

WELD PROPERTIES OF SANDVIK SAF 2707 HD®

P. Stenvall, M. Holmquist

Super duplex stainless steels have found extensive use in the oil & gas industry and in other areas in the (petro-) chemical processing industry. The recently developed hyper duplex grade Sandvik SAF 2707HD® allows extension of the application range of austenitic-ferritic alloys into even more aggressive conditions. In most applications for Sandvik SAF 2707 HD the equipment needs to be welded. Hence, weldability is of utmost importance for a stainless steel grade of this kind. Weld documentation was made for a number of joints to simulate various tube- and pipe applications. The welding method used was gas tungsten arc welding.

The joints were tested regarding mechanical properties, microstructure, pitting resistance and in some cases chloride stress corrosion resistance. The filler wire used, designated Sandvik 27.9.5.L, was developed specifically for Sandvik SAF 2707 HD.

Overlay welds were produced using submerged-arc welding and gas tungsten arc welding. The welds were documented regarding ductility, microstructure and pitting resistance. Tube-to-tube sheet welds were also produced to document the weld behaviour and pitting resistance.

Keywords: duplex stainless steels, gas tungsten arc welding, submerged-arc welding, pitting corrosion, stress corrosion cracking, tensile properties, impact toughness

INTRODUCTION

Super duplex stainless steels, such as UNS S32750, have been used for more than 15 years in various industrial segments with great success, e.g. offshore industry, oil refineries, chemical and petrochemical industry, and pulp and paper production [1, 2, 3, 4]. However, environmental requirements and raised productivity demands have, in many areas, forced the end-users into recirculation of process streams, with increased temperatures and increased pressures leading to more aggressive process environments. In some cases the process environment has become too aggressive for the super duplex grades. Therefore, a new hyper duplex stainless steel has been developed for these aggressive conditions – Sandvik SAF 2707 HD (UNS S32707) [5, 6]. The typical chemical composition is shown in Tab. 1. Parallel to the development of this grade a new welding consumable has been developed, Sandvik 27.9.5.L [7]. Typical chemical composition is shown in Tab. 1. The composition of the filler wire is similar to

that of the base material. However, the nickel content is higher and the molybdenum and nitrogen contents are somewhat lower in the wire in order to optimize the weld metal properties.

Weldability is an important feature for a duplex stainless steel intended for tubular and flat products since welding is the most common technique – and many times the only technique – for joining. Therefore, welding and weldability of SAF 2707 HD has been a vital part of the development work. So far two welding processes have been documented – TIG (GTAW) and submerged-arc welding (SAW). Some of the results are presented in this paper.

EXPERIMENTAL

All-weld-metal

All-weld-metals were produced with both TIG and SAW. For mechanical testing the weld metals were produced in grooves according to AWS A5.9 and for the corrosion testing the weld

Product	Designation	C (%)	Mn (%)	Cr (%)	Ni (%)	Mo (%)	N (%)	Others (%)
Tube/pipe	SAF 2707 HD	0.01	1	27	6.5	4.8	0.4	Co: 1
Filler	27.9.5.L	0.01	0.8	27	9	4.6	0.3	Co: 1
Plate*	S355N	0.15	1.5	-	-	-	-	-

*) Low alloy steel plate used as base for overlay welding.

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▲
Tab. 1

Nominal chemical composition of SAF 2707 HD, filler 27.9.5.L and other material included in the investigations.
Composizione chimica nominale dell'acciaio SAF 2707 HD, del filo d'apporto 27.9.5.L e dell'altro materiale impiegato.

metals were produced as overlay welds in 6-8 layers.

The TIG welds were produced with Ar + 2%N₂ as shielding gas. Wire diameter was 1.6mm. Mechanized TIG was used. The submerged-arc welds were produced with Sandvik flux 15W, a basic flux intended for duplex grades and austenitic high alloyed grades. Wire diameter was 2.4mm. In both cases the heat input was kept below 1.5kJ/mm and the interpass temperature was kept below 100°C.

The all-weld-metals were tested in the following way:

1. Documentation of microstructures including measurement of ferrite contents using linear analysis.
2. Evaluation of alloying vectors for the submerged-arc weld.
3. Tensile testing at RT according to EN 10002-1 using turned specimens.
4. Charpy-V impact toughness testing according to EN 10045-1. Testing was made at RT, -20°C, -40°C and -60°C. Three specimens were tested at each temperature.
5. Determination of critical pitting temperature (CPT) was made according to ASTM G48-03 Method E modified by Sandvik. (The same double specimens were used through out the CPT determination instead of new specimens at each temperature as stated in ASTM G48-03 Method E.) The surfaces of the specimens were ground using 120-grit abrasive paper.
6. Evaluation of resistance to chloride stress corrosion cracking was made in NaCl solution according to ASTM G123 using U-bend specimens according to ASTM G30. Four specimens per weld were tested. Total time for exposure was 1008h. The specimens were taken out of the solution for intermediate inspection five times.

Tube welds

Girth welds were produced in tubes with dim. 25.4 x 1,65mm. Square butt joint was used as joint preparation. Welding was performed with manual TIG using Ar + 2%N₂ as shielding gas and pure N₂ as root gas. Filler wire 1.6mm in diameter was used. The weld was made in one run and the top side was brushed subsequent to welding. The weld was not pickled after welding. The tube welds were tested in the following way:

1. Tensile testing transverse the weld at RT according to EN 10002-1 using rectangular section specimen t x 10mm.
2. Bend testing was made as root bend and face bend test according to ASME IX using two face bend specimens and two root bend specimens.
3. Determination of critical pitting temperature (CPT) was made according to ASTM G48-03 Method E modified by Sandvik. (The same double specimens were used through out the CPT determination instead of new specimens at each temperature as stated in ASTM G48-03 Method E.) Two specimens were used. The temperature increment was 2.5°C and the testing started at 40°C. Before testing the corrosion specimens were degreased but not pickled.
4. Documentation of microstructures, including measurement of ferrite contents using linear analysis.

Pipe welds

Girth welds were also produced in pipes 168.28 x 7.11mm (ANSI 6" Sch 40). Here a U-groove was used with 15° bevel, 1.5mm land having 2.5mm extension and 2.5mm radius between the bevel and the extended land. Manual TIG was used with Ar + 2%N₂ as shielding gas and pure N₂ as root gas. Filler wire diameter was 1.6mm. The weld was made in ten runs and the top side was brushed subsequent to welding. The weld was not pickled after welding.

The pipe weld was tested in the following way:

1. Tensile testing transverse the weld at RT according to EN 10002-1 using rectangular section specimen t x 10mm.
2. Bend testing was made as root bend and face bend test according to ASME IX using two face bend specimens and two root bend specimens.
3. Determination of critical pitting temperature (CPT) was made according to ASTM G48-03 Method E modified by Sandvik. (The same double specimens were used through out the CPT determination instead of new specimens at each temperature as stated in ASTM G48-03 Method E.) Two specimens were used. The temperature increment was 2.5°C and the testing started at 40°C. Before testing the corrosion specimens were degreased but not pickled.
4. Evaluation of resistance to chloride stress corrosion cracking was made in NaCl solution according to ASTM G123 using U-bend specimens according to ASTM G30. Four specimens were tested. The weld was located in the centre of the U-bend and transverse to the bend. Total time for exposure was 1008h. The specimens were taken out of the solution for intermediate inspection five times.
5. Documentation of microstructures including measurement of ferrite contents using linear analysis.

Overlay welds

One overlay weld was made with TIG and two with SAW, using two different welding fluxes.

The TIG weld was made in five layers using Ar + 2%N₂ as shielding gas. The filler diameter was 1.6mm. The submerged-arc welds were made in three layers using flux 15W, a basic flux without any alloying elements, and flux 10SW, a neutral chromium compensating flux. The basicity (calculated according Boniszewski) of flux 15W is around 1.7 and the basicity of flux 10SW is around 1.0. The filler diameter was 2.4mm. The base material was S355N, 50mm in thickness.

The overlay welds were tested in the following way:

1. Transverse side bend testing was made according to ASME IX using four specimens per weld.
2. Determination of critical pitting temperature (CPT) was made according to ASTM G48-03 Method E modified by Sandvik. (The same specimens were used through out the CPT determination instead of new specimens at each temperature as stated in ASTM G48-03 Method E.) Two specimens were used. The temperature increment was 2.5°C and the testing started at 40°C. The corrosion specimens were taken from layer 4 and 5 (top layer) of the TIG weld and from layer 3 (top layer) of the submerged-arc weld. The surfaces of the specimens were ground using 120-grit abrasive paper.
3. Chemical analysis of top layer.
4. Documentation of microstructure and determination of ferrite content in top layer using linear analysis.

Tube-to-tube sheet welds

The overlay weld produced with SAW and flux 15W was also used for tube-to-tube sheet trials. Sandvik SAF 2707 HD heat exchanger tubes, 25.4 x 1.65mm, were used for the trials. Three holes were drilled in the overlay weld and the base material in carbon steel to simulate a tube sheet. The holes were placed in the corners of a triangle with the sides measuring 55mm, 55mm and 80mm between the corners. Hence the distances between the holes were 30mm and 55mm. The reason for this pitch was to be able to cut out corrosion specimens without destroying the neighbouring tube. The joint type was according to Fig. 1.

The tube-to-tube sheet weld was tested in the following way:

1. Microstructure documentation of weld metal and HAZ.

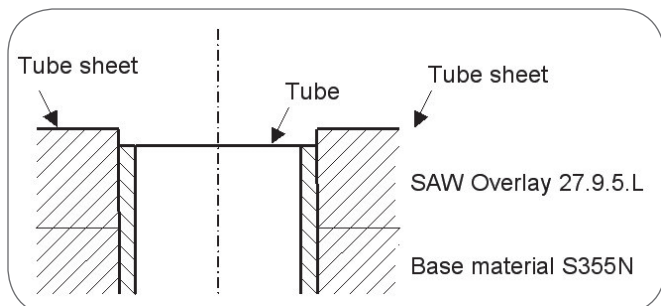


Fig. 1

Joint type tested in tube-to-tube sheet welding.

Tipo di giunzione eseguita con saldatura tubo-piastra.

2. Determination of critical pitting temperature (CPT) was made according to ASTM G48-03 Method E modified by Sandvik. (The same specimens were used through out the CPT determination instead of new specimens at each temperature as stated in ASTM G48-03 Method E.) Here the specimens were cut out from the surface of the tube sheet containing the TIG weld but not the tube to avoid the crevice between the tube and the tube sheet. Two specimens were used. The temperature increment was 2.5°C and the testing started at 40°C. The specimens were brushed and degreased but not pickled before testing.

RESULTS AND DISCUSSION**All-weld-metal**

The results in Tab. 2 show ferrite contents at reasonable levels for

Welding method	Flux	Shielding gas	Ferrite content (%)
TIG	n.a.	Ar + 2%N ₂	45
SAW	15W	n.a.	56

Tab. 2

Ferrite content in all weld metal measured with linear analysis.

Contenuto di ferrite nella saldatura misurato mediante analisi lineare.

both all-weld-metals. The ferrite contents are somewhat lower for the TIG weld due to the nitrogen addition in the shielding gas leading to higher nitrogen content in the weld deposit and, hence, lower ferrite content.

Composition and alloying vectors of all-weld-metal produced with SAW are presented in Tab. 3. The two elements subjected to the largest relative changes are chromium and nitrogen, which was expected. The burn-off of chromium is normally between 0.5 and 1 percent for flux 15W. High nitrogen filler normally loose considerable amounts of nitrogen in submerged-arc welding. Results of tensile testing are shown in Tab. 4. The yield and tensile strengths are very high compared to those of 25.10.4.L (filler for SAF 2507) where typical values for Rp0.2 and Rm are around 700MPa and 860MPa respectively for TIG.

The impact toughness of all-weld-metal produced with TIG, shown in Fig. 2, is generally good and impact toughness above 150J at -60°C is very good bearing in mind that this is a very high

Product	C (%)	Si (%)	Mn (%)	Cr (%)	Ni (%)	Mo (%)	N (%)	Co (%)
Chemical analysis	0.020	0.5	0.6	26.7	8.8	4.5	0.25	1.0
Alloying vector	+0.004	+0.1	-0.2	-0.4	0	0	-0.05	0

Tab. 3

Chemical analysis and alloying vectors of all-weld-metal produced with SAW using the basic flux 15W.

Analisi chimica e vettori di alligazione nel metallo deposto mediante SAW, utilizzando il flusso basico 15W.

Weld method	Rp0.2 (MPa)	Rp1.0 (MPa)	Rm (MPa)	A (%)	Z (%)
TIG	805	867	955	31	69
SAW	727	804	905	25	45

Tab. 4

Tensile properties of all-weld-metal of 27.9.5.L welded with Ar + 2%N₂.

Caratteristiche tensili del metallo deposto ottenuto con materiale 27.9.5.L sotto Ar + 2%N₂.

Welding method	Flux	Shielding gas	CPT (°C)
TIG	n.a.	Ar + 2%N ₂	77,5
SAW	15W	n.a.	70

Tab. 5

Critical pitting temperature of all-weld-metals.

Temperatura critica di pitting del metallo deposto.

Location	Ferrite content (%)
Top	60
Centre	54
Root	53

Tab. 6

Ferrite contents in weld metal of girth weld in tube, 25.4 x 1.65mm.

Contenuti di ferrite nel metallo deposto con saldatura circonferenziale in tubi 25.4 x 1.65mm.

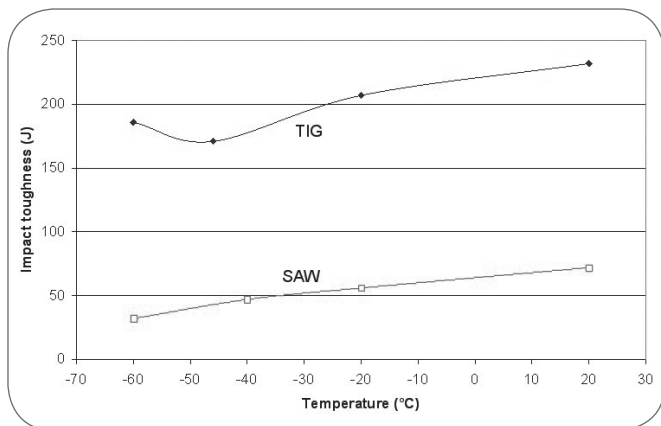


Fig. 2

Charpy-V impact toughness of all-weld-metal welded with TIG and SAW. TIG shielding gas: Ar + 2%N₂. SAW flux: 15W (basic).

IResilienza Charpy-V del metallo depositato mediante TIG e SAW. Gas di copertura TIG: Ar + 2%N₂. flusso SAW: 15W (basico).

alloyed duplex filler material.

It is interesting to note that the typical duplex behaviour for weld metals, where the curve shows a rather steep slope, is not present in the temperature interval tested. The slope is most likely present at lower temperatures. The TIG results at lower temperatures are somewhat strange showing an increase at the lowest temperature tested. This phenomenon might be an effect of limited basic data.

For SAW the toughness level is lower which is expected since slag processes give higher oxygen contents in the weld metal and hence lower toughness. In addition, the ferrite content is higher in the SAW weld metal compared the TIG weld metal and this is also contributing, to lesser extent, to the difference in impact toughness. Still, the toughness is above 40J at -40°C indicating that SAW can be used down to -40°C with acceptable impact toughness.

Critical pitting temperatures for the all-weld-metals are shown in Tab. 5. Both welding methods produce weld metals with very high CPT in comparison to that of all-weld-metals in the super duplex filler 25.10.4.L where CPT between 40 and 60°C have been reported [8, 9].

The results of SCC testing of the TIG all-weld-metal according to ASTM G123 with U-bend specimens according to ASTM G30 revealed no signs of stress corrosion cracking after testing for 1008h.

The SAW all-weld-metal showed the same results after SCC testing for 1008h: No signs of stress corrosion cracking.

Tube welds

The microstructures in weld metal and heat affected zone, shown in Fig. 3 and 4, are typical for duplex stainless steels. Ferrite contents in weld metal measured with linear analysis are shown in Tab. 6. The level is within the most common interval specified by standards and end users, 35-65% ferrite. There are no signs of intermetallic phases in weld metal or HAZ. Examples of the microstructures are shown in Fig. 2 and 3.

Results of tensile testing are shown in Tab. 7. In spite of high tensile values the ruptures are located to the weld metals. Still, the tensile strength is clearly above the minimum value for SAF 2707 HD base material, which is 920MPa.



Fig. 3

Microstructure in centre of weld metal in tube weld. Tube dim. 25.4 x 1.65mm. Magnification: 150x.

Microstruttura al centro del metallo depositato in un tubo saldato (dim. 25.4 x 1.65mm). Ingrandimento: 150x.

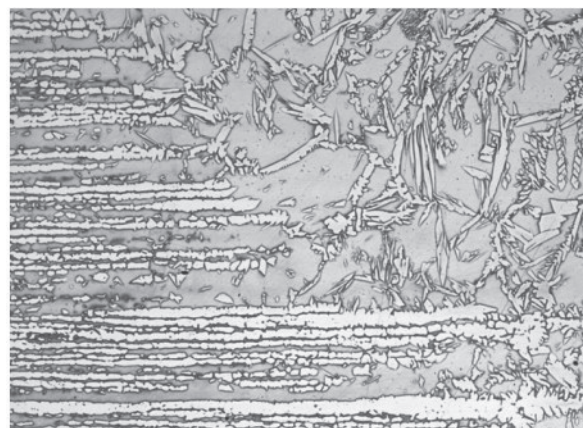


Fig. 4

Microstructure in HAZ and fusion line in tube weld. Tube dim. 25.4 x 1.65mm. Magnification: 150x.

Microstruttura nella ZTA e sulla linea di fusione in un tubo saldato (dim. 25.4 x 1.65mm). Ingrandimento: 150x.

Face and root bend test according to ASME IX was carried out to 180° with approved results. Only one fissure appeared in one of the face bend specimens. However, the fissure was only 0.3mm which is approved according to ASME IX where discontinuities below 3mm are allowed.

Critical pitting temperature of the tube weld was determined to 67.5°C, see Tab. 8. This level is markedly higher than that of welded joints in SAF 2507 where the CPT is around 50°C [10, 11].

Pipe welds

The microstructures in weld metal and heat affected zone, shown in Fig.5 and 6, are typical multi pass welds in duplex stainless steels. There are no signs of intermetallic phases in weld metal or HAZ.

Test temperature (°C)	Specimen no.	Rm (MPa)	Location of rupture
RT	1	970	Weld metal
	2	966	Weld metal

▲
Tab. 7

Results of tensile testing transverse girth weld in tube 25.4 x 1.65mm.

Risultati delle prove di trazione trasversale in tubi (dim 25.4 x 1.65mm) con saldatura circonferenziale.

Specimen no.	Attack temp. (°C)	Location of attack	CPT (°C)
1	67.5	Weld metal, top and root side.	67.5
2	70	Weld metal, top and root side.	

▲
Tab. 8

Result of CPT determination of girth weld in tube, 25.4 x 1.65mm.

Risultato della determinazione della CPT in tubi (dim 25.4 x 1.65mm) con saldatura circonferenziale.

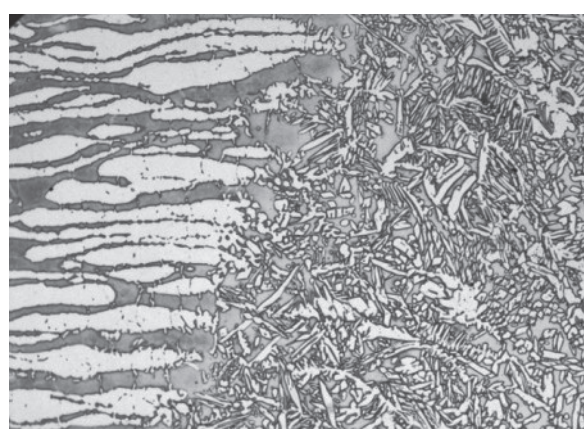


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Fig. 5

Microstructure in centre of weld metal in pipe weld.

Pipe dim. 168 x 7,1mm. Magnification: 150x.

Microstruttura al centro del metallo depositato in una saldatura di tubazione (dim. 168 x 7,1mm). Ingrandimento: 150x.



▲
Fig. 6

Microstructure in HAZ and fusion line in pipe weld.

Pipe dim. 168 x 7,1mm. Magnification: 150x.

Microstruttura nella ZTA e sulla linea di fusione in una saldatura di tubazione (dim. 168 x 7,1mm). Ingrandimento: 150x.

Ferrite contents in weld metal measured with linear analysis are shown in Tab. 9. The level is within the rather common interval specified by standards and end users, 35-65% ferrite.

Results of tensile testing are shown in Tab. 10. The ruptures are located in the parent material about 15mm from the fusion line. Face and root bend test according to ASME IX was carried out to 180° with approved results. One fissure measuring 1.5mm appeared in one root bend specimen. However, according to ASME IX this is approved.

Critical pitting temperature of the pipe weld was determined to 60°C, see Tab. 11. This value is lower than that of the tube weld described above, but it still is higher than that of SAF 2507 welds where the CPT is around 50°C [9, 10, 11]. With a further optimisation of the weld procedure used, a higher CPT for this type of multi-layer joint weld should be possible.

The results of SCC testing according to ASTM G123 with U-bend specimens according to ASTM G30 revealed no signs of stress corrosion cracking after testing for 1008h. These results were expected since duplex stainless steels normally have very good

Location	Ferrite content (%)
Top	60
Centre	46
Root	43

▲
Tab. 9

Ferrite contents in weld metal of girth weld in pipe, 168 x 7.1mm.

Contenuto di ferrite nel metallo depositato con saldatura circonferenziale in tubazioni (dim 25.4 x 1.65mm).

resistance to chloride induced stress corrosion cracking.

Overlay welds

The basic flux designated 15W produce a surprisingly smooth and sound overlay weld with no signs of porosity on the surface. Slag removal was good and no slag remnants could be noted.

Test temperature (°C)	Specimen no.	Rm (MPa)	Location of rupture
RT	1	910	Parent material
	2	910	Parent material

▲
Tab. 10

Results of tensile testing transverse girth weld in pipe, 168 x 7,1mm.

Risultati delle prove di trazione trasversale della saldatura circonferenziale in tubazioni (dim 25.4 x 1.65mm).

Specimen no.	Attack temp. (°C)	Location of attack	CPT (°C)
1	62.5	Weld metal, top side.	60
2	60	Fusion line, root side. Weld metal, top side.	

▲
Tab. 11

Result of CPT determination of girth weld in pipe, 168 x 7.1mm.

Risultato della determinazione della CPT in tubazioni con saldatura circonferenziale (dim 25.4 x 1.65mm).

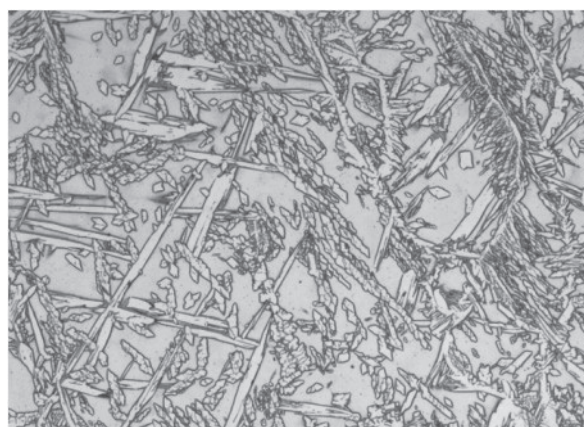


▲
Fig. 7

Microstructure in top layer of TIG overlay weld.

Magnification: 150x.

Microstruttura nello strato superiore della placcatura TIG. Ingrandimento: 150x.



▲
Fig. 8

Microstructure in top layer of SAW overlay weld.

Flux 15W. Magnification: 150x.

Microstruttura nello strato superiore della placcatura SAW. Ingrandimento: 150x.

Total bead thickness: 15mm.

The neutral Cr-compensated flux produced a rougher weld surface showing indents of pores trapped in the interface between the slag and the weld metal. The slag removal was inferior to that of flux 15W and the weld surface contained slag remnants in stripes transverse the weld ("zebra slag"). Total bead thickness: 14mm.

The microstructures of the TIG and SAW overlay welds are typical for duplex weld metals and free from intermetallic phases. See Fig. 7 and 8. Ferrite contents of top runs are shown in Tab. 12. The results are within normally specified ferrite intervals.

Transverse side bend test according to ASME IX was carried out to 180° with approved results for the overlay welds produced with TIG (no fissuring) and with SAW using flux 15W (basic flux). The overlay weld produced with flux 10SW (neutral flux) was not approved since one specimen showed one crack through out the full overlay weld (>3mm).

These results indicate that a basic flux is needed to obtain accept-

able ductility in the overlay produced with SAW.

Critical pitting temperatures of the overlay welds are shown in Tab. 13. The pitting resistance of the TIG weld overlay indicate that more than 5 runs might be required. However, it should be borne in mind that the corrosion specimen contains both top layer and the layer underneath. The pitting attacks were located to one side only most likely originating from layer no 4.

The overlay welds produced with submerged-arc welding show very high pitting resistance. Here, in contrast to the TIG overlay weld, the top layer is rather thick and a corrosion specimen can easily be taken from the top layer. These CPT results are very encouraging since SAW is a more productive welding process compared to TIG. It should also be noted that the chromium compensated flux, 10SW, did not give better CPT than the flux without chromium, flux 15W.

Chemical analyses of the top layers show that the dilution from the parent material is close to nil in the TIG weld. See Tab. 14. For the submerged-arc weld there is a small dilution. For flux 15W

Weld method	Flux	No. of layers	Ferrite content (%)
TIG	n.a.	5	53
SAW	15W	3	60
	10SW (Cr comp)	3	51

▲
Tab. 12

Ferrite contents of top layers in overlay welds.

Contenuti di ferrite negli strati superiori delle placcature.

Welding method	Flux	No. of layers	Attack temp. (°C)		CPT (°C)
			Specimen 1	Specimen 2	
TIG	n.a.	5	62.5	65	62,5
SAW	15W	3	75	72,5	72,5
	10SW (Cr comp)	3	70	72,5	70

▲
Tab. 13

Results of CPT determination of overlay welds.

Risultati delle determinazioni della CPT per le placcature.

Welding method	Flux	No. of layers	C (%)	Mn (%)	Cr (%)	Ni (%)	Mo (%)	N (%)
TIG	n.a.	5	0.013	0.8	27.0	8.8	4.5	0.30
SAW	15W	3	0.020	0.6	26.4	8.6	4.4	0.24
SAW	10SW (Cr comp)	3	0.017	0.5	26.2	8.4	4.3	0.26

▲
Tab. 14

Chemical analysis of top layers welded with filler 27.9.5.L.

Analisi chimica degli strati superficiali saldati con materia-
le d'apporto 27.9.5.L.

the composition is not far from that of all-weld metal in Tab. 3. It is also interesting to note that the chromium compensating flux 10SW is not giving any higher chromium content compared to flux 15W. Indeed, the dilution from parent material is somewhat larger with flux 10SW but this fact cannot explain why there was no effect of the chromium compensation flux.

Obviously flux 15W is the best flux for this purpose, giving better weld bead appearance, approved bend test results and pitting resistance equal to or better than that of flux 10SW.

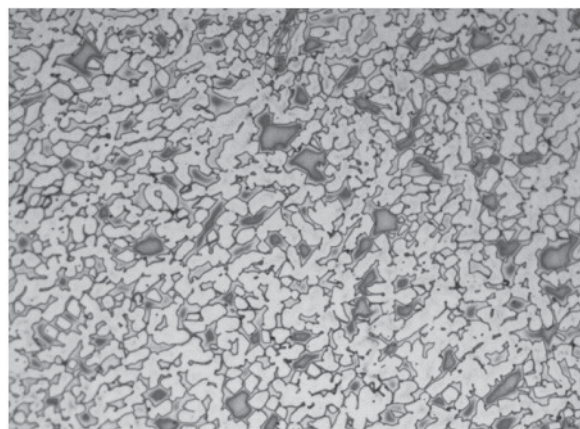
Tube-to-tube sheet welds

The ferrite content in the tube-to-tube sheet weld was determined to 33%. The microstructures of tube to tube sheet weld metals, HAZ in tube and HAZ in weld overlay are shown in Fig. 9 and 10. The microstructure in Fig. 9 and ferrite content of 33% indicate that the nitrogen content of the shielding gas can be lowered to get a slightly higher ferrite level.

Determination of pitting resistance in tube-to-tube sheet welds is difficult since the crevice between the tube and the tube sheet needs to be completely removed in order to avoid crevice corrosion during the pitting test. Here the testing was carried out successfully and the CPT was determined to 60°C. See Tab. 15.

CONCLUDING REMARKS

It should be noted that the welded joints were not pickled,



▲
Fig. 9

Microstructure in weld metal of tube-to-tube sheet weld (TIG). Magnification: 300x.

Microstruttura del metallo depositato nella saldatura TIG tubo-piastra. Ingrandimento: 300.

ground or polished after welding meaning that the testing was made at fairly severe conditions. If the welds would have been pickled the CPT level would most likely have been even higher. However, the conditions used in these trials are more similar to real conditions, even though pickling of the top side of the weld is rather common.

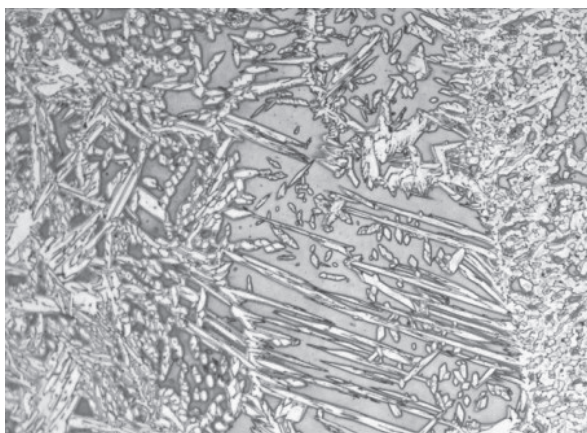


Fig. 10

Microstructure in HAZ of overlay weld in tube-to-tube sheet weld. TIG weld metal to the right. HAZ in SAW overlay in the centre and to the left. Magnification: 150x.

Microstruttura nella ZTA di una placcatura dopo saldatura TIG tubo-piastra. Metallo saldato mediante TIG a destra; ZTA nella placcatura SAW al centro e a sinistra. Ingrandimento: 150 x.

The overlay welds show very good properties and the submerged-arc welds show surprisingly good properties, especially with regard to the limited amount of layers. These results indicate that SAW, from both a technical and economical point of view, is a good technique for producing a hyper duplex tube sheet surface. The encouraging results of the tube-to-tube sheet welding trials strengthen this indication.

CONCLUSIONS

A new hyper duplex stainless steel, SAF 2707 HD, and matching filler, 27.9.5.L, has been developed with good weldability. Documentation of various welds produced with TIG and SAW shows that the welds possess:

- High strength – substantially better than that of SAF 2507 / filler 25.10.4.L.
- Good ductility.
- Good impact toughness.

Specimen no.	Attack temp. (°C)	Location of attack	CPT (°C)
1	60	T/TS weld	60
2	65	HAZ in overlay weld	

Tab. 15

Results of CPT determination of tube-to-tube sheet welds.

Risultati della determinazione della CPT per le saldature tubo-piastra.

- Good resistance to chloride induced stress corrosion cracking.
- High pitting resistance – substantially better than that of SAF 2507 / filler 25.10.4.L.

REFERENCES

- 1] J. M. A. QUIK, M. GEUDEKE, Chemical Engineering Progress 11, (1994), p.49.
- 2] P. LØVLAND, Proc. 25th Annual Offshore Technology Conference, Houston, Texas (1993), OTC, Richardson, Texas (1993), p.529.
- 3] H. LEONARD, F. STOLL, Stainless Steel World 4, (1997), p.55.
- 4] K. C. BENDALL, Anti-Corrosion Methods and Materials 3, (1997) p.170.
- 5] K. GÖRANSSON, M.-L. NYMAN, M. HOLMQUIST, E. GOMES: "Sandvik SAF 2707 HD (UNS S32707) – a hyper-duplex stainless steel for severe chloride containing environments" (Houston, USA: Stainless Steel World Conference, 2006) P6003.
- 6] K. GÖRANSSON, M. HOLMQUIST, M.-L. NYMAN, Corrosion 2007, Nashville, Tennessee (2007), NACE, Houston, Texas (2007) paper no.07189.
- 7] P. STENVALL, M. HOLMQUIST, Corrosion 2007, Nashville, Tennessee (2007), NACE, Houston, Texas (2007), paper No. 07190.
- 8] C.-O. PETTERSSON, Internal Report no. T9801209, Sandvik Steel R&D, Sandviken (1998).
- 9] S.-Å. FAGER, Proc. Duplex Stainless Steels, Beaune (1991), Les Editions de Physique, Les Ulis Cedix (1991), p.403.
- 10] S.-Å. FAGER, L. ÖDEGÅRD, Proc. Third Internat. Offshore and Polar Conference, Singapore (1993), The Int. Soc. of Offshore and Polar Engineers (1993), p.416.
- 11] S.-Å. FAGER, L. ÖDEGÅRD, Proc. Applications of Stainless Steels, Stockholm (1992), Jernkontoret (1992) p.307.

ABSTRACT

PROPRIETÀ DELLE SALDATURE IN ACCIAIO SANDVIK SAF 2707 HD®

Keywords: acciaio inossidabile, saldatura

Gli acciai inossidabili Super duplex, hanno trovato ampio impiego nell'industria petrolifera e in altri settori relativi alla chimica di trasformazione del petrolio. Il grado Hyper duplex SAF 2707HD®, recentemente sviluppato da Sandvik, consente l'estensione del campo di applicazione degli acciai austeno-ferritici a condizioni ancor più aggressive. Nella maggior parte delle possibili applicazioni dell'acciaio Sandvik SAF 2707 HD le attrezzature devono essere saldate, pertanto la saldabilità è estremamente importante per questo tipo di materiale.

E' stata quindi prodotta una documentazione sulla saldatura di questo acciaio per molteplici tipi di giunzioni, al fine di simulare diverse applicazioni in tubi e tubazioni. Il metodo di saldatura utilizzato è stato il TIG. Le giunzioni sono state sottoposte a prove per determinarne proprietà meccaniche, microstruttura, resistenza alla pitting (CPT-critical pitting temperature) e, in alcuni casi, la resistenza alla corrosione sotto sforzo da cloruri. Il filo d'apporto utilizzato, denominato Sandvik 27.9.5.L, è stato sviluppato specificamente per l'acciaio Sandvik SAF 2707 HD. Sono state indagate anche placcature prodotte utilizzando l'arco sommerso e il metodo TIG, che sono state caratterizzate in termini di duttilità, microstruttura e resistenza al pitting. Si sono poi realizzate anche saldature tubo-piastra per documentarne il comportamento e la resistenza al pitting.