WELDING SUPER DUPLEX STAINLESS STEEL

L. van Nassau, K. Bekkers, J. Hilkes and H. Meelker

Lincoln Norweld / Smitweld
NITO Conference
Amsterdam, 7/8 February
Welding Super Duplex Stainless Steel

Introduction
Commercial super duplex stainless steel grades have been introduced in industry for a variety of high technological applications. In comparison with the grades with 22%Cr, super duplex stainless steel grades are characterized by an increased Cr (~25%) and Mo (2-4%) content, a high N-level and frequently additions of Cu and/or W. Furthermore, selection criteria include the high strength properties and very good corrosion performance in Cl-containing fluids.
The service temperature ranges from -20 to +280 °C.
The well known grades in the European Market include:

Table 1 Manufacturers with their Super Duplex Stainless Steel Grades

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Grade</th>
<th>Chemical Composition w%</th>
<th>other</th>
<th>PREₚ</th>
<th>product forms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Böhler</td>
<td>A 905</td>
<td>25.5 3.7 2.3 0.37</td>
<td>Mn:5.8 39.0</td>
<td>plate, forgings</td>
<td></td>
</tr>
<tr>
<td>Carpenter</td>
<td>7-Mo Plus</td>
<td>27.5 4.5 1.5 0.25</td>
<td></td>
<td>36.5</td>
<td></td>
</tr>
<tr>
<td>Creusot Ind.</td>
<td>UR 47N</td>
<td>25 7 3.0 0.16 0.2</td>
<td></td>
<td>37.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>UR 52N</td>
<td>25 7 3.0 0.16 1.5</td>
<td></td>
<td>37.6</td>
<td></td>
</tr>
<tr>
<td>Langley</td>
<td>Ferralium 255</td>
<td>25.5 5.5 3.0 0.17 2.0</td>
<td></td>
<td>38.1</td>
<td></td>
</tr>
<tr>
<td>Sandvik</td>
<td>25.07</td>
<td>25 7 4.0 0.25</td>
<td></td>
<td>42.2</td>
<td></td>
</tr>
<tr>
<td>Sumitomo</td>
<td>DP 3</td>
<td>25 6.5 3.0 0.2 0.5</td>
<td>W: 0.3</td>
<td>38.1</td>
<td></td>
</tr>
<tr>
<td>WMS *)</td>
<td>Zeron 100</td>
<td>25.5 6.5 3.5 0.25 0.7</td>
<td>W: 0.7</td>
<td>41.1</td>
<td></td>
</tr>
</tbody>
</table>

*) together with:
- Fabr. de Fer - SSE
- Mather & Platt - Bentham Int.
- Butting - Schulz
- Barr Thomson

Note %C: all grades 0.03% except A905: 0.05% and Ferralium 255: 0.04%

The PREₚ (PREₚ = %Cr + 3.3x %Mo + 16x %N) values range from 38 to 42. Only Weir Material Services (WMS) Zeron 100 and Sandvik 25.07 material is produced with values above 40.
The original product form of super duplex stainless steel grades has been castings, in particular pump housing and valves. The break through came with the availability of other product forms, allowing to take full advantage of the high corrosion resistance combined with high strength properties in welded structures in:
- oil & gas process installations,
- seawater fire fighting systems
- drain piping in all kind of industries.
- chemical process equipment
- chemical tankers

Particularly in offshore installations it is convincingly demonstrated that weight savings up to 25-40% can be achieved by the usage of super duplex stainless steel in full thickness (up to 50 mm). This in comparison with fully austenitic 6% Mo alloyed stainless steel or clad steel with a high corrosion resistant material as alloy 825 or W.Nr. 1.4539 clad on a StE 355 as substrate.
The marketing of a wide range of product forms, combined with a fully organized service to provide welding consumables and welding technology has been developed as a policy of a group of companies, supplying ZERON 100®. Regarding the mechanical properties, extensive information has been made available for the grade Zeron 100.
The material can be characterized by the following properties:

Table 2  Mechanical properties plate material Zeron 100 (up to 30 mm) /1/
Condition: solution annealed

<table>
<thead>
<tr>
<th>Test temperature °C</th>
<th>plate (up to 30 mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20</td>
</tr>
<tr>
<td>test temperature</td>
<td>(°C)</td>
</tr>
<tr>
<td>0.2%-proof stress</td>
<td>(N/mm²)</td>
</tr>
<tr>
<td>ultimate tensile</td>
<td>(N/mm²)</td>
</tr>
<tr>
<td>strength</td>
<td>(%)</td>
</tr>
<tr>
<td>elongation</td>
<td>(HB)</td>
</tr>
<tr>
<td>hardness</td>
<td></td>
</tr>
<tr>
<td>test temperature</td>
<td>(°C)</td>
</tr>
<tr>
<td>impact CVN</td>
<td>(J)</td>
</tr>
<tr>
<td>CTOD</td>
<td>(mm)</td>
</tr>
</tbody>
</table>

Weldability of Duplex stainless Steel
Originally, some super duplex grades offered attractive strength and corrosion properties but failed in structures due to severe deterioration of the heat affected zone in weldments. The HAZ in such cases showed embrittlement due to ferrite grain growth. Corrosion properties were not optimal due to solid state transformations. As in regular duplex stainless steel grades, modern super duplex stainless steel making uses the effect of an increased N-content. The HAZ remains fine grained and is tolerant for a wider range of welding conditions with the corresponding temperature profiles.

Weld Metal Design
Welding of super duplex stainless steel has much in common with the technique as applied to regular duplex stainless steel. Regular duplex weld metal shows a basically ferritic matrix with a limited quantity of more ductile austenite. The austenite forming potential of the weld metal has to be correctly tuned to reach the preferred level of Ferrite Number /2/ 40-60. The weld metal, when applied in the as welded condition, must therefore contain sufficient levels of Ni and N, with C to be kept low (C <0.04%). Compared to the parent material, the weld metal is therefore overalloyed with Ni.
However, the weld metal could be matching when the structure is supposed to be solution annealed. Figure 1 shows the location of the parent material and related weld metal types in the new WRC 1989 Constitution Diagram which proved to be very useful in estimating the as solidified weld metal FN level /3/.

Zeron 100 is one of the highest alloyed grades amongst the super duplex stainless steel grades. Adopting the welding consumables to this base material will automatically make the weld metal suitable for the total range of super duplex stainless steels.
A sound weld metal design, i.e. alloying with high Cr, Mo, N and additional elements as Cu and W, requires fully alloyed core wire for covered electrodes. In particular alloying of tungsten via the electrode coating of covered electrodes might lead to a high portion of undiluted tungsten inclusions in the weld metal (figure 2). It is obvious that the solid wires for the processes GMAW and SAW processes are equally fully alloyed.
To obtain the most reliable mechanical properties the use of a fluoride basic electrode covering and welding flux is highly recommended. Taking into account the relatively high portion of remaining ferritic matrix in the weld metal structure, a low level of inclusions, as provided with basic welding consumables, assures consistent compliance with the impact and CTOD toughness requirements.

Welding Processes and Consumables
The weld metal composition of the commercial products as marketed by Smitweld, have been tuned to assure the optimal combination of:
- smooth welding characteristics in applicable welding positions,
- a high toughness level
- the high strength level and
- a high pitting and stress corrosion resistance.

The welding processes suitable for welding super duplex stainless steel grades are primarily SMAW, GTAW, GMAW and SAW. In addition to the before mentioned welding processes, also flux cored arc welding is considered to be very suitable. Experience, however, is limited.
The currently available welding consumables, matching or overalloying the parent material, are listed in table 3.

Table 3  
Welding Consumables for Super Duplex Stainless Steel  
All weld metal chemical composition (w%, typical)

<table>
<thead>
<tr>
<th>Process Consumables</th>
<th>SMAW</th>
<th>GTAW &amp; GMAW</th>
<th>SAW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jungo</td>
<td>Zeron 100</td>
<td>LNT</td>
</tr>
<tr>
<td></td>
<td>Zeron 100X</td>
<td>Zeron 100</td>
<td>Zeron 100X</td>
</tr>
<tr>
<td>C</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Mn</td>
<td>0.8</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Si</td>
<td>0.3</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Cr</td>
<td>25.2</td>
<td>24.8</td>
<td>24.8</td>
</tr>
<tr>
<td>Ni</td>
<td>6.8</td>
<td>6.8</td>
<td>9.8</td>
</tr>
<tr>
<td>Mo</td>
<td>3.7</td>
<td>3.7</td>
<td>3.7</td>
</tr>
<tr>
<td>N</td>
<td>0.21</td>
<td>0.22</td>
<td>0.22</td>
</tr>
<tr>
<td>Cu</td>
<td>0.7</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>W</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>PREw</td>
<td>40.8</td>
<td>40.5</td>
<td>40.5</td>
</tr>
<tr>
<td>FNw</td>
<td>80</td>
<td>75</td>
<td>48</td>
</tr>
</tbody>
</table>

Weld metal mechanical properties (typical)

<table>
<thead>
<tr>
<th>Process Consumables</th>
<th>SMAW</th>
<th>GTAW</th>
<th>SAW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jungo</td>
<td>LNT</td>
<td>Flux P2000</td>
</tr>
<tr>
<td></td>
<td>Zeron 100X</td>
<td>Zeron 100X</td>
<td>LNS Zeron 100X</td>
</tr>
<tr>
<td>Condition</td>
<td>As Welded</td>
<td>As Welded</td>
<td>As Welded</td>
</tr>
<tr>
<td>Strength</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rp0.2 (N/mm²)</td>
<td>740</td>
<td>680</td>
<td>715</td>
</tr>
<tr>
<td>Rm (N/mm²)</td>
<td>920</td>
<td>885</td>
<td>895</td>
</tr>
<tr>
<td>AS (%)</td>
<td>25</td>
<td>26</td>
<td>25</td>
</tr>
<tr>
<td>Impact CVN (J)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-20 °C</td>
<td>50</td>
<td>&gt;80</td>
<td>55</td>
</tr>
<tr>
<td>-30 °C</td>
<td>40</td>
<td>&gt;60</td>
<td>45</td>
</tr>
<tr>
<td>-40 °C</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>CTOD (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10 °C</td>
<td>0.3</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Hardness (HV10)</td>
<td>290-330</td>
<td>300-330</td>
<td>285-330</td>
</tr>
<tr>
<td>(HRc)</td>
<td>&lt; 32</td>
<td>&lt; 32</td>
<td>&lt; 32</td>
</tr>
</tbody>
</table>
Current requirements in offshore industry for high severity applications include:
- Yield Strength at 0.2% offset: $>550$ N/mm$^2$
- Ultimate Tensile Strength: $>750$ N/mm$^2$
- CVN impact at $-20^\circ$C: $>40$ J
- $-34^\circ$C: $>31$ J
- Hardness HRc: $<32$ (HV $<330$)

The strength and impact requirements are met with sufficient margin in the as welded condition. The hardness of the weld metal and HAZ in the parent metal may show locally a maximum level HV10 330 or HRc = 32. This level under conventional considerations is supposed to give risks of $\text{H}_2\text{S}$-cracking in sour gas service. Stress corrosion tests (see next paragraph) however, indicate that a relaxation of the hardness criterion to HRc = 32 or HV10 = 330 is acceptable.

**Corrosion Properties of Weldments**
Exposed to highly corrosive media, the HAZ and root weld metal of a welded construction in most of the special corrosion resistant materials as fully austenitic, regular duplex and super duplex stainless steel demonstrate a lower corrosion resistance when compared to the plain parent material. A major cause can be found in the solidification structure of the weld metal, with unavoidably local segregation effects in the weld metal and the unmixed zone of the HAZ. In addition, specific transformations and precipitation, may initiate local corrosion attack. In super duplex weldments, a high resistance in Cl-containing aqueous solutions is demanded at elevated service temperatures. The parent material and the weld metal demonstrated a good resistance against chloride and sulphide stress corrosion cracking in various tests and practice /4/, even at hardness values up to HRc 32.

The test program included a.o.:
- NACE TM 0177 at ambient and elevated temperature and pressure ($90^\circ$C, 16 bar), 30 days and more at stress levels of 90 and 110% of the yiel strength.
- ASTM G36 during 500h at $150^\circ$C in 45% MgCl$_2$, at a stress level of 262 n/mm$^2$.
- ASTM G30 U-bend different temperatures (80-110 $^\circ$C) and pressures (50-300 bar) in different conditions e.g. CO$_2$: 52 bar, H$_2$S 0.25 bar, Cl$: 46000$ppm during 30 days.

The sensitivity for pitting and crevice corrosion of weldments has been tested with the ferric chloride test, despite its severe and sometimes misleading results. In addition, electrochemical pitting potential determinations in simulated process conditions with aqueous solutions with 50000 ppm Cl$, pH 2$ at temperatures up to 60 $^\circ$C has been executed.

In general a CPT of 45 $^\circ$C in 6% FeCl$_3$ can be assured, providing good workmanship, particularly in welding has been applied.

Test results may show lower values if:
- machined test specimen surfaces are wrongly interpreted and
- welding is executed with incorrect heat control

The effect of heat input, relative to root runs in a one side welded joint (V- or U-bevels) on the pitting corrosion behaviour has been investigated /5/. GTAW, with filler material LNT Zeron 100X, has been used for making the root run with an applied HI = 1.0 and 2.0 kJ/mm resp., followed by a second pass with a HI of 0.8, 1.3 and 2.2 kJ/mm resp. Interpass temperatures ranged between 20 and 50 $^\circ$C. Figure 4 shows the obtained weld configuration.

Specimen with a size 50x20x13 mm with full exposure of all sides tested in the FeCl$_3$-test according ASTM G48A. Test temperatures started with 35 $^\circ$C and were raised, in steps of 5 $^\circ$C, to a level causing severe pitting. Weight loss measurements and visual examination has been used to determine the level of pitting attack.

The results are summarized in figure 3. It can be concluded that the specimen with a high heat input second pass showed pitting at 40 and 45 $^\circ$C, whereas conditions with a limited heat input of the second pass, the so called the "cold pass" technique, kept the specimen free of pitting up to 45 $^\circ$C.
The metallographical examination of the high heat input specimens revealed that the transformation of the weld heat affected zone (fig. 6), included causing formation of secondary austenite in ferrite grains throughout the complete first run, which is supposed to make the structure less resistant to pitting. Formation of secondary austenite which has a relatively higher alloy content of critical elements as Cr and Mo will denude the matrix thereby locally reducing the corrosion resistance. As demonstrated, this phenomena can be prevented by making the first run sufficiently thick (3-4 mm), and by welding the 2nd (and 3rd) layer with a heat input below 1.5 kJ/mm.

When welding constructions where welding from both sides is possible, the standing rule of welding the last pass at the corrosion side remains valid for welding super duplex stainless steel. A single thermal cycle associated with a heat input of 2.0 kJ/mm in plate or tubes with a wall thickness above 8 mm, affecting the HAZ at the corrosion side, does not decline the corrosion resistance in the pitting tests and weldments show critical pitting temperatures above 45 °C. The preheat- and interpass temperature should be controlled to be within the recommended range of 20-150 °C.

Welding Procedures

The application of the various welding processes requires appropriate welding procedures, tested for sound weldment properties. Experience has been built up in:
- plate welding
  SMAW in all positions except vertical down
  SAW in horizontal position in two-run and multi-run weldments
- pipe welding
  GTAW in root and fill layers in 1G, 2G, 5G and 6G position
  SMAW in the above mentioned positions for fill layers and, where acceptable also for root run welding
  SAW for longitudinal seam welding
- repair welding in castings
  SMAW in horizontal and vertical up position

In the following section some examples are described.
Plate welding in Zeron 100 has been tested in K-type joints in 20 mm plate thickness for the determination of properties as mentioned above.

SMAW has been used throughout the weldment in the position 3G. The applied electrode sizes included 2.5 and 4.0 mm. The welding procedure is presented in appendix 1.
SAW in a similar joint configuration has been executed in multi-layer welding with a overmatching welding wire LNS Zeron 100X, in combination with the fully (fluoride ) basic agglomerated flux P 2000. The same combination has been applied for welding a test vessel, with the purpose to qualify the material and welding procedure for application in oil/gas separation tanks. A typical welding procedure is shown in app. 2 and illustrated in figure 8.
One side pipe welding with the application of GTAW for the root passes and completion with covered electrodes has been applied in a number of projects. Heavy wall components (figure 10) in the process system of the Statoil platform Veslefrikk have been welded at the yard Moss Rosenberg Verft in all positions (incl. 5G). The welding procedure for the 2G position is shown in app. 3 and has been illustrated in fig. 9 and 10. The covered electrode Jungo Zeron 100X proved to be most reliable. The defect rate was minimal (0.2%) for the number of 700 welds.
Summary

- A variety of steel grades which fulfil the definition of a super duplex stainless steel ~25% Cr, 2-4% Mo, N-alloyed with increased pitting, crevice corrosion resistance and mechanical properties compared with regular duplex stainless steel grades, are presented to the industry.

- Welding of super duplex stainless steel grades has achieved a reliable status.

- Investigations concerning weld metal and welded structures have emphasized the importance of:
  - applying basic coated electrodes and welding fluxes
  - the application of well established welding procedures
  - the suitability of a variety of welding processes, including submerged arc welding

- Weld metal mechanical properties do not cause significant restrictions for industrial applications.

- The welded constructions provide high strength properties, combined with good corrosion resistance in process fluids and seawater.

- In offshore installations, important weight savings can be achieved

References

/1/ Zeron 100 Super Duplex Stainless Steel, Product information Weir Material Manchester 1988


/3/ Siewert T.A. e.a., Ferrite Number Prediction to 100FN in Stainless Steel Weld Metal, Welding Jnl. Research Suppl. dec (1989) p289s-p298s

/4/ Weir Material Services, private communication

/5/ Internal Research Reports, Smitweld / Lincoln Norweld
Fig. 1 WRC 1989 Constitution Diagram /3/

Location of:

- a: Regular duplex stainless steel weld metal
type W.Nr. 1.4462
- b: Super duplex stainless steel weld metal
Zeron 100 matching
- c: Super duplex stainless steel weld metal
Zeron 100X overmatching
- d: Parent material Zeron 100, remelted

Fig. 2 Tungsten inclusion in weld deposit, from covering alloyed electrode

V=100x
Fig. 3  Weld Pitting Corrosion in FeCl₃-Test
GTAW Zeron 100 (LNT Zeron 100X)

Heat Input 1st and 2nd weld pass in kJ/mm

A  1.0-0.8
B  1.0-1.3
C  1.0-2.2
D  2.0-0.8
E  2.0-1.3
F  2.0-2.2

P: Observed pitting in root run / heat affected zone

Weight Loss (mg)

Pitting Temp. degr.C

Test acc. ASTM G48A

Lincoln Norweld / Smitweld
Fig. 4 Weld configuration in test sample
Ferric chloride pitting test

Fig. 5 Test weld H.I. = 1.0/2.2 kJ/mm  \[ \times 5 \]

Fig. 6

Detail weld metal and HAZ
Parent metal at corrosion side
Test weld H.I. = 1.0/2.2 kJ/mm
Secondary austenite formation

Fig. 7

Detail test weld H.I. = 2.0/0.8 kJ/mm
Sound structure at corrosion side
Fig. 8 Macrostructure of welded joint in Zeron 100 plate

Root: SMAW Jungo Zeron 100X
Fill: SAW LNS Zeron 100X / P 2000
Weld. Pos.: 1G

Fig. 9 Macrostructure of welded joint in Zeron 100 pipe

Root: GTAW LNT Zeron 100X
Fill: SMAW LNS Jungo Zeron 100X
Weld. Pos.: 2G

Fig. 10 Process piping in Zeron 100
Fabrication at Moss Rosenberg Verft (Norway)
manufacturer: Moss Rosenberg Vetrl AS
project: STATOIL
reference spec: VESLEFRIKK
reference WPS: RVP-W-753.5TE, SW-MVR-VESSL1

identification of base materials
Identifications: standard delivery condition P no. Gr. no. thickness range pipe diameter range
1: ZERON 100 pipe 12.5 mm 10"

welding processes
1: GTAW 2: SMAW 3:

filler materials
brand name: classification AWS / EN / others sizes F no. A no.
A: LNT Zeron 100X DIN8556-SG2XCrNiMoNCuW2510 1.6 mm
B: Jungo Zeron 100X DIN8556-E 25103NCuWL B20+ 2.5/3.25 x 350 mm

welding conditions
joint design: groove preparation machining
joint type: V-70
welding position: 2G
backing: no
flux: n.a.
shielding gas: Ar Gr.2
U/min: 6-8
backing gas: Ar Gr.2
U/min: 9-12
back gouging: no
one/two side welding one
remarks:

welding parameters
run no. filler welding gas current type / voltage current travel run-out heat input temp.
material index process stick-out (mm) (l/min) (A) (V) type / polarity speeds (mm/min) length (mm) input (kJ/mm) temp. (°C)
1 A-1.6 GTAW n.a. 6-8 88 12 DC- 36 1.76 20
2 A-1.6 GTAW n.a. 6-8 123 13 DC- 80 1.17 40
3 B-2.5 SMAW n.a. n.a. 70 22 DC+ 100 0.92 70
4 B-3.25 SMAW n.a. n.a. 110 23 DC+ 133 1.13 85
5 B-3.25 SMAW n.a. n.a. 110 23 DC+ 96 1.58 75
6 B-3.25 SMAW n.a. n.a. 110 23 DC+ 144 1.05 40
7 B-3.25 SMAW n.a. n.a. 110 23 DC+ 114 1.05 75
8 B-3.25 SMAW n.a. n.a. 110 23 DC+ 102 1.48 85

heat treatment
standard regulation
preheat temperature min. (°C) 20 interpass temperature max. (°C) 150 method: n.a.
post weld heat treatment (°C) na tol. (°C) up (°C/h) cooling

approval
issue sign./date: AB 88.12.06 approval sign./date: authority sign./date: HM 89.01.10
manufacturer: SMITWELD BV, Nijmegen, The Netherlands
project: ZERON 100
reference spec. VM 77
reference WPS

identification of base materials
1: ZERON 100 plate
2:

welding processes
1: GTAW
2: SMAW
3:

filler materials
brand name classification AWS / EN / others sizes F no. A no.
A: LNT Zeron 100X DIN8556-SGX2CrNiMoNCuW2510 1.6 mm
B: Jungo Zeron 100X DIN8556-E 25103NCuWL B20+ 2.5/4.0 x 350 mm
C:

welding conditions
joint design
groove preparation machining
joint type single V-45
welding position 3G
backing no
flux n.a.
shielding gas Ar Gr.2
I/min 6-8
backing gas Ar Gr.2
I/min 9-12
back gouging no
one/two side welding one
remarks:

welding parameters
run no. filler welding stick-out gas current voltage current travel run-out heat input temp.
material index process (mm) (A/min) (A) (V) type / polarity time length (K/J/mm) (°C)
1 1 A-1.6 GTAW n.a. 6-8 90 11 DC- 107 60 1.8
2-4 1 A-1.6 GTAW n.a. 6-8 110 11 DC- 111 100 1.3
5-6 2 B-2.5 SMAW n.a. n.a. 70 27 DC+ 54 70 1.4
7-9 2 B-2.5 SMAW n.a. n.a. 70 27 DC+ 51 60 1.6
10-14 2 B-4.0 SMAW n.a. n.a. 115 25 DC+ 83 135 1.8
15-17 2 B-2.5 SMAW n.a. n.a. 70 27 DC+ 51 70 1.4

heat treatment
standard regulation
preheat temperature min. (°C) 20 interpass temperature max. (°C) 150 method: n.a.
post weld heat treatment (°C) na tol. (°C) up (°C/h) cooling

approval
issue sign/date: RH 88.11.11 approval sign/date: authority sign/date: HM 88.11.11

formal
manufacturer: SMITWELD
project: Marathon Oil
identification of base materials:
1. Zeron 100
   - type: plate
   - thickness range: 47 mm

welding processes:
1. MMAW
2. SAW
3. ...
filler materials:
A: Jungo Zeron 100X
   - classification: DIN8556-E 25103NCuWnC B20+
   - sizes: 3.25 x 350 mm
B: Jungo Zeron 100X
   - classification: DIN8556-E 25103NCuWnC B20+
   - sizes: 4.0 x 350 mm
C: P2000/LNS Zeron 100X
   - classification: 2.5 mm
welding conditions:
- Joint design:
- Groove preparation: machining
- Joint type: X-70
- Welding position: 1G
- Backing: no
- Flux: P2000EMR
- Shielding gas: n.a.
- U/min: n.a.
- Backing gas: n.a.
- U/min: n.a.
- Back gouging: no
- One/two side welding: two
- Remarks: Fully Restraint welding conditions
welding parameters:
<table>
<thead>
<tr>
<th>Run no.</th>
<th>Filler material index</th>
<th>Welding process</th>
<th>Stick-out (mm)</th>
<th>Gas (L/min)</th>
<th>Current (A)</th>
<th>Voltage (V)</th>
<th>Current type / polarity</th>
<th>Travel speed (mm/min)</th>
<th>Run-out length (mm)</th>
<th>Heat input (kJ/mm)</th>
<th>Temp. (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A-3.25</td>
<td>MMAW</td>
<td>n.a.</td>
<td>n.a.</td>
<td>80</td>
<td>22</td>
<td>DC+</td>
<td>87s</td>
<td>110</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>B-4.0</td>
<td>MMAW</td>
<td>n.a.</td>
<td>n.a.</td>
<td>140</td>
<td>26</td>
<td>DC+</td>
<td>68s</td>
<td>180</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>B-4.0</td>
<td>MMAW</td>
<td>n.a.</td>
<td>n.a.</td>
<td>140</td>
<td>26</td>
<td>DC+</td>
<td>68s</td>
<td>145</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>14-15</td>
<td>B-4.0</td>
<td>MMAW</td>
<td>n.a.</td>
<td>n.a.</td>
<td>140</td>
<td>26</td>
<td>DC+</td>
<td>70s</td>
<td>190</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>4-13</td>
<td>C</td>
<td>SAW</td>
<td>20</td>
<td>n.a.</td>
<td>305</td>
<td>30</td>
<td>DC+</td>
<td>500</td>
<td>n.a.</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>16-53</td>
<td>C</td>
<td>SAW</td>
<td>20</td>
<td>n.a.</td>
<td>305</td>
<td>30</td>
<td>DC+</td>
<td>500</td>
<td>n.a.</td>
<td>1.1</td>
<td></td>
</tr>
</tbody>
</table>
heat treatment:
- Preheat temperature min. (°C): RT
- Interpass temperature max. (°C): 200
- Method: n.a.
- Post weld heat treatment (°C): na
- Tol. (°C): up (°C/h)
- Cooling
approval:
Issue sign/date: FR 89.08.21
Approval sign/date: authority sign/date: JH 89.08.21