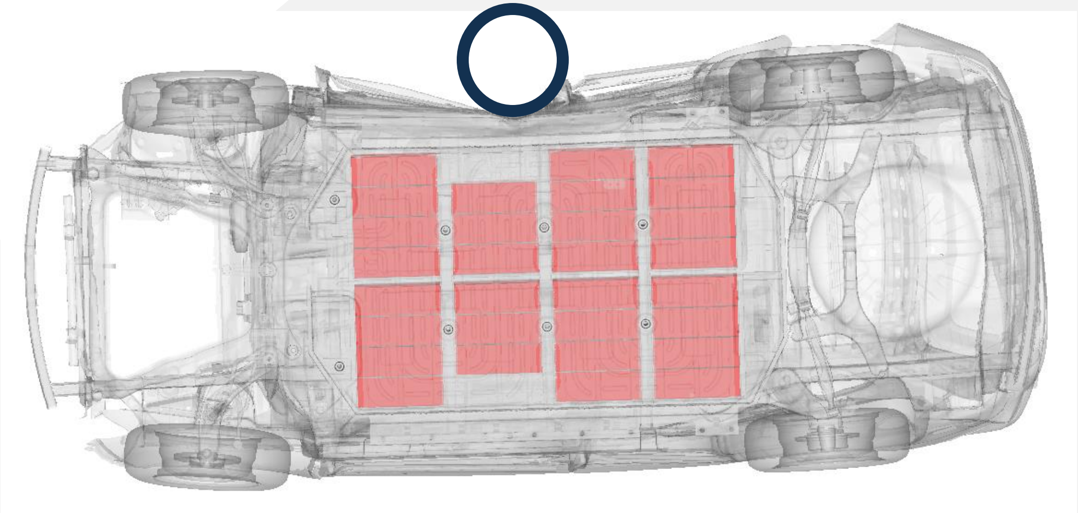
- For BEVs, increased vehicle weight needs a more robust structure.
- Design of side structure needs to be efficient due to the limited lateral deformation zone.
- Long and uniform design area is ideal for roll form/tubular products.
- Tubular products demonstrates a better dimensional accuracy and manufacturing consistency especially for AHSS.



Tube Making Business Overview

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Locations

- Walbridge, OH
- Columbus, IN

Tube mills:

- 11 Tubes mills
- 220K tons capacity

Capabilities:

✓ Conventional carbon grades
✓ Conventional stainless grades
✓ Advanced high strength steel
✓ 3rd Gen advanced high strength steels

Tube Making - Process Flow:

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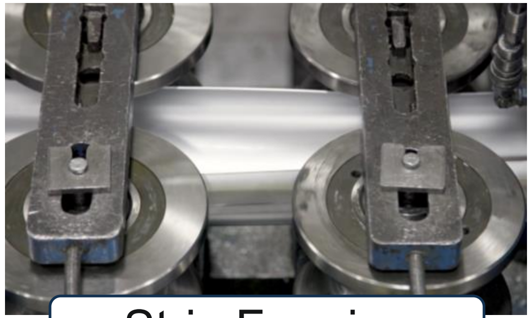
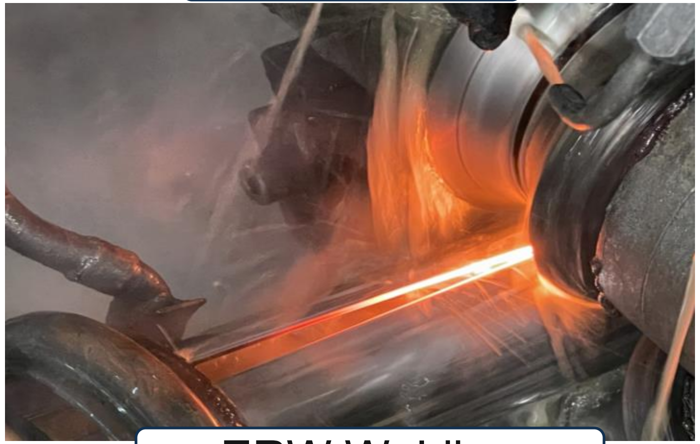
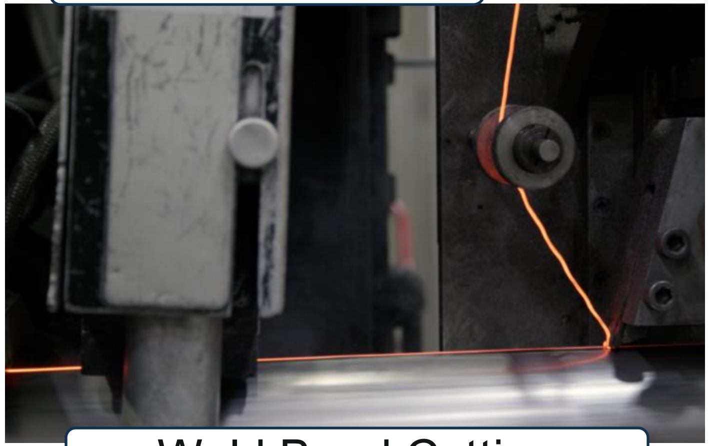
Coil Slitting



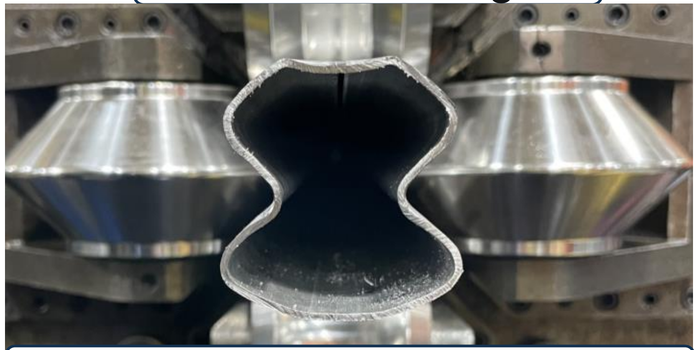
Strip Forming



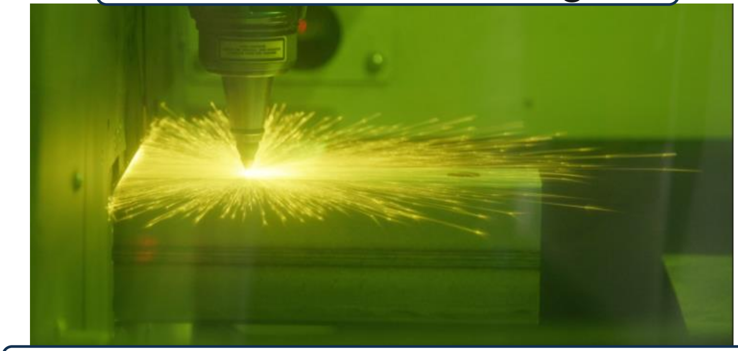
ERW Welding



Weld Bead Cutting



Final Tube Shape Rolling



Tube Laser Cutting and Piercing

Tube Making – Line-Side Quality:

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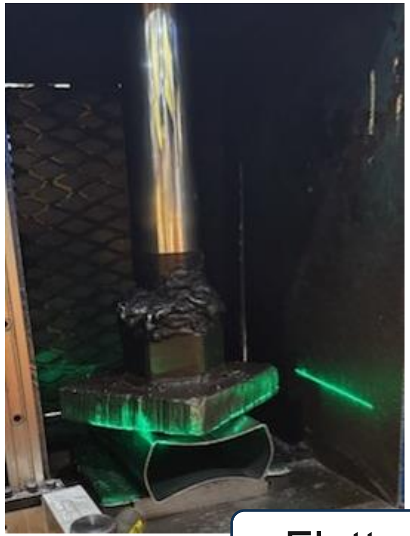
Weld Validation

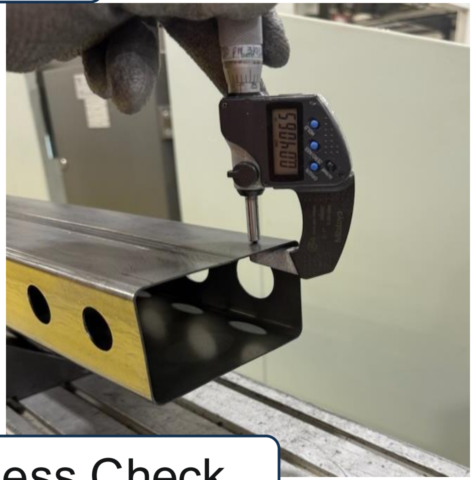
Cone Test



Flattening Test

Dimensional Validation

Twist Check



Size and Thickness Check

Tube Making – Final Part Validation:

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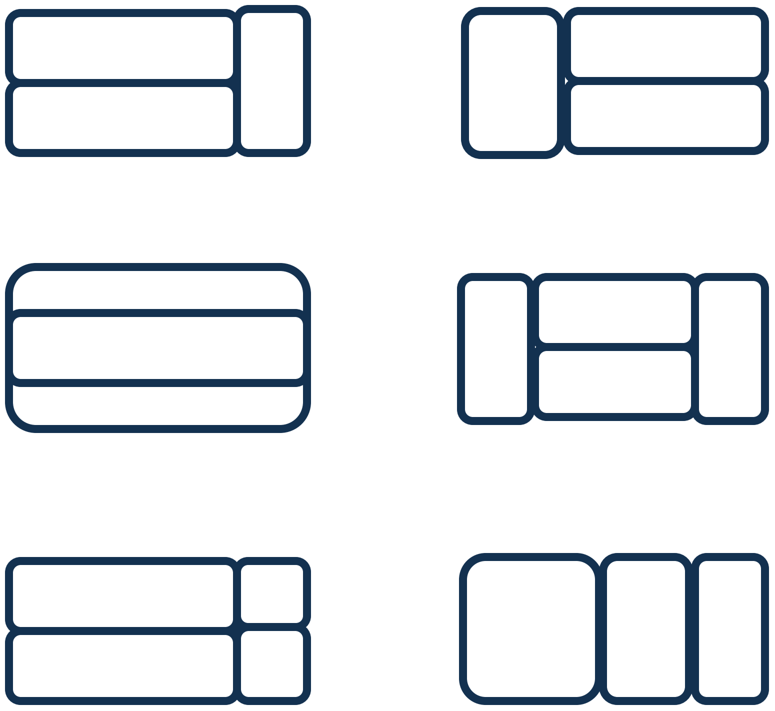
Fixture Verification

Design Details:
Validation Steps

Design Profile



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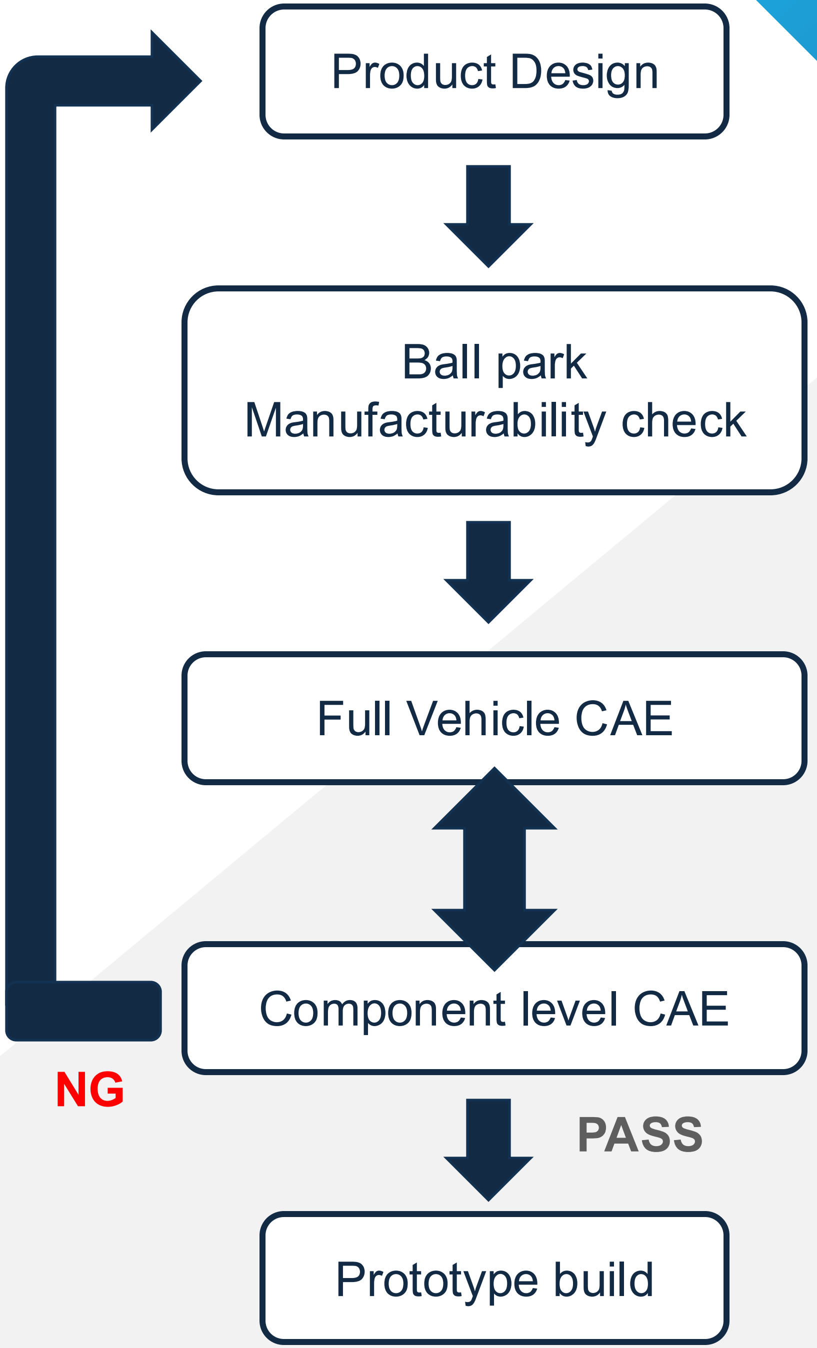

Virtual Design Validation
→ CAE Methodology and Approach

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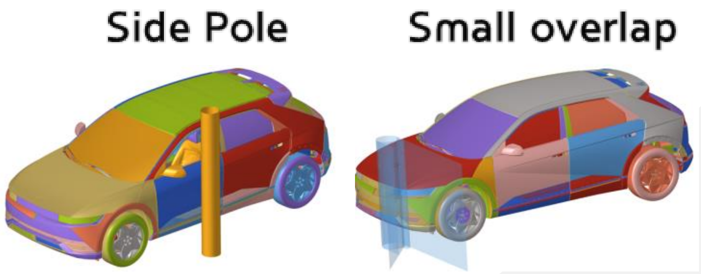
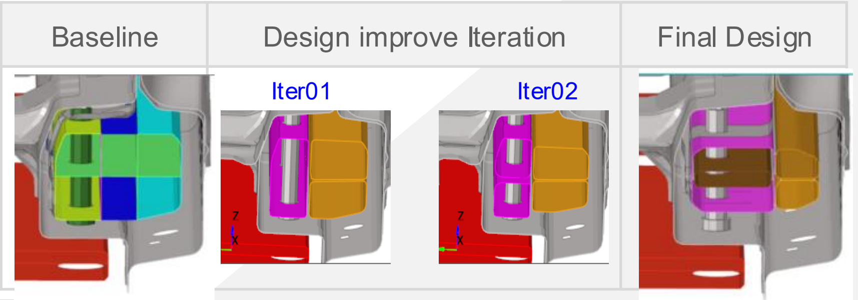
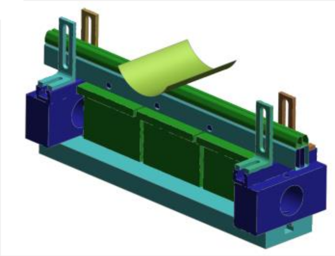
Full Vehicle CAE
To establish baseline performance targets

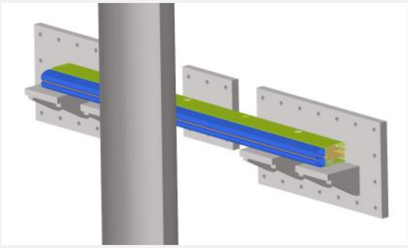


Utilize Full Vehicle to improve Steel Tubular Design



Develop Component level validation to confirm structural performance
- weld strength, manufacturability check (gauge, material grade)





Virtual Design Validation
→ Full Vehicle Level CAE Assessments

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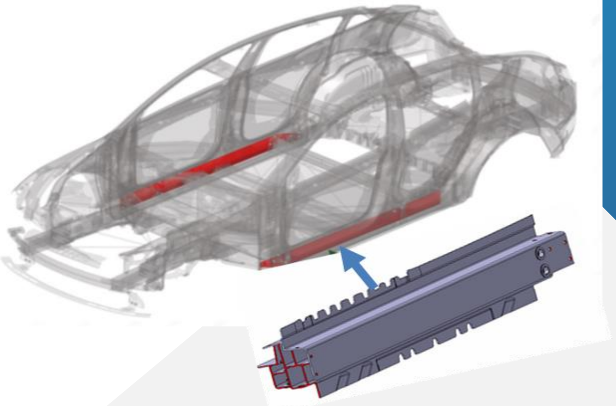
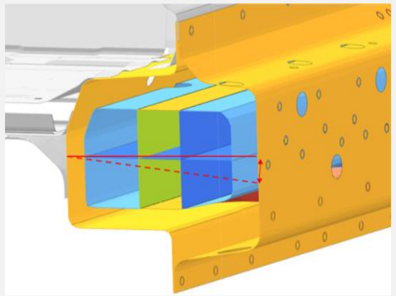
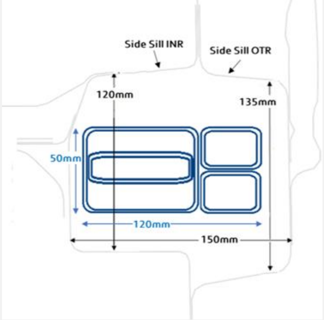
- Full vehicle model was used to check the section forces being applied on the currently used Aluminum part during Side and Small Overlap Impact
- The behavior of the part was studied under two load cases –
  - IIHS Side Pole : [Performance check] Lateral loading conditions
  - Small Overlap Impact: [Performance check] Axial loading conditions
- Base Aluminum design used as reference point that was used to establish minimum performance targets for the Steel Tube design
- Different Steel Tube designs were considered and validated (varying number of tubes, sizing, gauge, etc.) before settling on the final design for its optimal performance and manufacturability



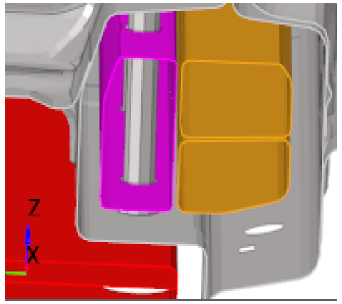
[AL Design]



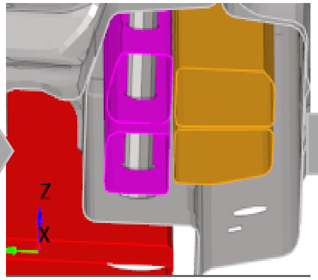
[Final Steel Design]



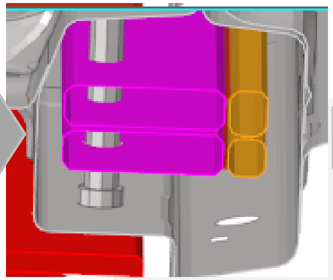
Tube Design 01



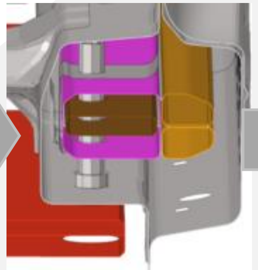
Tube Desing 02



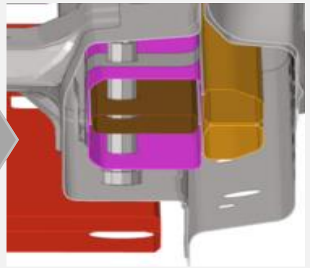
Tube Design 03



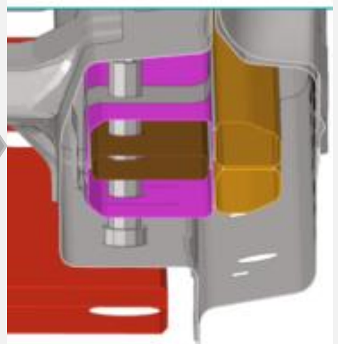
Tube Design 04



Tue Design 05



Final Design



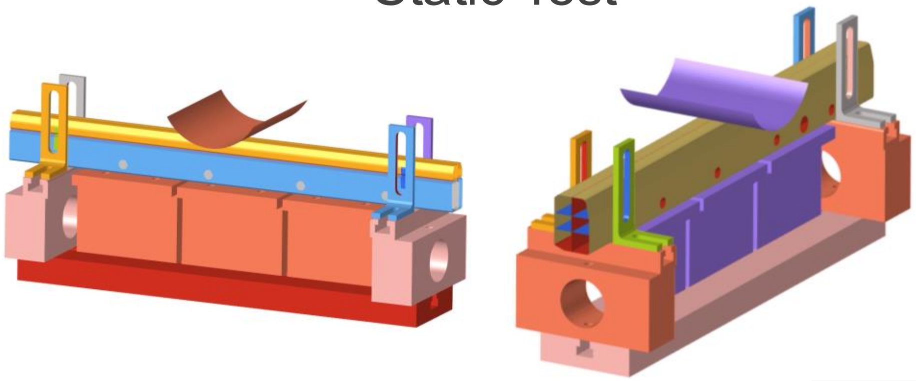
Virtual Design Validation

→ Component Level CAE Assessments

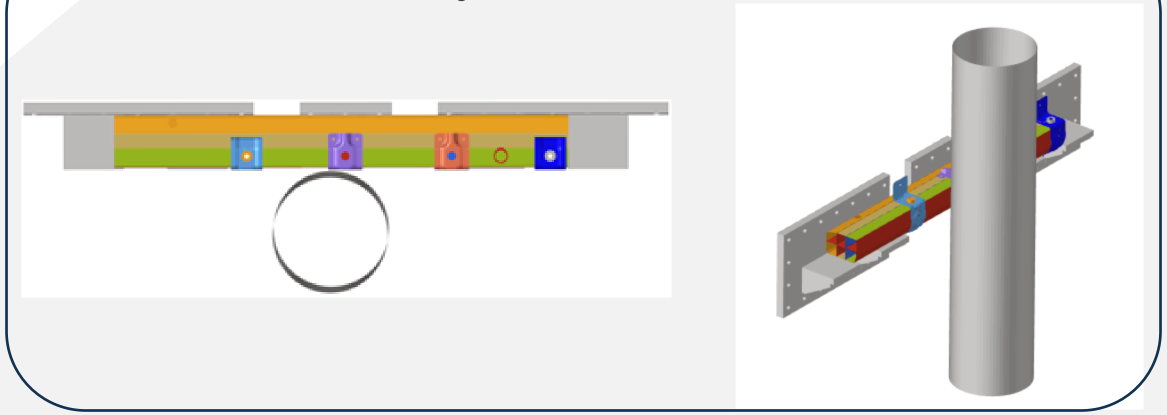
- For cost and time effective testing, Component level CAE models were developed to subject parts to the same loading conditions seen in full vehicle simulations.
- The behavior of the part was studied under two load cases:
  - Static Test: Displacement target – 90mm
  - Dynamic Test: Impact energy target – 17kJ
  - Setups were designed to ensure parts are subject to same loading conditions, deformation patterns and failure modes as seen in full vehicle simulations

Developed in collaboration with fixture fabrication teams to make sure the same fixture and loading conditions would be used for component level testing.

Static Test



Dynamic Test



Virtual Design Validation
→ Static Test and CAE Results Comparison

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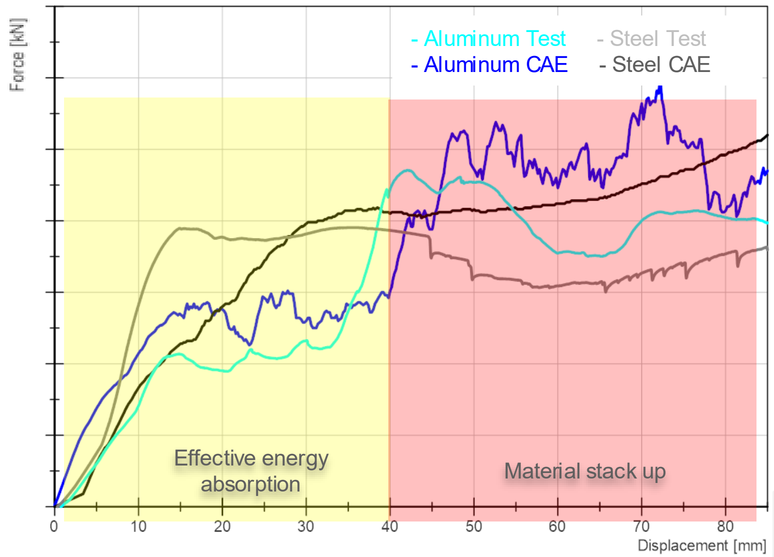
- ✓ Location and mode of deformation is the same in both CAE and testing
- ✓ Steel part shows improved response and energy absorption in the first 40mm of applied deformation

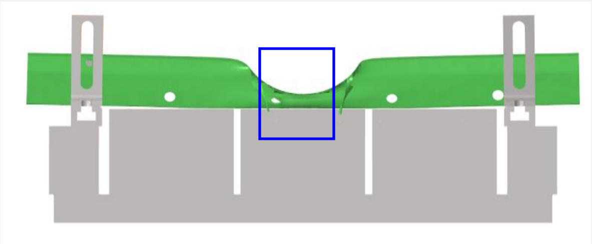
Load Case:

#	Material	Max Force(kN)	Max Displacement (mm)	Observations
Test	Aluminum	231	90	✓ Results correlate with CAE ✓ Steel part shows improved response before ~40mm ✓ CAE shows slightly stiffer response
	Steel	194		
CAE	Aluminum	300		
	Steel	261		

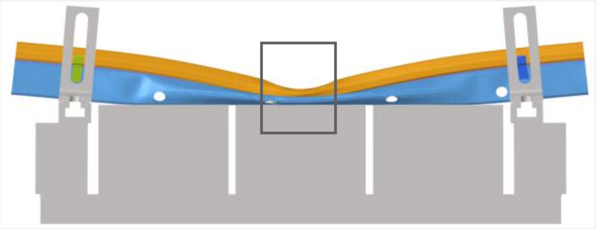
Force-Displacement Curve:



Deformation of Aluminum Part in Test:



Deformation of Steel Part in Test:



Virtual Design Validation
→ Dynamic Test and CAE Results Comparison

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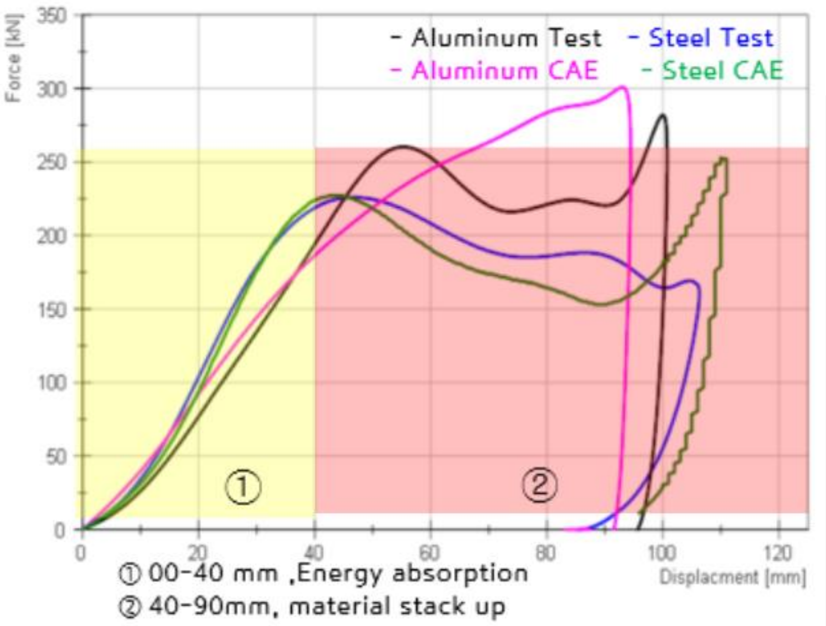
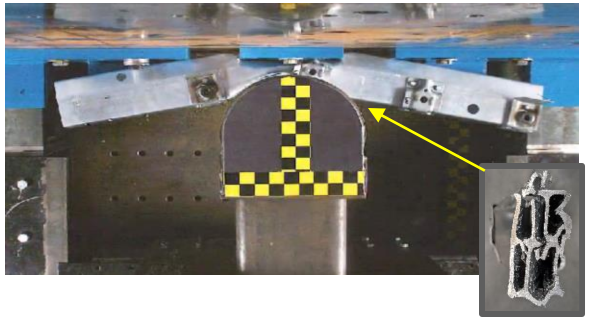
- ✓ Steel Design shows similar performance to Aluminum
- ✓ CAE shows stiffer response compared to tests

Load Case:

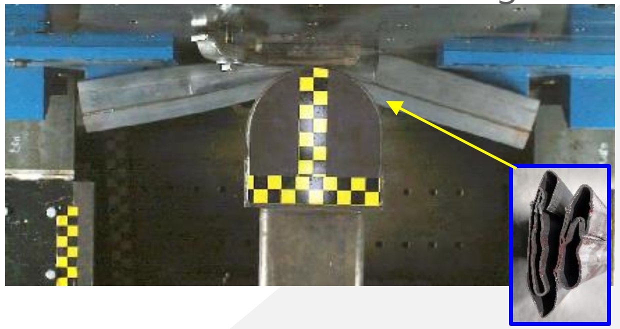
Mat	#	Peak Force [at~40mm] (kN)	Max Disp (mm)	Impactor Energy (kJ)	Energy Absorbed (kJ)
Aluminum	Test 1	260	101	17.10	16.8
	Test 2	252	100	17.49	17
	CAE	240	92	17.2	17
Steel	Test 1	176	108	17.2	16.2
	Test 2	226	105	17.32	16.8
	Test 3	195	107	17.17	16.5
	Test 4	205	114	17.04	16.7
	CAE	206	111	17.2	16.9



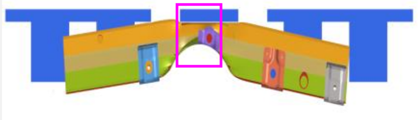
Aluminum Test: Deformed Image



Steel Test: Deformed Image

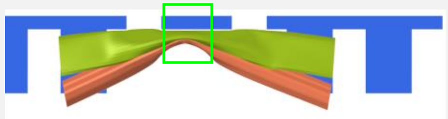


Aluminum CAE: Deformed Image

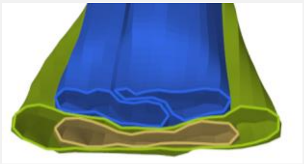


→Test vs CAE Cross Section View

Steel CAE: Deformed Image



→Test vs CAE Cross Section View



Prototyping and Manufacturing PHS Quench Process OP1

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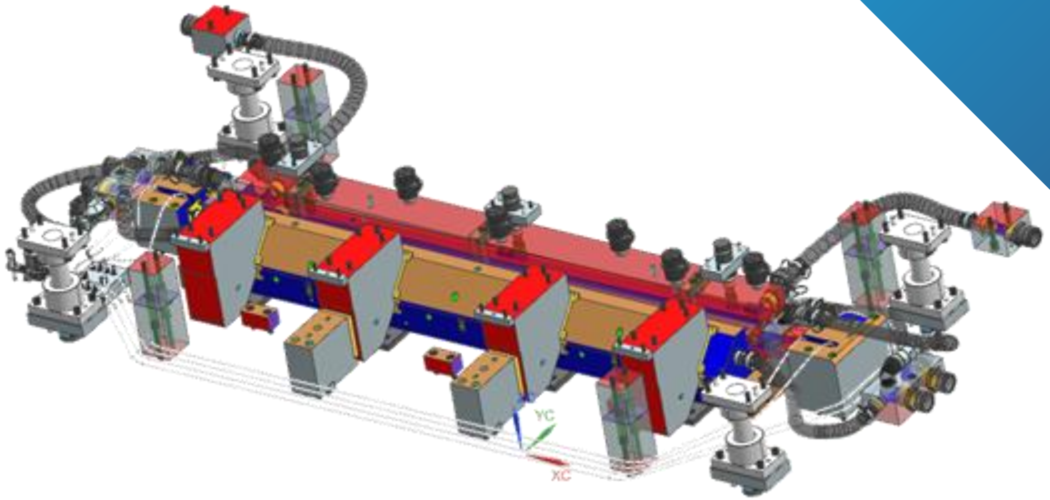
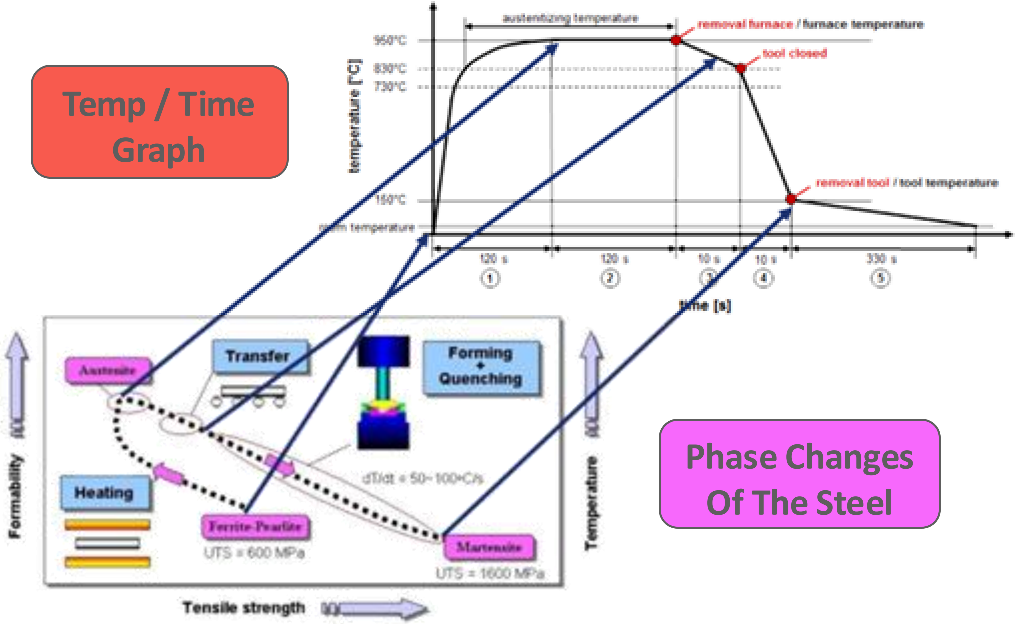
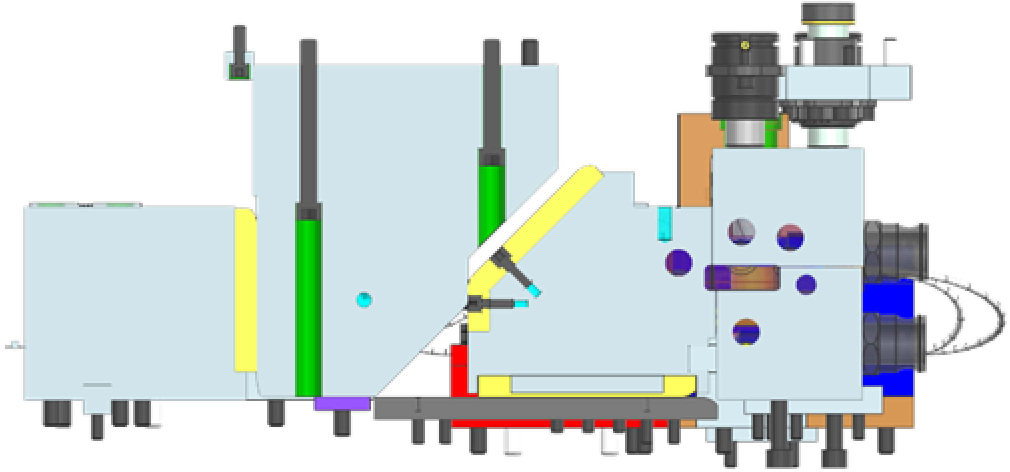
Station 1: Robotic Load – Incoming tube to Oven
Station 2 : Oven Heating Phase @ 950°C
Station 3 : Robotic Transfer/Dropoff to Quench Tool
(Part Temp tool close @ 770°C -830°C)
Station 4 : Quench Process – Critical Cooling Rate -30°C/sec
Station 5 : Robotic Unload/Stack



Temp / Time Graph



Phase Changes Of The Steel



Prototyping and Manufacturing PHS Quench Results

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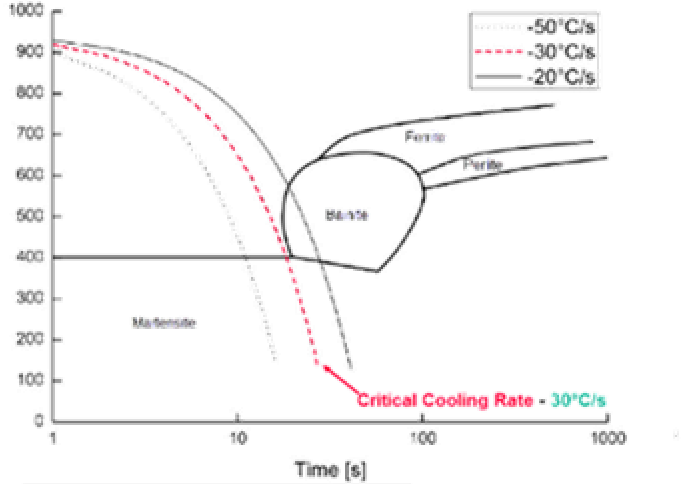
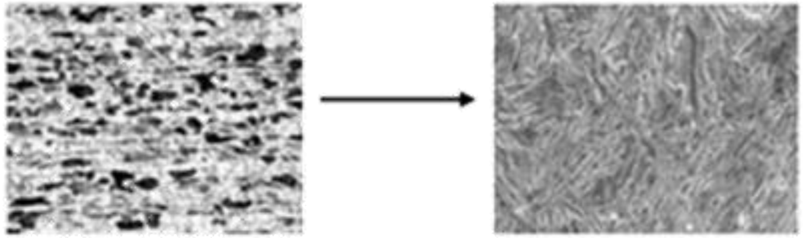
TTT-Curve for 22MnB5



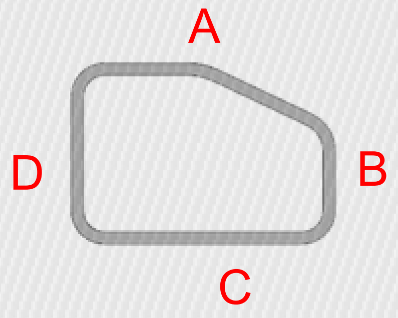
$A_{C1} = 720°C$ $M_s = 410°C$
$A_{C3} = 845°C$ $M_f = 230°C$



Delivery Condition*
Perlite/Ferrite

Final State*
Martensite

Post Quench Material Sample Locations



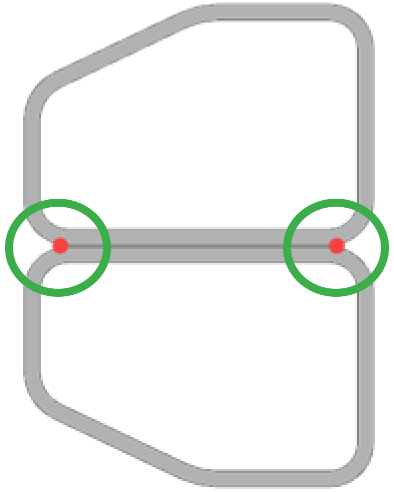
Post Quench Material Property Results

MECHANICAL PROPERTIES

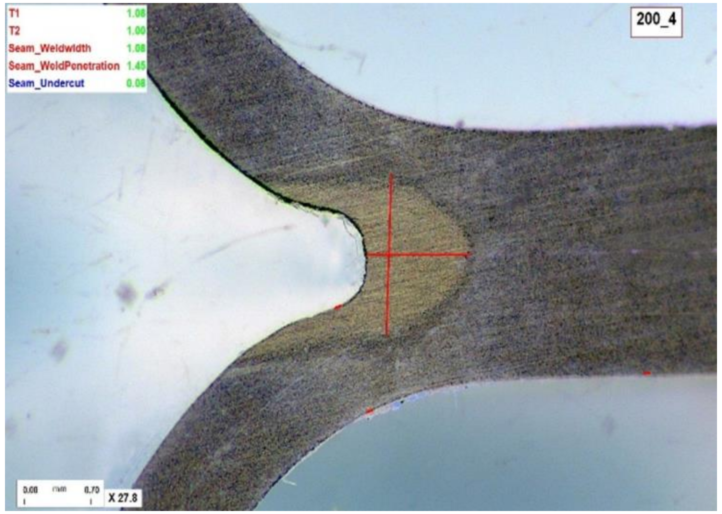
Part Number		Vickers Hardness (HV) Area 1 Indent 1	Indent 2	Indent 3	HRC	Ultimate Tensile Strength (1300-1650 Mpa)	Elongation(%)	Yield Strength (950-1250 Mpa)
SIDE A	LEFT	425	424	437	41.5	1414.1	7.7	1092.1
	MIDDLE	460	443	428	45.4	1413.2	6.4	1047.4
	RIGHT	463	470	446	42.3	1441.7	6.0	1048.1
SIDE B	LEFT	462	460	460	44.5	1452.3	5.6	1129.0
	MIDDLE	471	473	473	43.6	1451.5	6.9	1200.2
	RIGHT	476	490	460	44.1	1468.8	6.7	1185.0
SIDE C	LEFT	483	492	468	41.2	1436.6	6.2	1159.4
	MIDDLE	460	468	471	46.6	1406.6	6.1	1088.3
	RIGHT	447	446	438	41.5	1429.5	6.1	1235.3
SIDE D	LEFT	451	435	427	44.3	1422.9	5.9	1133.8
	MIDDLE	466	471	490	42.0	1454.0	7.8	1208.3
	RIGHT	471	470	443	43.1	1444.6	6.1	1136.4

Prototyping and Manufacturing Assembly Process OP2

Post Quench Operation
Laser Seam Weld Side Impact tubes
1910mm length of weld x 2
Non-Contact Laser Weld System
Seam Tracker System ensures uniform penetration

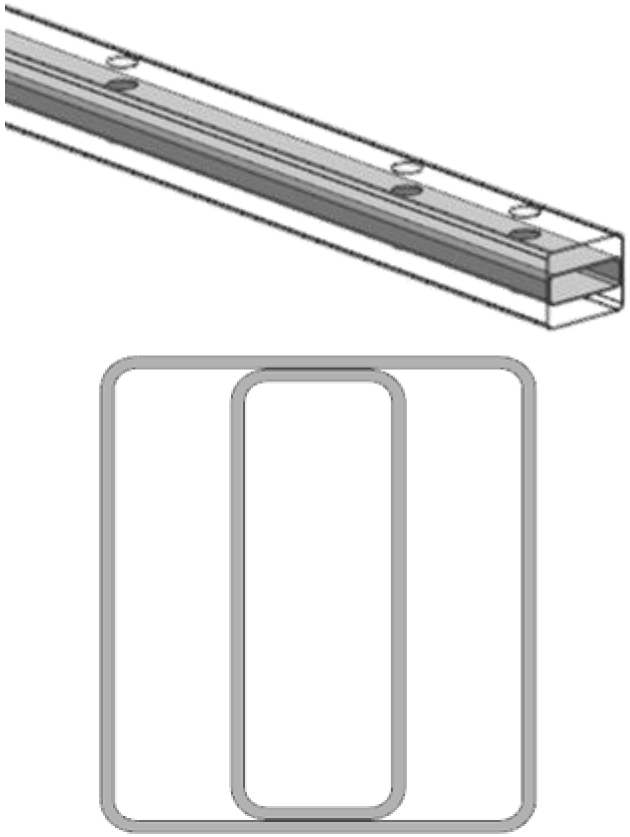


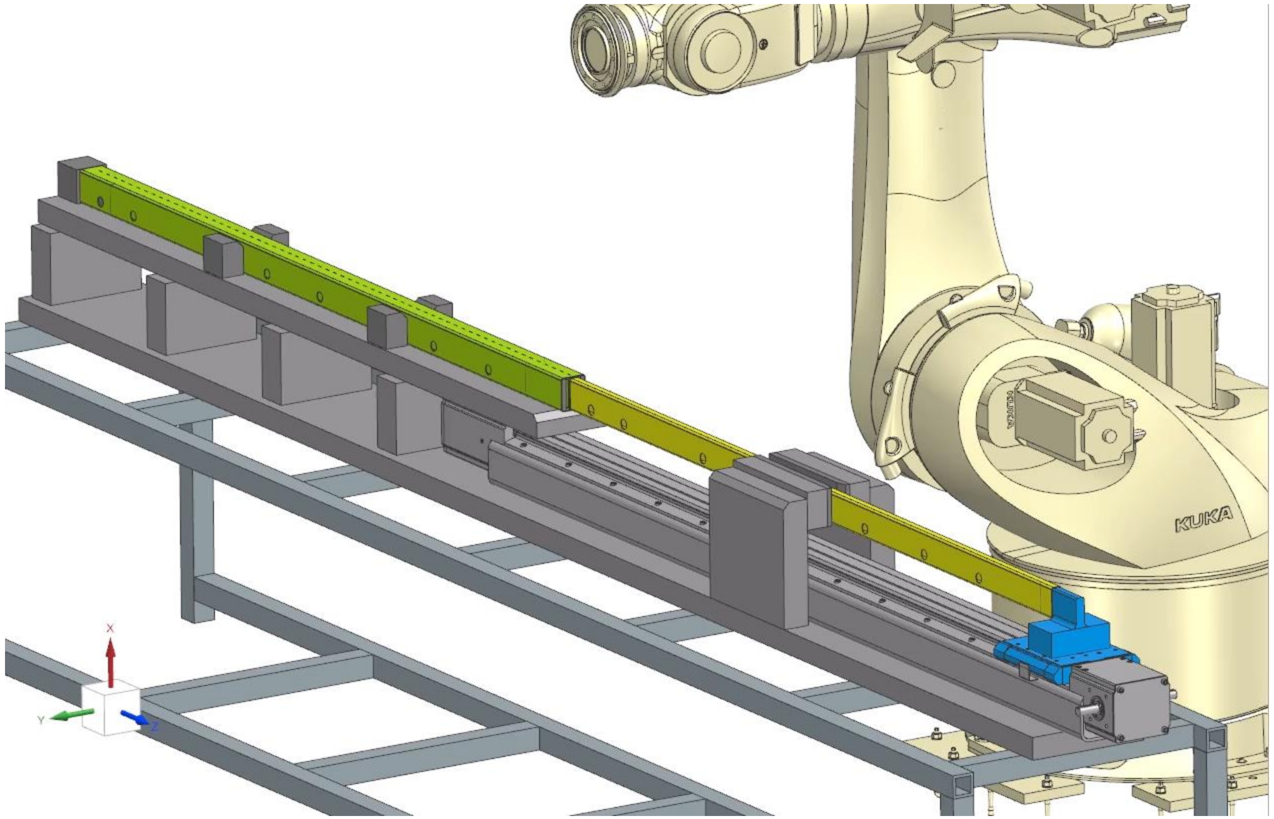
Post Laser Weld
Cross Sectional Weld Inspection



Prototyping and Manufacturing Assembly Process OP3

Post Quench Operation
Linear Tube Insertion/Assembly
Linear Actuator with Int/Ext guidance





Prototyping and Manufacturing Assembly Process OP4

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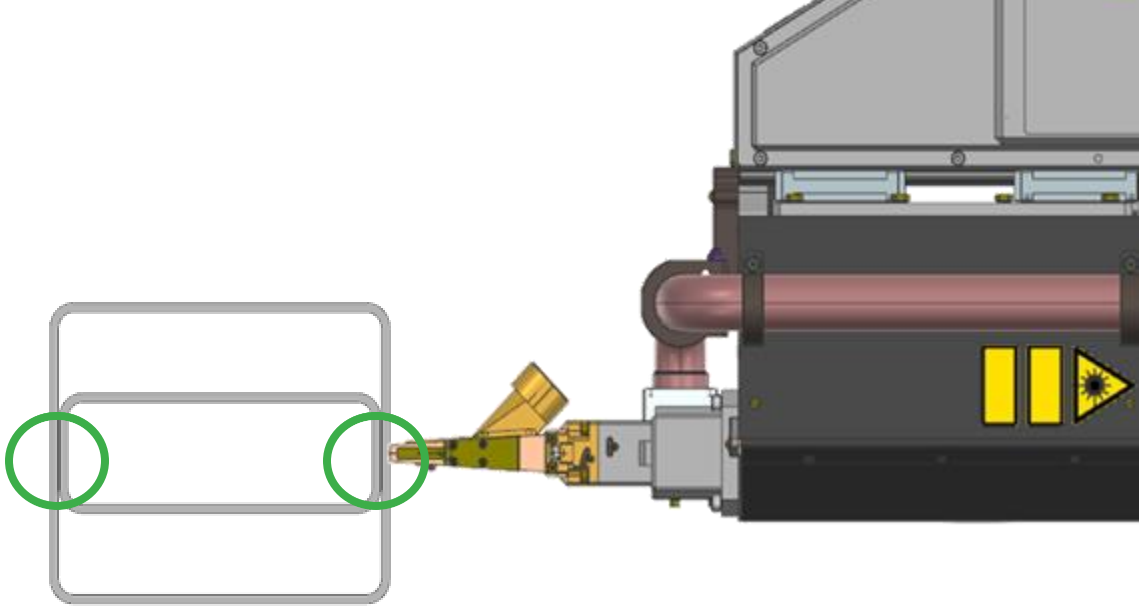
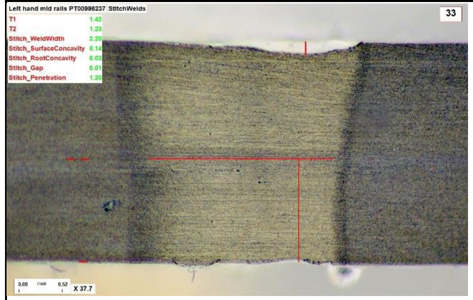
Post Quench Operation
Laser Stitch Weld Inner to Outer Tube
LSS Weld Application
Variable Frequency/Modulation provides adjustability of weld profile/penetration



StitchWelds 33



Measure	Min	Max	Value
T1	0	-	1.42
T2	0	-	1.23
Stitch_WeldWidth	1.11	-	2.2
Stitch_SurfaceCor	0	0.43	0.14
Stitch_RootConca	0	0.37	0.03
Stitch_Gap	0	-	0.01
Stitch_Penetration	0.37	-	1.2

Porosities O
Cracks O
Other O

OK

Prototyping and Manufacturing Assembly Process OP5

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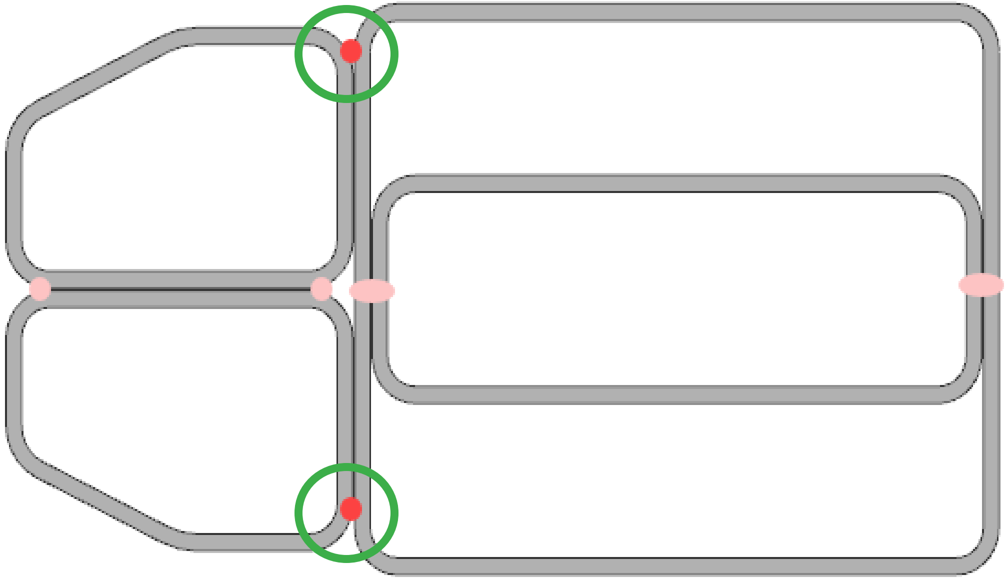
Post Quench Operation
Laser Seam Weld
Inner Sub Assembly to Outer Sub Assembly



Prototyping and Manufacturing Inspection Process

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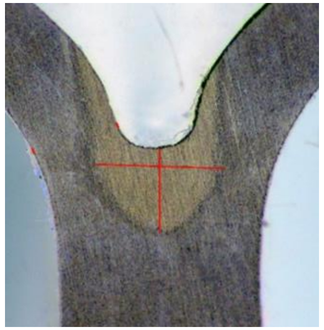
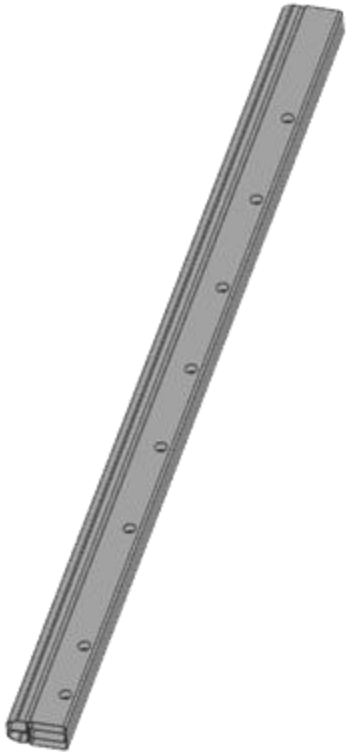
Post Assembly Weld Validation

Laser Seam Stepper Weld
Ultrasonic NDT /
Microscopic Cut/Etch



Laser Seam Stepper Weld
Metallurgical Stereoscope
Microscopic Cut/Etch

Post Assembly Dimensional Validation



Optical CMM Scanner

Summary

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Performance

Weight

Manufacturability

Sustainability

Acknowledgments & Contact information

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Acknowledgments

HATCI:
Safety Integration and Material team

Cleveland-Cliffs:
Brandon Floro
Sobhan Nazari Tiji
John Makrygiannis
Jimmy Zhang
Yu-Wei Wang
Scott Stevens
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