A Best Practice Guide for Welding of Newly Developed Duplex Stainless Steel (UNS S82551) Seamless Pipes

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Outline

1. Introduction

2. Material design concept
   - Concept of Material Design for New Alloy Grade
   - Category of newly developed UNS S82551

3. Performance of newly developed UNS S82551
   - Base metal properties and weldability

4. Conclusion

5. Future plan
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5. Future plan
Martensitic and duplex stainless steels have been exploited by a wide range of industrial sectors for many years because of their availability, workability, strength, toughness and corrosion resistance.

In slightly H$_2$S-containing environments, super martensitic stainless steel (13Cr SMSS) pipes have been used in the oil and gas industries for many years.

In early 2000’s, girth welded joints in 13Cr SMSS were reported to be susceptible to SCC at HAZ in sweet conditions. Post weld heat treatment (PWHT) is effective at preventing SCC.

However, PWHT could have a negative impact on the efficiency of pipe laying operations in some cases.
1. Introduction - Background

Duplex stainless steels:
- 22Cr duplex (e.g. UNS S31803)
- 25Cr super duplex (e.g. UNS S39274)
  - Applicable in as-welded condition (No PWHT)
  - Widely used for flow line applications

However, these higher grade DSSs incur greatly increased cost

A new DSS containing 25Cr-5Ni-1Mo-2.5Cu has been developed (UNS S82551)*, which can be used in the as-welded condition in slightly sour conditions and has a lower cost than the existing DSS grades.

*D. Motoya, et.al; Eurocorr 2012
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2. Material design concept

**Concept of Material Design for New Alloy Grade**

- **S13Cr**: Required PWHT for SCC resistance
- **Add Cr**: Enhancement of passive film stabilization
- **Difficult to maintain martensitic structure**

**Existing DSS**: Contain more than 3Mo for SSC resistance

- **Used for low amount of H₂S environment**
- **Lower cost than existing duplex stainless steel**

**Material Design of SM70-2505 (UNS S82551)**
2. Material design concept

**Category of newly developed UNS S82551**

- **Chemical composition of UNS S82551**
  - 25Cr-5Ni-1Mo-1Mn-2.5Cu-0.2N (mass%)

New material can be categorized as "Modified" grade from conventional duplex.

**Development target**
- Superior corrosion resistance without PWHT (>13CrSMSS)
- Lower price index than existing DSS (>22CrDSS, 25CrSDSS)
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3. Performance of newly developed UNS S82551

**Base metal properties**

- Chemical compositions of production pipe for UNS S82551

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>N</th>
<th>PREW</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>&lt; 0.02</td>
<td>1.09</td>
<td>2.45</td>
<td>4.96</td>
<td>24.95</td>
<td>1.09</td>
<td>0.19</td>
<td>31.6</td>
</tr>
</tbody>
</table>

- Pipe making process
  
  Pipe making: Rotary single piercing - mandrel mill process
  Heat treatment: Solution heat treatment

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![Pipe making process diagram](image)
3. Performance of newly developed UNS S82551

**Base metal properties**

- Chemical compositions of production pipe for UNS S82551

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Mn</th>
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<th>Cr</th>
<th>Mo</th>
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<th>PREW</th>
</tr>
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<td><strong>1.09</strong></td>
<td>0.19</td>
<td>31.6</td>
</tr>
</tbody>
</table>

- Microstructure

  [Phase balance]
  Ferrite : Austenite
  approx. 50 : 50 (%)

  [Sigma phase]
  No Sigma phase precipitation
3. Performance of newly developed UNS S82551

**Base metal properties**

[Tensile properties]

- **Longitudinal**
- **Transverse**

<table>
<thead>
<tr>
<th>Yield Strength (MPa)</th>
<th>Number of Specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>450</td>
<td></td>
</tr>
<tr>
<td>470</td>
<td></td>
</tr>
<tr>
<td>490</td>
<td></td>
</tr>
<tr>
<td>510</td>
<td></td>
</tr>
<tr>
<td>530</td>
<td></td>
</tr>
<tr>
<td>550</td>
<td></td>
</tr>
<tr>
<td>570</td>
<td></td>
</tr>
<tr>
<td>590</td>
<td></td>
</tr>
<tr>
<td>610</td>
<td></td>
</tr>
</tbody>
</table>

**Specification of 70ksi grade(API 5L)**

[Toughness properties]

- **Test Specimen**: 10 x 10, 2mm V notch
- **Direction**: Transverse

<table>
<thead>
<tr>
<th>Temperature (deg.C)</th>
<th>Absorbed energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-140</td>
<td></td>
</tr>
<tr>
<td>-120</td>
<td></td>
</tr>
<tr>
<td>-100</td>
<td></td>
</tr>
<tr>
<td>-80</td>
<td></td>
</tr>
<tr>
<td>-60</td>
<td></td>
</tr>
<tr>
<td>-40</td>
<td></td>
</tr>
<tr>
<td>-20</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
# 3. Performance of newly developed UNS S82551

Welding record for UNS S82551 (OD273.1 x WT14.3 (mm)) by Nippon steel

<table>
<thead>
<tr>
<th>Process</th>
<th>GMAW</th>
<th>Filler Metal</th>
<th>Process</th>
<th>Current (Amps)</th>
<th>Volts</th>
<th>Speed (cm/min)</th>
<th>Heat Input (kJ/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root 1</td>
<td>25Cr SDSS</td>
<td>GMAW</td>
<td>148</td>
<td>20.6</td>
<td>42.8</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>Fill 2-4</td>
<td>25Cr SDSS</td>
<td>PGMAW</td>
<td>172-185</td>
<td>20.4-21.2</td>
<td>37.4-38.5</td>
<td>0.57-0.59</td>
<td></td>
</tr>
<tr>
<td>Cap 5</td>
<td>25Cr SDSS</td>
<td>PGMAW</td>
<td>119</td>
<td>19.9</td>
<td>26.0</td>
<td>0.55</td>
<td></td>
</tr>
</tbody>
</table>

**Joint design**

![Joint design diagram](image)

**Macro Photo**

- **Preheat**
  - None
- **Interpass temp.**
  - 150°C max.
- **Shielding gas**
  - 69%Ar+30%He+1%CO₂ (30 L/min)
  - Back shield gas
    - Ar 100% (5 L/min)
- **PWHT**
  - Not applied
3. Performance of newly developed UNS S82551

Welding record for UNS S82551(OD273.1 x WT25.4 (mm)) by Nippon steel

<table>
<thead>
<tr>
<th>Process</th>
<th><strong>GTAW</strong></th>
<th>Position: &lt;ASME 1G&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pass</td>
<td>Filler Metal</td>
</tr>
<tr>
<td></td>
<td>Root 1</td>
<td>25Cr SDSS</td>
</tr>
<tr>
<td></td>
<td>Fill 2-30</td>
<td>25Cr SDSS</td>
</tr>
<tr>
<td></td>
<td>Cap 31-34</td>
<td>25Cr SDSS</td>
</tr>
</tbody>
</table>

**Joint design**

![Joint design diagram](image)

**Preheat** None

**Interpass temp.** 150°C max.

**Shielding gas** Ar 100% (20 L/min)

**Back shield gas** Ar 100% (5 L/min)

**PWHT** Not applied
3. Performance of newly developed UNS S82551

**Microstructure**

Photo. GMAW welded joint of UNS S82551 (OD273.1mm x WT14.3mm)

<table>
<thead>
<tr>
<th>Pipe size</th>
<th>Fill</th>
<th>Ferrite Count</th>
<th>Position</th>
<th>ASTM E562</th>
<th>DNV OS F101 requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>OD273.1xWT14.3</td>
<td>GMAW</td>
<td>25Cr SDSS</td>
<td>Weld metal</td>
<td>45%</td>
<td>WM/HAZ: 35～65%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HAZ</td>
<td>62%</td>
<td></td>
</tr>
<tr>
<td>OD273.1xWT25.4</td>
<td>GTAW</td>
<td>25Cr SDSS</td>
<td>Weld metal</td>
<td>46%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HAZ</td>
<td>58%</td>
<td></td>
</tr>
</tbody>
</table>
3. Performance of newly developed UNS S82551

**Hardness distribution**

Test procedure: ASTM E384  
Number of specimens: 2 specimens  
Location: 1.5mm from both surfaces and 1/2 WT

<table>
<thead>
<tr>
<th>Position</th>
<th>Maximum hardness (Hv10) (GMAW/GTAW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside</td>
<td>294/303</td>
</tr>
<tr>
<td>Mid-wall</td>
<td>303/310</td>
</tr>
<tr>
<td>Inside</td>
<td>313/331</td>
</tr>
<tr>
<td>WM</td>
<td>289/294</td>
</tr>
<tr>
<td>HAZ</td>
<td>309/296</td>
</tr>
<tr>
<td></td>
<td>306/312</td>
</tr>
</tbody>
</table>

**Performance of newly developed UNS S82551**

Maximum hardness 350 Hv by DNV OS F101
3. Performance of newly developed UNS S82551

**Charpy impact properties**

Test procedure: ASTM A370  
Test specimen: 10 x 10mm  
Direction: Longitudinal  
Test temp.: 0, -30, -47, -60, -80 deg.C

![Graph showing Charpy impact properties for different temperatures and materials.](attachment:image.png)

- **Base metal**  
- **Weld metal**  
- **Fusion line**  
- **HAZ 2mm**

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(a) GMAW Joint (OD273.1xWT14.3)  
(b) GTAW Joint (OD273.1xWT25.4)

Mean: 45J  
Single: 35J

DNV OS F101 Requirement
3. Performance of newly developed UNS S82551

**SCC and SSC resistance**

- **Test Method**: 4 point bent beam test
- **Specimen Size**: 115\(L\) x 15\(W\) x 3\(t\) (mm)
- **Position of Weld metal**: Center of specimen
- **Inner surface**: As intact
- **The other surface**: 600# paper finish
- **Applied stress**: 100% AYS
- **Number of specimens**: Two

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mark</th>
<th>Solution</th>
<th>pH</th>
<th>(H_2S)(MPa)</th>
<th>(CO_2)(MPa)</th>
<th>Temp. (deg.C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCC</td>
<td>X1</td>
<td>25wt%NaCl (Cl(^-):180,000mg/L)</td>
<td>4.5</td>
<td>0.004</td>
<td>0.096</td>
<td>130</td>
</tr>
<tr>
<td></td>
<td>Y1</td>
<td>1.6wt%NaCl (Cl(^-):10,000mg/L)</td>
<td>4.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSC</td>
<td>Y2</td>
<td>1.6wt%NaCl (Cl(^-):10,000mg/L)</td>
<td>4.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Y3</td>
<td>0.17wt%NaCl (Cl(^-):1,000mg/L)</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Photo: Specimen of corrosion test
3. Performance of newly developed UNS S82551 Material

### SCC resistance

<table>
<thead>
<tr>
<th>Material</th>
<th>Welding procedure</th>
<th>PWHT</th>
<th>Test condition</th>
<th>SCC results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Method</td>
<td>Consumable</td>
<td>Cl [mg/L]</td>
<td>Temp. [°C]</td>
</tr>
<tr>
<td>UNS S82551</td>
<td>GMAW (1G)</td>
<td>25Cr SDSS</td>
<td>No</td>
<td>180,000</td>
</tr>
<tr>
<td>Weldable 13Cr</td>
<td>GMAW (5G)</td>
<td>25Cr SDSS</td>
<td>No</td>
<td>180,000</td>
</tr>
</tbody>
</table>

* ○: No SCC for UNS S82551
* : No SCC for UNS S31603*

* B.K.Holmes, et.al
Corrosion/2010, Paper No.10308

**Applicable with as-welded condition**

### The application at wider region of temperature and Cl- than 316L can be expected.
3. Performance of newly developed UNS S82551

**SSC resistance**

<table>
<thead>
<tr>
<th>Material.</th>
<th>Solution</th>
<th>pH</th>
<th>H$_2$S (MPa)</th>
<th>Temp.</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNS S82551</td>
<td>0.17%NaCl (Cl$:1,000mg/L)</td>
<td>3.5</td>
<td>0.004</td>
<td>90 deg.C</td>
<td>No SSC</td>
</tr>
<tr>
<td></td>
<td>1.6%NaCl (Cl$:10,000mg/L)</td>
<td>4.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25%NaCl (Cl$:180,000mg/L)</td>
<td>4.5</td>
<td></td>
<td></td>
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</table>

**UNS S82551** can be used in slightly sour conditions (≤0.004MPa) and has a lower cost than the existing DSS grades.
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4. Conclusion

• A new duplex stainless steel containing 25mass%Cr- 5mass%Ni- 1mass%Mo- 2.5mass%Cu has been developed (UNS S82551), which is intended for flowline application in slightly sour environments.

• The characteristic property of this material is **SSC resistance in slightly sour conditions despite a lower molybdenum content** than that of the existing duplex stainless steels, and it can be used in the as-welded conditions because it is duplex stainless steels rather than super-martensitic stainless steel.

• The as-welded joints of this material provide sufficient mechanical properties as well as corrosion resistance in slightly sour conditions, therefore this material is considered to be **the most cost effective material** depending on the corrosion resistance required.
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Nippon Steel and The Welding Institute (TWI) are collaborating on a development programme to establish best practice guide for welding of this new alloy grades.

Part 1: To evaluate the feature of developed DSS (Nippon steel in-house testing)
- Alloy design
- Performance of material (Mechanical and corrosion properties)

Part 2: To investigate the effect of welding condition on intermetallic precipitation, microstructure, mechanical and corrosion properties (conducted at TWI)
- The maximum heat input and interpass temperature limits for welding
- Modelling approach (Metallurgical model with welding heat transfer)
Thank you for your attention.