Development of UOE Clad Linepipe

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ABSTRACT

With the recent increase in Oil and Gas prices and the predicted production decline of mature fields, reserves containing high levels of corrosive species operating at high temperature and pressure, are becoming increasingly attractive and financially viable to develop.

Operation safety and protection of the surrounding environment are always the first priorities for pipeline engineers. The stringent requirements of the industry are traditionally guaranteed through selection of suitable materials type e.g. carbon steel or corrosion resistant alloys. The decision is taken based on physical properties, cost and life cycle analysis.

Due to their excellent track record and cost saving benefits, the demand for offshore clad pipes has risen rapidly. Some examples include the BP Rhum and Talisman Tweedsmuir projects for the UK, Chevron Gorgon and Jansz projects in Australia.

Clad pipe manufacturers employ several production methods and cover a wide range of sizes but capacity in the larger diameters is limited. To tackle this issue, Corus Tubes Energy Business (CTEB) has actively developed clad pipes, manufactured using the UOE process route. To aid this development CTEB has recently invested in dedicated manufacturing equipment.

This paper explores the analysis undertaken to prove the capability to produce large diameter clad linepipe using the UOE production process, through which the paper summarises the manufacture of 316L metallurgically clad plates, into longitudinally submerged arc welded UOE pipes at the Hartlepool 42” Pipe Mill. The report identifies the production route and chemistry of typical feedstock material, followed by the manufacturing route within the pipe mill, the selection of welding process for the replacement of the CRA layer, and finally, the mechanical properties of the pipe material are presented.

1 INTRODUCTION

High strength low alloy steels (HSLA) such as carbon steel linepipe exhibit corrosion rates of approximately 0.2 mm.yr⁻¹ (under environmental conditions such as 10 bar CO₂ @ 60°C), whereas CRA materials would exhibit ≤ 0.005 mm.yr⁻¹, under the same
conditions. This would mean for a 30 year lifetime of a pipeline, a wall thickness loss of 6 mm would occur for the HSLA steel, whereas the CRA would lose approximately 0.15 mm.[1]

This difference in corrosion resistance between carbon steel and CRA materials, in addition to the development of oil and gas fields, where the parameters of the line / fluid result in an increase in the “corrosive activity” of Chloride ions, Hydrogen Sulphide, and Carbon Dioxide, have resulted in an increase in the demand for CRA pipe material. In the past carbon steel pipe material has been used for such applications, and as such the following corrosion mitigation measures have needed to be employed during the operation of the pipeline, i.e.

- Use of carbon steel pipe material with the injection of inhibitors – can be difficult due to variations in efficiency of the inhibition and downtime of the pipeline.

- Use of carbon steel pipe material after dehydrogenation and desulphurisation.

These measures are expensive, and difficult to maintain at the required level to ensure minimal, or no corrosion.

Corrosion resistant alloys (CRA) include austenitic and martensitic stainless steels, nickel-based, and titanium-based alloys. As a guide, materials with ≥ 11 wt% chromium are required for the environments considered to ensure adequate corrosion resistance. As the corrosivity of the solution increases, the cost and technical issues associated with the first three options also increases. However, corrosion resistant alloys can exhibit acceptable rates of corrosion, for their use to be considered economically feasible. For offshore application, the use of corrosion resistant alloys on their own would not provide sufficient strength to resist hydrostatic collapse for the depths considered, or the level of strain induced during the pipe-laying procedure. Therefore corrosion resistant alloys are used as the “corrosion resistant inner sleeve” to a higher strength outer casing, such as carbon steel. It is possible to use solid CRA pipe material, but, to achieve the required strength properties, the wall thickness of the pipe would be uneconomically thick.

Clad linepipe is a structure where the CRA is metallurgically bonded to the higher strength material. Corrosion resistant alloys have been used, and are being used, where the CRA is mechanically bonded to the higher strength material through deformation, i.e. expansion. This form of CRA linepipe is referred to as “lined”.

Due to the increasing market requirements for clad and lined pipe material, CTEB are assessing the feasibility, and determining a production route for the manufacture of clad linepipe, using the UOE method, which would enable the business to supply large quantities of clad linepipe, with the same dimensional and mechanical tolerances which are available for offshore grade carbon steel material.
2 FEEDSTOCK MATERIAL

2.1 Composition

Four plates with a carbon steel thickness of 25.4 mm (WT), and a CRA (316L) thickness of 2.5mm were sourced, with the composition of the 316L and carbon steel materials as listed in Tables 1 and 2, respectively.

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.020</td>
<td>0.49</td>
<td>0.88</td>
<td>0.028</td>
<td>0.000</td>
<td>16.97</td>
<td>10.12</td>
<td>2.08</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 1: Chemical composition of 316L layer (wt %).

<table>
<thead>
<tr>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Al</th>
<th>Cu</th>
<th>Mo</th>
<th>Ni</th>
<th>Cr</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.065</td>
<td>0.287</td>
<td>1.55</td>
<td>0.010</td>
<td>0.0008</td>
<td>0.0028</td>
<td>0.041</td>
<td>0.0253</td>
<td>0.025</td>
<td>0.423</td>
<td>0.049</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nb</th>
<th>As</th>
<th>Sn</th>
<th>Ti</th>
<th>B</th>
<th>Ca</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.020</td>
<td>0.004</td>
<td>0.001</td>
<td>0.001</td>
<td>0.000</td>
<td>0.0017</td>
</tr>
</tbody>
</table>

Table 2: Chemical composition of carbon steel (wt%).

All the elements of the 316L material are within the specification tolerances of ASTM A240, although the Chromium, Nickel, and Molybdenum levels are towards the bottom end of the allowable range, i.e. Cr: 16.0 – 18.0%, Ni: 10.0 – 14.0%, and Mo: 2.0 – 3.0%.

3 PIPE PRODUCTION

3.1 Production Process

The production route of clad linepipe material within the 42" Pipe Mill is illustrated in Figure 1. The majority of the route is the same as for CMn steel pipes; however, there are a few exceptions:

- Addition of an offline welding station for the deposition of the CRA layer along the internal weld seam, after completion of the carbon steel longitudinal weld seam, prior to mechanical expansion.
- NDT (X-Ray) of pipes seam welds after the replacement of the CRA layer, as well as after SAW welding.
- Dye penetrant testing of the CRA layer.
- Endoscopic examination of internal SAW and overlay weld.
- Surface cleaning of the CRA layer.

The pipe material (24" OD x 25.4 mm WT (X65), + 2.5 mm thick 316L) was manufactured in accordance with API 5LD & ASTM A240. During the forming trials the surface of the some of the plates were protected with matting, in the areas where the
plate would come into contact with the forming dies. After the completion of pipe forming, and surface preparation, the surfaces of the CRA layer were inspected for any signs of visible damage, and compared against the plates where no protection was applied. There was no evidence of degradation on the plates where protection was not used, when compared with the plates that were not protected.

3.2 Pipe Welding

Although the internal & external SAW welding procedures are the same for clad pipes as they are for standard CMn pipes, careful consideration and expertise must be applied to the selection of the welding parameters for the internal SAW weld, to ensure a bead height of 0 – 0.5 mm, whilst at the same time maintaining the correct through thickness profile of the internal weld bead to achieve the required mechanical properties within the carbon steel backing material, and also to ensure that the toe of the internal SAW welds is free of any defects, i.e. undercut.

The selection of the dimensions at the plate edges (Figure 2a) is critical to ensure the optimal welding profile, both of the SAW welds, and of the CRA replacement weld. CTEB utilises a double V-preparation (Figure 2b) within the carbon steel, and in addition, the CRA layer is removed to a pre-determined dimension. The ability to gain the required dimensions along the longitudinal edges of the plate is achievable due to the recent investment in a new plate-milling machine, for which bespoke cutting heads can be manufactured for any desired application.

A large number of techniques were considered, in partnership with Air Liquide Welding, for the deposition of the CRA layer on top of the internal SAW weld, including MIG, twin SAW, multi-pass SAW, oscillating SAW, and electro-slag. During the assessment of these techniques, the parameters listed below were considered:

- Welding time
- Achievable quality levels (spatter)
- Weld shape (contour, bead height)
- Minimal dilution of SAW weld
- Availability of consumables for various CRA layers
- Level of HAZ heat tint
- Consistency of consumable feed to the welding head
- Dimensions of the welding head

Electro-slag welding was chosen as the method for the deposition of the CRA layer, as this technique was considered to be able to achieve the required levels of quality, flexibility, and productivity targets. This operation will be an offline operation using a purpose built facility. For the CRA material (316L) welded in the latest trial work, 309L Mo strip was used as the welding consumable.
3.3 Pipe Inspection

- Dye penetrant examination was used to identify the presence of any disbondment on the bevel face at the pipe ends, between the carbon steel backing material and the CRA layer, and also to inspect for any delamination of the CRA surface layer.

- Although some linepipe specifications do not specifically state a requirement for ultrasonic inspection of the completed clad weld, CTEB inspected the weld seam after internal & external SAW welding, and also after overlay welding. This was conducted using state-of-the-art Krautkramer automatic ultrasonic equipment. The ultrasonic machine was set-up with an 18-probe configuration to identify all types of weld related features.

- All clad linepipe specifications request X-ray inspection of the completed weld (SAW + overlay), which was also conducted without any issues being raised.

3.4 Surface Preparation of CRA Layer

API 5LD requires the following: “the corrosion-resistant behaviour of the CRA layer is adversely affected by poor surface condition. Therefore, blasting, pickling, brushing, or a combination of these methods shall remove scale spatter and heat treatment surface residues of the CRA layer”. The maximum specified surface roughness is 12.5 µm. Two methods have been explored namely blasting with Met-abrasive SO60 shot, and pickling.

3.4.1 Shot Blasting

To assess the suitability of shot-blasting to prepare the surface of the CRA layer to the required standard, a pipe was processed through the facilities at the BSR Coating plant, which is on the same site as the 42” Pipe Mill.

3.4.2 Pickling

Test rings were pickled using adherent paste in lieu of liquid solution, at a local sub-contractor. For comparison purposes, 50% of the internal surface of the ring was pickled for three different periods of time (30, 60 and 90 minutes). The remaining 50% of the internal surface was left untouched. The results show that there are no significant differences between pipes pickled for 60 and 90 minutes. However the difference between no cleaning and pickling was very significant as shown in Figure 3. From this trial it was concluded that pickling was more effective than shot blasting.

The average surface profile in the transverse direction was 1.0 µm, and in the longitudinal direction it was 2.2 µm.
3.5 Material Properties

3.5.1 Mechanical Properties

The mechanical properties of one of the pipes manufactured are listed in the following tables. The transverse weld tensile properties were measured at room temperature, and after PWHT. The tensile strength (Rm) was 600 MPa, and 612 MPa respectively. The shear strength of 370 MPa was also determined using the ASTM A264 method, compared to the minimum specified requirement is 140 MPa.

For all the mechanical tests mentioned, with the exception of the shear test, the CRA was removed by machining prior to testing, and are therefore the mechanical properties of the carbon steel material itself.

<table>
<thead>
<tr>
<th>Acceptance Criteria (DNV OS-F101)</th>
<th>Transverse</th>
<th>Longitudinal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R_{0.5} (MPa)</td>
<td>Rm (MPa)</td>
</tr>
<tr>
<td>Strap</td>
<td>493 min</td>
<td>596 min</td>
</tr>
<tr>
<td>Strap (PWHT)</td>
<td>465 min</td>
<td>586 min</td>
</tr>
<tr>
<td>Strap (Proportional Gauge Length)</td>
<td>518 min</td>
<td>597 min</td>
</tr>
<tr>
<td>Round Bar – Test 1</td>
<td>470 min</td>
<td>564 min</td>
</tr>
<tr>
<td>Round Bar – Test 2</td>
<td>478 min</td>
<td>566 min</td>
</tr>
</tbody>
</table>

Table 3: Tensile properties (90° to the weld)

<table>
<thead>
<tr>
<th>Impacts</th>
<th>Energy (J)</th>
<th>Shear (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Body (Mid-Thickness)</td>
<td>281 319</td>
<td>80 100 90</td>
</tr>
<tr>
<td>Transverse Weld Centreline (Mid-Thickness)</td>
<td>125 121</td>
<td>90 80 90</td>
</tr>
<tr>
<td>Transverse Fusion Line (Mid-Thickness)</td>
<td>150 233</td>
<td>50 70 90</td>
</tr>
<tr>
<td>Transverse Body PWHT (Mid-Thickness)</td>
<td>319 413</td>
<td>100 100 100</td>
</tr>
</tbody>
</table>

Table 4: Impact toughness properties @ -30°C.

Forward and reverse bend tests (180°) were conducted on the carbon steel base material of the pipe, around an 83 mm diameter former. No test samples showed any evidence of cracking.

The hardness values of the SAW and overlay weld region (Figure 4) were measured, and are reported below in Table 5.


<table>
<thead>
<tr>
<th>Minimum</th>
<th>Carbon Steel</th>
<th>CRA Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>182</td>
<td>165</td>
</tr>
<tr>
<td></td>
<td>254 (below overlay weld)</td>
<td>259 (body)</td>
</tr>
<tr>
<td>Average</td>
<td>221</td>
<td>201</td>
</tr>
</tbody>
</table>

Table 5: Hardness values SAW & overlay weld.

3.5.2 Corrosion Resistance

Material sensitisation tests (ASTM 262 Method E) were conducted in both plate and pipe form, and both passed without issues. Tests are ongoing to assess the resistance of the 316L layer to the ferric chloride test (ASTM G48 Method A).

4 CONCLUSIONS

• Due to the increasing demand for linepipe material resistant to more corrosive environments, CTEB has developed the capability and equipment required for the production of clad linepipe material, manufactured using the UOE process route.
• Through consideration of the critical parameters affecting the quality, flexibility, and productivity targets of the deposition of the CRA layer, along the internal weld bead, the electroslag welding process was chosen to be the most suitable method.
• As a result of the recent development work CTEB is now in a position to go into full-scale manufacturing.
• CTEB is now capable of producing clad pipe in linepipe volumes, and 12 m lengths, in external diameters between 406.4 mm – 1067 mm.
• Discussions are required with the companies who specify the type of linepipe product required, to inform them of the availability of large volumes of clad linepipe material. Due to the current low requirements of high volume orders, there is limited capacity in plate mills for the production of clad plate material. A visible increase in demand would prove an incentive to the plate mill to invest in greater capacity.
Figure 1: Production route of clad linepipe material within the 42" Pipe Mill.

Figure 2: Configuration of Welding Preparation.
Figure 3: Pipe ring showing difference between pickling and no pickling.

Figure 4: SAW & overlay weld region of pipe.