WELDING SUPER DUPLEX STAINLESS STEEL

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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

		Chemical Composition w%							
Manufacturer	Grade	Cr	Ni	Mo	N	Cu	other	PRE_N	product forms
Böhler	A 905	25.5	3.7	2.3	0.37		Mn:5.8	39.0	plate, forgings
Carpenter	7-Mo Plus	27.5	4.5	1.5	0.25			36 5	
Creusot Ind.	UR 47N	25	7	3.0	0.16	0.2		37.6	
	UR 52N	25	7	3.0	0.16	1.5		37.6	plate
Langley	Ferralium 255 UNS 32250	25.5	5.5	3.0	0.17	2.0		38.1	castings
Sandvik	25.07 UNS 32750	25	7	4.0	0.25			42.2	tubes, castings, forgings
Sumitomo	DP 3	25	6.5	3.0	0.2	0.5	W: 0.3	38.1	plate, bars, wire, pipe
WMS *)	Zeron 100 UNS 32760	25.5	6.5	3.5	0.25	0.7	W: 0.7	41.1	plate, forgings, tubes, fittings, castings, fasteners

*) together with:
- *Fabr. de Fer* - *SSE* - *Brit.Steel Corp.* - *Sterling*
- *Mather & Platt* - *Benthum Int.* - *Stockbridge Eng. Steels* - *INCO Int.*
- *Butting* - *Schulz* - *Valinox* - *Barworth Flockton*
- *Barr Thomson*

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

The PRE_N (PRE_N = %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 R. 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

		Test temperature °C castings			plate (up to 30 mm)		
test temperature	(°C)	20	150	250	20	150	250
0.2%-proof stress	(N/mm²)	>450	>360	>330	>550	>450	>400
ultimate tensile strength	(N/mm²)	>700	>630	>570	>750	>680	>650
elongation	(%)	>25			>25		
hardness	(HB)	200-270			200-270		
test temperature	(°C)	-20	-40		-20	-40	
impact CVN	(J)	>100	>75		>250	>200	
CTOD	(mm)				>1.0		

Weldability of Duplex stainless Steel
Originally, some super duplex grades offered attractive strength and corrosion properties but failed in structures due to severe detorioration 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 for regular duplex stainless steel. Regular duplex weld metal shows a basicly 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 estamating 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)

Process	SMAW		GTAW & GMAW		SAW	
Consumables	Jungo		LNT		Flux P2000	
	Zeron 100	Zeron 100X	Zeron 100	Zeron 100X	Zeron 100	Zeron 100X
C	0.03	0.03	0.02	0.02	0.02	0.02
Mn	0.8	0.8	0.5	0.5	0.6	0.6
Si	0.3	0.3	0.5	0.5	0.4	0.5
Cr	25.2	25.1	24.8	24.8	24.8	25.0
Ni	6.8	9.8	6.8	9.8	6.8	9.2
Mo	3.7	3.7	3.7	3.7	3.7	3.7
N	0.21	0.22	0.22	0.22	0.20	0.20
Cu	0.7	0.6	0.6	0.6	0.6	0.6
W	0.6	0.6	0.6	0.6	0.5	0.6
PRE_N	40.8	40.8	40.5	40.5	40.2	40.4
$FN_{as\ welded}$	80	42	75	48	85	60

Weld metal mechanical properties (typical)

Process		SMAW	GTAW	SAW
Consumables		Jungo	LNT	Flux P2000
		Zeron 100X	Zeron100X	LNS Zeron 100X
Condition		As Welded	As Welded	As Welded
Strength				
Rp0.2	(N/mm^2)	740	680	715
Rm	(N/mm^2)	920	885	895
A5	(%)	25	26	25
Impact CVN	(J)			
	-20 °C	50	>80	55
	-30 °C			
	-40 °C	40	>60	45
CTOD (mm)	-10 °C	0.3	0.3	0.4
Hardness	(HV10)	290-330	300-330	285-330
	(HRc)	< 32	< 32	< 32

Current requirements in offshore industry for high severity applications include:
- Yield Strength at 0.2% offset: >550 N/mm²
- Ultimate Tensile Strength : >750 N/mm²
- CVN impact at -20 °C : >40 J
  -34 °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 H_2S-cracking in sour gas service. Stress corrosion tests (see next paragraph) however, indicate that a relaxation of the hardness criterium 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 °C, 16 bar), 30 days and more at stress levels of 90 and 110% of the yied strength.
- ASTM G36 during 500h at 150 °C in 45% $MgCl_2$ at a stress level of 262 n/mm².
- ASTM G30 U-bend different temperatures (80-110 °C) and pressures (50-300 bar) in different conditions e.g. CO_2: 52 bar, H_2S 0.25 bar, Cl^-: 46000ppm 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 aquous solutions with 50000 ppm Cl^-, pH 2 at tempertaures up to 60 °C has been executed.

In general a CPT of 45 °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 °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 °C and were raised, in steps of 5 °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 °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 °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.

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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

/2/ Kotecki D.J., Ferrite control in duplex stainless steel weld metal, Weld.Jnl. Research Suppl. Oct (1986), p273s-278s

/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

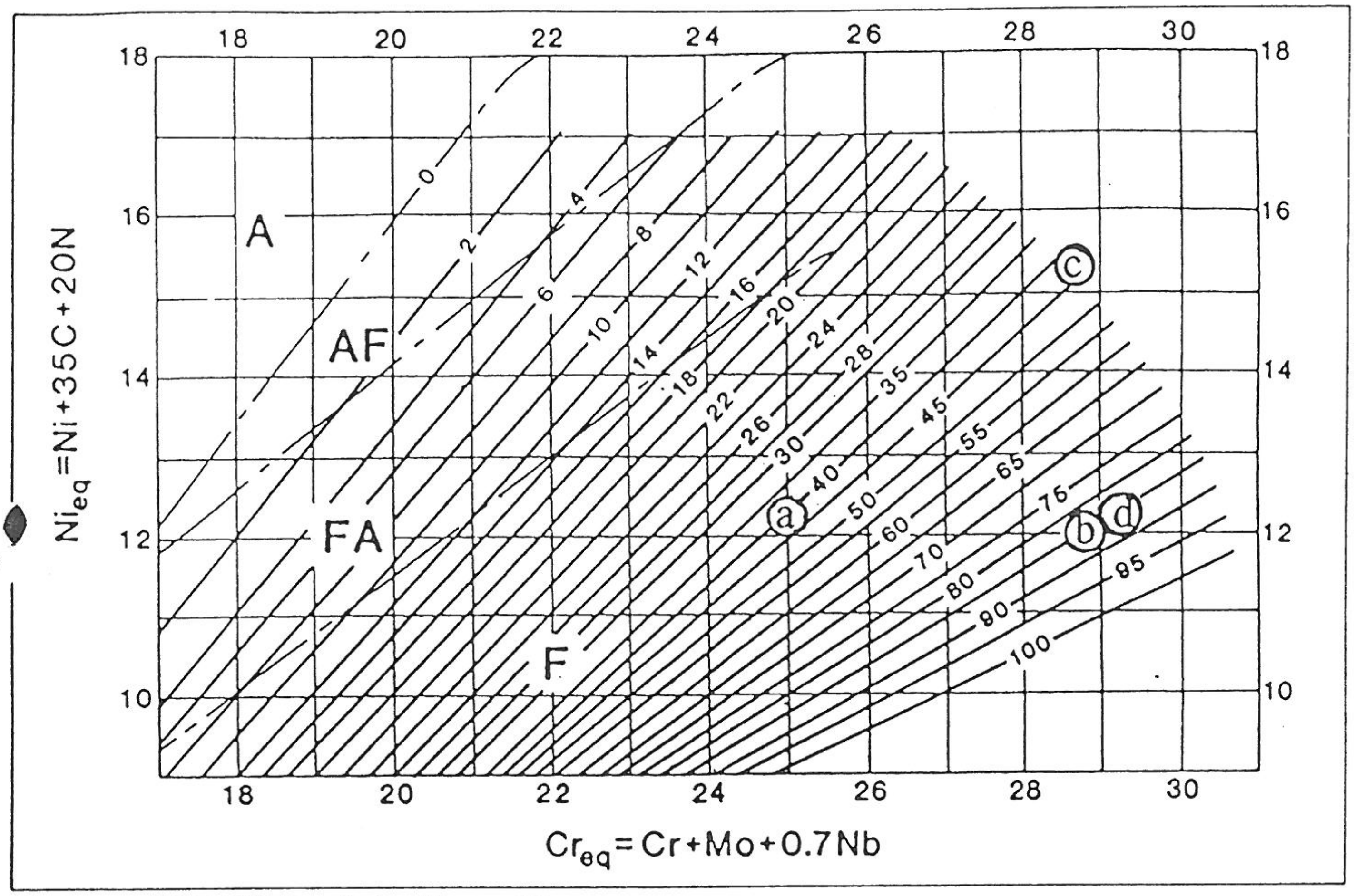


Fig.1 WRC 1989 Constitution Diagram /3/

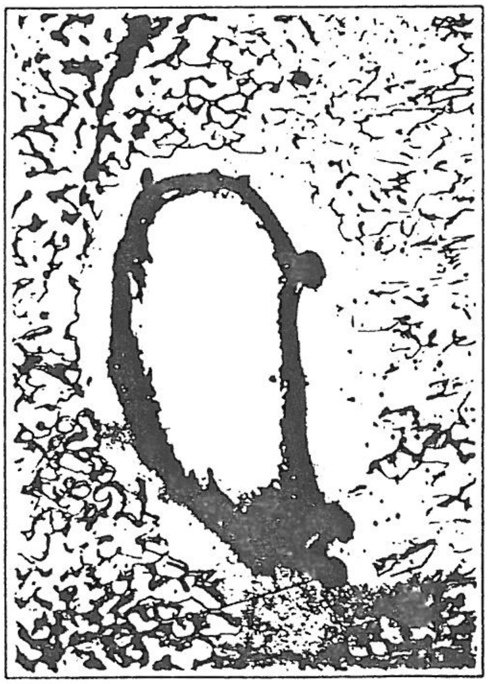
Location of:

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

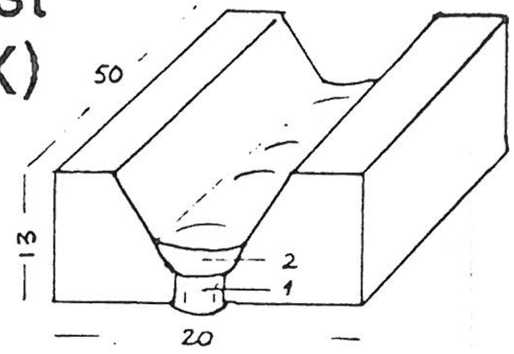
d: Parent material Zeron 100, remelted

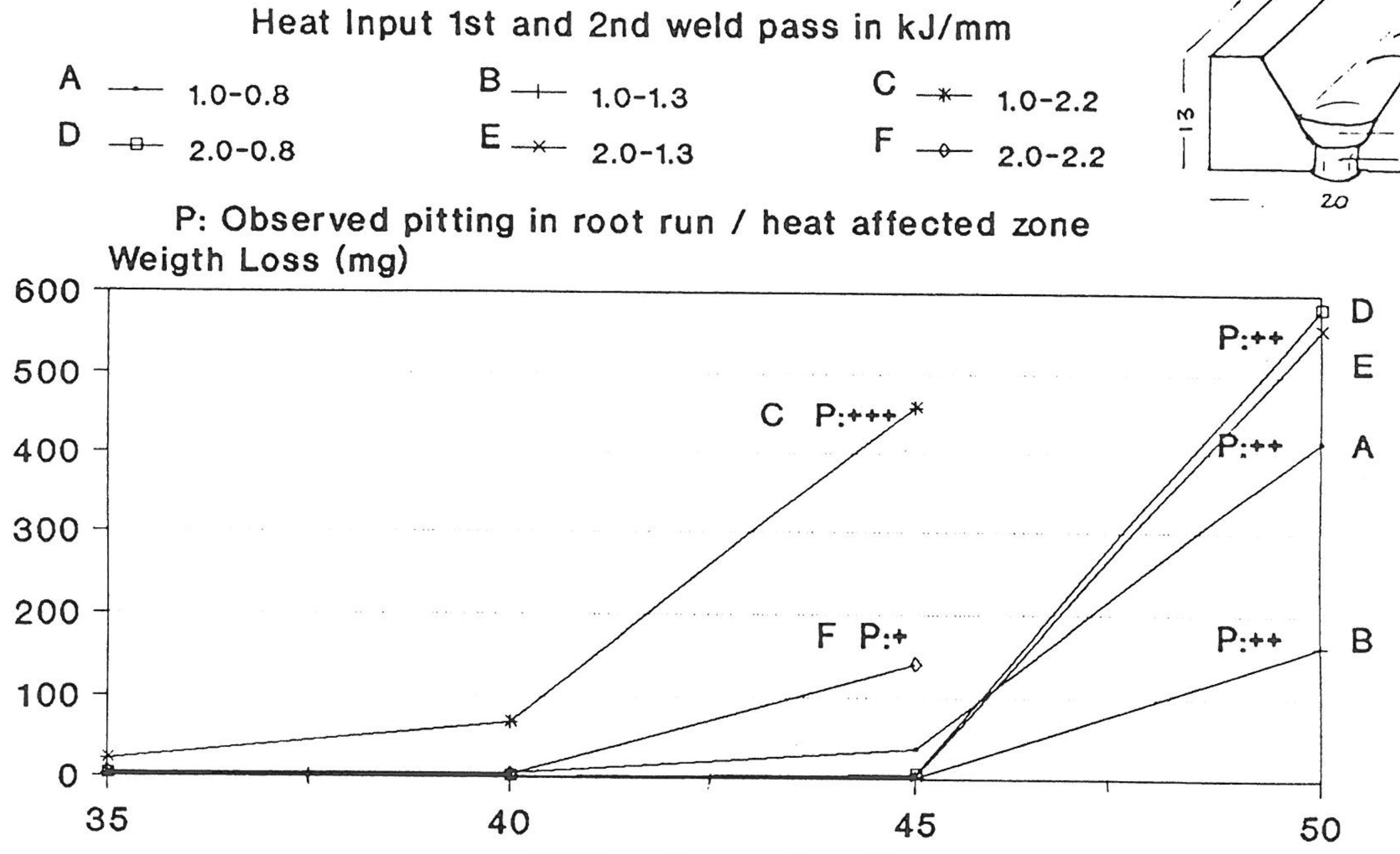


Tungsten inclusion in weld deposit, from covering alloyed electrode

Fig.2 V=100x

Fig. 3 Weld Pitting Corrosion in $FeCl_3$-Test GTAW Zeron 100 (LNT Zeron 100X)





Test acc. ASTM G48A

In667-2

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HI (kJ):
1st/2nd run
1.0 / 0.8

1.0 / 1.3

1.0 / 2.2

Fig.4 Weld configuration in test sample
Ferric chloride pitting test

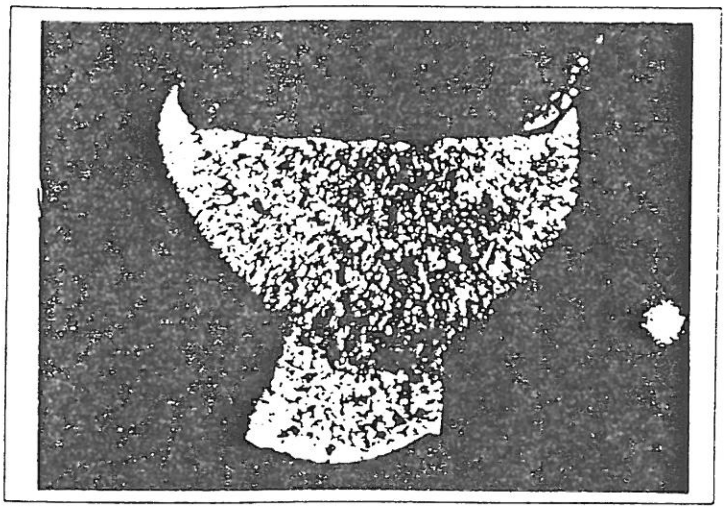

Fig.5 Test weld H.I.= 1.0/2.2 kJ/mm V=5x

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

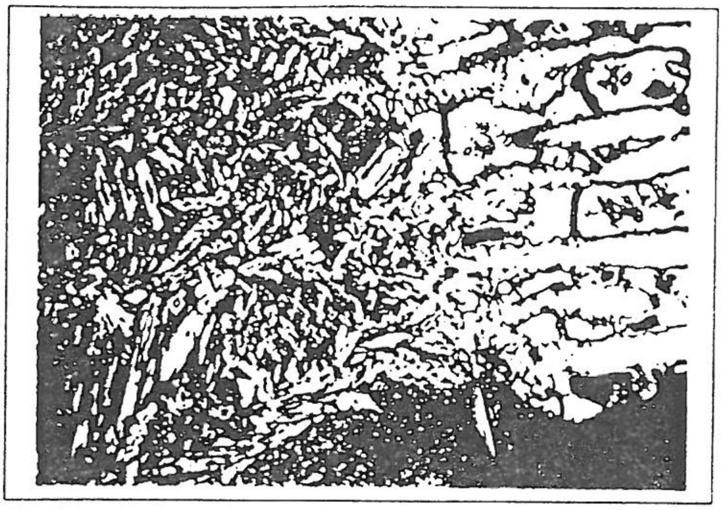

Fig.6 V=300x

Detail test weld H.I.= 2.0/0.8 kJ/mm
Sound structure at corrosion side

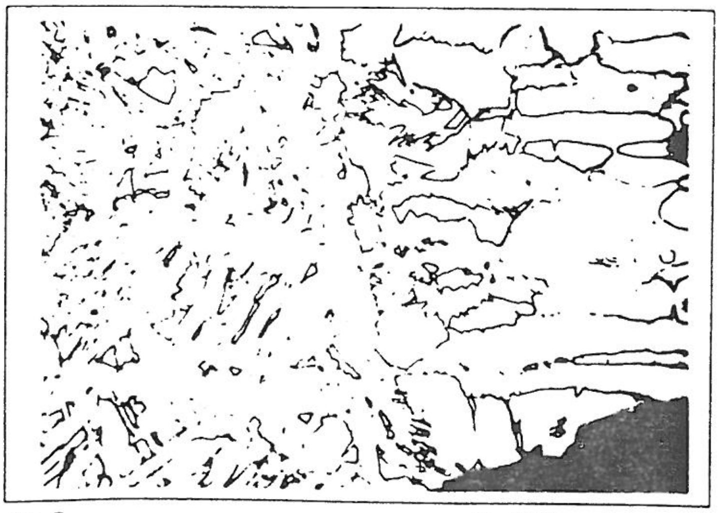

Fig.7 V=300x

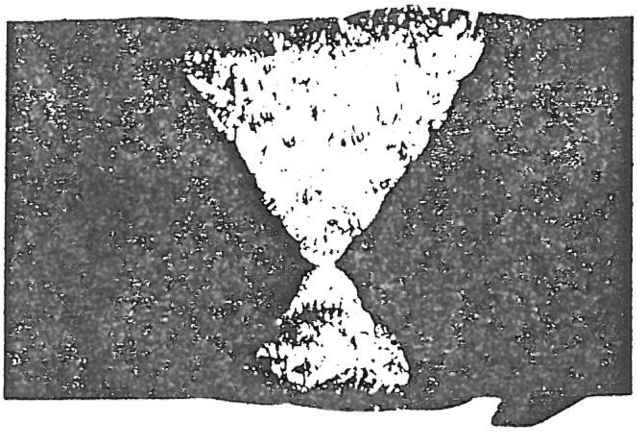

Fig.8 Macrostructure of welded joint in Zeron 100 plate

Root: SMAW Jungo Zeron 100X

Fill: SAW LNS Zeron 100X / P 2000

Weld. Pos.: 1G

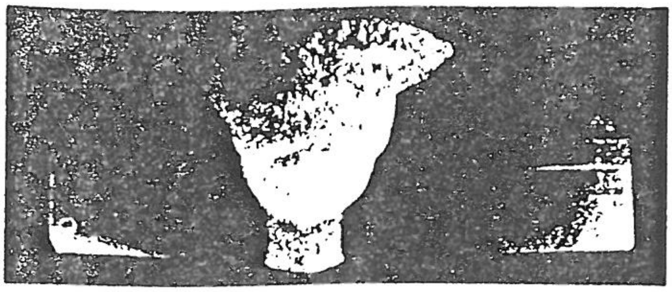

Fig.9 Macrostructure of welded joint in Zeron 100 pipe

Root: GTAW LNT Zeron 100X

Fill: SMAW LNS Jungo Zeron 100X

Weld. Pos. 2G

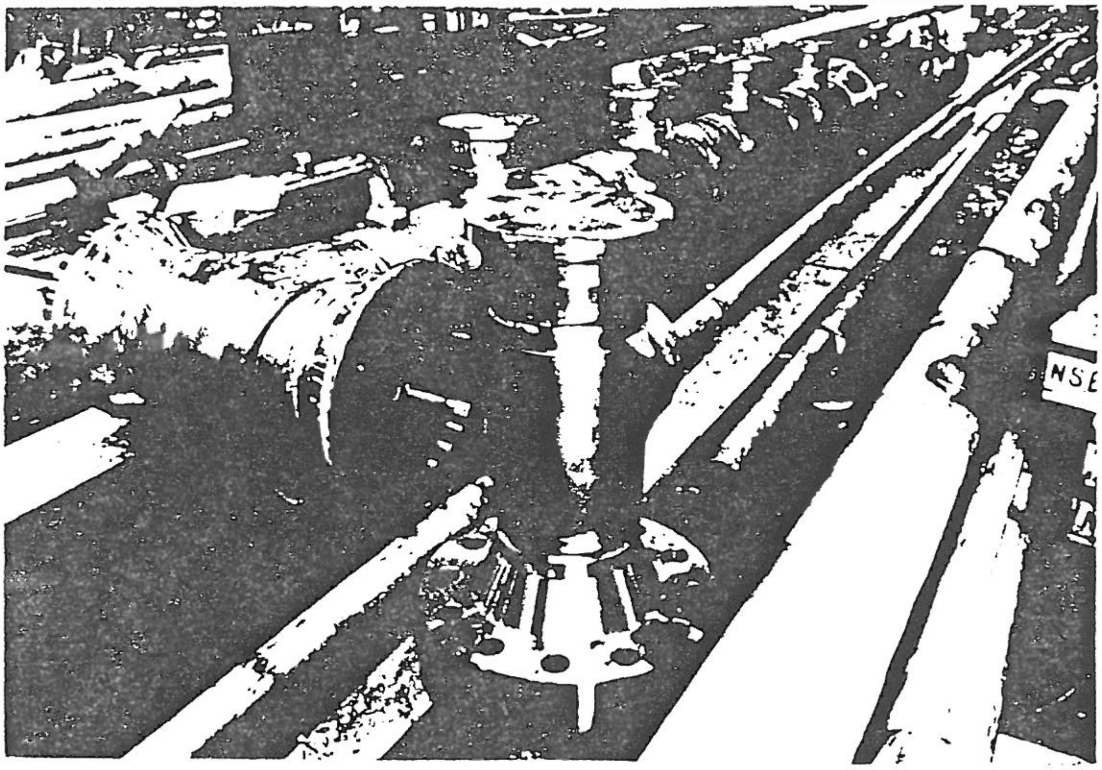

Fig.10 Process piping in Zeron 100 Fabrication at Moss Rosenberg Verft (Norway)

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WELDING PROCEDURE RECORD

WPR : Appendix 3
Rev. : 01
Date : 89.01.10

manufacturer Moss Rosenberg Verft AS

project STATOIL-VESLEFRIKK   reference spec.
reference WPS   RVP-W-753.5TE, SW-MVR-VESL1

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"
2:							

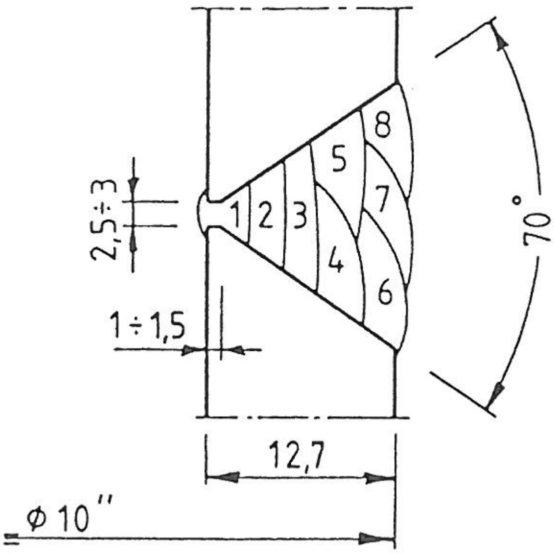
welding processes   1: GTAW   2: SMAW   3:

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+	2.5/3.25 x 350 mm		
C:					

welding conditions

joint design



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

welding parameters

run no.	filler material index	welding process	stick-out (mm)	gas (l/min)	current (A)	voltage (V)	current type / polarity	travel speed (mm/min)	run-out length (mm)	heat 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

forms\wps

SMITWELD

WELDING PROCEDURE RECORD

WPR : Appendix 1
Rev. :01
Date :88.11.11

manufacturer SMITWELD BV, Nijmegen, The Netherlands

project ZERON 100 reference spec.
reference WPS VM 77

identification of base materials

	identifications	standard	delivery condition	P no.	Gr.no.	thickness range	pipe diameter range
1:	ZERON 100		plate			20 mm	
2:							

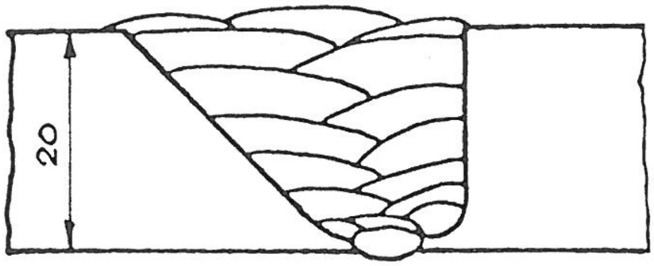
welding processes 1: GTAW 2: SMAW 3:

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
l/min	6-8
backing gas	Ar Gr.2
l/min	9-12
back gouging	no
one/two side welding	one
remarks:	

welding parameters

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

forms\wps

SMITWELD

WELDING PROCEDURE RECORD

WPR : Appendix 2
Rev. : 02
Date : 89.08.21

manufacturer Smitweld bv

project Marathon Oil-WMS
reference spec.
reference WPS A1120/35

identification of base materials

	identifications	standard	delivery condition	P no.	Gr.no.	thickness range	pipe diameter range
1:	ZERON 100		plate			47 mm	
2:							

welding processes

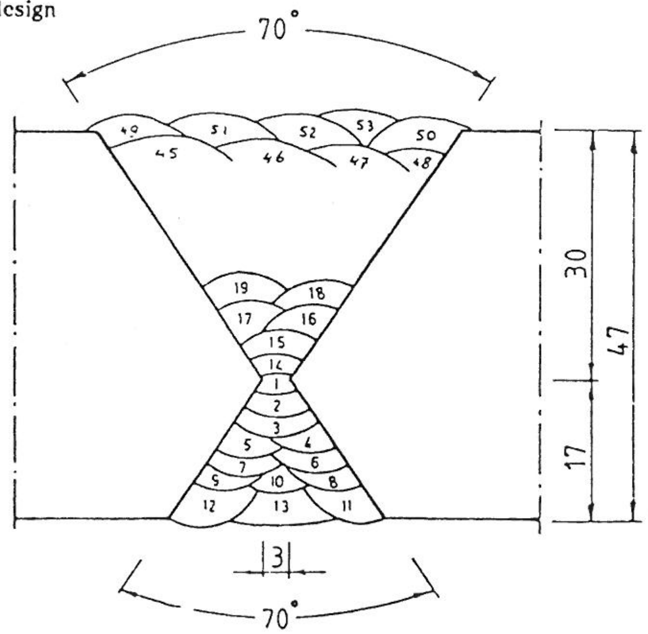
1: MMAW 2: SAW 3:

filler materials

	brand name	classification AWS / EN / others	sizes	F no.	A no.
A:	Jungo Zeron 100X	DIN8556-E 25103NCuWnC B20+	3.25 x 350 mm		
B:	Jungo Zeron 100X	DIN8556-E 25103NCuWnC B20+	4.0 x 350 mm		
C:	P2000/LNS Zeron 100X		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.
l/min	n.a.
backing gas	n.a.
l/min	n.a.
back gouging	no
one/two side welding	two

remarks:
Fully Restraint welding conditions

welding parameters

run no.	filler material index	welding process	stick-out (mm)	gas (l/min)	current (A)	voltage (V)	current type / polarity	travel speed (mm/min)	run-out length (mm)	heat input (kJ/mm)	temp. (°C)
1	A-3.25	MMAW	n.a.	n.a.	80	22	DC+	87s	110	1.0	
2	B - 4.0	MMAW	n.a.	n.a.	140	26	DC+	68s	180	1.3	
3	B - 4.0	MMAW	n.a.	n.a.	140	26	DC+	68s	145	1.6	
14 - 15	B - 4.0	MMAW	n.a.	n.a.	140	26	DC+	70s	190	1.4	
4 - 13	C	SAW	20	n.a.	305	30	DC+	500	n.a.	1.1	
16 - 53	C	SAW	20	n.a.	305	30	DC+	500	n.a.	1.1	

heat treatment

standard regulation

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

forms\wps