Tankers—A Composition in Duplex Stainless

By Fred Neessen
Piet Bandsma
Lincoln Smitweld
Eindhoven, the Netherlands

Introduction

Duplex stainless steel is finding an increasing frequency of application in the shipbuilding sector, mainly due to its high yield strength and corrosion resistance properties. The design and fabrication of a recent chemical tanker project illustrates the trend.

The higher yield strength and superior corrosion resistance of duplex stainless governed the choice of material

The ship owner Gesellschaft fur Oltransport (GEFO) of Hamburg, Germany, contracted the Shipyard K. Damen of Rotterdam, the Netherlands, to build six ships designed for both inland and seagoing navigation, featuring cargo tanks fabricated of duplex stainless steel. The resulting double-hull tankers, designed by GEFO to transport up to 2,750 tonnes (2700 tons) or 3,250 m^3 (4,250 $yd.^3$) of liquid in twelve separate tanks, are 95 m (312 ft.) long and 6.35 m (21 ft.) high with a 12.5 m (41 ft.) beam. The separate cargo tanks allow fully independent loading and emptying, permitting the simultaneous transportation of different chemicals. On an interesting note, each ship was named for a famous musical composer: Rossini, Puccini, Verdi, Bellini, Mozart, and Donizetti.

Choice of Material

The cargo tanks were fabricated of duplex stainless steel (WNr 1.4462), which has a higher alloy content than the austenitic AISI 316LN grade often used in the construction of similar inland navigation tankers. The higher yield strength and superior corrosion resistance of duplex stainless governed the choice of the material. These two properties increased the number of different chemical products that can be loaded and transported by the tankers. While the ultimate tensile strength of WNr 1.4462 is approximately 20 percent higher than that of 316L, its yield strength is 120 percent higher. Since European shipbuilding codes are based on yield strength, not tensile strength, WNr 1.4462 was particularly attractive in this application. Furthermore, the lower nickel content of WNr 1.4462 made it a more economical choice for this application than either 316LN or 317LN.

Another factor taken into consideration was the resistance of the base materi-

Table 1. Mechanical properties of base materials according to ASTM A 240.

UNS	AISI	Yield (MPa)	Tensile (MPa)	A4 (%)
S 31653	316LN	≥ 205	≥515	≥40
S 31753	317LN	≥ 240	≥550	≥40
S 31803	DSS (1.4462)	≥ 450	≥620	≥ 25

al to pitting corrosion, as expressed by the "Pitting Resistance Equivalent" or PRE. The PRE may be expressed with or without the influence of nitrogen (N), as shown in the following formula:

PRE(N) = %Cr + 3.3 * %Mo (+16 * %N)

This formula clearly shows that molybdenum (Mo) makes an important contribution to pitting resistance. The higher the PRE number, the higher the resistance to pitting and crevice corrosion.

Specific comparisons of the mechanical properties and chemical compositions of the three grades of steel are shown in Tables 1 and 2. To sum up, the duplex stainless was chosen for reasons of economy, high strength, and excellent resistance to both chloride corrosion cracking and pitting corrosion. The material's high yield strength translated to reduced plate thickness and reduced weight, which really means increased cargo carrying capacity.

Process and Consumable Selection

For both CrNi and CrNiMo stainless steels, any conventional welding process can produce welds of optimum quality, provided that the correct welding parameters are maintained, and that the correct consumables are used. For this chemical tanker project, Shipyard K. Damen considered the total cost of various processes, including the costs of any necessary pre- and post-weld treatment, before deciding to use a combination of GMAW, FCAW and SAW. Welding positions, base material combinations, and the selection of welding processes and consumables were all decided in accordance with Germanischer Lloyd rules. Lincoln Smitweld provided technical support and assistance with development of the welding procedures, process and consumables selection, welder qualification and test-

Table 2. Chemical composition of base materials according to ASTM A 240.

Base material		Chemical composition					Pitting Resistance Equivalent %Cr + 3.3 * %Mo (+ 16 * %N)		
UNS	AISI	C max.	Cr	Ni	Mo	N	min.	max.	average
S 31653	316LN	0.030	16 - 18	10 - 14	2 - 3	0.10 - 0.16	24.2	30.5	27.3
S 31753	317LN	0.030	18 - 20	11 - 15	3 - 4	0.10 - 0.22	29.5	36.7	33.1
S 31803	(1.4462)	0.030	21 - 23	4.5 - 6.5	2.5 - 3.5	0.08 - 0.20	30.5	37.8	34.2

Table 3. Duplex stainless welding consumables.

Product	AWS classification	EN classification	C	Mn	Si	Cr	Ni	Mo	N	FN
Arosta 4462	A5.4: E 2209-16*	EN 1600: E 22 9 3 N L R 3 2	0.02	0.8	1.0	22.5	9.5	3.2	0.16	30–55
Arosta 4462-145	A5.4: E 2209-16*	EN 1600: E 22 9 3 N L R 5 3	0.025	0.7	1.0	22.5	9.5	3.0	0.16	30–55
LNM 4462	A5.9: ER 2209	EN 12072: G 22 9 3 N L	0.018	1.5	0.5	22.7	8.5	3.0	0.15	
Cor-A-Rosta 4462	A5.22: E 2209T0-4	EN 12073: T 22 9 3 N L R M 3	0.03	0.9	0.6	22.9	9.3	3.4	0.14	40
Cor-A-Rosta P 4462	A5.22: E 2209T1-4	EN 12073: T 22 9 3 N L P M 2	0.03	0.7	0.6	22.9	9.2	3.4	0.14	40
LNS 4462	A5.9: ER 2209	EN 12072: S 22 9 3 N L	0.03	0.9	0.7	22	8	3.0	0.15	30–50
P 2000	-	EN 760: S A AF 2 6 3 DC								
Cor-A-Rosta 309L	A5.22: E 309LT0-1/4	EN 12073: T 23 12 L R C/M 3	0.03	1.4	0.6	24	12.6	-		15
Cor-A-Rosta P 309L	A5.22: E 309LT1-1/4	EN 12073: T 23 12 L P C/M 2	0.03	1.2	0.6	23.3	12.6	-		15

Table 4. Overview of welding methods.

Reference No. (fig. 2)	Material	Welding position	Welding process	Welded joint	Testing
1	Duplex / Duplex	PB (2F)	FCAW (P 4462)	Double fillet weld throat = 4 mm	Dye check HV10 Fracture
2		2PD (4F)			
3		PA (1G)	SAW	I-joint (square)	As 5-6 and 7
4		PB (2F - 2G)	FCAW (P 4462)	1/2 V-50° incl. fillet weld	Dye check HV10
5		PA (1G)		V-60° with ceramic backing	X - Ray Corrosion Ferrite Mechanical
6		PF (3G up)			
7	Duplex / Grade A	PA (1G)	FCAW (P 309L)	Double fillet weld throat = 4 mm	Dye check HV10 Fracture
8		PB (2F) manual			
9		PB (2F) machined			
10		PD (4F)			
11		PF (3F up)			
12	Duplex / Duplex	PG + PF (3Gd + 3Gu)	GMAW + FCAW	V-60°	As 5-6 and 7

ing, and welder training. The welders needed training and qualification (t&q) on duplex stainless steel as well as on welding of dissimilar materials joints.

Pulsed gas metal arc welding was used to create a root run in a V-60° joint in the vertical down position on a ceramic backing strip. The shielding gas employed was a three part $ArHeCO_2$ blend.

Stainless flux cored electrode accounted for most of the welding of the tankers. The Lincoln Smitweld Cor-A-Rosta® range of products was used, as follows:

- Cor-A-Rosta 4462 was employed for downhand welding of grooves and horizontal-vertical fillets. Shielding gas selections include 100% CO_2, as well as 80% Argon + 20% CO_2.

The material's high yield strength translated to reduced plate thickness and reduced weight

- Cor-A-Rosta P 4462 was employed for out-of-position welding. The shielding gas is restricted to 80% Argon + 20% CO_2.

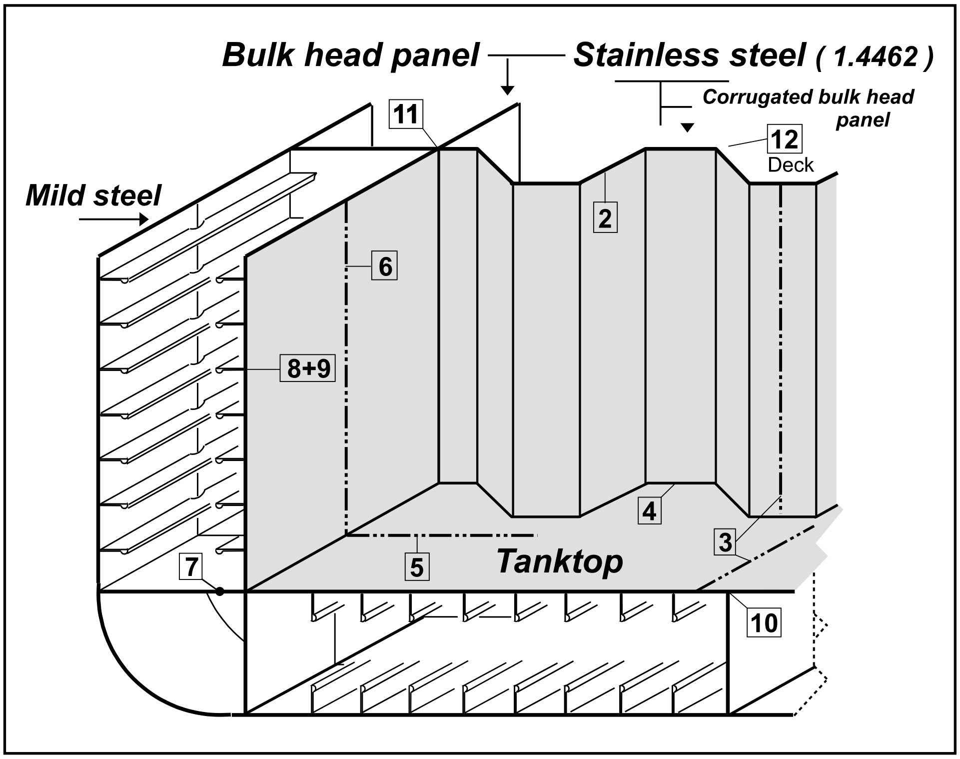

Figure 1. Schematic cross section of a chemical tanker.

The use of stainless steel flux cored electrode offered the following advantages over solid electrode:

- Weldable using conventional MIG/MAG power sources
- Wide current setting
- 30% higher deposition rate
- Smooth bead surface
- Fewer undercuts and less oxidation of adjacent areas
- Less spatter; less post-weld cleaning
- Better wetting properties
- Out-of-position welding capability
- Less expensive shielding gas ($Ar + CO_2$ or 100% CO_2)
- High operator appeal

Figure 2. Actual view of the layout of the tanks.

Submerged arc welding, although offering very high productivity, is usually limited to welding in the flat position. Because of this, its use on this project was limited to the butt weld joining of sheets. Cor-A-Rosta 4462 wire and a neutral flux were selected for the SAW process.

Manual metal arc welding was employed in those areas of the fabrication that could not be welded with mechanized processes. The covered electrodes selected were Arosta 4462 and Arosta 4462-145 (145% efficiency). Tack welds were made using Arosta 4462 (without high efficiency).

For further details of welding methods, consult Table 4, with its references keyed to Figure 1.

Testing

Fillet welds were given Vickers hardness and fracture tests as prescribed by Germanischer Lloyd (GL) rules.

Butt welds were subjected to mechanical tests per GL rules, as follows:

- Vickers hardness
- Ferrite content measured with Magne Gage
- Reduced-section tensile test
- Root and face bend tests
- Impact test: center line weld, fusion line and fusion line + 2 mm (0.08 in.) Charpy samples

Butt welds were also corrosion-tested in accordance with GL rules, which for chemical tankers require:

- Intergranular corrosion attack according to DIN 50914. There were no defects.

- ASTM G48 method A during 24 hours @20 – 22 - 23° C (68 – 72-73° F). No pitting was observed.