Theory and practice of welding duplex and superduplex stainless steel

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Abstract
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 Joule 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.

Keywords
duplex_stainless_steel, superduplex_stainless_steel, welding, properties, applications

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 standardized 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% Cr DSS with its PRE_N 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 25 mm. 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 and
PRE_W = %Cr +3,3x (%Mo+0,5x %W) +16x %N (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 stabilization 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 desulphurization 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 45Joule, depending on the operator, and a proof strength Rp0,2 min. 500 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% 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).

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

Manufacturer	Grade	Cr	Ni	Mo	N	Cu	other	PRE_N	PRE_W	product forms
22%Cr Duplex Stainless Steel										
UNS S31803 EN X2 CrNiMoN 22-5-3										
Avesta	2205									
Creusot Loire Ind.	UR 45N & 45N+				|					
	PRE_N>32/34			|						
Fabr. de Fer.	Fafer 4462			|						
	PRE_N >33/35									
Thyssen Krupp Nirosta	Falc 223	22,0-	5,5	2,8-	0,15-	-		32-37		all product
forms,										
Sandvik	SAF 2205	22,8		3,4	0,18					dep. on
ma-										
Nippon Kokan	NKCr22			|						nufacturer
Sumitomo	SM22Cr			|						
25%Cr Super-Duplex Stainless Steel										
UNS J										
Pleissner	9.4462 S	26	7	3,5	0,25	0.6		42		castings
UNS S32550 EN X2 CrNiMoCuN 25-6-3										
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
UNS S32750 EN X2 CrNiMoN 25-7-4										
Avesta / Sandvik	SAF 2507	25	7	4,0	0,27	-		42.5		{ plate, { forgings, { tubes,
Creusot Loire Industrie	UR 47N+	25	7	3,8	0,28	-				{ fittings, { castings
UNS S32760 EN X2 CrNiMoCuWN 25-7-4 (wrought)										
J93380 (cast)										
Weir Materials	Zeron 100									{ plate, { forgings,
		25	7-8	3,6	0,22	0,7	W: 0,7	>40	41,5	{ fittings, { castings
Fabr. de Fer plate	UNS 32760									
class.?										
Sumitomo	DP3W	25	7	3,0	0,27	-	W=2	39	42,5	pipes

C max 0.03 or 0.04%

2.2 Surface condition

The surface condition of the plates and pipes have been improved. For 22% Cr duplex stainless steel is standardized 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 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 accomodate 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 oxidizing 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 χ (Mo rich Fe-Cr-Mo) and σ (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 draft ISO 8249;1997 or AWS A 4.2- 92).
The international standardization for the determination of ferrite has made progress. The ISO and AWS standard incorporated the need to cover the high ferrite contents occuring 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. 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 catagory 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).

Table 2 Critical Pitting Corrosion Temperature for root welds; GMAW-STT versus GTAW

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

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 consumables 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

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

Process/Standard		Chemical composition w%									Mech. 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 Cu N L	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 3 Cu N L	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 4 Cu N L	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			

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 fill of butt welds and fillets. The typical impact toughness of the weld, due to its oxygen level of 500-700 ppm, is limited to CVN -20°C > 40 Joule. 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 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.

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

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

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% CO_2 added to the main component argon. Linde (ref. 9) claims that as low as 0,05% CO_2 is aleady sufficient to stabilize 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% N_2 to the shielding gas is applied for GTAW of root welds. In particular in welding SDSS the N-emission is compensated. More N_2 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% N_2 mixture. Industrial clean N_2 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 H_2 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 turbulance is recommended as well (ref. 10). A standard for the allowance of weld and HAZ oxidation for DSS, supported by the NAM is published (ref. 11). The allowable discolorisation can be obtained with maximum 500 ppm O_2 in the pipe during root and subsequent second and third layer welding. In welding SDSS a higher O_2 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. Only at very high ferrite contents of FN = 100 and a hydrogen level of 5 ml/100g hydrogen-induced delayed cold cracking may occur after plastic deformation. The determination methods are under dispute. TWI claims that only the vacuum hot extraction method determines the correct hydrogen 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 disimilar 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 25 mm 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.

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

Process			SMAW-fill		SMAW-fill		SAW
Consumables classification		EN	E 22 9 3 NL B32		E 22 9 3 LR 53		wire:S 2293NL/flux:BAB3 64
		AWS	E 2209-15		E 2209-16		
			JUNGO 4462		**AROSTA 4462-145**		**LNS 4462 / P 2000**
			25 9 3 NL CuW:		25 9 3NL CuW:		
			LNT Zeron 100X		LNT Zeron 100X		
type of weld / dimensions			girth weld U-prep.		girth weld U-prep.		plate butt weld
			t =15mm		t = 12,7mm		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	-20 °C	79	-40 °C	73-103
		-60 °C	53	-50 °C	65		
CTOD	mm/	-40 °C	0,28-0.37				n.d.
		-60 °C	0,21-0,31				
HV5/10		HV5	265-294	HV10	250-303		n.d.
HRc					24-30,5		
corrosion properties ASTM G48A							
CPT	°C		test ongoing		>25		

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

Process			SMAW		GTAW		SAW
Consumables classification			EN E 25 9 4 CuW LB		W 25 9 4 CuW L		wire: S2594NLCuW/fl BAB
			JUNGO ZERON 100X		**LNM ZERON 100X**		**LNS ZERON 100X/ P2000**
type of weld / dimensions			plate butt weld		plate butt weld		plate butt weld
			V-prep.;t = 16 mm		V20-prep.;t = 20 mm		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	-20 °C	57	-40 °C	58
		-40 °C	44	-40 °C	48	-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

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.

7. References

1. L. van Nassau e.a. Welding duplex and superduplex stainless steel, Weld. In the World, Vol.31, pp 323-343, 1993
2. H. Okamoto, Proc. of Stainless’92, Stockholm 1992, pp360-369
3. J.J. Dufrane Fabrique de Fer, private communications
4. BIL Research Project: Weldability, corrosion resistance and fracture behaviour of duplex and superduplex stainless steels, doc. ED 60003.W61, 1996
5. L. Karlson, Review on Intermetallic phase precipitation in duplex stainless steels and weld metals, IIW doc. IX-H-381/97
6. E. Stava, Welding Jnl , pp , 1993
7. L. van Nassau e.a., Paper at 1st Italian Welding Symposium, Genova 1996
8. TWI Group Sponsored Project
9. Linde brochure 8938/9, 1994
10. H.Geipl, Applications technology in the limelight, Linde publication no.7, 1994
11. L. Smith, M. Klein: Acceptance criteria for oxidation of stainless steel weldments, Stainless Steel World, p.44,45 1996
12. Weir Materials Ltd.: Guidelines for welding Zeron 100 super duplex stainless steel (1966).
13. TWI Group Sponsiored Project, Hydrogen cracking of duplex stainless multipass weldments, doc. 5669/7a/97
14. S-Å. Fager, L. Ödegård: Welding of superdupplex stainless steel Sandvik SAF 2507 (UNS 32750), Stainless Steel Europe Dec. pp 40-45 1993.
15. DSM project Investigations of weldments in 50 mm 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