Welding procedure development for welding of High strength carbon steel pipe cladded with Austenitic stainless steel 316L by using overmatching filler metal.

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Typical Field of Applications

- Clad pipe, riser
- Oil and Gas production
- Chemical industry
- Pressure vessel
CLADDING ADVANTAGE

- Providing a long-life and high-reliability corrosion resistance to harsh environment applications

- Very economical way to provide excellent corrosion resistance for steel structures without jeopardizing design thickness
Corrosion resistant alloy clad pipe are widely used for the transport of hot and corrosive fluids in flow lines and associated risers in oil and gas production systems.

Solid CRA pipe materials contain expensive alloying elements,

Since high strength substrates can be used with CRA clad pipes, wall thicknesses and pipeline weight can be reduced when compared to solid CRAs.
Full joint welding by using CRA Filler metal. In this case, overmatching filler metal is required because 316L or 309MoL filler will not be able to meet required strength of X65 base metal.

**Advantage**
- Access from one side only suitable for small ID pipe
- Less risk of hot cracking

**Disadvantage**
- Low productivity
- Need perfect fit-up
- High cost (Gas purging, CRA filler, Labor)
- For high strength base metal, matching CRA filler may not be able to meet strength criteria
Welding of Clad pipe

(2) Clad peel back / strip back method

Advantage

* Suitable for High strength base metal
* Less cost than full joint welding by using CRA filler.

Disadvantage

* Low productivity
* Need multipass overlay Inside, difficult to control welding direction in small ID
* Risk of defects on clad restoration weld. Due to difficulty for inside interpass cleaning
Some manufacturer success welding on clad side by Electroslag welding (ESW) using strip electrode EQ309MoL complete clad restoration welding within one pass only.

* But ESW strip electrode head set up is not able to fit within small ID pipe. Normally this method will be best for pipe with internal diameter greater than 20 inch.
Objective

Develop welding procedure for longitudinal weld of small ID clad line pipe

Reduce risk of weld defect by reducing a number of passes

Weld metal properties meet service requirement

Increase productivity and reduce cost
This study intends to develop welding procedure for:

- Clad pipe made by clad plate of High strength Carbon steel (X65) base metal bonded with 316L clad layer, requirement as per DNV OS F101
- Small Internal diameter (ID) 297 mm
- Pipe length 6 meter
Experimental Procedure

Clad pipe made of 12.7 mm high strength carbon steel with Minimum Specified Yield Strength (SMYS) of 65 KSI bonded with 3.0 mm of ASTM A240 Grade 316L. Clad layer is made by hot rolling method.

This application is sub-sea line pipe therefore manufacturing and testing requirement will refer to DNV OS F101 standard.

<table>
<thead>
<tr>
<th>Layer</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Ni</th>
<th>Mo</th>
<th>Cr</th>
<th>Cu</th>
<th>Nb</th>
<th>V</th>
<th>Ti</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel</td>
<td>0.08</td>
<td>1.38</td>
<td>0.25</td>
<td>0.27</td>
<td>-</td>
<td>0.13</td>
<td>0.17</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Balance</td>
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<tr>
<td>Clad 316L</td>
<td>0.02</td>
<td>1.64</td>
<td>0.51</td>
<td>12.7</td>
<td>2.6</td>
<td>17.86</td>
<td>0.11</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Balance</td>
</tr>
</tbody>
</table>

High strength carbon Steel, 12.7 mm

316L clad, 3.0 mm
Experimental Procedure

1) Bevel preparation by machining

Bevel design concept

* Bevel is designed to prevent clad metal melting into carbon steel weld to avoid weld cracking.

* Number of pass is minimized to avoid risk of defect and reduce welding cost and time.

* Welding sequence first starts on external side by using Carbon steel electrode, then complete clad side by using Nickel base filler metal.

* This joint design, clad weld penetration depth will be prepared down to base metal substrate therefore the over matching filler metal such as Nickel base is required according to high yield base metal property and reduce the risk of weld metal cracking.
2) Clad pipe forming by Press

Pipe become oval shape but not completely closed there is some gap around 40-60 mm
Experimental Procedure

3) Close pipe by hydraulic press and root pass welding

Pipe is closed completely without gap to prevent carbon steel weld penetrate and melt with clad layer on another side which can cause cracking.

Root pass welding is done by SMAW High strength low alloy electrode only one pass is required.

Welding electrode used is A5.5 E8018-G, dia 3.2 mm

Welding parameter: 130A, 26V, 10-12 cm/min
Welding Sequence

Weld carbon steel side first

Fill clad side by Over matching filler 1-2 pass

Deeper than CRA layer 2-3 mm
4) Complete Carbon steel base metal weld on external side

External pipe (carbon steel base metal) was welded by SAW process.
Low alloy steel electrode is used
Filler metal is A5.23 EG, dia 2.4 mm

Welding parameter: 350A, 34V, 40 cm/min
5) Complete Clad weld on Internal side

Two pipes with difference welding procedures on internal side were studied as following:

**Procedure-1** (SAW process)

SAW welding was used to complete clad side welding with one pass only. This will be benefit on reduce welding time.

Filler metal used is A5.14 ERNiCrMo-3, dia 2.4 mm

Welding parameter : 450 A, 33V, 35 cm/min. heat input 25.5 Kj/cm,
5) Complete Clad weld on Internal side

1\textsuperscript{st} pass inside is done by \textbf{GTAW}. This GTAW is selected for the first pass because it gave better control on penetration and torch setup is fit to small ID pipe.

2\textsuperscript{nd} pass is done by \textbf{GMAW pulse}. It gives higher deposition rate therefore complete welding can be done by one cap pass only.
Experimental Procedure

Both processes use ERNiCrMo-3 (dia 1.2 mm)

GTAW shielding : Argon

GMAW-P shielding : 75%Ar + 25%He

Welding parameter (GTAW) : 280A, 18V, 15cm/min, heat input 20.2 kJ/cm

Welding parameter (GMAW pulse): background current 120A, peak current 410A, pulse width 2.3ms, frequency 125Hz, The average RMS amperage is 220A, 30V and the travel speed is 27 cm/min, heat Input 14.7 kJ/cm.
# Experimental Procedure

## Chemical composition of filler metals for each welding process

<table>
<thead>
<tr>
<th>Welding sequence</th>
<th>process</th>
<th>Filler class</th>
<th>C</th>
<th>Mn</th>
<th>Si</th>
<th>Ni</th>
<th>Mo</th>
<th>Cr</th>
<th>Nb+Ta</th>
<th>Ti</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root CS-Ext</td>
<td>SMAW</td>
<td>E8018-G</td>
<td>0.045</td>
<td>1.24</td>
<td>0.29</td>
<td>1.05</td>
<td>0.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Bal.</td>
</tr>
<tr>
<td>Weld out CS-Ext</td>
<td>SAW</td>
<td>EG</td>
<td>0.10</td>
<td>1.49</td>
<td>0.21</td>
<td>0.96</td>
<td>0.23</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Bal.</td>
</tr>
<tr>
<td>Weld out Clas-Int</td>
<td>SAW GTAW&amp;GMAW</td>
<td>ERNiCrMo-3</td>
<td>0.08, 0.01</td>
<td>0.04, 0.12</td>
<td>0.05, 0.18</td>
<td>64.5, 65.2</td>
<td>8.6, 8.68</td>
<td>22.1, 21.5</td>
<td>3.61, 3.46</td>
<td>0.23, 0.21</td>
<td>0.48, 0.34</td>
</tr>
</tbody>
</table>
Results and Discussions

Procedure – 1
SAW

Smooth weld bead was obtained but crack is visually observed at Centerline along the pipe. Linear crack indication detected by Liquid penetration test

Procedure-2
GTAW & GMAW-p

Smooth weld bead, no crack is observed. Liquid penetration test is acceptable to DNV OS F101 Radiographic test is acceptable to DNV OS F101

Weld appearance and soundness
Results and Discussions

Procedure – 1
SAW

Procedure – 2
GTAW & GMAW-P

Crack is visually observed. Crack propagation is at center of weld through fusion line

Visually inspection with low magnification shows complete fusion, no crack is observed

Macro examination
Microstructure examination shows crack in vertical direction at centerline of weld.

Crack is transverse to solidification direction which is the last part that solidify and is also observed along grain boundary in dendrite orientation.

Aqua regia etchant for General structure at 100X
Intergranular crack or crack that is along grain boundary of weld metal and it occurs during the terminal stage of solidification. This crack occurs in SAW procedure is so called “Solidification crack”
Results and Discussions

10% Chromic acid electrolytic etching; Carbide outline, 1000X
Scanning Electron Microscopy (SEM)

Procedure-1
SAW
Energy dispersive spectroscopy (EDS)

Procedure-1
SAW procedure

![Micrograph with NbC marked](image)

![Spectra](image)
Result and Discussion

Solidification crack on SAW clad weld was found to be related to NbC precipitation. SAW procedure tends to give larger grain size than that of GTAW & GMAW procedure.

High heat input welding process results in relatively slow cooling through solidification temperature range and it allows enough time for NbC to form, resulting in greater chance of cracking.

(*) Refer to I.L.W. Wilson, R.G. Gourley, R.M. Walksak, and G.J. Brick. had studied The effect of Heat Input on microstructure and cracking in alloy 625 weld overlays.
Results and Discussions

Procedure-2
GTAW & GMAW

No crack observed

Aqua regia etchant for General structure at 100X
Microstructure

Procedure-2
GTAW&GMAW

10% Chromic acid electrolytic etching, 1000x
Energy dispersive spectroscopy (EDS)

Procedure-2
GTAW&GMAW p
GTAW & GMAW procedure is a lower heat input process resulting in a cooling rate, therefore only a small amount of NbC precipitations are observed.

No cracking is observed on all tested samples.
Only Procedure -2 GTAW & GMAW-P procedure could produce weld soundness. Therefore only this procedure was cut for further testing:

- Bend test
- Tension test (Transverse and Longitudinal)
- Macro hardness test
- Toughness test
- Corrosion test
Mechanical properties

Four side bend tests are carried out according to DNV OS F101 requirement, (plunger size 50 mm)

Samples were bended 180 degree: No opened defect was found on weld area
Bend test results show that GTAW&GMAW procedure can give good weld soundness.
# Mechanical properties

<table>
<thead>
<tr>
<th>Description</th>
<th>Yield strength (Mpa)</th>
<th>Ultimate tensile strength (Mpa)</th>
<th>Elongation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNV requirement</td>
<td>485-605</td>
<td>570-760</td>
<td>&gt;22</td>
</tr>
<tr>
<td>Base metal value</td>
<td>522</td>
<td>600</td>
<td>32</td>
</tr>
<tr>
<td>Longitudinal weld - 1</td>
<td>530</td>
<td>620</td>
<td>34</td>
</tr>
<tr>
<td>Longitudinal weld - 2</td>
<td>535</td>
<td>655</td>
<td>34</td>
</tr>
<tr>
<td>Transverse weld - 1</td>
<td>N/A</td>
<td>620</td>
<td>N/A</td>
</tr>
<tr>
<td>Transverse weld - 2</td>
<td>N/A</td>
<td>655</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Hardness

Row B: 1.5 mm below Clad / CS interface
Row A: 1.5 mm below Clad surface
Hardness

Row A: 1.5 mm below Clad surface

Row B: 1.5 mm below Clad / CS interface
Charpy impact test at -10C (service temp) is found to be acceptable according to DNV standard (required minimum 50 J average, 40 J minimum).
Intergranular Corrosion test according to ASTM A262 Practice E is carried out on transverse clad weld where Carbon steel side is removed completely.

The corrosion sample was bent to 180 degree by using plunger 10 mm. No cracking is observed. No intergranular Corrosion at weld and 316L HAZ is observed.
Welding consumable cost x100 THB per one 6-m pipe
Welding time (minute) per one 6-m pipe

- CRA filler full joint
- Peel back
- Without peel back

- Welding cost
- Welding time
Conclusions

For SAW process on clad weld side, solidification cracking (centerline cracking) is observed. High heat input is believed to cause high level of NbC precipitation along grain boundary causing cracking along grain boundary.

For GTAW&GMAW –P process on clad weld side, the results show good ductility and higher strength than that of base metal. Higher hardness value at weld metal a little lower toughness at weld metal still exceed minimum requirement for clad line pipe standard.

Corrosion resistance of weld and HAZ is found to be acceptable for service.

Welding cost and welding time is reduced compare to peel back method.