HIGH PRODUCTIVITY WELDING METHODS FOR AVESTAPOLARIT 2205 DUPLEX STAINLESS STEEL (EN 1.4462, UNS S31803 AND S32205)

B Holmberg and M Larén, AvestaPolarit Welding,

Introduction

The introduction of modern duplex stainless steel, mainly of type AvestaPolarit 2205, has been a success within a number of industries and applications. The high corrosion resistance has made it possible to replace not only common standardised grades such as AISI 304 and 316, but also more highly alloyed grades such as 904L. The high strength has permitted reduced gauges not only for pressure vessels, but also for storage tanks, which are so high that wall thickness calculations of the lower sections are based on the proof strength of the material. The consequences of reduced gauges are obvious, including lower weight, easier workshop handling, less bevelling prior to welding, less welding, and at the end of the day, reduced cost for the finished fabricated item. The cost reduction is so significant that pressure vessels made of 2205 can be less costly than if made of 316L, a very common alternative.

However, one concern still expressed is welding. The most common method is fusion welding but not everyone has realised that welding of duplex stainless steel is not so different from the welding of standard austenitic grades, in terms of methods and in terms of productivity.

This paper will demonstrate the advantage of using high productivity welding methods such as SAW, FCAW and GMAW for 2205. The corrosion resistance properties of the weld will be at least on a par with those of 316L and 317L welds and sometimes even as good as the more highly alloyed 904L.

General welding characteristics of AvestaPolarit 2205

During the introduction of the steel 2205 many questions regarding welding were highlighted. The reasons for these questions had a historical background. The first generation duplex stainless steels (those without an intentional nitrogen addition) had a limited weldability (1). Due to sensitivity in grain growth in the HAZ and poor austenite reformation, those steels showed a strong reduction in ductility and corrosion resistance.

The second-generation duplex steels, notably 2205 (first as UNS S 31803) and then as S32205) have a much better weldability due to a better balance in alloying elements. The most important element to improve the weldability in duplex steels is nitrogen (N). By using about 0,17% N in the steel AvestaPolarit 2205, reformation of austenite during welding is satisfactory in almost every situation. (resistance welds and tube/tubesheet welds still need so special precautions)

When welding duplex steels, it is necessary to use filler material unless the weld is to be fully annealed after welding. When using the type AvestaPolarit Welding 2205 filler with about 9% nickel (Ni) and high N, a balanced microstructure will be obtained even with a rather wide welding parameter window. Experience has shown that weldments with a ferrite level between 25-75% will give sufficient corrosion and mechanical properties. Situations when it is easy to exceed 75% ferrite are resistance spot welding and GTA-dressing without filler. Situations when lower ferrite values than 25% might be measured, could be after Post Weld Heat Treatment (PWHT) of welds having higher nickel content, originally designed to be used in as-welded condition.

Some times the high level of N might cause a porosity problem. But by using the right welding parameters and a correct joint geometry this risk can be overcome.

Secondary phases (sigma, nitrides) sometimes occur in the weld metal but they very seldom play any significant role. If the heat input during arc welding, dependent also of the material thickness, is in between the area 0.5-4 kJ/mm, the weldments will not have a detrimental amount of secondary phases. A micrograph showing the austenite/ferrite balance in the HAZ including traces of nitrides is shown in Enc 2.

The most common defect type in welding of austenitic stainless steels, hot cracking is a rare phenomenon in 2205. The reason is the high ferrite content in the welds. This situation increases the possibility to use high productive welding procedures. Fabrication of austenitic stainless steels with fusion welding methods using very high heatinput is, for example in EN 1.4539 (904L), not always possible.

AvestaPolarit 2205 can be welded to the most common austenitic stainless steels as well as to mild steels.

Welding Consumables

Today welding consumables for welding duplex stainless steels are standardized by for example ISO, AWS and EN. The greatest product variety exists for covered electrodes. The most common type is the rutile/acid type, in AvestaPolarit called the AC/DC-types. If higher ductility and better low temperature impact values are required, basic covered electrodes are also available.

Other product forms include solid- and flux-cored wires and are used for GTAW, GMAW, SAW and FCAW.

Some of AvestaPolarit Welding fillers used for welding the grade AvestaPolarit 2205 are given in table 1. Observe the over alloying with Ni. By this over alloying the correctly balanced microstructure can be obtained. Welding without filler might affect weldment properties negatively.
The last filler in the table is a super duplex wire sometimes used when the recommended shielding/ purging gases not are available for GTAW. By using this filler and pure Ar as shielding gas, adequate pitting resistance results can be obtained.

Table 1. Filler material composition and mechanical properties (Typical)

Name	ISO	Product form	C	Cr	Ni	Mo	N	Rp02 (MPa)	Rm (MPa)	ISO-V RT (J)	ISO-V -40°C (J)
2205-PW AC/DC	22 9 3 N L	Electrodes	0.02	22.5	9.5	3.1	0.14	635	830	50	40
2205 Bas	”	“	0.03	23.0	9.5	3.1	0.14	635	820	100	70
2205	“	Wire	0.02	22.5	8.0	3.0	0.14	550	770	150	110
2205-H	“	FCAW	0.03	23.5	9.5	3.4	0.14	610	820	55	40
2205-PW	“	“	0.03	23.0	9.5	3.5	0.16	610	840	60	45
2507/P100	25 9 4 N L	Wire	0.02	25.0	9.5	4.0	0.25	570	830	140	-

Welding with processes where no fillers are used (autogenously welding), will in many cases give some reduction of corrosion resistance and weldments ductility.Qualified Welding Procedure Specifications (WPS) using filler materials designed to weld AvestaPolarit 2205, are therefore in many cases very important for achieving the stipulated weldments properties.

Welding methods giving high productivity

SAW (Submerged Arc Welding)

When it comes to high productivity welding methods, SAW is in practice the most common one. For standard austenitic steels, such a high productivity method might cause hot cracking/microfissures in the welds. For this reason SAW in stainless steels is mostly carried out with some limitations in heat-input. When it comes to the duplex steel AvestaPolarit 2205, this restriction in heat input to avoid hot cracking is today seldom a critical issue. Use of SMAW has strongly improved productivity. The deposition rate for SAW of 2205 with single wire technique can be as high as 8 kg/h. By selecting the right joint type for the application, fewer beads are necessary. As one example, by choosing a X-joint preparation in a butt weld of 16-17 mm thick plates, with a root face of up to 8 mm (the root face is normally 3-5 mm), the weld can be completed with only two passes. The welding current can be relatively high giving a heat input even above 3.0 kJ/mm. No grinding of the backside is necessary. This procedure can be used for a plate thickness of up to about 20 mm, but above that thickness a multi-layer welding will be necessary.
If the plates are thin, V-joints are mostly used. For example, 10-12 mm thick plates prepared, with a V-joint, will give good weld geometry. For somewhat thicker plates, a symmetrical X-joint is preferable.
When subarc-welding AvestaPolarit 2205, Flux 805 with high bacisity is recommended. In the Enclosure 1, a WPS for 16.5 mm plates with a X-joint preparation is shown. (SAW-1).

GMAW (Gas Metal Arc Welding)

GMAW of 2205 has been considered as difficult due to low weldability (spatter, incomplete fusion and lack of penetration). A new generation of welding machines (having synergic pulsed arc) has made 2205 as weldable as when using standard austenitic filler type ER316L-Si. The development of new shielding gases is also a contributing factor. 2205 is often welded using a three component shielding gas such as; Ar + 30%He + 2-3%CO_2. The addition of helium will increase the energy in the arc and will improve penetration into base material. The higher energy also makes it possible to increase travel speed and thereby also the productivity. For GMAW it can be possible with single wire technique and spray arc to reach as high productivity as 6 kg/hour. The high productivity is mostly used in horizontal position. If full automatic high speed welding (m/h) shall be performed, Twin- or Tandem arc welding can be an alternative. Another alternative is Rapid Melt. When this rotating arc mode is possible to use, productivity can be as high as 10kg/h.
A typical high speed welding WPS in 3mm thick plates welded with spray arc and using three components mixed gas is shown in Enclosure 2 (GMAW-2).

FCAW (Flux Cored Arc Welding)

The weldability as well as the productivity for FCAW 2205 are generally better than for GMAW. The deposition rate is typically 4-7 kg/hour. The high productivity and great versatility makes FCAW well suitable for position welding of thick walled material (t>5 mm). This is often done as single-side welding against ceramic backing. A situation when welding against ceramic backing with FCAW has proven to increase productivity strongly, is when gap tolerances are wide and irregular. Then the “over-bridging” possibility with FCAW gives a great advantage compared SAW and GMAW. Three types of AvestaPolarit Welding FCW are available. When welding against backing the FCW *2205-H* gives the nicest rot appearance. FCW *2205-PW* is mostly used for capping or in for example fillet welds. In vertical position, the possibility to use higher welding currents when using the PW type with easier slag control is an option. The standard FCW *2205* type is used as an all-around product. In Enclosure 2, a WPS for vertical position is given (FCAW-1).

Table2. Typical welding parameters in horizontal position

Method	Plate Thickness	Joint	Current, I	Heat Input (kJ/mm)
SAW	10-20 mm	X-joint	550-650	2.5-3.0
GMAW	2-4 mm	I-joint	160-180	1.0-1.5
GMAW	3-6 mm	Fillet weld	170-220	1.0-2.0
FCAW	10-20 mm	V-joint	200-220	1.5-2.0

SMAW (Shielded Metal Arc Welding)

When it comes to the question of high productivity welding with SMAW, covered electrodes have their limitations. Tacking with electrodes is still a quite common technique due to its flexibility. Another application for electrodes is to use high yield electrodes (HX) when gas shielding methods or SAW are not practical. Examples include when strong winds cannot be avoided or the plate thickness is too small.

Vertical down electrodes (VDX) can sometimes be a very highly productive technique when wallpapering/lining in thin-walled 2205 sheets. This process can be much faster than the conventional GTAW process.

Maybe the strongest argument to use covered electrodes is in pipe welding, when there is access only from one side and the backside is the exposed area. A typical WPS in such case is to use GTAW. If standard filler is to be used and nitrogen-containing shielding/purging gases are not available/applicable, there is a risk for strongly reduced pitting corrosion resistance (2). For such cases SMAW offers a very good option. The reason is that the slag covers both sides of the weld metal and by this protection, the loss of nitrogen can be minimised to provide unaffected corrosion resistance. The most preferred electrode for pipe welding is the PW type.

Other high productive processes

When it comes to high speed welding, Laser is the most well known process. Today some experience exists, but the limited possibility of adding filler will give some reduction in weldment properties. If however the weld can be subsequently PWHT, very good results have been achieved. Other high productivity processes are PAW and spot/seam welding. These methods create problems for using fillers.

Hybrid welding with Laser/GMAW can be a very interesting future high productivity process because filler is used. GTAW, or in EU still mostly called TIG, can be a rapid process for thin gauge materials. In our pipe mills the process is used often with 3 tandem torches to make it possible to weld the longitudinal seam at a speed up to about 4 m/min.

Fabrication Costs /Weld metal properties

The use of AvestaPolarit 2205 can be an interesting material alternative to AISI 316L. The main reason is the big difference in strength. The minimum yield strength for cold rolled 316L is 240 MPa and for 2205 it is 480 MPa. This makes it sometimes possible to reduce material thickness up to 50%, depending on the shape of the device. Even if 2205 is somewhat more expensive compared to 316L, a material cost reduction up to 40% could be achievable. On top of that the costs for fabrication (bevelling and welding) might decrease. The plant owner will as a bonus also have a construction with better corrosion resistance than 316L for most applications. If good corrosion properties are required and for example 904L today is used, the choice of 2205 can sometimes even here offer a cheaper construction. Examples of such an application are in handling of diluted acids containing chlorides. One such practical example was a customer storing diluted phosphoric acid in big 904L tanks. By instead using 2205 great savings in material costs were possible. Examples of weldment properties from different types of welds are given in table 3.

Table 3.Weld metal properties

Method	Thickness (mm)	Yield (N/mm^2)	Tensile (N/mm^2)	Impact (J, RT)	Impact (J, -40°C)	Ferrite (%)	CPT** (°C)	Position
SAW	16	501	705	180	60	55/54*	>25	PA
SAW	13	556	748	192	49	50/60*	27.5	PA
GMAW	4	606	798	-	-	43/44*	>25	PA
GMAW	12	558	773	142	70	37/40	-	PA
FCAW	14	542	786	53	43	44/36*	>25	PF
FCAW	20	578	774	80	-	-	>25	PA

*Ferrite content according. to ASTM E562 (root/face). **Critical Pitting Temperature ASTM G 48-Method A

Applications

Some examples where high productivity welding procedures in thick-walled constructions have been used are given below.
The biggest single use of the duplex steel 2205 has been for cargo tanks and pipe systems in chemical tankers. By using a high strength steel, and thereby reducing the thickness of the tank partitions, the effective load capacity of the ships can strongly increase. In fig 2 one example of a chemical tanker is shown.
One of the first big areas for duplex steels (pipes) was for processing and distribution of high-pressure oil and gas.
Another big area where 2205 is used is equipment for production of pulp and paper. Many digesters are today built in this new material. In the pulp bleach plants, use of 2205 in oxygen delignification and in extraction stages is highly cost efficient. Today it is becoming more common to use 2205 in the chemical recovery circuts of the pulp mill, often replacing carbon steel constructions.. In Enclosure 2, a picture of a digester in 2205 under production is shown.

The limiting factor can sometimes be very low and very high temperatures applications. The duplex material have namely a transition impact curve comparable with mild steels, which can be critical at temperatures below -70°C.
At the high temperature side, the maximum long time exposure temperature shall be +250°C due to alpha prime embittlement of the material.

Summary

- The modern duplex steel 2205 can be a cost effective solution compared to standard austenitic stainless steels.
- 2205 offers a welded construction with very high corrosion resistance as well as high strength
- The steel can be welded with high productivity welding procedures.
- Due to the possibility of reduced weld preparation and welding associated with reduced wall thickness, the total welding costs can be decreased further.

References

1. M. Liljas. The welding metallurgy of duplex stainless steels. Duplex Conf. Glasgow-94.
2. B Holmberg. Filler material selection for optimum duplex weldments properties in steel UNS 31803. Duplex Conf Glasgow-94

AvestaPolarit STAINLESS

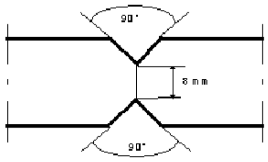
WPAR	WPAR No SAW-1
Welded acc. to pWPS: 1	Side:
Issued by: M. Larén	Date: 98-07-30

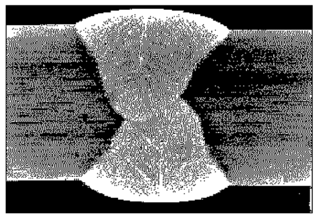
		Charge:	Thickness:	Group:	Pipe Ø:
Base-material:	A: 2205		16,5 mm		
	B: 2205		16,5 mm		

Preheat: °C
Interpass temp.: <150°C
PWHT: °C h

Backing:
No grinding of backside.

Welding position: 1G (PA)





Thickness: 16.5 mm Root face: 8 mm
Joint angel: 80°

Notes:
Drag angle 15° towards travel direction (backhand).

Run	Process	Filler material	Dia.	Batch No	Gas/Flux
1-2	SAW	2205	3.20 mm	0322	AVESTA 805
					Lot 2779

Run	Polarity	Current Ampère	Voltage Volt	Speed cm/min	Energy kJ/mm	Stick out	Wire feed m/min	Note:
1	DC+	635	32,5	50	2,48	20 mm		
2	DC+	635	32,5	50	2,48	20 mm		

Chemical analysis (Pure weld metal)

C	Si	Mn	P	S	Cr	Ni	Mo	N and Cu
0,016	0,51	1,44	0,016	0,001	22,7	8,65	3,05	0,17/0,10

Tensile test Rp0.2	Rm	As (%)	Impact test Notch	Temp	Joule	Average	Bend test Mandrell dia. 3xT
507 Mpa	716 Mpa	29	KV	+20 °C	198,184,173	185	Root, Cap, Side: OK
495 Mpa	694 Mpa	30	KV	-40 °C	63, 58, 68	63	

Corrosion test Type:	Temp	Result Weight loss	Preparation (Pickling, brusching, As welded)
ASTM G48-A	27.5°C	No attacks.	Pickling+brushing
	30°C	Attack in weld: 0.0012 g.	

X-ray: Grade 5 Aa Note: Some small porosity

Liquid penetrant: None Note:

Micrographic examination:

		ASTM E562	Ferite scope MP-3
Ferrite content: (weld metal)	1.	54.7%	51.4%
	2.	54.0%	50.6%

Note: See report No.: LR 222/98

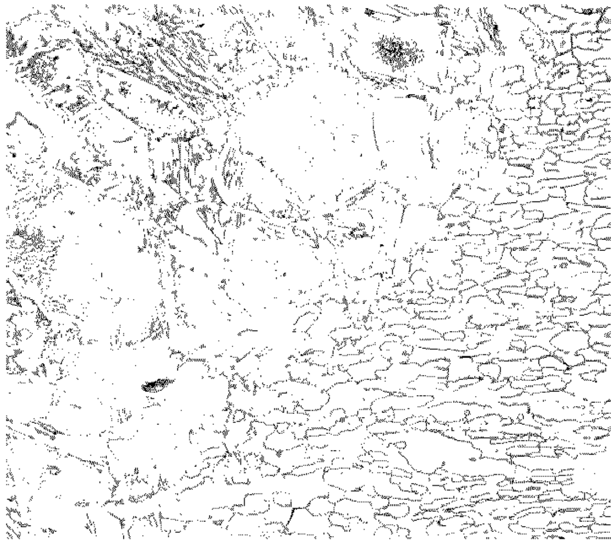


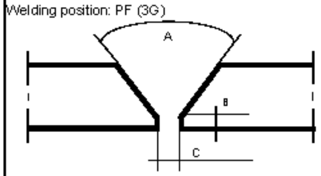
Figure 1. HAZ 2205 SAW. Traces of nitrides can be observed in the top of the picture.

AvestaPolarit STAINLESS

WPAR		WPAR No: FCW-1
Welded acc. to pWPS	1	Side: 1
Issued by:	M. Lar?	Date: 2002-05-0

Base-material:		Charge:	Thickness:	Group:	Pipe ?:
A:	2205 (UNS 31803)	811788	14 mm	10	
B:	2205 (UNS 31803)	811788	14 mm	10	

Welding position: PF (3G)



A 60 B Land 1,5 mm
C Root gap 4 mm

Preheat: None
Interpass temp. <150
PWHT 없
Backing: Ceramic backing
Joint prep.
Notes:
Welding against ceramic backing.
Stick out: 15-25 mm

Run	Process	Filler material	Dia.	Batch No.	Gas
1-2	FCW	2205-PW	1,20 mm	13414	Ar+25%CO2
					20 l/min

Run	Polarity	Current Ampere	Voltage Volt	Speed cm/min	Energy kJ/mm	Ipeak (A)	Ibkg (A)	Frequency (Hz)
1	DC+	137	24,6	9,3	2,17			
2	DC+	116	23,8	6,4	2,59			

C	Si	Mn	P	S	Cr	Ni	Mo	N
0,025	0,60	0,85	0,020	0,007	23,2	9,4	3,6	0,16

Tensile test Rp0.2	Rm	A5 (%)	Impact test Notch	Temp.	Joule	Average	Bend test Mandrell dia 2xT
530	782	31	Weld	RT		53	Face 2 st 180? OK
555	790	30	Weld	-40없		43	Root 2 st 180? OK

Corrosion test Type	Temp.	Temp	Result Weight loss	Preparation (Pickling, brusching, As welded)
ASTM G48-A		+20	0,000 mg OK	Brushed and pickled
		+20	0,000 mg OK	Brushed and pickled

X-ray: Note:
Liquid penetrant: Note:

Micrographic examination. (point counting)
Ferrite content: Root=44% Face=36%

Hardness Root (HV10): Base metal: 240; Weld metal: 270
Hardness Face (HV10): Base metal: 240; Weld metal: 255

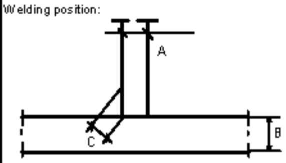
Note: See report No.:

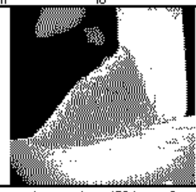
AvestaPolarit STAINLESS

WPAR		WPAR No: GMAW-2
Welded acc. to pWPS:	1	Side:
Issued by:	Martin Larén	Date: 2002-06-11

Base-material:		Charge:	Thickness:	Group:	Pipe Ø:
A:	2205 (UNS 31803)		3 mm	10	
B:	2205 (UNS 31803)		3mm	10	

Welding position:





A 3 mm B 3 mm
C 3 mm

Interpass temperature: 150degreeC

Run	Process	Filler material	Dia.	Batch No.	Gas
1	GMAW	AVESTA 2205	1.20 mm	12011	MISON 2 He (15 l/min)

Run	Polarity	Current Ampere	Voltage Volt	Speed cm/min	Energy kJ/mm	Pulsed arc	Wire feed m/min	Note:
1	DC+	212	22.6	72	0.40		7.7	Pulsed

Chemical analysis (Pure weld metal)

C	Si	Mn	P	S	Cr	Ni	Mo	N

Tensile test Rp0.2	Rm	A5 (%)	Impact test Notch	Temp.	Joule	Average	Bend test Mandrell dia

Corrosion test Type	Temp.	Result Weight loss	Preparation (Pickling, brusching, As welded)

X-ray: Note:
Liquid penetrant: Note:

Micrographic examination.

Ferritescope (MP-3) = 43FN

Note: See report No.:

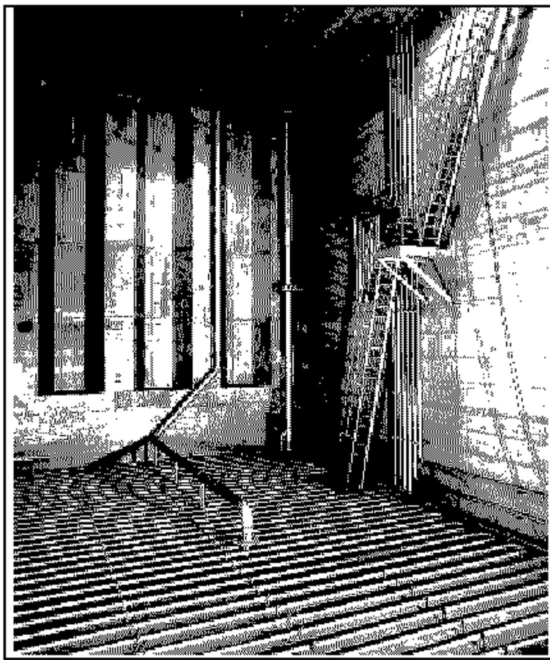


Fig 2a. Chemical tanker in 2205.

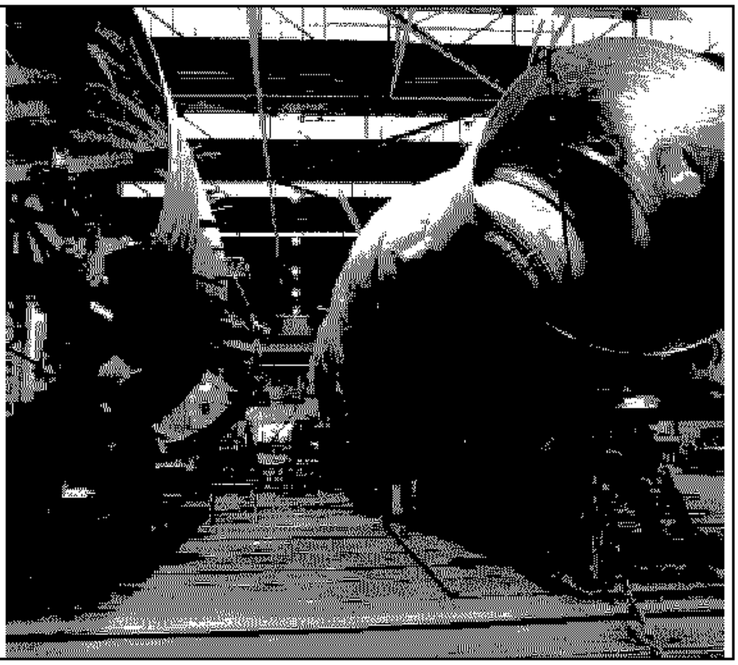


Fig 2b. Continuous kraft pulp digester in 2205.