Weldability of Niobium Microalloyed Steels for Structural Application

June, 2018
About half of all steel produced worldwide goes to the construction industry.

The use of a higher strength steel can enable substantial savings in structural weight and material costs.

Previous Project: A36 -> ASTM A572 Grade 50 with Nb

- Weight savings = 22%.
- CO₂ emissions savings = 21.7% or 27 ton of CO₂.
- Energy savings = 21% or 1,779 GJ.
- Cost savings = 17% of the cost of the structure.

Source: Silvestre et al. (2012)
Added value with better financial results are perceived from steel maker to project owner

Source: Published price list in Europe
How to improve structural steels?

“The best substitute for steel is a better steel”
Niobium HSLA benefits to the construction chain

- Higher Strength
- Smaller Cross Section
- Reduced weight
- Reduced costs

**Reduced Steel weight leads to:**

- Reduced purchasing volume
- Reduced costs for transport, assembly and foundations
- Reduced costs during further processing, especially in **welding**
  - Less filler material
  - Less welding time
  - Less expense for checking the welds

Reduced thickness leads to super proportionally reduced weld volume

Source: Adapted from Voestalpine - brochure
Benefits of Niobium in HSLA

Effect of Niobium refining grains and precipitation hardening

Source: Ichikawa et al. (2011)
Benefits of Niobium in HSLA

Correlation of grain size and yield strength

Source: Morrison (2000)

ASTM 992 beam (S355) Charpy V-notch strength comparison

Source: Jansto (2011)
New Building Project

>1,000 tons of structural steel

**Main beam:**
H welded sections, ASTM A572 Grade 65 (as-rolled not available):

- SAW process
- FCAW process

**Secondary beam:**
H as-rolled sections, Grade 50
Welding of ASTM A572 Grade 65

About the steel:

In order to achieve improved toughness, low C equivalent and YS over 460 MPa. Grain refinement was the main strengthening mechanism. Hence 0.03% of Nb added to steel.

<table>
<thead>
<tr>
<th>C (%)</th>
<th>Si (%)</th>
<th>Mn (%)</th>
<th>P (%)</th>
<th>S (%)</th>
<th>Nb (%)</th>
<th>Cu (%)</th>
<th>N (%)</th>
<th>Ti (%)</th>
<th>CEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.09</td>
<td>0.25</td>
<td>1.50</td>
<td>0.014</td>
<td>0.002</td>
<td>0.030</td>
<td>0.143</td>
<td>0.004</td>
<td>0.013</td>
<td>0.35</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>YS (MPa)</th>
<th>TS (MPa)</th>
<th>El (%)</th>
<th>Charpy test (-50 °C) (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>503</td>
<td>615</td>
<td>22</td>
<td>215</td>
</tr>
</tbody>
</table>
Welding of ASTM A572 Grade 65

Welding Procedures

**SAW (Submerged Arc Welding)**

- Width: 31,5 mm
- Height: 22,4 mm
- Length: 1800 mm
- Thickness: 500 mm

**FCAW (Flux Cored Arc Welding)**

- Width: 25 mm
- Height: 25 mm
- Length: 1360 mm
- Thickness: 770 mm
Welding of ASTM A572 Grade 65
The new grade was designed to be positioned in Zone 1 of Granville diagram. This means less chances of welding defects.

Welding Procedure Specification - Preheating

- AWS D1.1 – Structural Welding Code – Steel Standard (Tables)

- AWS D1.1 – Structural Welding Code – Steel Standard (Annex I)
## Welding tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduction in area (Through-thickness tensile test)</td>
<td>&gt;60%</td>
<td>Greater than 30%, no lamellar tearing susceptibility in the steel.</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>570 MPa (SAW) 600 MPa (FCAW)</td>
<td>Matches A572 Grade 65 specification (minimum 550 MPa)</td>
</tr>
<tr>
<td>Hardness</td>
<td>203 HV (SAW HAZ) 213 HV (FCAW HAZ)</td>
<td>The hardness results are below 350 HV and do not indicate hard zones and susceptibility to cracks from martensitic formation.</td>
</tr>
<tr>
<td>Bending test</td>
<td>SAW and FCAW no fracture in the weld</td>
<td>Even when bent, the welded joint does not crack, qualifying the welding procedure.</td>
</tr>
<tr>
<td>Impact test (at 23 °C)</td>
<td>293 J (SAW HAZ)</td>
<td>While not a requirement in structural steels in Brazil, the result shows the welded material has good toughness at typical regional temperatures (Araxá, Brazil).</td>
</tr>
</tbody>
</table>
Welding of ASTM A572 Grade 65

Weld Hardness and microstructure (SAW fillet weld)

About the weld:
Low hardness and bainitic microstructure formation in CGHAZ increase toughness and reduce crack susceptibility.
Welding of ASTM A572 Grade 65

Weld Hardness and microstructure (SAW, T join)

About the weld:
Low hardness and bainitic microstructure formation in CGHAZ increase toughness and reduce crack susceptibility.
Welding of ASTM A572 Grade 65 and Grade 50

Weld Hardness and microstructure (FCAW fillet weld)

About the weld:
Low hardness and bainitic microstructure formation in CGHAZ increase toughness and reduce crack susceptibility.

About hardness peak:
The peak refers to Grade 50. Even with a lower mechanical resistance the material showed higher hardness due to the higher carbon content comparing to the new Nb-Low C steel.
Other advantages of welding new Nb - low C steel

About the CGHAZ:
Low carbon allows changes in the temperature transformation and the grain growth can be better controlled. The size and hardness of HAZ is reduced resulting in a better performance in the joints.

Same tensile class (over 345 MPa)
- **EN 10025-S355**: TMCP steel, C = 0.08%
- **A572 grade 50**: QT steel, C = 0.17%
What about pre-heating. Is it really necessary in new Nb - low C steel?

Microstructure and mechanical results in welds of ASTM A572 grade 65 with and without preheating

<table>
<thead>
<tr>
<th>Without preheating</th>
<th>Mechanical results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microstructure</td>
<td>Hardness HV0,7 = 170</td>
</tr>
<tr>
<td></td>
<td>Charpy V @25°C = 160 J</td>
</tr>
<tr>
<td></td>
<td>Transition temperature 27J= - 52 °C</td>
</tr>
<tr>
<td></td>
<td>Tensile Strength: 565 MPa</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>With preheating</th>
<th>Mechanical results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microstructure</td>
<td>Hardness HV 0,7 = 180</td>
</tr>
<tr>
<td></td>
<td>Charpy V @25°C = 150 J</td>
</tr>
<tr>
<td></td>
<td>Transition temperature 27J = - 33 °C</td>
</tr>
<tr>
<td></td>
<td>Tensile Strength: 575 MPa</td>
</tr>
</tbody>
</table>

This result shows that the new Nb - low C steel can be welded without preheating, delivering a better performance.

The preheating procedure for this steel is therefore not necessary.

It is also important to remark that the Annex I of AWS D1.1 has a methodology to identify preheating needs according to the real carbon content and procedures variables that confirm the results of this study.
Compared with a Project in ASTM A572 Grade 50:
- 10% weight reduction
- 9% less CO\textsubscript{2} emission and energy consumption
- 5% savings in total project costs

Real welding needs (without preheating)
- 6,770 GJ in energy savings
- Saves of more than US$ 200,000 in LPG and Oxygen consumption
- 428 tons of CO\textsubscript{2} not emitted
- 3,600 machine-hours saved

Other effects
- Improve safety in building assembly (lighter sections and cranes)
- Lower crack susceptibility in future repairs
- Lower brittle crack probability
Conclusion

- TMCP steels are a very good solution for structural applications;
- Weldability of these steels are much easier with low carbon content;
- Niobium played a very important role, assuring fine grain with excellent toughness and high strength simultaneously;
- The use of Nb as microalloying element makes possible an important reduction in C content and C eq.;
- Niobium addition are important to allow a faster and more efficient weld and to avoid a big effect in the CGHAZ (Coarsened Grain Heat Affected Zone)