

Welding duplex and superduplex stainless steel

An update of the guide for industry

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Keywords: duplex stainless steel, super duplex stainless steel, welding, properties, applications

Abstract

The 1992 guide for welding duplex stainless steel has been updated. The growth in the application of duplex stainless steel has been substantial. The current status of engineering aspects of the mostly used base material has been reviewed. New welding processes such as the GMAW-STT process have been described. The new AWS and EN standards for welding consumable standards with their requirements for the chemical composition have been listed. Extensive mechanical testing of weldments in DSS and SDSS has been performed and show that the modern welding consumables meet enhanced requirements such as CVN 40 J at -46°C . In addition CTOD tests and even wide plate tests have been reported in the literature. Those tests demonstrated the reliability of various welding procedures. Engineers express their confidence in applying DSS grades.

1 Introduction

In 1993, in the IIW journal *Welding in the World* a paper was published with the title 'Welding of duplex and superduplex stainless steel', which was to be used as a guide for industry (IIW document, agreed upon in 1992, ref. 1). After that the 4th duplex conference has been held (Glasgow 1994). The material engineers in the petrochemical industry and chemical tanker shipbuilding became convinced that the combination of the higher strength and increased corrosion properties, compared to the common austenitic stainless steel grades offers a real and reliable advantage. The use of both, duplex (DSS) and superduplex (SDSS) stainless steel, increased significantly. A growth in sales of 22%Cr duplex stainless steel in particular, has been spectacular and is still increasing with over 20% per year. The current world wide consumption has been estimated to be within 100,000–150,000 ton. Many projects have been completed and new projects with 22%Cr duplex and 25%Cr superduplex (approx. 5–10% of the

duplex stainless steel volume) are in the design or already in the fabrication phase. The grade UNS S31803 has now reached the third place in stainless steel consumption. The progress in material technology including base material manufacture and handling as well as welding technology has been evident over the last four years.

Rather than expanding the number of specific grades one can observe a certain concentration on those grades with proven records. Generic grades are standardised in UNS and EN 10088 specifications. These materials have become readily available in most product forms. No specific attention has been given to the Mo-free 23% Cr DSS and to 25% DSS with its PREN below 38. Their use is rather limited.

With the growing application also the increase in severity of properties is noticeable. Only 4 years ago most of the authorities and oil companies limited the allowable design temperature to -20°C and a material thickness of 25mm. Application research work in various countries showed the reliability of welded joints, also at lower temperatures and heavier thicknesses. Recent requirements in the oil and gas industry refer to -46°C for impact toughness. In some cases CTOD properties at -20°C or -40°C have been required for information.

With reference to the 1992 guide this paper reviews the subjects where the developments in welding technology provided the basis for the compliance with the increased requirements, in some cases even combined with an increased productivity.

Regarding the corrosion properties, reference is limited to the pitting corrosion testing which should be considered as suitable for ranking and QC purposes only.

2 Base materials

2.1 Material grades

The combination of properties such as high proof strength and high resistance to pitting and crevice corrosion makes the DSS and SDSS most attractive for installations in the oil & gas industry. In particular the pitting

corrosion resistance is determined by the chemical composition. Two pitting resistance indices are in use:

$$PRE_N = \%Cr + 3,3x \%Mo + 16x \%N \text{ and}$$

$$PRE_W = \%Cr + 3,3x (\%Mo + 0,5x \%W) + 16x \%N \text{ (ref. 2)}$$

Under the common 22%Cr duplex stainless steel grade with the classifications UNS S31803 steel manufacturers present their steels in compliance with a pitting index $PRE_N > 32$ up to $PRE_N > 35$. The modern steel grades typically contain 22.5%Cr, 5.5%Ni and Mo varying between 3,0–3,5%. The nitrogen content $N=0,14-0,20\%$ with the average being 0,16%. The PRE_N value is controlled mainly by the Mo-content. Table 1 shows the best known commercial 22%Cr duplex stainless steel grades.

The stabilisation of the duplex microstructure with the austenite (γ)-promoting element N proved to assure good properties, particularly in the HAZ.

Standard 22%Cr DSS has been applied mainly in the transport and handling of natural gas with condensates. Examples of important applications are certainly the Dutch NAM underground natural gas storage projects, the ARCO transport pipe lines in Alaska, the process equipment of the Statoil platform Sleipner West, and under preparation the piping and flowlines of the Oman LNG project. Additionally, numerous applications in the pulp and paper industry, in chemical tankers and flue gas desulphurisation projects have been recorded.

Specifying bodies in the oil & gas industry tend to 'enhance' the material requirements such as impact toughness CVN -46°C of average 35 to 45J, depending on the operator, and a proof strength $Rp0,2 \text{ min. } 500 \text{ N/mm}^2$. These requirements have been fulfilled with generic UNS S31803 products. Three standard 25%Cr superduplex stainless steel grades (wrought products) are on the market. One grade typically contains 25%Cr, 6,5–7,5%Ni, 3,5–4,0%Mo and $N=0,22-0,26\%$ (UNS S32750). The other grades are additionally alloyed with 1,5% Cu (UNS S32550) or with 0,6%Cu and 0,6%

Manufacturer	Grade	Cr	Ni	Mo	N	Cu	other	PRE_N	PRE_W	product forms
22%Cr Duplex Stainless Steel										
<u>UNS S31803 EN X2 CrNiMoN 22-5-3</u>										
Avesta	2205									
Creusot Loire Ind.	UR 45N & 45N+									
Fabr. de Fer.	Fafer 4462									
Thyssen Krupp Nirosta	Fale 223	22,0-	5,5	2,8-	0,15-	-		32-37		all product forms, depending on manufacturer
Sandvik	SAF 2205	22,8		3,4	0,18					
Nippon Kokan	NKCr22									
Sumitomo	SM22Cr									
25%Cr Super-Duplex Stainless Steel										
<u>UNS J</u>										
Pleissner	9.4462 S	26	7	3,5	0,25	0.6		42		castings
<u>UNS S32550 EN X2 CrNiMoCuN 25-6-3</u>										
Creusot Loire Industrie	UR 52N & 52N+	25	6,0-	3,2-	0,22-	1,6		39-41		plate, forgings,
										bars,
Langley Alloys	Ferr255/SD 40		6,3	3,7	0,25					castings
<u>UNS S32750 EN X2 CrNiMoN 25-7-4</u>										
Avesta / Sandvik	SAF 2507	25	7	4,0	0,27	-		42.5		{ plate, forgings,
										{ tubes,
										{ fittings, castings
Creusot Loire Industrie	UR 47N+	25	7	3,8	0,28	-				
<u>UNS S32760 EN X2 CrNiMoCuWN 25-7-4 (wrought)</u>										
<u>J93380 (cast)</u>										
Weir Materials	Zeron 100									{ plate, forgings,
										{ tubes,
										{ fittings, castings
Fabr. de Fer	UNS 32760	25	7-8	3,6	0,22	0,7	W: 0,7	>40	41,5	plate
class.?										
Sumitomo	DP3W	25	7	3,0	0,27	-	W=2	39	42,5	pipes

C max 0.03 or 0.04%

Table 1. Well known trade names and products in 22%Cr DSS and 25%Cr SDSS; typical chemical compositions.

W (UNS S32760) with $PRE_N=40-41$ and $PRE_W=41,5-42,5$. Table 1 lists the main commercial grades of this type.

The increase crevice, pitting and stress corrosion of the superduplex grades (viz. UNS 32760) showed substantial benefits in severe conditions such as:

Gas/condensate transport pipe lines (viz. King Fisher...), platform process equipment (Maersk, Phillips Petroleum), swivel stack buoyings on vessels (SBM) and reactors in the chemical industry (Hoechst).

2.2 Surface condition

The surface condition of the plates and pipes have been improved. For 22%Cr duplex stainless steel is standardised as annealed, blasted & pickled, sufficient for most engineering conditions (ref. 3). Nevertheless the fabricators occasionally come across surface problems which can be traced back to hot rolling conditions.

It is stated that duplex material manufacture requires special rolling and heat treatment procedures which make the products generic, despite a common classification according to UNS and EN standards.

2.3 Forming and straightening

In the further processing of plate material cold forming is applied for products such as vessel heads, bends and longitudinal welded pipes. The understanding today is that sound plate material can accommodate a substantial amount of plastic deformation (max. 15%) before an unacceptable loss of toughness occurs. When weldments are included in the plate a limit of 10% should be respected (ref. 3).

Hot forming always requires an annealing solution heat treatment.

Flame straightening is a subject of discussion and research (ref. 4). In practice it is almost impossible to weld complex plate structures without the need to correct flatness or dimensions. Flame straightening should not be applied but is often the only way. Knowing the detrimental effects to the material when exposed to temperatures in the range of 700–1000°C, limitation to short but effective heating and fast cooling is required. A rule could be to allow the flame straightening only once on a specific spot by heating the non corrosion side of the base material, with a high energy oxidising burner to a red hot temperature for max 1–2 minutes, immediately followed by quenching with water. Flame straightening of weldments must be avoided completely.

3 Weld metal metallurgy

3.1 Transformation and precipitation reactions

Review of physical properties including basic metallurgic transformation processes in general is beyond the scope of this paper. The past years further extensive fundamental research has been executed on then various base materials. For the transformation of structures in the weld metal an extensive review of the literature has been executed by Karlson (ref. 5, plenary conference paper).

The formation and the effects of deleterious phases in DSS and SDSS and the associated weld metals have been reviewed. The literature indicates that the precipitation of intermetallic phases such as (Mo rich Fe-Cr-Mo) and (Fe-Cr-Mo) effect significantly the toughness of the base and weld metal. 25% Cr SDSS is more prone than DSS to form these phases when cooling down from temperatures > 1000°C. In the austenite-ferrite structure a level of intermetallic phases of 0% at the surface and 1–2% in the mid thickness zone of plate material and weld metal has been considered as acceptable.

3.2 Ferrite

The balance of the phase components ferrite and austenite, also in the weld metal, remains basic issue. No major changes in the acceptance limits have been observed. It is now a common understanding that the base material as delivered contains 40–60% austenite in an originally ferritic matrix whereas the as welded weld metal may show variations between 25 to 70%, or in measurable terms: 35 to 100 FN (Ferrite Number according to draft ISO 8249;1997 or AWS A 4.2-92).

The international standardisation for the determination of ferrite has made progress.

The ISO and AWS standard incorporated the need to cover the high ferrite contents occurring in DSS and SDSS.

4 Welding processes and procedures

4.1 Arc welding processes

Over the last number of years developments in the arc welding processes for DSS and SDSS have been reported. These developments are in particular regarding the GMAW process.

With recently invented controls of the welding arc characteristics, it is possible to program the current supply and metal transfer.

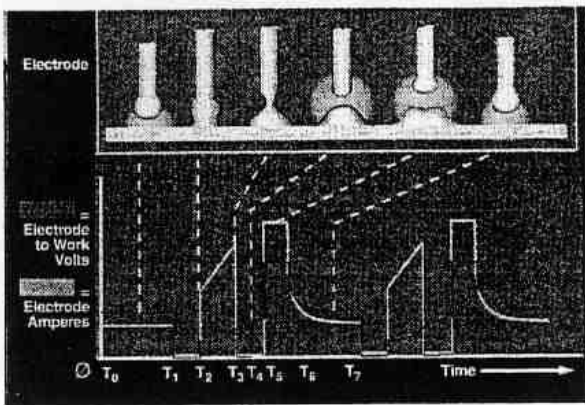


Figure 1. GMAW-STT wire electrode current and voltage wave forms for a typical welding cycle.

Weld metal grade	Process	
	GTAW	GMAW-STT
22 9 3 NL	LNT 4462 23-24 °C	LNM 4462 >30 °C
25 9 3 NL CuW	LNT Zeron 100X 37.5-40 °C	LNM Zeron 100X 45 °C

Table 2. Critical pitting corrosion temperature for root welds; GMAW-STT versus GTAW.

LINCOLN ELECTRIC Lincoln Smitweld		Welding Procedure Approval Record			WPAR: STT.008 Rev.: 1 Ref. WPQ: 95.048																																																																							
Procedure Specification				Test Results																																																																								
Base material Duplex SS Grade 1.4462 Welding processes A: GMAW - STT B: SAW Manual or machine Manual and machine Welding position 5G down and 1G (PG / PA) Filler metal (trade) 1: LNM 4462 2: LNS 4462 Flux P2000 EN 760: A AF 2 63 DC Filler metal classific. 1: EN 12072: G 22 9 3 N L 2: EN 12072: S 22 9 3 N L Shielding gas [l/min] 98Ar + 2% CO ₂ Flow 15 Backing (gas) [l/min] STT: Ar 99.99% Flow 12 - 15 Purging gas SAW N ₂ dry Current / polarity DC + Preheat temp. [°C] RT Interpass temp. [°C] max. 140 Postheat treatment N.A. Welder's name D. Ritsema and J. Tersteeg Laboratory Test No. DM 32 Remarks: Specification-code: Stoomwezen T220/T210; EN 288-3 NAM NSS-60C-7-02				Radiographic Examination: Acceptable Visual Examination: Good Reduced-section tension test Tensile strength [MPa] 17.7 x 11.5 779 Fracture location Base material All-weld-metal tension test Yield point [MPa]: Tensile strength [MPa]: Elongation, A5 [%]: Reduction, Z [%]: Bend tests Former diameter: 3 x t + 3.8 x t Root 20 x 15 180° No remarks Face 20 x 15 180° No remarks Side 10 x 15 180° No remarks Impact tests ISO - V [Joule] Test temp. [°C]: see below Size of specimen: 10 x 10 x 55mm Required 40 Joule <table border="1"> <thead> <tr> <th></th> <th>Chw</th> <th>av.</th> <th>av.</th> </tr> </thead> <tbody> <tr> <td>- 20°C</td> <td>80 73 72</td> <td>75</td> <td></td> </tr> </tbody> </table>					Chw	av.	av.	- 20°C	80 73 72	75																																																														
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Corrosion tests Modified ASTM G48a 24 hours CPT > 30°C				We the undersigned, certify that the statements in this record are correct. Manufacturer or Contractor Lincoln Smitweld by Nijmegen Authorized by L. van Nassau Issued by Fred Neessen Date 23 September 1995																																																																								

Figure 2. Welding Procedure Approval Record: GMAW-STT and SAW.

Pulsed open arc welding is not new but the application of GMAW in practice was limited. A new generation of power sources, with a programmed full control of the wave form, provides a high productivity in all position welding.

A most advanced process in this category is the 'GMAW-STT' process (ref. 7, 8) with wave form control®. In this process a sensor monitors the arc current and voltage. A specific sequence of fast current switching, at moments where overheating of the weld droplet at the wire end would otherwise cause spatter, has been build-in in the process (figure 1). The process enables in particular the welding of root runs in pipes. The energy efficiency, in terms of heat supply to the wire and the base metal, is better

than known for other arc welding processes. At low heat input the welding speed in root runs is 3–4 times as fast as regular GTAW. At the same time the root weld thickness allows to continue with other processes like SAW (figure 2 and figure 3). The weld metal pitting corrosion properties are significantly better than obtained with regular GTAW (table 2).

4.2 Welding consumables

The revised AWS standards such as AWS A5.4-92, A5.9-93 and A5.22-95 as well as the new European Standards EN 1600, EN 12072 and EN 12073 contain the specification limits for the chemical composition and mechanical properties of the welding con-

Process/Standard	Chemical composition w%										Mechanical properties		
	C	Mn	Si	Cr	Ni	Mo	N	Cu	other	Rp0.2 N/mm ²	Rm N/mm ²	A5/A4 %	
SMAW (covered electrodes)													
AWS A5.4-92													
E2209-XX	min.			0,5	21,5	8,5	2,5	0,08					
	max.	0,04	2,0	0,90	23,5	10,5	3,5	0,20	0,75				
E2553	min.			0,5	24,0	6,5	2,9	0,10	1,5				
	max.	0,06	1,5	1,0	27,0	8,5	3,9	0,25	2,5				
EN 1600													
E 22 9 3 N L	min				21,0	7,5	2,5	0,08			450	550	20
	max.	0,04	2,5	1,2	24,0	10,5	4,0	0,20	0,75				
E 25 7 2 N	min.				24,0	6,0	1,0				500	700	15
	max.	0,08	2,0	1,2	28,0	8,0	3,0	0,20	0,75				
E 25 9 3 CuNL	min.				24,0	7,5	2,5	0,10	1,5		550	620	18
	max.	0,04	2,5	1,2	27,0	10,5	4,0	0,25	3,5				
E 25 9 4 NL	min.				24,0	8,0	2,5	0,20			550	620	18
	max.	0,04	2,5	1,2	27,0	10,5	4,5	0,30	1,5	W: 1,0			
GTAW/GMAW/SAW welding wire													
AWS A5.9-93													
ER 2209	min			0,50	21,5	7,5	2,5	0,08					
	max.	0,03	2,0	0,90	23,5	9,5	3,5	0,20	0,75				
ER 2553	min.				24,0	4,5	2,9	0,10	1,5				
	max.	0,04	1,5	1,0	27,0	6,5	3,9	0,25	2,5				
EN 12072													
G/W/S	min				21,0	7,0	2,5	0,10			450	550	20
22 9 3 N L	max.	0,03	2,5	1,0	24,0	10,0	4,0	0,20	0,75				
G/W/S	min.				24,0	6,0	1,5				500	700	15
25 7 2 N L	max.	0,03	2,5	1,0	27,0	8,0	2,5	-	0,75				
G/W/S	min.				24,0	8,0	2,5	0,10	1,5		550	620	18
25 9 3CuNL	max.	0,03	2,5	1,0	27,0	11,0	4,0	0,25	2,5				
G/W/S	min.				24,0	8,0	2,5	0,20			550	620	18
25 9 4CuNL	max.	0,03	2,5	1,2	27,0	10,5	4,5	0,30	1,5	W: 1,0			
FCAW (tubular cored wire electrodes)													
AWS A5.22-95													
E2209T0-X	min.		0,5		21,0	7,5	2,5	0,08					
	max.	0,04	2,0	1,0	24,0	10,0	4,0	0,20	0,5				
E2553T0-X	min.		0,5		24,0	8,5	2,9	0,10	1,5				
	max.	0,04	1,5	0,75	27,0	10,5	3,9	0,20	2,5				
EN 12073													
T 22 9 3 N L	min				21,0	7,5	2,5	0,08			450	550	20
	max.	0,04	2,5	1,2	24,0	10,5	4,0	0,20	0,3				

Table 3. Chemical composition and mechanical properties, specified for all-weld-metal samples.

sumables for SMAW, GMAW & GTAW and FCAW (table 3).

The SMAW process conditions have not been changed since 1992. Some electrode manufacturers, however, extended the range of covered electrodes. Details such as the typical impact toughness and chemical composition may show substantial differences between the manufacturers. The minimum and maximum ferrite content in the weld metal is not specified in the above-mentioned standards. In practice a range of FN 30-70 is usually obtained in the all weld metal and in the actual weldments.

Rutile/basic electrodes have been in use for all position pipe welding. Today the welding characteristics of a new DSS fully basic electrode (Jungo 4462, see also table 4 and 5) receive a welders preference, mainly due to the low defect rate, the perfect weld pool control and the higher mechanical properties.

For the downhand position, filling joints as well as welding fillets, a high recovery electrode proved to be economically attractive. Both deposition rate and the properties

made it possible to combine productivity and reliability.

Welding procedures, qualified for Maersk and Occidental projects respectively, are shown in figure 4 and 5.

GTAW pipe welding in the field has a low productivity. Most specifications require full penetration root GTAW welds. Due to the generally respected minimum N-level (0,14%) in the filler rod and the associated HAZ, lack of austenite is no longer a problem. Good toughness and corrosion properties in DSS have been obtained. For highest pitting corrosion resistance, SDSS root weld metal has been recommended (ref. 8). This recommendation has been followed in many projects where a CPT min. 24°C must be achieved. At least for the filling and capping layers the use of the SMAW process is more appropriate.

Another trend in welding DSS is the application of tubular cored wire. In practice the wires had porosity problems. New wires discriminate between welding downhand (PA, PB) and out of position (PC, PF, PD) and provide user benefits as productivity for the

Steel grade	Welding process				
	SMAW	GTAW	GMAW	FCAW	SAW
22%Cr DSS	Arosta 4462	LNT 4462	LNM 4462	Cor-A-Rosta 4462	LNS 4462 /
	E 22 9 3 NL R 32	W 22 9 3 NL	G 22 9 3 NL	T 22 9 3 NL R C/M3	P2000
	Arosta 4462-145			Cor-A-Rosta P4462	
	E 22 9 3 NL R 53			T 22 9 3 NL M2	
	Jungo 4462				
25%Cr SDSS	E 22 9 3 NL B 22				
	Jungo Zeron 100X	LNT Zeron 100X	LNM Zeron 100X		LNS Zeron 100X /
	E 25 9 3 NL B 32	W 25 9 3 NL	G 25 9 3 NL		P2000

Table 4. A commercial range of DSS and SDSS welding consumables with their EN classification.

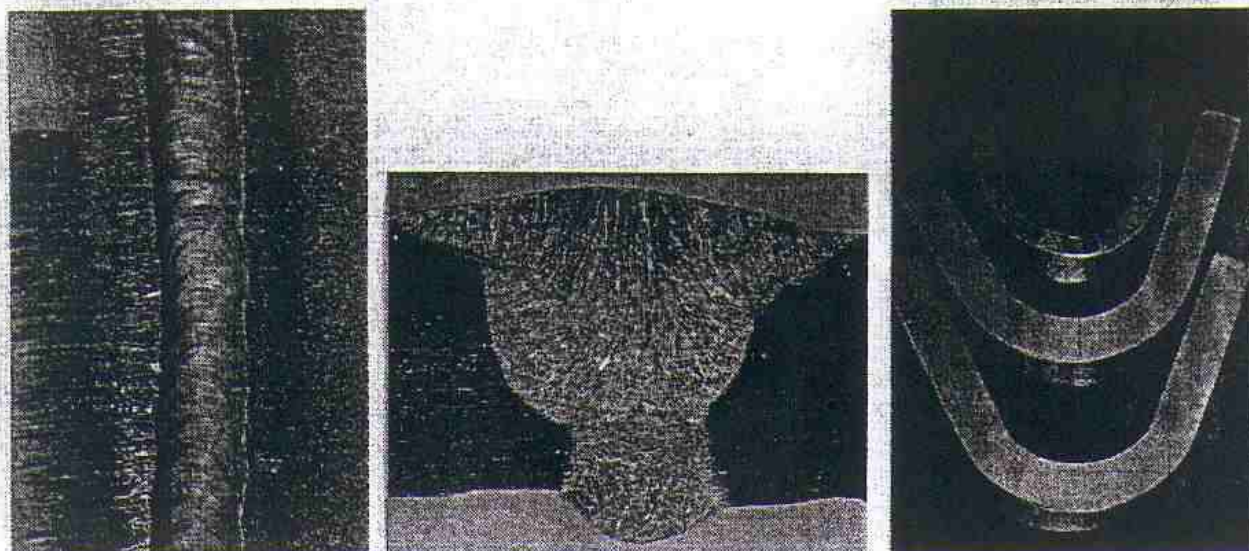


Figure 3. GMAW-STT root weld in X2 CrNiMo 22-5-3.

LINCOLN ELECTRIC Lincoln Smitweld		Welding Procedure Approval Record				WPAR Ar.145.01 Rev. No. 1 Ref. WPC: 95.049																																																																																																												
Procedure Specification				Test Results																																																																																																														
Base material Duplex SS Grade 1.4462 Welding processes A: GTAW (141) B: SMAW (111) Manual or machine Manual Welding position 3G up and 1G (PF / PA) Filler metal (trade) 1: LNT Zeron 100X 2: Arosta 4462-1462 Flux N.A. Filler metal classific. 1: EN 12072: W 25 9 4 N L 2: EN 1600: E 22 9 3 L N R 53 Shielding gas [l/min] Ar 99.99% Flow 12 Backing (gas) [l/min] Ar 99.99% (R + F) Flow 25 Gouge method N.A. Current / polarity GTAW = DC - and SMAW = DC + Preheat temp. [°C] min. 15 Interpass temp. [°C] Max. 130 Postheat treatment N.A. Welder's name				Radiographic, Penetrant Examination: Acceptable Reduced-section tension test Tensile strength [MPa] 25 x 11.5mm 753 Fracture location 25 x 11.6mm 766 Base material Microscopical investigation The microstructure shows a good ferrite/austenite distribution and no harmful precipitations. Bend tests Former diameter: 3 x t Root 3 x 180° Accepted Face 2 x 180° Accepted Impact tests ISO - V [Joule] Test temp. [°C]: see table Size of specimen: 10 x 10 x 55mm <table border="1"> <thead> <tr> <th></th> <th colspan="3">- 20°C</th> <th colspan="3">- 50°C</th> </tr> <tr> <th></th> <th>av.</th> <th></th> <th></th> <th>av.</th> <th></th> <th></th> </tr> </thead> <tbody> <tr> <td>CIw</td> <td>72</td> <td>83</td> <td>81</td> <td>79</td> <td>65</td> <td>64 66</td> </tr> <tr> <td>FI</td> <td>114</td> <td>114</td> <td>116</td> <td>115</td> <td>93</td> <td>109 101</td> </tr> <tr> <td>FI + 2</td> <td>162</td> <td>205</td> <td>204</td> <td>190</td> <td>133</td> <td>193 147</td> </tr> <tr> <td>FI + 5</td> <td>299</td> <td>266</td> <td>299</td> <td>288</td> <td>244</td> <td>299 233</td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td>259</td> <td>259</td> </tr> </tbody> </table>					- 20°C			- 50°C				av.			av.			CIw	72	83	81	79	65	64 66	FI	114	114	116	115	93	109 101	FI + 2	162	205	204	190	133	193 147	FI + 5	299	266	299	288	244	299 233						259	259																																																										
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Laboratory Test No. Remarks: Specification - Code: Stoomwezen T0210, NEN EN 288-3 ASME IX				Ferrite Content (FN) Magne Gage method <table border="1"> <thead> <tr> <th rowspan="2"></th> <th colspan="3">Specimen 6</th> <th colspan="3">Specimen 12</th> </tr> <tr> <th>BM</th> <th>HAZ</th> <th>WM</th> <th>BM</th> <th>HAZ</th> <th>WM</th> </tr> </thead> <tbody> <tr> <td>Face</td> <td>69.6</td> <td>68.6</td> <td>31.8</td> <td>67.9</td> <td>69.6</td> <td>33.8</td> </tr> <tr> <td>Centre</td> <td>66.6</td> <td>68.4</td> <td>34.6</td> <td>69.6</td> <td>67.4</td> <td>34.1</td> </tr> <tr> <td>Root</td> <td>65.9</td> <td>66.4</td> <td>49.1</td> <td>67.1</td> <td>67.6</td> <td>46.6</td> </tr> </tbody> </table>					Specimen 6			Specimen 12			BM	HAZ	WM	BM	HAZ	WM	Face	69.6	68.6	31.8	67.9	69.6	33.8	Centre	66.6	68.4	34.6	69.6	67.4	34.1	Root	65.9	66.4	49.1	67.1	67.6	46.6																																																																									
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Corrosion tests ASTM G48 method A 24 hours at 20 - 22.5 and 25°C No pitting was observed				We the undersigned, certify that the statements in this record are correct. Manufacturer or Contractor Maersk Oil, Harald West, Module A Authorized by Det Norske Veritas Issued by Fred Neessen Date 23 September 1995																																																																																																														

Figure 4. SMAW Welding Procedure Approval Record of a high recovery electrode for the downhand position.

fill of butt welds and fillets. The typical impact toughness of the weld, due to its oxygen level of 500–700ppm, is limited to CVN $-20^{\circ}\text{C} > 40$ J. For SDSS some consumable manufacturers have products still in the experimental stage. The incentive to make a SDSS tubular wire is high due to the difficult manufacturing conditions of bare welding wire.

The GMAW wires and GTAW rods for 22%Cr DSS have all a similar composition

with 23%Cr, 8.5%Ni, 3%Mo and 0.15%N. Trace elements, however, determine the welding characteristics. In particular the wetting action and weld bead appearance may therefore vary.

For smooth pulsed GMAW and GMAW-STT welding specific wire compositions have been selected.

The availability of filler materials for welding 25%Cr SDSS has shown a supply problem. Rolling and drawing of overalloyed SDSS

Process		SMAW-fill	SMAW-fill	SAW
Consumables classification	EN AWS	E 22 9 3 NL B32 E 2209-15 JUNGO 4462 GTAW-root 25 9 3 NL CuW: LNT Zeron 100X	E 22 9 3 LR 53 E 2209-16 AROSTA 4462-145 25 9 3NL CuW: LNT Zeron 100X	wire:S 2293NL/flux:BAB3 64 LNS 4462 / P 2000
type of weld / dimensions		girth weld U-prep. t = 15mm	girth weld U-prep. t = 12,7mm	plate butt weld 1/2V-prep.; t = 50 mm
chem.composition w%				
	C	0,022	0,015	0,025
	Cr	24,1	22,5	22,7
	Ni	8,6	8,4	7,9
	Mo	3,0	3,0	3,3
	N	0,15	0,12	0,11
	PRE _N)	36,4	34,3	35,5
ferrite	FN	40-50	55-65	% 36-38
mech.properties condition		as welded	as welded	as welded
Rp0.2	N/mm ²	686		626
Rm	N/mm ²	852	Transv. 753-766 base mat.	773
A5	%	24,7		26
CVN	J/	-46 °C 60 -60 °C 53	-20 °C 79 -50 °C 65	-40 °C 73-103
CTOD	mm/	-40 °C 0,28-0,37 -60 °C 0,21-0,31		n.d.
HV5/10	HV5	265-294	HV10 250-303 24-30,5	n.d.
HRc				
corrosion properties ASTM G48A				
CPT	°C	test ongoing	> 25	

Table 5. Weld metal properties; weldments in 22%Cr duplex stainless steel type; Typical values (ref. 15, 16, 17).

Process		SMAW	GTAW	SAW
Consumables classification	EN	E 25 9 4 CuW LB JUNGO ZERON 100X	W 25 9 4 CuW L LNM ZERON 100X	wire: S 25 9 4NL CuW/ flux: BAB LNS ZERON 100X/ P2000
type of weld / dimensions		plate butt weld V-prep.; t = 16 mm	plate butt weld V20-prep.; t = 20 mm	plate butt weld U-prep.; t = 35 mm
chem.composition w%				
	C	0,03	0,024	0,016
	Cr	25,1	24,8	25,4
	Ni	9,2	9,1	8,56
	Mo	3,7	3,65	3,70
	N	0,22	0,23	0,19
	PRE _N *)	40.8	40,5	40.65
ferrite	FN	35-45	35-40	67-73
mech.properties condition		as welded	as welded	as welded
Rp0.2	N/mm ²	629	691	713
Rm	N/mm ²	827	846	873
A5	%	26	23	18
CVN	J	-20 °C 60 -40 °C 44	-20 °C 57 -40 °C 48	-40 °C 58 -60 °C 46
CTOD	mm			-40 °C 0,32-0,42 -60 °C 0,34-0,56
Wide plate test; strain at fracture %		n.d.	n.d.	1,60
HV10		290-330	300-330	HV5 283-317
HRc		18-25	24-26	
corrosion properties ASTM G48A ¹⁾				
CPT	°C	> 40	> 40	> 40

Table 6. Weld metal properties; weldments in 25%Cr super-duplex stainless steel; Typical values (ref. 3, 16).

wire compositions require extra-ordinary skills.

The established material manufacturers are now confident with their production procedures so that these consumables became readily available.

The use of SDSS rods for GTAW of pipe root runs and the 'cold pass' welding technique (ref. 1), assuring increased pitting corrosion resistance, has become a common practice.

For submerged arc welding the welding wires have the same composition as the GMAW wires. The flux can be of the fused or the agglomerated type. Only basic fluxes are used. SAW welding procedures require precise voltage, current and travel speed control, this to avoid hot cracking due to the weld geometry.

4.3 Shielding and purging gases

The composition of shielding gases for GMAW have been further developed. The most commonly used shielding gas is lightly oxidising with 2–2,5% CO₂ added to the main component argon. Linde (ref. 9) claims that as low as 0,05% CO₂ is already sufficient to stabilise the arc. Addition of He from 20–50% increases the heat conductivity and heat transfer to the base material. This increases the wetting action of the weld pool and the welding speed.

Adding 2–2,5% N₂ to the shielding gas is applied for GTAW of root welds. In particular in welding SDSS the N-emission is compensated. More N₂ in the shielding gas and use for the filling and capping layers is not recommended. It may cause uncontrolled N pick-up and result in porosity.

Purging in pipe welding (GTAW, GMAW) is mostly done with pure argon or with an Ar/5%N₂ mixture. Industrial clean N₂ is applied as well but this gas may have a problem with its moisture content which can cause excessive oxidation. The gas is much cheaper and N-emission may be limited slightly. The use of H₂ containing purging gases is often wished for by the fabricator. Risks to mixing hydrogen with the shielding gas and consequently the risk of hydrogen induced cracking cannot be avoided and make the method unacceptable for most specifying companies.

The need to do the purging effectively remains a problem. The use of devices to localise the purging helps in decreasing the required purging time. Avoiding turbulence is recommended as well (ref. 10). A standard for the allowance of weld and HAZ oxi-

dation for DSS, supported by the NAM is published (ref. 11). The allowable discoloration can be obtained with maximum 500ppm O₂ in the pipe during root and subsequent second and third layer welding. In welding SDSS a higher O₂ level has been tolerated (ref. 12), with the objective to limit the N-emission.

Open joints have been recommended for manual GTAW, this to assure sufficient supply of filler material. In field welding open joints do cause problems, for instance when wind and traffic cause pressure waves.

4.4 Hydrogen

Following the discussion on the effects of hydrogen (ref. 13), a group sponsored project at The Welding Institute has been arranged and recently completed.

Consensus has been reached about the effect of hydrogen, entrapped in the specific DSS structure. Weld metal with a hydrogen content H_{DM} up to 25 ml/100g did not show H-induced cracking, provided that the ferrite content does not exceed FN=90. The determination methods are under dispute. TWI claims that only the vacuum hot extraction method determines the correct H-level. Welding consumables may show a hydrogen content of 5 to 20 ml/100g.

4.5 Welding dissimilar joints

Frequently DSS has to be welded to a ferritic mild or low alloyed steel. In chemical tankers the internal containers have to be connected to the hull sections, in process equipment only the critical area is sometimes made of DSS (or SDSS). Furthermore, related to preferences or restrictions in procurement, various grades of SDSS or DSS to SDSS have to be welded.

For butt welds between CMn-steel grades and DSS, the standard duplex welding consumables proved to be very suitable. The WRC 1992 Constitution Diagram provides the limits of dilution in various cases (figure 6). The resulting weld metal structure shall be a ferrite containing austenitic matrix which is resistant to hot cracking, providing that the weld geometry (height/width ratio < 1) is correct.

A welding procedure record for the qualification of dissimilar butt welds in pipe welding is shown as figure 7.

The butt weld between SDSS grades has been investigated and has not found to be detrimental to pitting resistance (ref. 14).

5 Properties of weldments

In particular the use of welded structures with wall thicknesses over 25mm and at low design temperatures required the availability of mechanical test data.

A sophisticated mechanical testing programme, in which The Genth University, fabricators and consumable manufacturers participated under supervision of the Belgium Institute of Welding, provided important information (ref. 15). The work is continuing. Other sources have been the work of Weir Materials for a ASME Code Case, a DSM project (ref. 16), authority approvals and various procedure qualifications.

Some recent typical test results in various thicknesses have been compiled in table 5 and 6.

6 Conclusions

The use of duplex stainless steel has grown to big volumes in the world. This applies in particular for the UNS 31803 base material and the associated welding consumables. Superduplex stainless steel welding consumables are in use for welding regular DSS and also 13% Cr soft martensitic steel for its strength properties.

New GMAW welding processes have been invented. GMAW-STT provides benefits in root pipe welding. Productivity (3–4 times faster) and pitting corrosion resistance, compared to GTAW, improved substantially. Mechanical properties have been determined in heavy wall pipe and plate material.

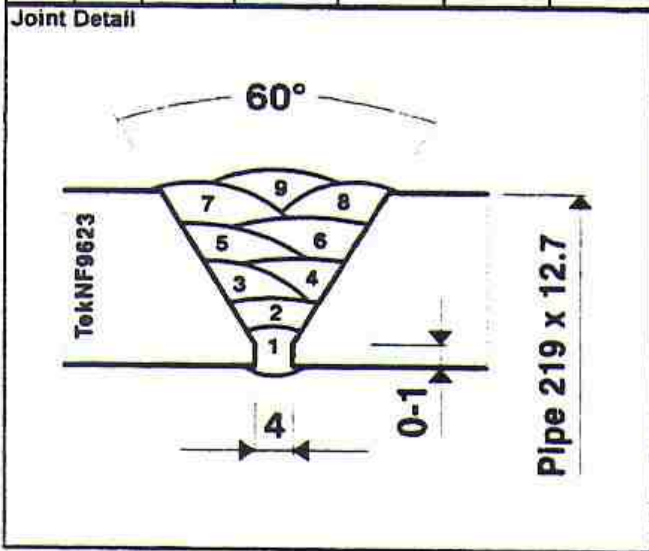
The CVN, CTOD and wide plate testing proved that DSS and SDSS weldments can be applied down to -40°C in most cases.

References

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- 3 J.J. Dufrane Fabrique de Fer, private communications.
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- 5 L. Karlson, Review on Intermetallic phase precipitation in duplex stainless steels and weld metals, IIW doc. IX-H-381/97.
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- 14 S-Å. Fager, L. Ödegård: Welding of superduplex stainless steel Sandvik SAF 2507™ (UNS 32750), *Stainless Steel Europe Dec.* pp 40-45 1993.
- 15 DSM project Investigations of weldments in 50mm DSS, proj.no. 511040001, 1996.
- 16 Lincoln Smitweld WPAR Z100X.01, Z100X.02.
- 17 BIL Research Project: Weldability, corrosion resistance and fracture behaviour of duplex and superduplex stainless steels, doc. ED 70090.W61, 1997.

Procedure Specification		Test Results	
Base material	Duplex SS Grade 1.4462	Visual and Radiographic Examination: Acceptable	
Welding processes	A: GTAW (141) B: SMAW (111)	Reduced-section tension test	
Manual or machine	Manual	Tensile strength [MPa]	Fracture location
Welding position	6G up (H-L045)	12,37 x 24,58 mm	830 base metal
Filler metal (trade)	1: LNT 4462 2: Jungo 4462	All-weld-metal tension test	
Flux	N.A.	Yield point [MPa]:	
Filler metal classific.	1: AWS A5.9: ER 2209 2: AWS A5.4: E 2209-15	Tensile strength [MPa]:	
Shielding gas [l/min]	Argon 99.998 Flow 10	Elongation, A5 [%]:	
Backing (gas) [l/min]	Argon 99.998 Flow 15 - 20	Reduction, Z [%]:	
Gouge method	N.A.	Bend tests	
Current / polarity	GTAW = DC - / SMAW = DC +	Root	3x 12,5 x 23 > 150° acceptable
Preheat temp. [°C]	RT	Face	1x 12,5 x 23 > 150° acceptable
Interpass temp. [°C]	max. 150	Impact tests : Charpy - V [Joule] Test temp. [°C]: - 40	
Postheat treatment	N.A.	Size of specimen: 10 x 10 x 55 mm	
Welder's name		av. av.	
Laboratory Test No.		Chw	86 75 85 82
Remarks :	Welding and testing in accordance with Stoomwezen T 0210		

Welding Procedure							CTOD testing				
Pass No.	Consumable index	Ø [mm]	Welding Current Ampere	Volts	Speed [mm/min]	H.I. [kJ/mm]	Notch location	Temp. [°C]	CTOD value [mm]	Fracture mode	
1	A1	2.4	95	14	61	1.3					
2	A1	2.4	115	15	65	1.6					
3	B2	3.2	90	24	118	1.1					
4 - 9	B2	3.2	90	25	169	0.8					
							Ferrite Content (%) see sketch by Magne Gage				
							BM	HAZ	WM	HAZ	BM
Face								41.1	34.4	48.1	
Mid							40.5		28		41
Root								49.1	40	52.1	



Hardness

Test type : Vickers Load : 10 kg

Weld metal 258 - 254 - 276
Heat Affected Zone 274 - 274 - 285 - 270 - 264 - 285
Base metal 251 - 251 - 251 - 253 - 236 - 253

Sketch

We the undersigned, certify that the statements in this record are correct.

Manufacturer or Contractor Occidental (Placid)
Authorized by Stoomwezen
Issued by Fred Neessen
Date 7 July 1996

Figure 5. SMAW Welding Procedure Approval Record of basic covered electrode.

