New developments in Laser Welded Blanks using AlSi coated Boron Steel

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• Why is partial ablation used prior to welding for Aluminum-Silicon (AlSi) coated steels?
• Allowable aluminum thresholds in AlSi-1500 - AlSi-500 joints
• Why investigate a new process for joining?
• Testing requirements for validation of new process
• Achieving Robustness with our new process for AlSi-1500 and AlSi-500 joints
• Conclusions
Weld pollution with conventional laser welding of AlSi coated steels

1. Heterogeneous microstructure
2. Zones rich in Al leading to low hardness

1. AlSi-1500 – AlSi-1500 Fracture in the weld along Al-rich area
2. AlSi-1500 – AlSi-500 Fracture in base material in static but in the weld in dynamic loading (3m/s)

Dedicated laser welding are therefore necessary to weld AlSi-1500 and AlSi-500
ArcelorMittal developed a process for the laser welding of AlSi coated PHS

Before laser-welding, the Aluminum-Silicon coating near the edge is partially removed in both sides by using a laser ablation process (ArcelorMittal patented process)

- The top layer is removed to avoid excessive Al dilution in the weld
- The intermetallic layer is intentionally kept to help with corrosion protection and avoid decarburization

Process helps achieve the required weld strength performance for all AlSi coated PHS combinations
## Welding process of AlSi-1500 - AlSi-500

### General trend

<table>
<thead>
<tr>
<th>Average Aluminium %</th>
<th>AISi-1500 - AISi-1500 combinations</th>
<th>AISi-1500 - AISi-500 combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>No δ-ferrite</td>
<td>&lt; 1.1% *</td>
<td>&lt; 1.2% *</td>
</tr>
<tr>
<td>Fully Martensite</td>
<td>&lt; 0.3% **</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

* values depend on the chemistry of filler wire

** values depend on hot stamping conditions and filler wire chemistry

AM patented partial ablation process is today the only safe way to reach less than 0.3% of Aluminum content in the weld for AISi-1500 - AISi-1500 laser welded assembly. To reach 1.2% however other processes may be acceptable.
Why investigate a new processes for AlSi-1500-AlSi-500?

Cost & processing efficiency
- Reduction in capital
- Less processing steps
- Filler wire a key enabler
- Potential for cost saving

ArcelorMittal Global R&D continues to innovate and develop new processes leading to better cost efficiency
Products metallurgy of current AlSi PHS grades
AlSi-500 & AlSi-1500

• **AlSi-500**
  - Dedicated to laser welded blanks for structural and safety components
  - Chemistry: C-Mn-Si
  - As heat-treated $\rightarrow$ Ferrite + Martensite (5-15%)
  - Available thicknesses from 0.8 to 2.5 mm
  - Typical properties obtained after hot stamping:

<table>
<thead>
<tr>
<th>YS (MPa)</th>
<th>TS (MPa)</th>
<th>TE (%)</th>
<th>Bending angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 400</td>
<td>≥ 550</td>
<td>≥ 16</td>
<td>≥ 120°</td>
</tr>
</tbody>
</table>

• **AlSi-1500**
  - Intended for laser welded blanks for structural and safety components
  - Chemistry: C-Mn-B
  - As heat-treated $\rightarrow$ Martensite (90-100%)
  - Typical properties typical values of 5 to 10 minutes at 880°C to 930°C heat treatment followed by die quenching (cooling speed $\geq 30°C/s$):

<table>
<thead>
<tr>
<th>YS (MPa)</th>
<th>TS (MPa)</th>
<th>TE (%)</th>
<th>Bending angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 1100</td>
<td>≥ 1500</td>
<td>≥ 3</td>
<td>≥ 50°</td>
</tr>
</tbody>
</table>
Testing: ArcelorMittal Methodology

- **Mechanical tests on coupons:**
  1. Estimate weld strength - static tensile test
  2. Assess the dynamic effect on weld behavior - dynamic tensile test
  3. Determine the ability of a weld to be plastically deformed and absorb energy – Fracture test

- **Mechanical testing on stamped Omega shape:**
  4. Estimate the effect of complex loading on Omega part

- **Mechanical testing on automotive parts:**
  5. Estimate the effect of complex loading on real parts

ArcelorMittal has developed validation tools to ensure safe design.
In some cases, only dynamic test can highlight weld weakness. For structural and safety applications, dynamic tests are important.
Dynamic fracture test demonstrates that brittle fracture occurs when average Aluminum content in the weld is above 1.2% wt.

Results from dynamic toughness test with different welding processes leading to different aluminum content in the laser weld.

**Dynamic fracture test demonstrates that brittle fracture occurs when average Aluminum content in the weld is above 1.2% wt.**
Risk of brittle fracture with high Al content

- Dynamic loading, weld with Aluminum content

AISi-1500 - AISi-500

Brittle fracture is observed at locations where a high Al content leads to δ-ferrite grains that through the hot stamping process are transformed to big grain sizes.

Average Aluminum content > 1.2% wt.
• Maximum Aluminum Content (MAC) for avoiding δ-ferrite formation at high temperature

For pure Iron-Al mixing:
• Inter-metallics (AlFe) are formed when Aluminum content is higher than about 20 at.% (about 10 wt.%)
• δ-ferrite is created at high temperature from the liquid state when Aluminum content is higher than about 0.7 wt.%

For pure Iron-Al mixing, δ-ferrite is formed at high temperature when Al content is higher than 0.7 wt.%. This ferrite is known as a brittle structure.
Equilibrium diagrams of AlSi-1500-AlSi-500 combinations

Example with same thicknesses for AlSi-1500 and AlSi-500

- For each AlSi-1500-AlSi-500 combination, the binary diagram can be estimated from the average chemical composition.
- Further, the effect of chemical composition of filler wire could be also estimated.
- The limit of Average Al content to avoid weld brittleness is about ~1.2 wt.%

For AlSi-1500-AlSi-500 combinations, δ-ferrite is created if av. Al content higher than 1.2 wt.%
Several criteria are necessary to ensure that the weld is not the weak point:

- Weld Strength intermediary between AlSi-1500 and AlSi-500
- No δ-ferrite grains for avoiding the risk of brittle fracture

### Criteria for AlSi-1500 - AlSi-500

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>No δ-ferrite</td>
<td>Average Aluminum &lt; 1.2% wt.</td>
</tr>
<tr>
<td>Weld Strength</td>
<td>AISi-1500 &gt; Weld &gt; AISi-500</td>
</tr>
</tbody>
</table>
Limitations

• Aluminum content measurements require careful protocol and specific equipment (SEM, EDS with special methodology) to reach required accuracy for low value (close to 1%).

• Dynamic tensile test and component testing are long and sometimes difficult to implement.

• ArcelorMittal is developing a new dynamic fracture test to expedite results.

For AlSi-1500-AlSi-500 combination, Aluminum thresholds are hard to monitor in production, so process control and achieving weld strength are key measurables.
Why is filler wire a key enabler for product robustness?

Filler wire is key ingredient to the process and it improves robustness in 3 ways:

1. Weld geometry control (gap bridging)
2. Aluminum dilution
3. Gamma stabilizer (C, N) element increase in molten area:
   Introduction of some elements like Carbon can counter balance Aluminum effect on weld quench ability.

Combined effects of these three items, weld performance is more robust.
Al content max = 100 g/m² per side upper limit of coating

AS 150 PHS Steel

Calculation depends of weld geometry

- The two side partial ablation (AMTB patented) process is safe for all thicknesses
- One side partial ablation also works for average thickness higher than 1 mm
- Filler wire gives more robustness and increases thickness range
Conclusion

• ArcelorMittal is global leader in advancing hot stamped laser welding process.

• Our standard partial ablation process is the proven way in industry to meet weld seam requirements for all hot stamped combinations (AlSi-1500+AlSi-1500, AlSi-1500+AlSi-500).

• New industrial process with reduced ablation and filler wire is robust and in production for AlSi-1500+ AlSi-500 combinations.

• However, this new process bears new risk which requires dynamic validation:
  - The key point is to avoid δ-ferrite grains created during the welding from the liquid state. That needs to have an average Al% below 1.2 % wt.
  - Low alloy filler wire mainly acts by a dilution effect

• Welding process with one side ablation in combination with filler wire addition is a good compromise between industrial production constraints and weld performance.

• ArcelorMittal continues to research ways for improving product robustness and save time in the development of new product and processes.
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