STUDIES REGARDING SUBMERGED ARC WELDING OF DUPLEX STAINLESS STEEL IN SHIPBUILDING INDUSTRY

Marian PUCHIANU[1], Adrian FLOREA[2], Gheorghe SOLOMON[3] Iuliana DUMA[4] George PASCU[5]

An analysis of the welding behavior of duplex stainless steel joined by submerged arc welding is presented in this article. The article summarizes experimental results of welded joints of duplex stainless steel for shipbuilding industry. The experimental study was caried out for the design of welding technology in accordance with the specific requirements of the shipbuilding industry, highlighting the main elements that must be considered. The choice of filler material was made in correlation with the base material, and the values of welding parameters, such as heat input and welding sequences were established in close connection with the joint design requirements. Later, the welded joint was examined by non-destructive and destructive methods, the results obtained confirming the correct choice of the welding regime.

Keywords: duplex stainless steel, shipbuilding industry, submerged arc welding.

1. Introduction

Stainless steel is widely used in various applications in engineering world proving that is one of the most reliable materials.

It has very well been known that nickel-based alloys suffer from stress corrosion cracking (SCC) in the primary water of pressurized water reactors (PWRs), irradiated or oxygenated conditions.

The ferritic-austenitic grade has a ferrite matrix intermix with austenite called duplex having a 30% to 70% ferrite with high pitting and stress corrosion cracking resistance (SCC) in a chloride-containing environments due to high level of Cr, Mo, and N [1-2].

Since 1980 the second generation of duplex stainless steel alloyed with nitrogen having improved welding properties was devolved and used.

[1] PhD Candidate, Department of Quality Engineering and Industrial Technologies, University POLITEHNICA of Bucharest, Romania, e-mail: puchianumarian@ymail.com

[2] PhD Candidate, Department of Quality Engineering and Industrial Technologies, University POLITEHNICA of Bucharest, Romania, e-mail: florea.adrian1994@gmail.com

[3] Prof., PhD, Department of Quality Engineering and Industrial Technologies, University POLITEHNICA of Bucharest, Romania, e-mail: ghe.solomon@gmail.com

[4] Technological Engineer Grade III, Head of Laboratory for Testing, Examinations and Analysis - LIEA, ISIM Timișoara, Romania, e-mail: iduma@isim.ro

[5] Technological Development Engineer, ISIM Timișoara, Romania, e-mail: gpascu@isim.ro

The most common grade today is 1.4462 (X2CrNiMoN22-5-3) with the addition of nitrogen from 0.14% to 0.20% N which strengthens both ferrite and austenite phases by dissolving as an interstitial alloying element in solid solution, increasing the yield and tensile strength of the material [3].

Nowadays, using of duplex stainless steel in shipbuilding industry is increasing heavily, due to its high yield strength and corrosion resistance properties, replacing common austenitic stainless steel due to his susceptible behavior to stress corrosion cracking in seawater, chloride, caustic, or nitrogen enviroments, phenomenon afflicts the base material, weld seam and the heat affected zone.

The main objective of this article is to present, analyze and validate an welding procedure in the shipbuilding industry, showing all the technological welding parameters used, together with the results of examination and tests.

This article is describing the correct way of joining to avoid all related problems related to welding regime of duplex stainless steels butt welds from the tankers tank top of the cargo ships, by avoiding the formation of brittle phases with catastrophic effect on the toughness of the steels [4-7].

2. Materials

This paper is investigating the welding behavior with submerged arc welding process of 12 mm thickness X2CrNiMoN22-5-3 (W-Nr. 1.4462) duplex stainless steel plate, used for building the chemical tanks of a cruise ship.

A Ø2.4 mm solid wire for submerged arc welding (SAW) has been selected as filler material in combination with a basic flux.

The chemical composition of materials used together with their associated mechanical properties are presented in table 1 and 2 to from below [8-9].

Table 1

Chemical composition of materials

Material	Alloying elements (%)								
	C	Si	Mn	P	S	Cr	Ni	Mo	N
X2CrNiMoN22-5-3 (Base material)	0.015	0.40	1.36	0.027	0.001	22.45	5.66	3.13	0.17
S 22 9 3 N L (Filler material)	0.02	0.5	1.3	0.02	0.01	22.5	9.0	3.1	0.17

Table 2

Properties of materials

Material	Tensile strength [MPa]	Impact [Joule] -40°C	Elongation [%]	Ferrite content [%]
X2CrNiMoN22-5-3 (Base material)	784	140	36.8	47
S 22 9 3 N L (Filler material)	780	110	30	45

2. Welding process

A butt weld joint was made using a V-groove joint type as shown in figure 1 and following the welding sequence presented in Fig. 2, with welding parameters and heat input shown in table 3.

The welding parameters detailed below have been determined by previous experimental testing, using the same welding power source LAF 1250 DC with A2 welding tractor.

The root and cap of the butt weld joint can be seen in Figs. 3 and 4, showing the good transition with the base material and layer deposition.

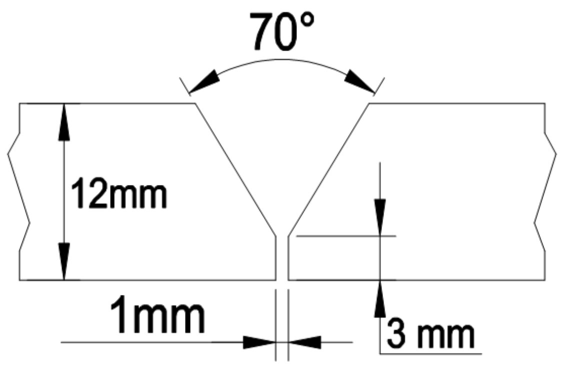


Fig. 1. Design of weld joint

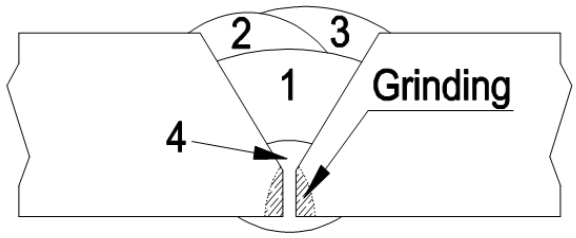


Fig. 2. Welding sequence

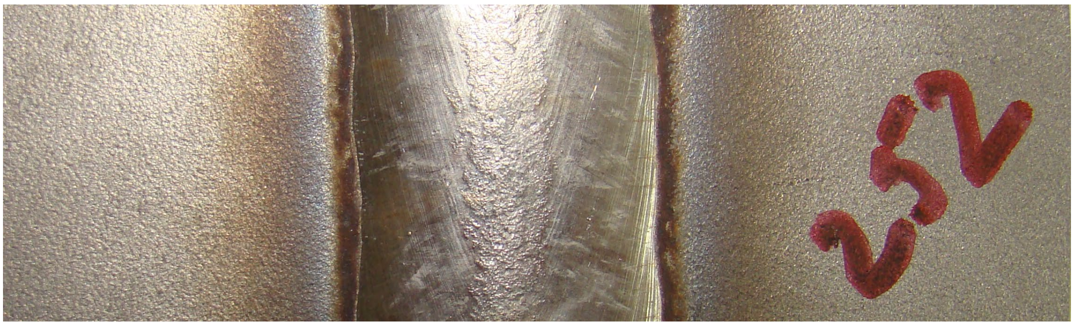


Fig. 3. Top view of the weld root

Fig. 4. Top view of the weld cap

Table 3

Heat input during welding

Weld seam number	Inter-pass temperature [°C]	Current [A]	Voltage [V]	Polarity	Welding Speed [cm/min]	Heat input [kJ/mm]
1	23	430	31.0	DC+	45.5	1.76
2	100	450	31.0	DC+	54.5	1.54
3	95	435	31.5	DC+	55.0	1.49
4	100	465	31.0	DC+	45.5	1.90

3. Destructive testing procedure

In the first stage, the welding evaluation was carried out using non-destructive methods, such us visual testing and penetrant testing, to identify surface defects. For internal imperfections, radiographic tests were used to certify that the weld meets the requirements of the standard.

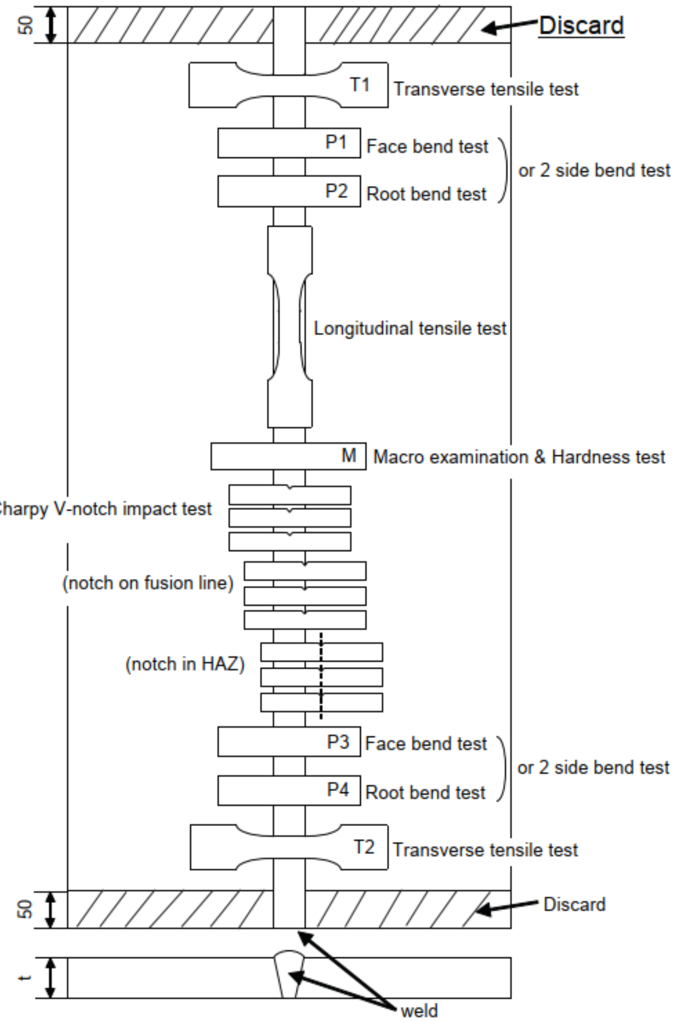


Fig. 5. Location of test specimens

Second stage and final weld evaluation is from destructive point of view using macroscopic examination, bend testing, impact testing, tensile testing, hardness testing, ferrite content analysis, pitting corrosion testing and micrographic examination. Specimens' location according to shipbuilding industry requirements, shown in figure 5, were taken from the 1000x600x12 mm butt weld joint [18].

a) Macroscopic Examination

Macroscopic analysis according to EN ISO 17639 was made on specimens taken from the beginning and end of the butt weld to demonstrate the integrity of the weld on its entire length, a picture of the weld side-view showing that the specimen is free of defects, being accepted after evaluation according to standard requirements is shown in figure 6.

The misalignment shown is not requested to be evaluated by the application standards because is not affecting the results of the tests [10].

Fig. 6. Macroscopic examination specimen

b) Bend Testing

Information of how the bend testing was perform according to EN ISO 5173 on the specimens are presented in table 4, while pictures of the specimens before and after the testing, free of defects, that are accepted according to the shipbuilding requirements, are presented in figure 7 [11, 18].

Table 4

Bend testing details

Bend type	Dimensions [mm]	Mandrel diameter [mm]	Distance between rolls [mm]	Bend Angle [°]
Lateral	300x12x10	∅ 40	70	180
Lateral	300x12x10	∅ 40	70	180
Lateral	300x12x10	∅ 40	70	180
Lateral	300x12x10	∅ 40	70	180

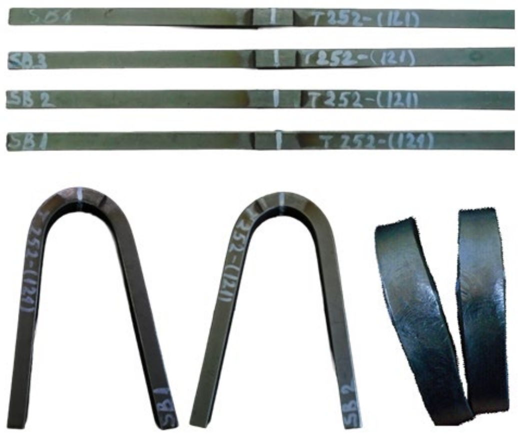


Fig. 7. Bend testing specimens

c) Impact Testing

The impact testing was performed according to EN ISO 148-1, at -20°C testing temperature, having the V-notch location at 2 mm below surface according to EN ISO 9016, as shown in figure 8. According to the shipbuilding rules the minimum impact value is 27 Joule, table 5 showing the results and confirming that the specimens had passed the test [12, 18, 19].

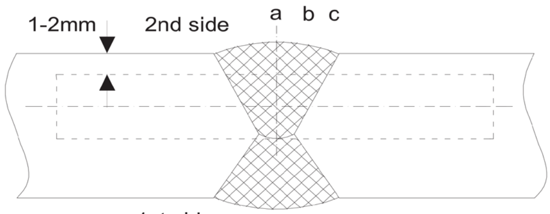


Fig. 8. Impact test specimens location

Table 5

Impact test results

V-notch Location	Dimensions [mm]	Fracture strength – Average [Joule]
Weld center	55x10x10	111
Fusion line	55x10x10	78
2 mm from the fusion line	55x10x10	74

d) Tensile Testing

Tensile testing was performed according to EN ISO 4136, at 20°C testing temperature. According to the shipbuilding rules the tensile test values need to be in 660-800 MPa interval, table 6 showing the results and confirming that the specimens had passed the test [13, 18].

Table 6

Tensile testing results

Specimens Dimensions [mm]	Area [mm^2]	Fracture force – [kN]	Fracture strength [MPa]	Fracture Location
25.0x12.1	302	240	794	Base material
25.0x12.1	300	239	796	Base material

e) Hardness Test

Hardness testing was performed according to ISO 9015-1 and respecting requirements from Fig. 9 at ambient temperature of 28°C. Maximum value permitted according to shipbuilding rules is 380HV10, showing that the specimens are accepted according to the values resulted and presented in table 7 [14, 18].

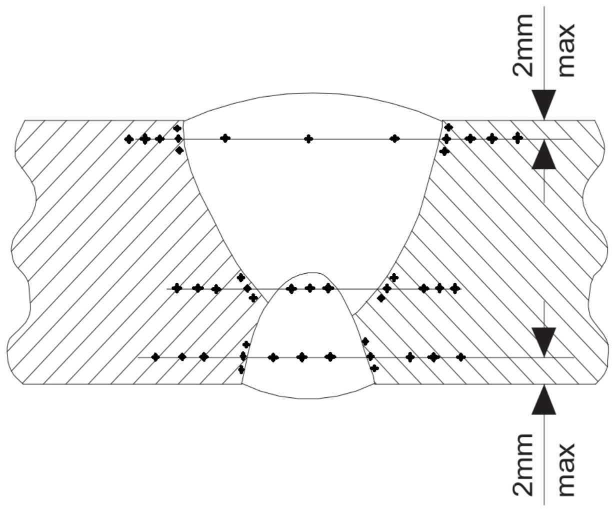


Fig. 9. Hardness lines location

Table 7

Hardness testing results [HV10]

Line / Position	Base material		Heat affected zone		Deposited material
	Left	Right	Left	Right	Middle
L1 2 mm below weld face	219	221	268	272	251
	225	221	270	272	251
	224	232	270	270	266
	Left	Right	Left	Right	Middle
L1 middle of the joint	227	224	268	274	253
	235	224	268	276	249
	224	221	268	276	247
	Left	Right	Left	Right	Middle
L3 2 mm below weld root	233	232	266	268	251
	224	230	266	268	251
	232	227	266	268	253

f) Ferrite Content Analysis

Ferrite content analysis was performed according to EN ISO 8249, at ambient temperature of 23°C, by taking 6 measurements for each side of base plate material and 3 measurements along the approximate centerline for the deposited material. According to the shipbuilding rules the ferrite content needs to in 35-55% interval, table 8 showing the results and confirming that the specimens had passed the test [15, 18].

Table 8

Ferrite content analysis [%]

Type of Result	Base material		Heat Affected Zone		Deposited material
	Left	Right	Left	Right	Middle
Singular Value	47.0	47.8	47.2	47.8	48.1
	47.5	48.3	47.3	48.0	48.0
	47.2	48.0	47.6	47.6	47.6
Average	47.2	48.0	47.4	47.8	47.8

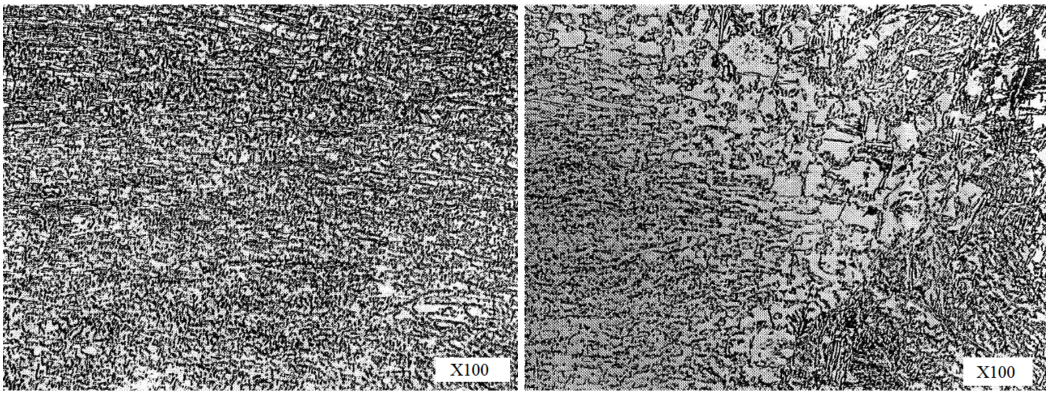
g) Pitting Corrosion Testing

Pitting corrosion was performed according to of ASTM G48-Method C at 25°C, by immersing the specimen in ferric chloride acid for 72 hours. After the testing, corrosion points shown in Fig. 10 were measured and their penetration depth was lower than 0.025 mm, the specimen passing the corrosion test. [16].

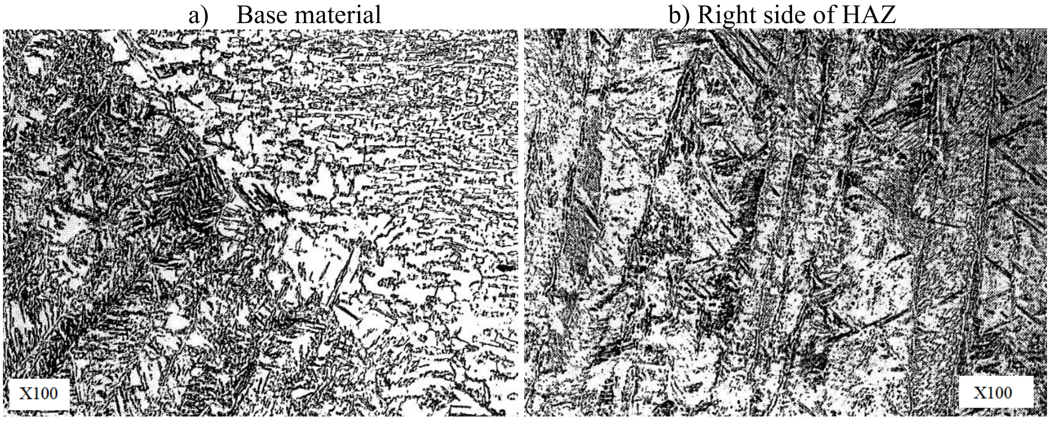
Fig. 10. Corrosion specimen after testing

h) Microscopic Examination

Microscopic examination was performed at 23°C, according to EN ISO 643, showing that the base material is having fine polyhedral austenite and ferrite microstructure, heat affected zone is having polyhedral austenite and ferrite with intense precipitation of chromium carbides microstructure and deposited material is having a columnar microstructure (figure 12), with approximatively equal quantity of austenite and ferrite confirmed by the results described in table 8. Ferrite in black and austenite in white [17].



a) Base material b) Right side of HAZ



b) left side of HAZ c) weld deposition

Fig. 11. Joint microstructure

6. Conclusions

As conclusion of this article based on the obtain results we can resume to the following points:

- Joint misalignment didn't have any impact on test results of the weld. This imperfection can be avoided by fixing jigs or increasing the number of tack welds.
- The quality of the welded joints depends on the groove preparation, welding sequence, welding parameters, heat input and correct correlation with the filler material.
- Predicting a heat input value of 1.5-2.0 kJ/mm for submerged arc welding of 12 mm duplex stainless-steel plates results in very good mechanical properties, ferrite content and corrosion resistance of welded joint.
- The results obtained from the destructive test validate all the variables selected and confirm that the welded seam didn't present any defects.
- The analysis and confirmation of the results presented in this article validate the qualification of welding procedure for submerged arc welding of duplex stainless steel in shipbuilding industry.

R E F E R E N C E S

[1] *S. D.Kahar*, Duplex Stainless Steels-An overview, Int. Journal of Engineering Research and Application, ISSN : 2248-9622, **Vol. 7**, Issue 4, (Part -4) 2017, p. 27-36.

[2] *M.M. Beşliu, I. Voiculescu, Gh. Solomon*, Effects of Dilution on Weld Overlays Realized with Flux-Cored Arc Welding (FCAW) Process Using 309LV Filler Metal on the S235JR Steel, *UPB, SCI. Bull.Series B-Chemistry and Materials Science*, **Vol.** 79, Iss. 1, (**2017)** p: 173-182.

[3] *B. Varbai, Y. Adonyi, R. Baumer, T. Pickle, J. Dobránszky, and K. Májlinger*, Weldability of Duplex Stainless Steels — Thermal Cycle and Nitrogen Effects, Welding Journal (2019**) Vol.** 98, p. 78-87.

[4] *V. Papantoniou*, "Welding stainless steel in Shipbuilding", National Technical University of Athens – Department of Naval Architects and Marine Engineers, Athens, 2010, pp 55-97.

[5] *F. Neessen, P. Bandsma*, "Tankers – A composition in Duplex Stainless", Welding Innovation, **vol. XVIII**, No. 3, 2021, pp. 1-4.

[6] *A. Higelin, S. Le Manchet, G. Passot, S. Cissé, J. Grocki*, Heat-affected zone ferrite content control of duplex stainless steel grade to enhance weldability, Welding in the World 66, 1503-1519, 2022.

[7] *S. Chacón-Fernández, A. Portolés García, G. Romaní Labanda,"* Influence of parameters on the microstructure of a duplex stainless-steel joint welded by a GMAW welding process", Vol. 32, Issue 4, 2022, p. 415-423.

[8] ***Certificate of base material from the producer.

[9] ***Certificate of filler material from the producer.

[10] EN ISO 17639 - Destructive tests on welds in metallic materials - Macroscopic and microscopic examination of welds.
[11] EN ISO 5173 - Destructive tests on welds in metallic materials - Bend tests.
[12] EN ISO 9016 - Destructive tests on welds in metallic materials - Impact tests - Test specimen location, notch orientation and examination.
[13] EN ISO 4136 - Destructive tests on welds in metallic materials - Transverse tensile test.
[14] EN ISO 9015-1 - Destructive tests on welds in metallic materials - Hardness testing – Part 1: Hardness test on arc welded joints.
[15] EN ISO 8249 - Welding - Determination of Ferrite Number (FN) in austenitic and duplex ferritic-austenitic Cr-Ni stainless steel weld metals.
[16] ASTM G 48 - Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution.
[17] EN ISO 643 - Steels - Micrographic determination of the apparent grain size.
[18] Rules for the classification of Ships, Part D – Materials and Welding, RINA.
[19] EN ISO 148-1 - Metallic materials - Charpy pendulum impact test - Part 1: Test method.