GREAT DESIGNS IN STEEL

DEVELOPMENT & APPLICATION OF NEW UHSS MULTI-PHASE GRADES

Brian Oxley
Shape Corp
Product Manager, Advanced Product Development

Stefano Lepre
ArcelorMittal Global R&D
Section Leader, Automotive Product Applications
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** $\geq$ 6%
  - **Local formability**
    - **Bend R/t (radius to thickness ratio)** $\leq$ 2.5
    - **Hole Expansion Ratio (HER)** $\geq$ 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
PRODUCT ATTRIBUTES

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

### MP 1300 CR (uncoated)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield Strength (MPa)</td>
<td>1030 MIN</td>
</tr>
<tr>
<td>Tensile Strength (MPa)</td>
<td>1300-1550</td>
</tr>
<tr>
<td>Total Elongation (%)</td>
<td>6% MIN</td>
</tr>
<tr>
<td>HER (%)</td>
<td>Avg. 50%</td>
</tr>
<tr>
<td>Bendability</td>
<td>Avg. 2.0 R/t</td>
</tr>
</tbody>
</table>

### MP 1300 GI (coated)

<table>
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<td>Yield Strength (MPa)</td>
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<td>1300-1550</td>
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<tr>
<td>Total Elongation (%)</td>
<td>6% MIN</td>
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<tr>
<td>HER (%)</td>
<td>Avg. 40%</td>
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<tr>
<td>Bendability</td>
<td>Avg. 2.0 R/t</td>
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### MP 1500 CR (uncoated)

<table>
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<tr>
<th>Property</th>
<th>Value</th>
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<tbody>
<tr>
<td>Yield Strength (MPa)</td>
<td>1100 MIN</td>
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<tr>
<td>Tensile Strength (MPa)</td>
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</tr>
<tr>
<td>Total Elongation (%)</td>
<td>6% MIN</td>
</tr>
<tr>
<td>HER (%)</td>
<td>Avg. 50%</td>
</tr>
<tr>
<td>Bendability</td>
<td>Avg. 2.2 R/t</td>
</tr>
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</table>

Flatness meets requirement (image from MP 1500 CR)

HER Avg. 50% on MP 1500 CR

Bendability Avg. 2.2 R/t on MP 1500 CR
• 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**

\[
k \approx \frac{(YS + UTS) (R_o)}{(E*T)}
\]

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

<table>
<thead>
<tr>
<th>Pass</th>
<th>Inner Radius</th>
<th>Outer Radius</th>
<th>Angle</th>
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<tbody>
<tr>
<td>1</td>
<td>Flat</td>
<td>flat</td>
<td>180</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>7.5</td>
<td>150</td>
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<tr>
<td>3</td>
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<td>140</td>
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<tr>
<td>4</td>
<td>5</td>
<td>6.5</td>
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<td>5</td>
<td>4.5</td>
<td>6</td>
<td>120</td>
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<tr>
<td>6</td>
<td>4</td>
<td>5.5</td>
<td>110</td>
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<td>7</td>
<td>3.5</td>
<td>5</td>
<td>100</td>
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<td>8</td>
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<td>4.5</td>
<td>90</td>
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<td>60</td>
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<tr>
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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.
DIMENSIONAL PERFORMANCE - INCUMBENT

- 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

- 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

TENSILE TEST COMPARISON

Mechanical Property Comparison

<table>
<thead>
<tr>
<th></th>
<th>Yield (MPa)</th>
<th>Tensile (MPa)</th>
<th>Elongation (%)</th>
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<tbody>
<tr>
<td>MP1500</td>
<td>1391</td>
<td>1659</td>
<td>6.75</td>
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<tr>
<td>1700 MPa</td>
<td>1499</td>
<td>1759</td>
<td>5.45</td>
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</table>
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

AM MP1500 1.38 mm

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

- 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

Brian Oxley
Shape Corp.
Oxleyb@shapecorp.com

Stefano Lepre
ArcelorMittal
Stefano.Lepre@arcelormittal.com