GREAT DESIGNS IN STEEL

DEVELOPMENT & APPLICATION OF NEW UHSS MULTI-PHASE GRADES

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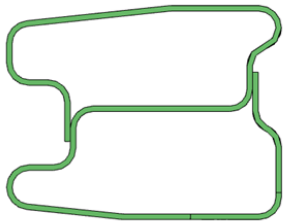
2023

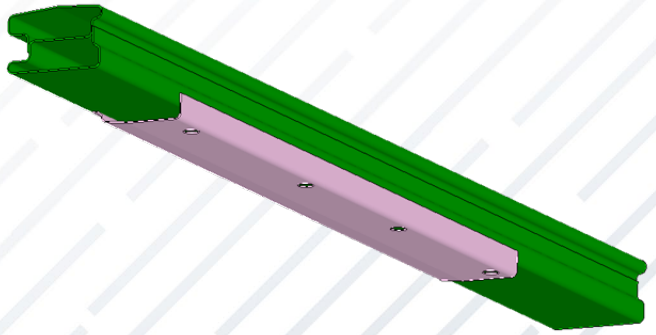
ARCELORMITTAL - OVERVIEW

- The world's leading steel and mining company, with around 158,000 employees in more than 60 countries.
- Leader in all major global steel markets, including Automotive, Construction, Household appliances and Packaging, with leading R&D and technology.
- Primary steelmaking facilities in 16 countries expose the company to all major markets, from emerging to mature.
- A major producer of steel in the EU, North and South America, Africa and in the CIS region, and a growing presence in Asia, namely in China and India.
- One of the world’s largest producers of iron ore and metallurgical coal strategically positioned to serve our network of steel plants and the external global market.
- We are leading the industry in providing low-carbon solutions to our customers.
- Group target: 25% reduction in carbon emissions intensity by 2030, net zero by 2050.

INTRODUCING UHSS MULTI-PHASE GRADES

- Multiple OEM's and Tier 1's expressed need for **Ultra High-Strength Steels (UHSS) with improved formability**
- Expand MP concept from 980 and 1180 MPa TS to higher strengths
- Target applications included bumpers, rockers, roof rails, and battery enclosures
- BEV structures: – **vehicle mass** ↑
  - **crash energy absorption** ↑
  - **space available** (to protect battery system) ↓
- Product targets defined by **ArcelorMittal Automotive Product Applications Center**, in collaboration with automotive customers
- Customer requirements:
  - ✓ **Ultimate Tensile Strength: 1300 MPa, 1500 MPa, 1700 MPa**
  - ✓ Global Formability – **Total Elongation ≥ 6%**
  - ✓ Local formability
    - ➢ **Bend R/t (radius to thickness ratio) ≤ 2.5**
    - ➢ **Hole Expansion Ratio (HER) ≥ 30%**
  - ✓ Good **flatness**
  - ✓ **Minimal residual stress**

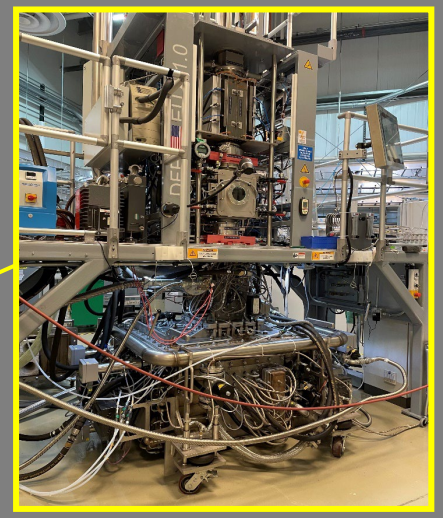




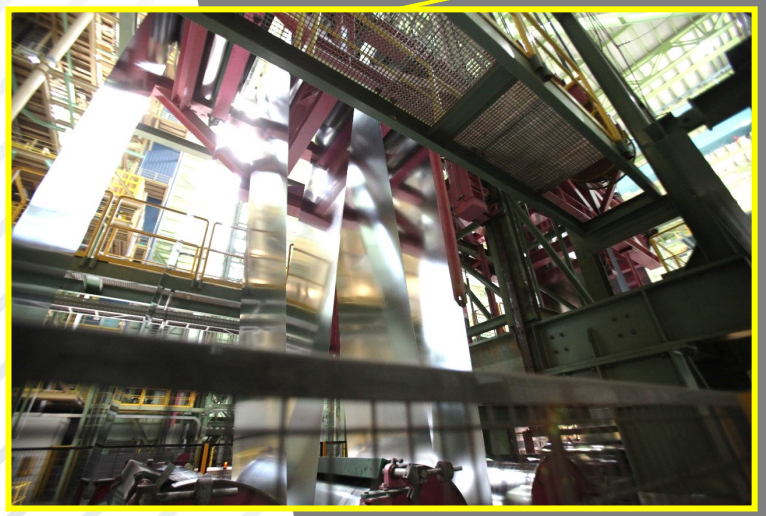
PRODUCT DEVELOPMENT MAP

Conception and Market Analysis

Laboratory Development and Testing



Mill Trials, Optimization of Properties, Gauge and Width Expansion



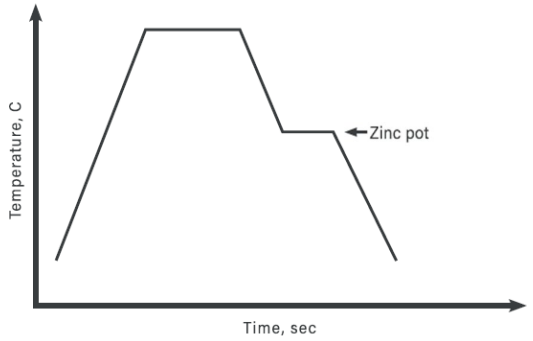
Limited Commercial Production, Customer Feedback

Full Commercial Production

THERMAL PROFILE & MICROSTRUCTURE

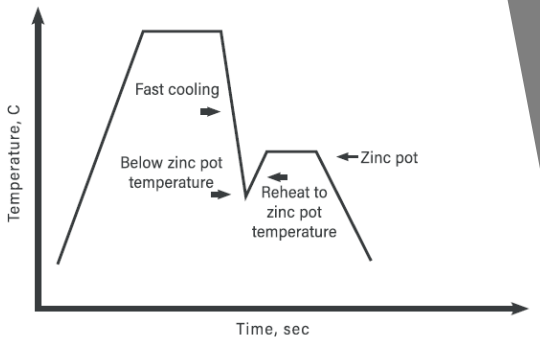
- Low-end cooling
- Specialized equipment for unique anneal practice
- Microstructure constituents: tempered martensite, bainite

Traditional Hot Dip Thermal Profile

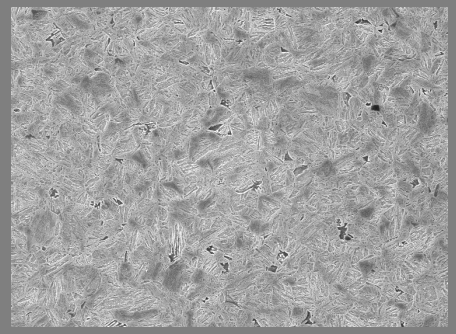


This traditional anneal process would produce, for example, 780DP.

Modified Hot Dip Thermal Profile

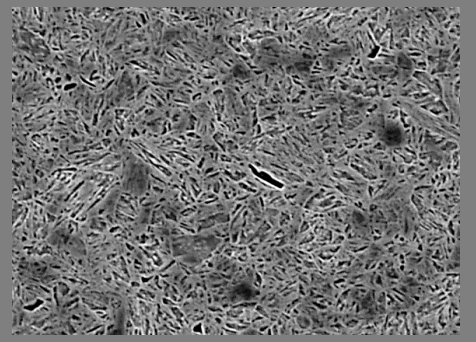


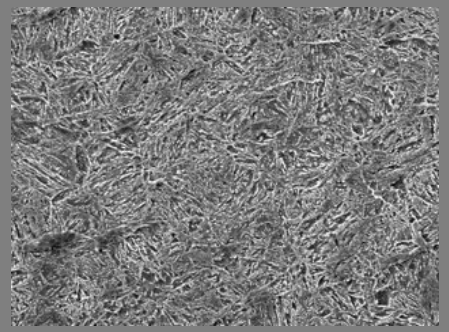
This anneal process produces MP and CP microstructures.



TYPICAL MICROSTRUCTURE MP 1300 CR

TYPICAL MICROSTRUCTURE MP 1500 CR





TYPICAL MICROSTRUCTURE MP 1300 GI

PRODUCT ATTRIBUTES

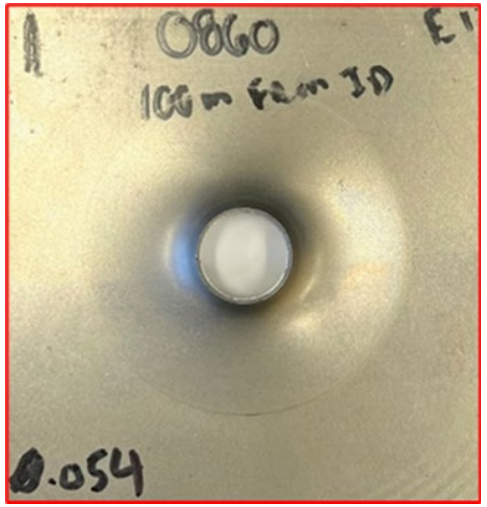
- Improved Functionality: TE%, HER% and Bendability
- Mechanical Properties based on Limited Mill Trials

Flatness meets requirement
(image from MP 1500 CR)

MP	1300 CR (uncoated)			
Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)	HER (%)	Bendability
1030 MIN	1300-1550	6% MIN	Avg. 50%	Avg. 2.0 R/t
Microstructure	B, M	Gauge	1.0 -2.3 mm (Aim)	Width (max) 1425 mm

MP	1300 GI (coated)			
Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)	HER (%)	Bendability
1030 MIN	1300-1550	6% MIN	Avg. 40%	Avg. 2.0 R/t
Microstructure	B, M	Gauge	1.0 -2.3 mm (Aim)	Width (max) 1095 mm

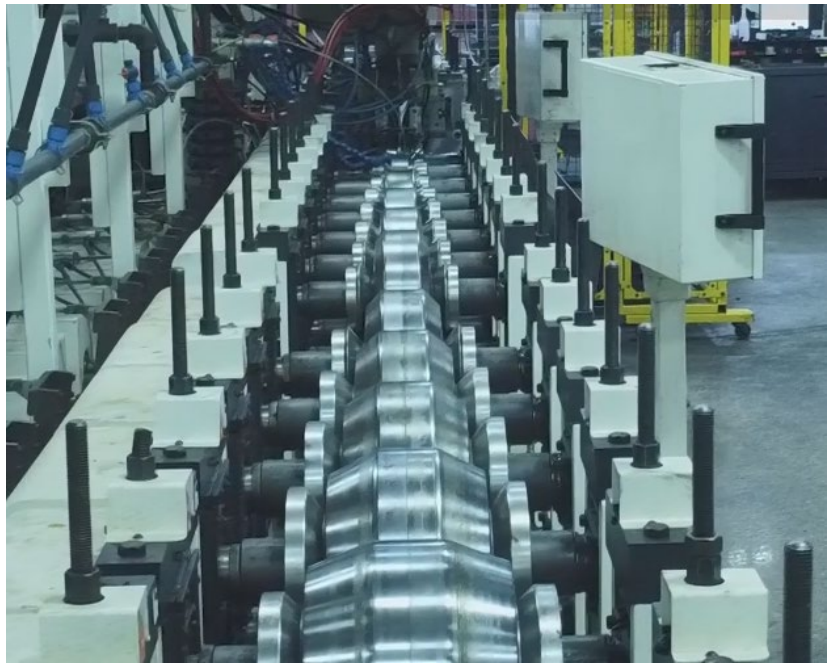
MP	1500 CR (uncoated)			
Yield Strength (MPa)	Tensile Strength (MPa)	Total Elongation (%)	HER (%)	Bendability
1100 MIN	1500 MIN	6% MIN	Avg. 50%	Avg. 2.2 R/t
Microstructure	B, M	Gauge	1.0 -2.3 mm (Aim)	Width (max) 1370 mm



HER Avg. 50% on MP 1500 CR

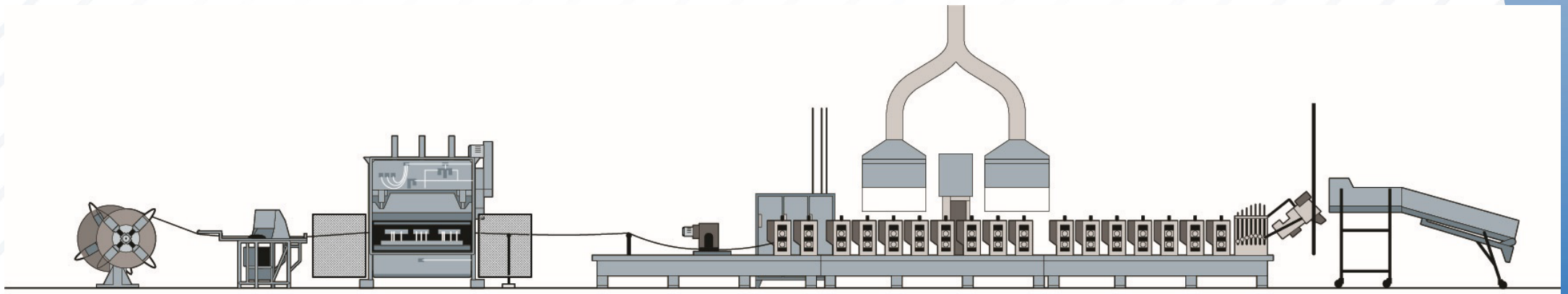
Bendability Avg. 2.2 R/t on MP 1500 CR

SHAPE CORPORATION - OVERVIEW

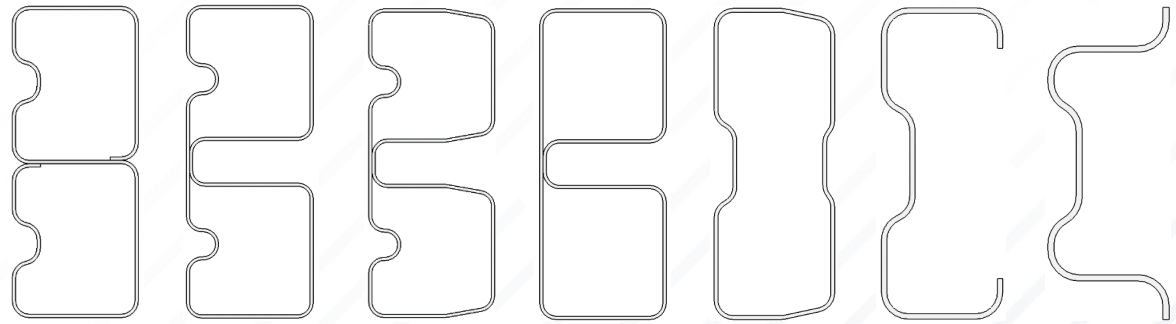


- A privately owned company founded in 1974, headquartered in Grand Haven Michigan
- Shape started as a local manufacturer and has grown to a global engineering and manufacturing company with facilities throughout North America, Europe and Asia
- 4,000+ associates worldwide with 14 manufacturing facilities & numerous sales & engineering offices
- Specializing in full-service supply of lightweight automotive solutions with a core competency in roll forming Advanced High Strength Steel

THE ROLL FORM PROCESS



- Roll form tooling is capable of producing complex, custom profiles of varying lengths
- Tooling can accept a range of gage and grades
- Laser, high frequency induction and rotary spot welding are used to create closed profiles in-line
- **Minimum radius size is a primary design driver for the profile**



PROCESS BENEFITS: SPRING-BACK

$$k \approx (YS + UTS)(R_o) / (E*T)$$

Spring-back (k) increases with:
1. Higher yield strength
2. Higher tensile strength
3. **Larger radius**

Spring-back (k) decreases with:
1. Higher stiffness
2. Thicker metal

- Minimizing bend radius size reduces spring-back in roll forming
- For closed sections residual stress is reduced and distortion from secondary cutting and forming operations is minimized

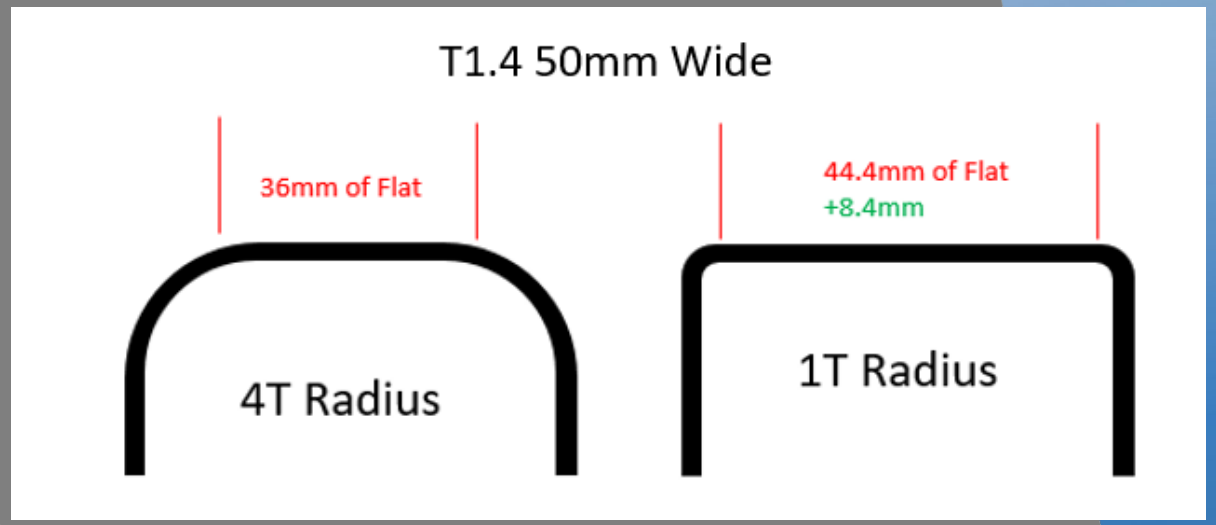
PRODUCT PERFORMANCE & APPLICATION

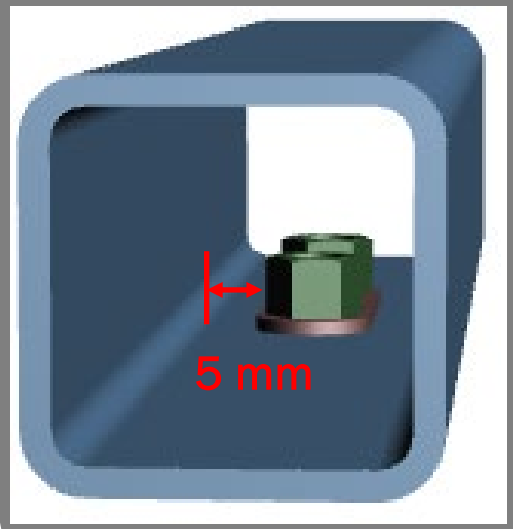
Tighter bend radii:

- Provide increased bending strength for products like bumper beams
- Create more flat surface area for integration of fasteners, clips or sensors
- Gives additional package space for installation of nuts or piercing of holes within the roll form line

Improved bendability:

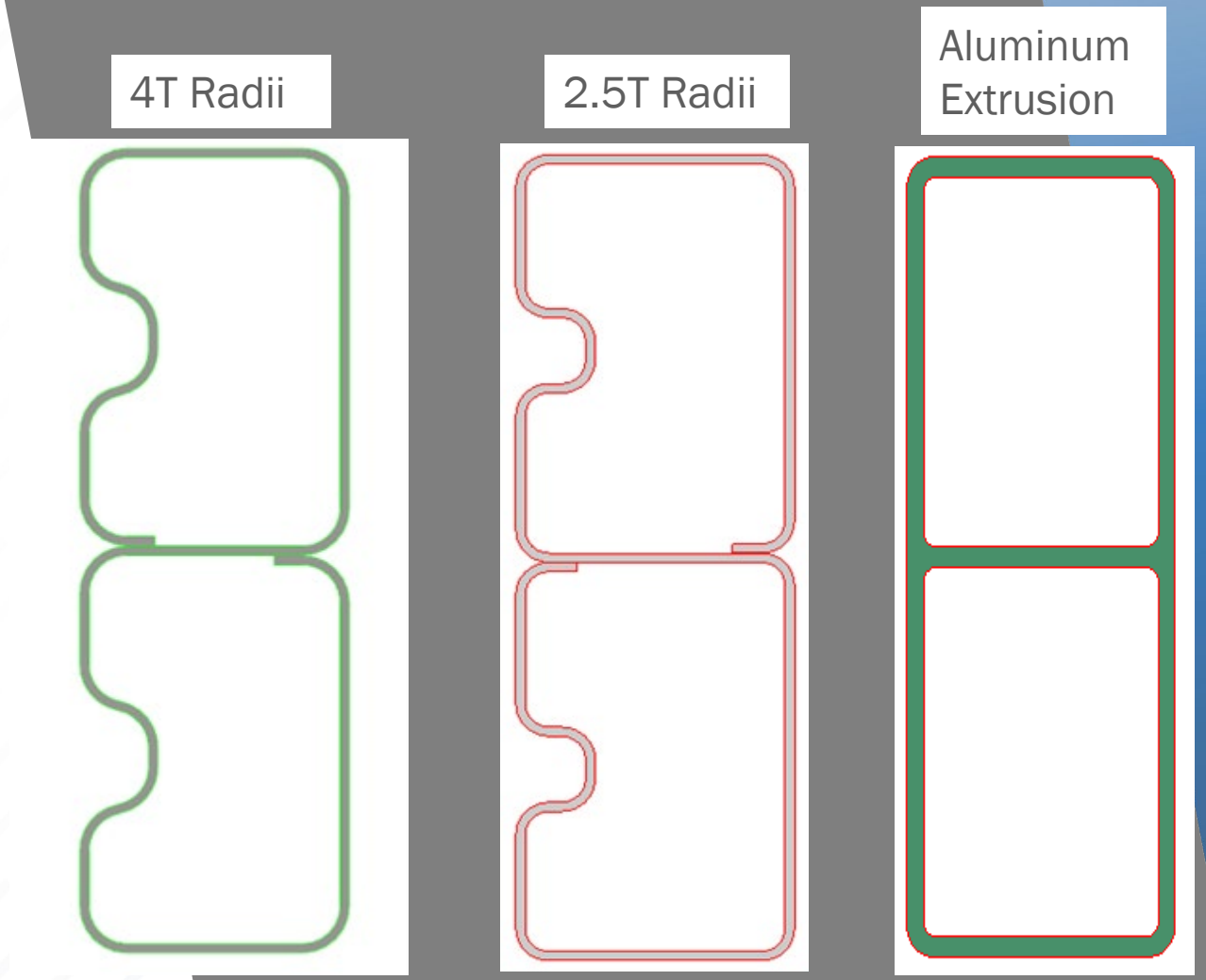
- Allows for more energy absorption during events such as side pole impact for BEV rocker structures



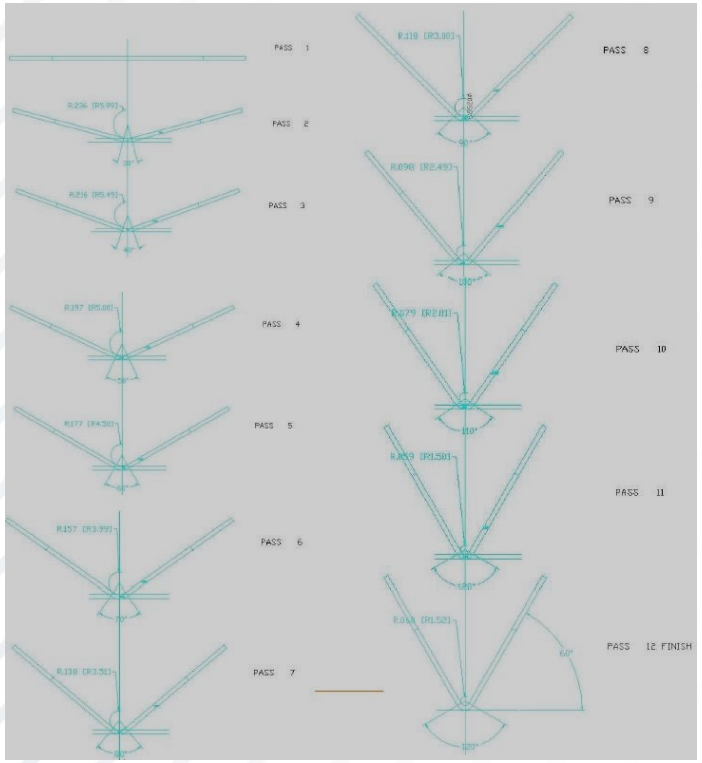


PRODUCT PERFORMANCE & APPLICATION

- Example bumper profile showing decrease in bending radii from 4T to 2.5T
- Flat surface area increase by 3*T
- Slight increase in bending strength due to tighter radii



BENDABILITY ASSESSMENT V-BEND ROLL FORM TOOLING

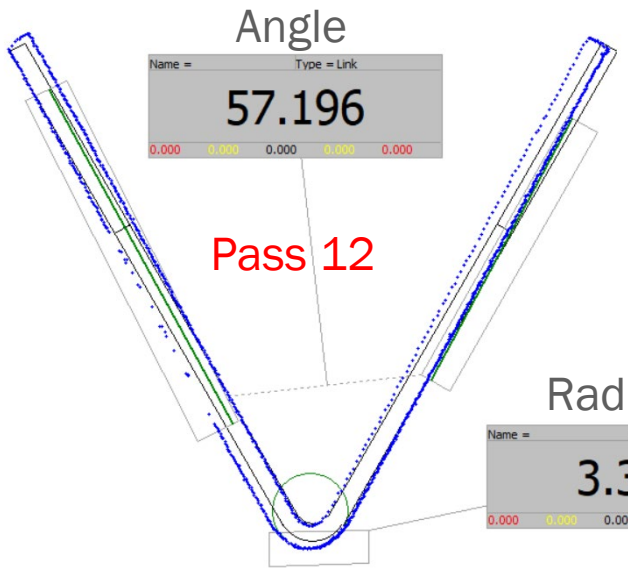


BENDING PROGRESSION

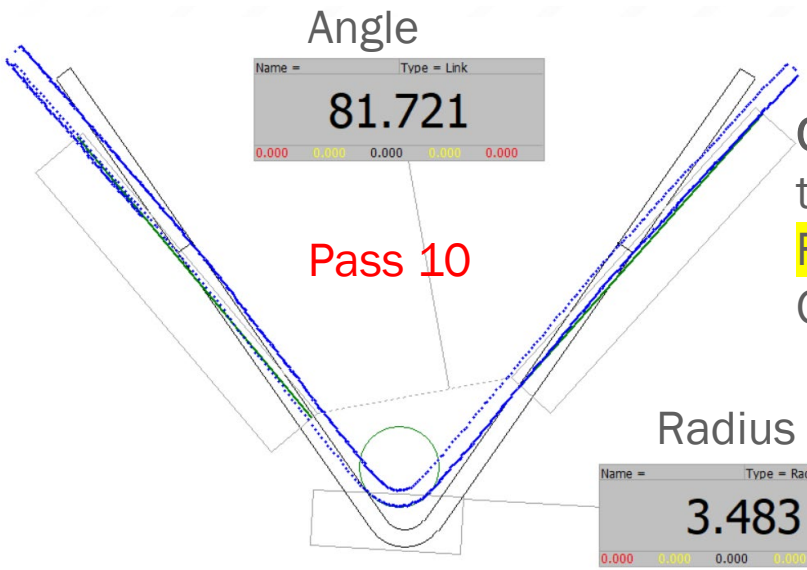
Pass	Inner Radius	Outer Radius	Angle
1	Flat	flat	180
2	6	7.5	150
3	5.5	7	140
4	5	6.5	130
5	4.5	6	120
6	4	5.5	110
7	3.5	5	100
8	3	4.5	90
9	2.5	4	80
10	2	3.5	70
11	1.5	3	60
12	1	2.5	60

BENDABILITY ASSESSMENT

Pass	Inner Radius	Outer Radius	Angle
1	Flat	flat	180
2	6	7.5	150
3	5.5	7	140
4	5	6.5	130
5	4.5	6	120
6	4	5.5	110
7	3.5	5	100
8	3	4.5	90
9	2.5	4	80
10	2	3.5	70
11	1.5	3	60
12	1	2.5	60



GI MP1300
t= 2.0 mm
Ri/t = 0.67
Closed 2.8°



CR MP1500
t= 1.4 mm
Ri/t = 1.49
Open 11.7°

DIMENSIONAL PERFORMANCE

To quantify the improvements in spring-back control parts were produced using a production “monoleg” section. Part profile was measured in two conditions:

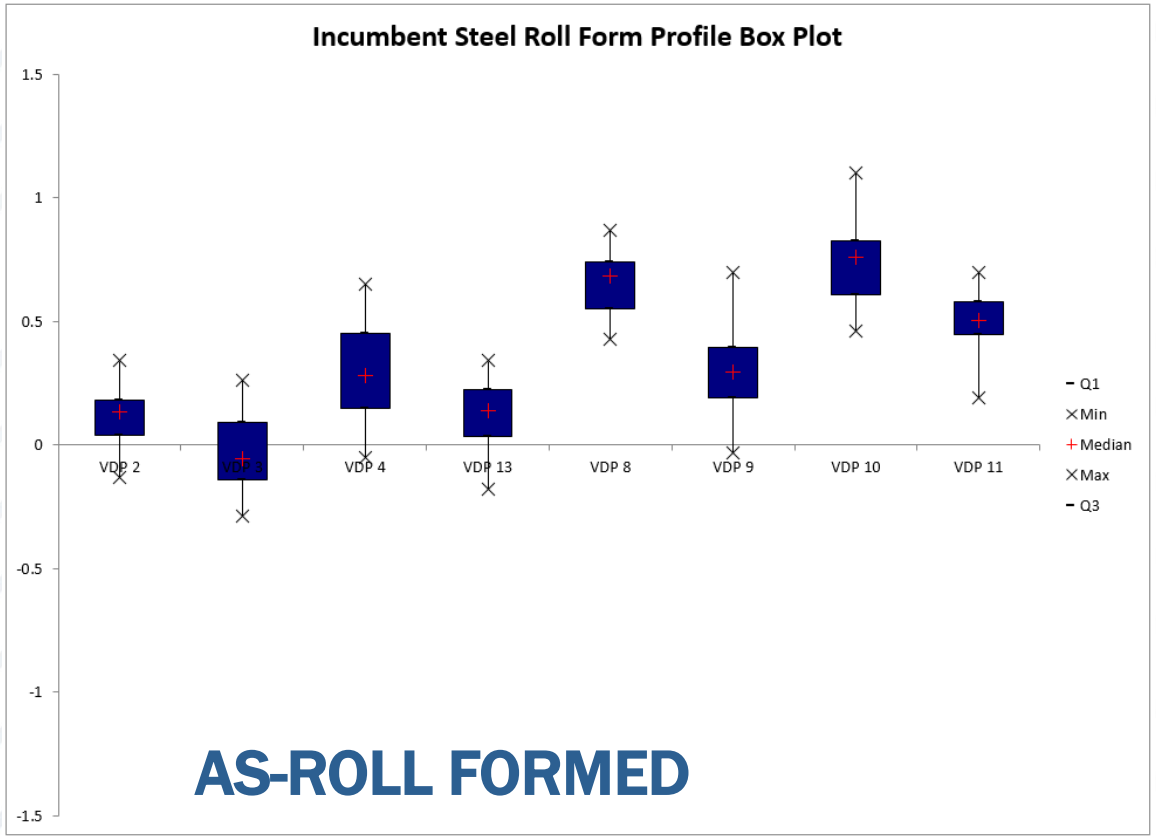
1. As-roll formed
2. Same parts after laser cutting large access holes

The data was compared to the incumbent, 1700 MPa part to assess the tendency of the material to retain its shape

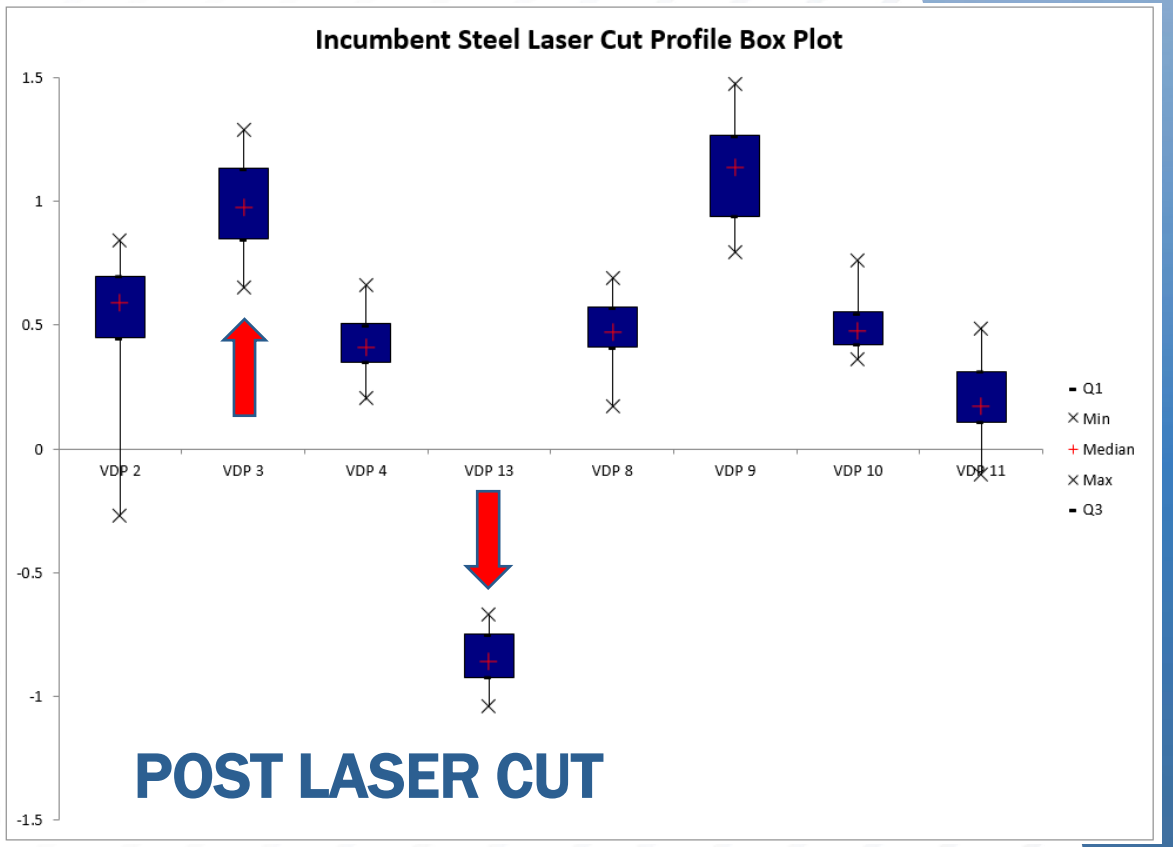
AS-ROLL FORMED

POST LASER CUT

DIMENSIONAL PERFORMANCE - INCUMBENT



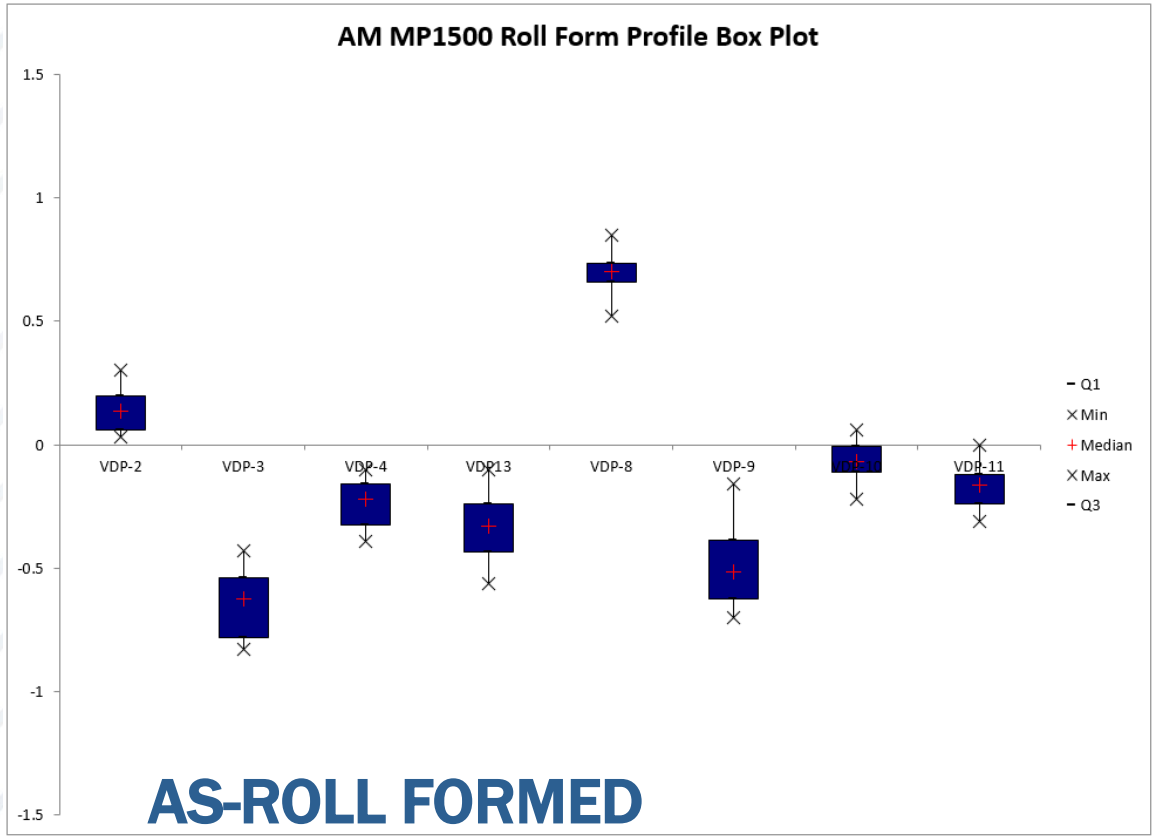
AS-ROLL FORMED



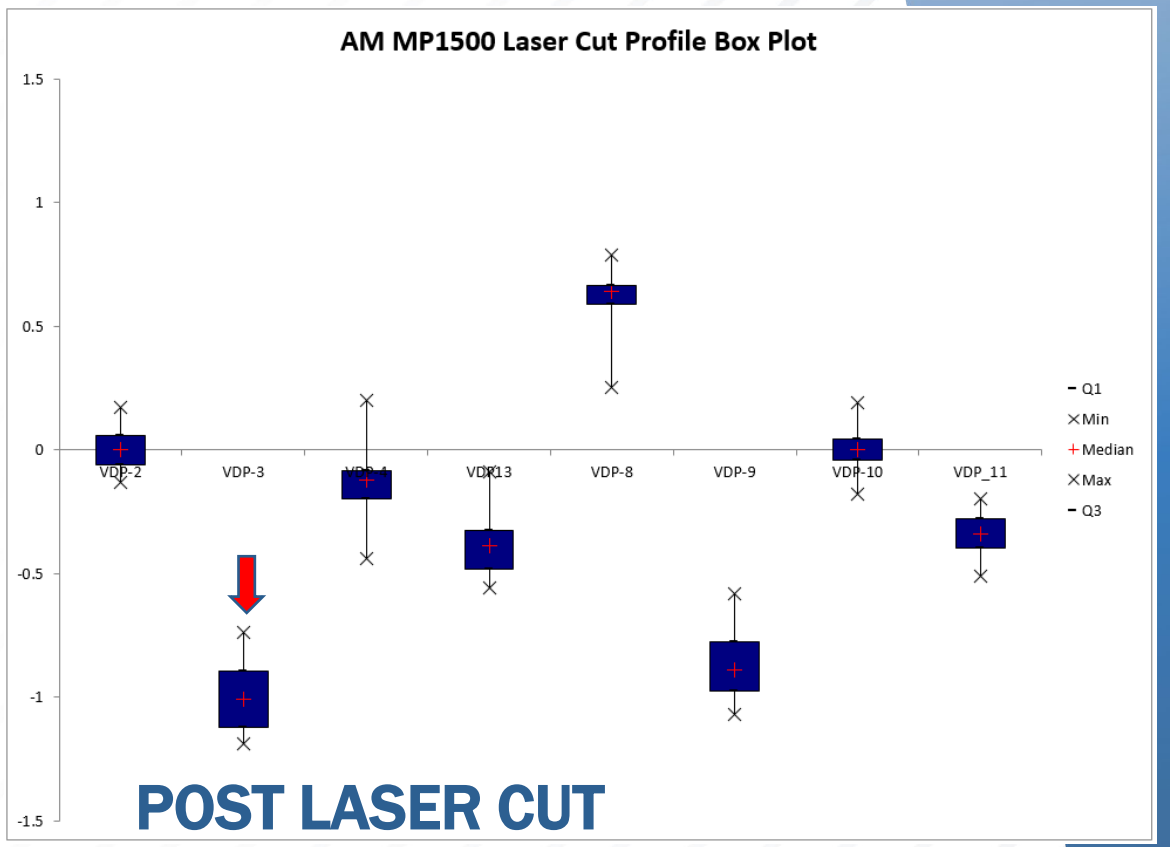
POST LASER CUT

- Incumbent material is 1700 MPa steel
- Average profile shift is > 0.5 mm (n=30)
- Max profile shift is ~1.0 mm

DIMENSIONAL PERFORMANCE – ARCELORMITTAL MP1500



AS-ROLL FORMED

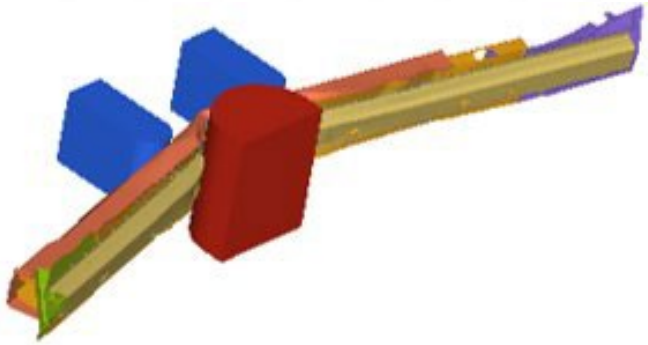


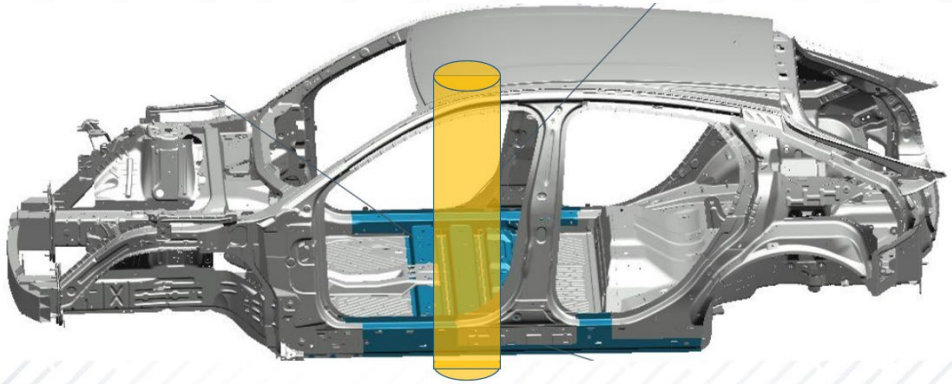
POST LASER CUT

- Average profile shift is 0.17 mm
- Max profile shift is <0.4 mm (n=30)
- The average and max profile shift were both >60% less compared to the incumbent, 1700 MPa steel despite a strength difference of ~15%

3-POINT BENDING SETUP

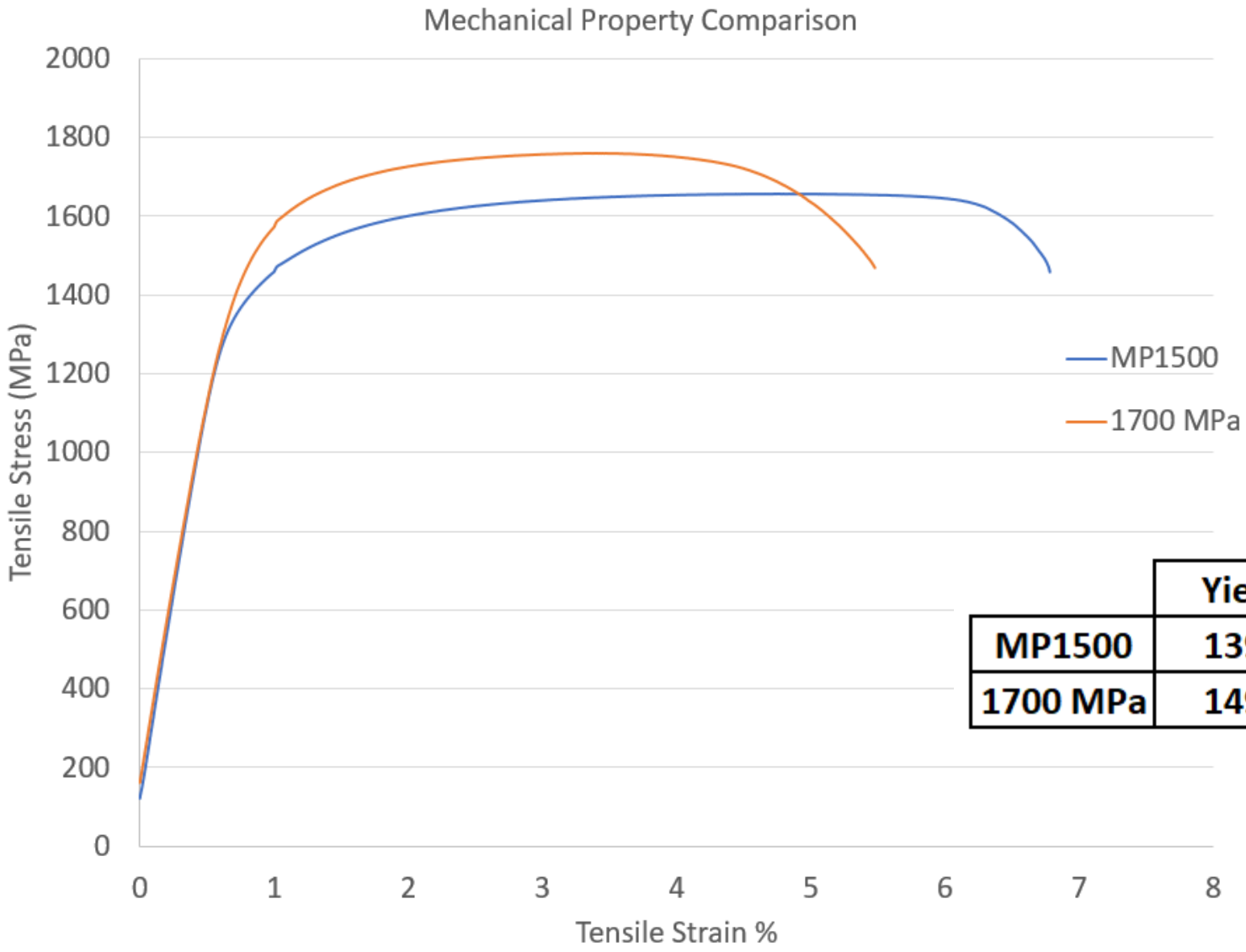
- 360 mm support span
- 250 mm diameter indenter
- 100 mm diameter support
- 50 mm/min test speed
- Narrow support span emphasizes strength as well as ability to absorb energy
- The narrow span also simulates BEV side impact loading





Ford Motor Company, Mikolaiczik, “2020 Ford Mach-E” Great Designs in Steel 2021

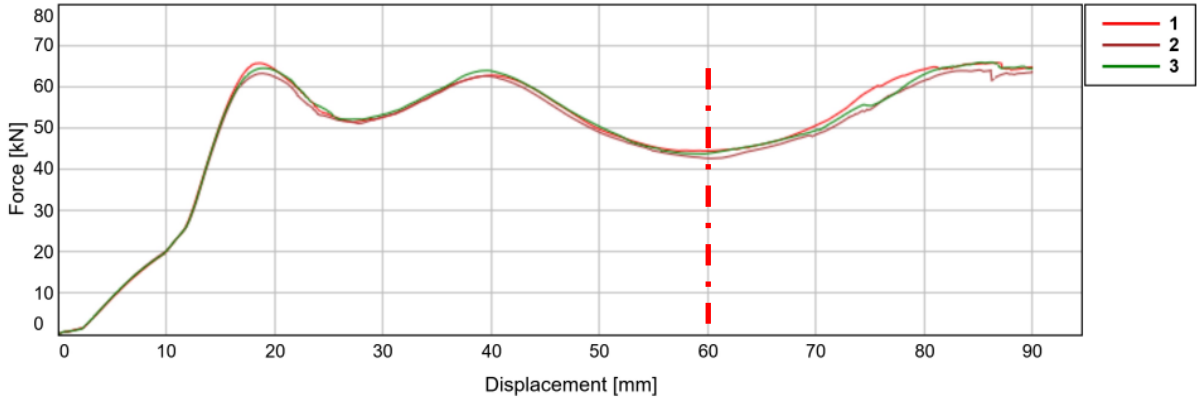
TENSILE TEST COMPARISON



	Yield	Tensile	Elongation%
MP1500	1391	1659	6.75
1700 MPa	1499	1759	5.45

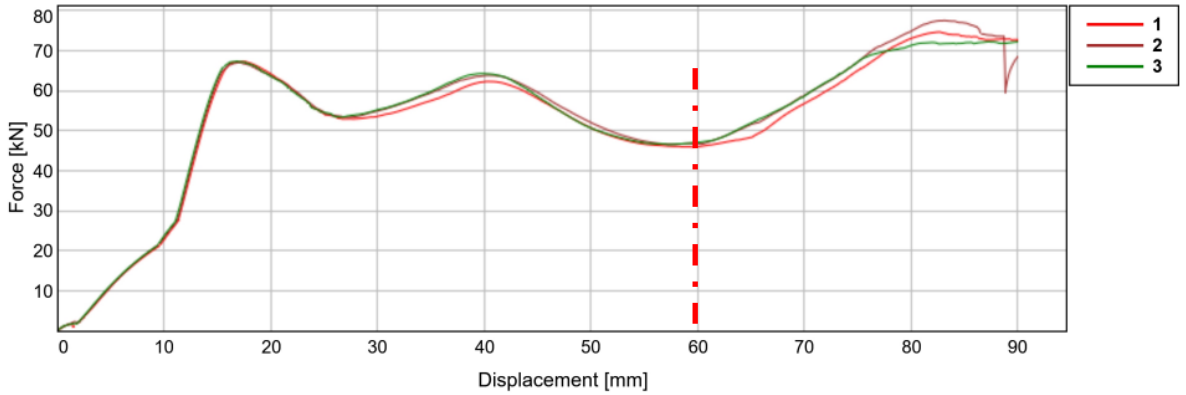
3 POINT BEND TESTING COMPARISON

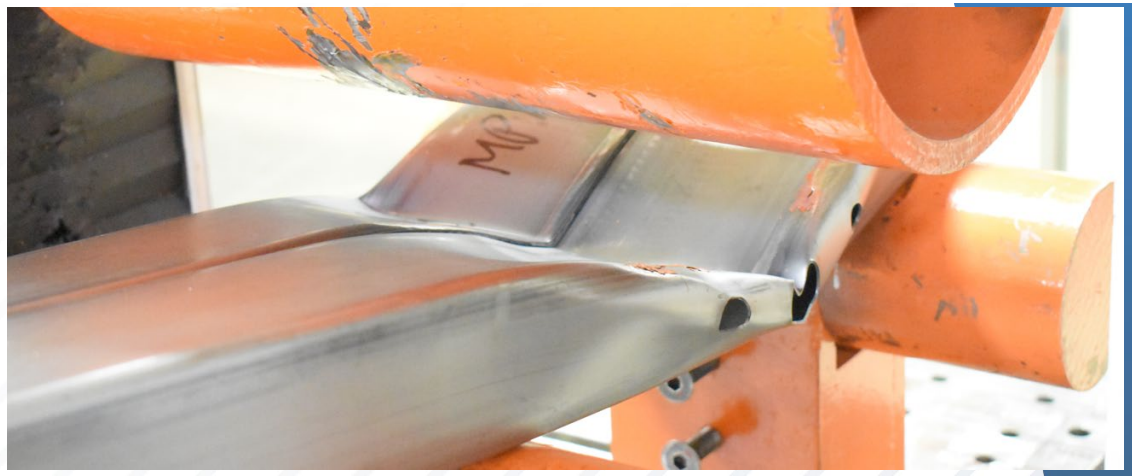
Incumbent 1700 MPa 1.35 mm



- Average first peak force: **65.22 kN**
- Average energy absorbed @ 60 mm displacement: **2720 J**

ArcelorMittal MP1500 1.38 mm





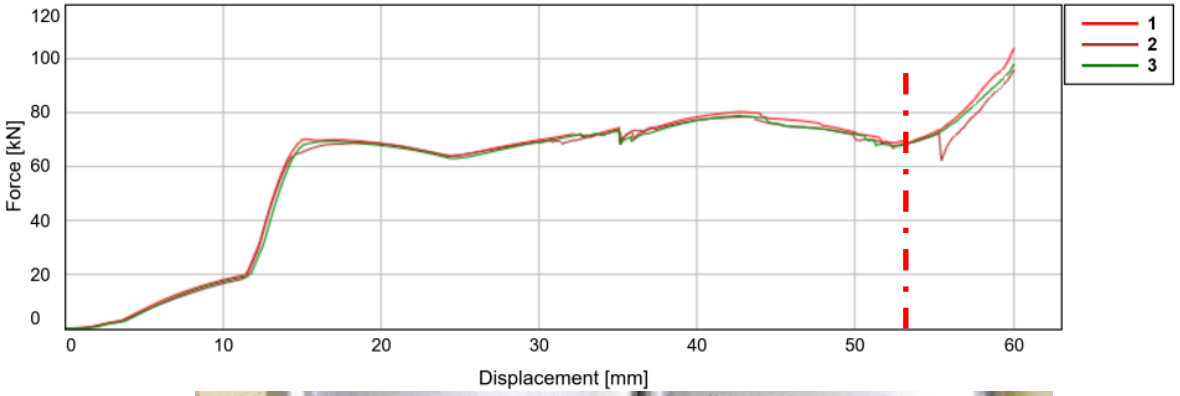
- Average first peak force: **67.24 kN**
- Average energy absorbed @ 60 mm displacement: **2859 J**

SECTION CRUSH TEST SETUP

- Localized section crush test
- 200x65 mm rectangular impactor
- 50 mm/min test speed
- Crush performed with fully length part

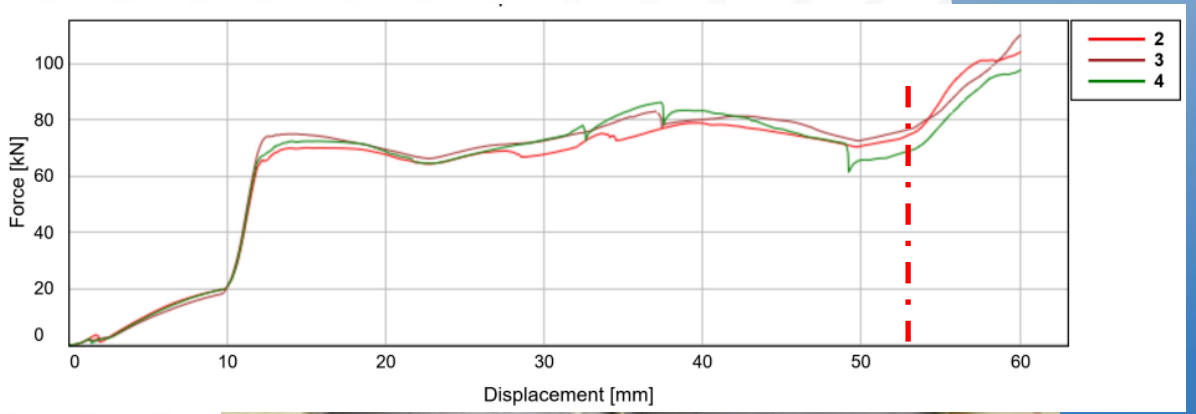
SECTION CRUSH TESTING COMPARISON

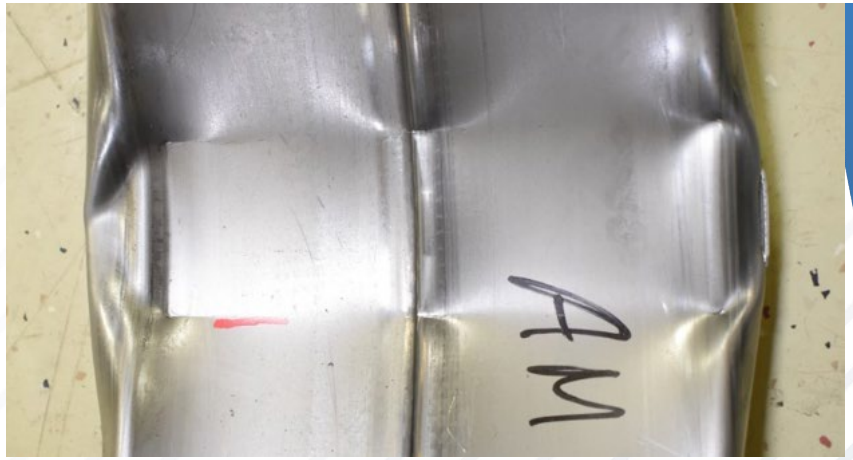
Incumbent 1700 MPa 1.35 mm



- Average first peak force: **69.39 kN**
- Average energy absorbed @ 53 mm displacement: **2967 J**

AM MP1500 1.38 mm





- Average peak force: **72.48 kN**
- Average energy absorbed @ 53 mm displacement: **3184 J**

SUMMARY

- ArcelorMittal has developed a family of new Multi-Phase (MP) grades to introduce cold-stamping UHSS products with improved elongation, bendability, and flangeability, to address unique design challenges posed by automotive structures with very high strength requirements
- Shape has evaluated the MP grades from ArcelorMittal for both process and product attributes
  - Improved bendability increases design flexibility for roll forming
  - Less spring-back of the material is observed during post-forming cutting operations compared to 1700 MPa steel
  - Product performance is comparable to 1700 MPa steel in applications where both strength and energy absorption are desirable, such as BEV side impact protection

FOR MORE INFORMATION

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