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Stress corrosion cracking susceptibility of dissimilar stainless steels welded joints

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Properties

ABSTRACT

Purpose: The aim of the current study is to reveal the influence of welding conditions on structure and stress corrosion cracking resistance of dissimilar stainless steels butt welded joints.
Design/methodology/approach: Butt joints between duplex 2205 and austenitic 316L steels were performed with the use of submerged arc welding (SAW) method. The plates 15 mm in thickness were welded with heat input in the range of 1.15 – 3.2 kJ/mm using duplex steel filler metal. Microstructure examinations and corrosion tests were carried out. Slow strain rate tests (SSRT) were performed in inert (glycerin) and aggressive (boiling 35% $MgCl_2$ solution) environments.
Findings: It was shown that place of the lowest resistance to stress corrosion cracking is heat affected zone at duplex steel side of dissimilar joins. That phenomenon was connected with undesirable structure of that zone consisted of great amount of coarse ferrite grains and acicular austenite precipitates. High welding inputs do not deteriorate stress corrosion cracking resistance of welds.
Research limitations/implications: High welding heat inputs should enhance the precipitation process of intermetallic phases in the HAZ. It is necessary to continue the research to determine the relationship between welding parameters, obtained structures, and corrosion resistance of dissimilar stainless steels welded joints.
Practical implications: Application of more productive joining process for dissimilar welds like submerged arc welding instead of currently employed gas metal arc welding (GMAW) method will be profitable in terms of reduction the welding costs.
Originality/value: The stress corrosion cracking resistance of dissimilar stainless steel welded joints was determined. The zone of the weaker resistance to stress corrosion cracking was pointed out.
Keywords: Crack resistance; Welded joints; Corrosion; Duplex stainless steel

1. Introduction

Tanks and pipelines at chemical carriers that come into direct contact witch corrosive media are fabricated of different grades of stainless steels. The most common stainless steel used has been the austenitic 316LN grade, and in lesser extent, 317LN grade. These steels have a good corrosion resistance are easy to form and easy to weld. However, today the movement towards the use of duplex stainless steels (of austenitic-ferritic structure) instead of austenitics is evident. An evaluation to establish the relative benefits of the two steel types has been carried out on the basis of cost, corrosion resistance, and welding.

Utilization of duplex stainless steels in chemical tankers has many advantages over conventional austenitics. Duplexes give higher pitting corrosion resistance, and enhanced stress corrosion cracking resistance. In addition, the cargo tanks form an integral part of the hull structure and the high yield strength of duplex steels > 450 MPa enables the plate thickness of the tanks to be reduced considerably [1, 2, 3].

Welded joints of stainless steels can be a weak point of whole tank construction. That is why so much attention has been paid on

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the weldability aspects of high alloyed stainless steels in the direction to extend their use to more demanding applications.

Weldability of the 316L grades is not problematical. It is necessary to choose consumables that can give 5 to 10 % of delta ferrite in the welded microstructure that is essential to prevent solidification cracking.

In duplex stainless steels arc welding operation gives more or less undesired heat treatment of the area close to the weld. The high-temperature area of heat affected zone (HAZ) is brought to a temperature, where the material is almost fully ferritic. Upon cooling, a reformation of austenite starts at the grain boundaries and then continues in the ferrite grains. The extent of ferrite to austenite transformation depends on the steel composition and welding conditions. When cooling is rapid, high ferrite content can remain in the heat-affected zone. If, on the other hand, the heat input is too high, precipitation of intermetallic phases can occur and phase transformation ferrite to austenite can be suppressed [4,5]. This can significantly reduce mechanical properties and corrosion resistance [6]. For maintain acceptable properties of the joints the ferrite content in weld metal and HAZ should be in the range 25-70% [7,8].

Certain problems can arise when dissimilar austenitic-duplex welds are performed. It is important for chemical tankers, because such welds are there unavoidable [9].

Welding of thick plates require using of more productive process like submerged arc welding (SAW) instead of currently employed gas metal arc welding (GMAW) method. The double sided, two pass welding process for duplex and austenitic plates was considered to be undesiredable, as the required high heat input would generate too low a ferrite content in the weld metal and create favorable conditions for the precipitation of intermetallic phases [7]. Other opinions [10] say that thick plates of stainless steels can be successfully welded with the use of higher heat inputs. So far there is not clearly established the maximum heat input limit that give joints mechanical and corrosion properties that can meet requirements of ship classification societies [8,11-13].

This paper describes structure and corrosion resistance of dissimilar stainless steels welds obtained through the submerged arc welding. Investigations focused on stress corrosion resistance of welded joints.

2. Experimental

The plates 15 mm in thickness made of UR45N+ (UNS 31803, 1.4462) duplex stainless steel and AISI 316L (1.4432) austenitic steel were used. Chemical compositions and mechanical properties of the steel plates are presented in Tables 1 and 2, respectively.

Duplex stainless steel filler metal with increased nickel content relative to the base material was used. The chemical composition of the ϕ 3,2 mm wire ESAB OK Autrod 16.86 is presented in Table 1. Basic non-alloyed agglomerated flux (ESAB Flux 10.93) was used. Three butt joints were performed using Y, 2Y and square edge preparations in order to obtain different dilutions between base and welded metal (Fig. 1).

Joints were filled with two or more beds with the use of heat input as indicated in Table 3. All beds were performed using SAW method with single wire. The interpass temperature was in all cases limited to 100°C maximum. Each weld was X-rayed and crack tested, and found to be satisfactory with B quality class according to PN-EN 25817.

Table 1.
Chemical composition of steels used for welding trials, wt %

Material	C	Si	Mn	Cr	Ni	Mo
UR45N+	0.017	0.4	1.5	21.9	5.7	3.0
316L	0.019	0.38	1.7	16.0	11.0	2.5
ESAB 16.86	0.02	0.46	1.6	23.0	8.6	3.1

Table 2.
Mechanical properties of austenitic and duplex stainless steel plates (producer data)

Material	T.S. MPa	YP$_{min}$ MPa	A$_{5\ min}$ %	HV	KV (L) min, J
UR45N+	640-840	460	25	290	90
316L	530-670	220	45	146	90

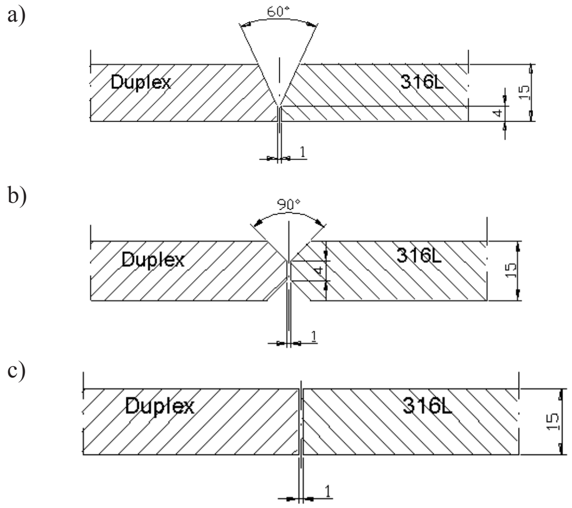

Fig. 1. Edge preparation for dissimilar welded joints; a) Y, b) 2Y, c) I edge preparation

Table 3.
Welding parameters of dissimilar joints

Thickness mm	Preparation	Number of passes	Heat input kJ/mm	Side/pass
15	Y	4	1.15	1/1
			1.15	1/2
			1.50	1/3
			1.44	2/1
15	2Y	2	2.16	1/1
			2.37	2/1
15	I	2	2.6	1/1
			3.2	2/1

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3. Results and discussion

In the metallographic examinations three aspects were considered. Firstly the general microstructure was assessed and in particular the presence of secondary austenite. Secondly, the width and structure of heat affected zones, and in the end, the solidification pattern of the root beds was examined with special attention to any solidification cracking.

The HAZ microstructure could be critical for welded joint properties [14,15]. For examined welds the very narrow zones of about 300-500 µm were observed on the duplex steel side (Fig. 2). The ferrite content in that zone was significantly higher in comparison to bulk weld metal. The width of heat affected zones from 316L steel side (Fig. 3) was extremely narrow and reach 100-150 µm. The microstructure consists of lamellar ferrite precipitates that surround equiaxial austenite grains. There was no evidence of excessive austenite grain growth.

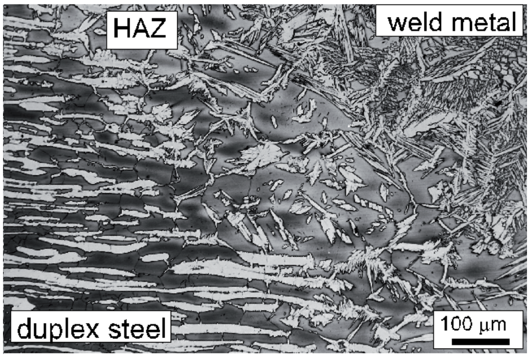

Fig. 2. Heat affected zone microstructure. Duplex steel side. "I" edge preparation weld, face line

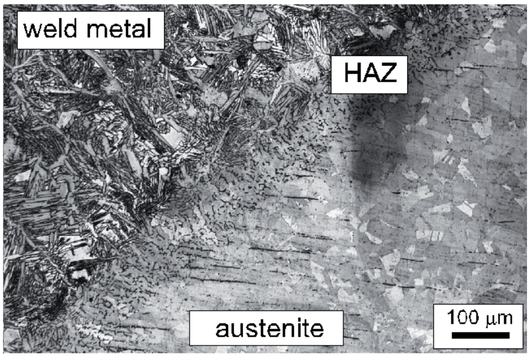

Fig. 3. Heat affected zone microstructure. Austenitic steel side. "I" edge preparation weld, face line

The ferrite content measured across the weld in the centerlines and in the lines 2 mm below root and the face of the welds are indicated in Table 4. A leaser amount of delta ferrite in centerlines is associated with slow cooling or creation of secondary austenite during reheating by the subsequent beds of the weld. Heat affected zones from the duplex steel side exhibit rather high ferrite content, but due to the very low dimensions (width) of this zone the influence on mechanical properties of the whole joints can not be significant.

Table 4.
Ferrite content in welds

	Ferrite content, mean values, %		
	Y joint	2Y joint	I joint
Face line of the weld	55.6	41.1	45.4
Root line of the weld	49.0	46.8	42.7
Centerline	42.0	30.0	35.8
HAZ from duplex side	72.2	65.5	69.3

The susceptibility to stress corrosion cracking was determined in slow strain rate tests (SSRT) with the strain rate of 2.2 x 10^{-6} s^{-1} in 35% boiling water solution of $MgCl_2$ at 125°C. The supplementary tests in an inert environment (glycerin) were also performed. Shape and dimensions of specimens are shown in Fig. 4. Tested zones of specimens contain whole welded joint e.g. weld metal, heat affected zones and base materials.

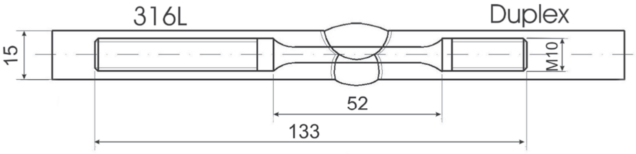

Fig. 4. Specimen for stress corrosion cracking test

Maximum force, elongation (E) and fracture energy (En) were recorded during SSRT tests. Reduction in area (RA) in fracture area was also measured. Results of slow strain rate tests for one set of specimens are shown in Fig.5

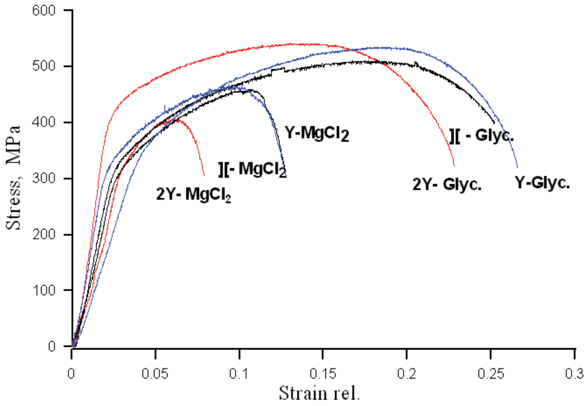

Fig. 5. Stress-strain curves obtained in slow strain rate tests for welded specimens. Tests performed in boiling 35% $MgCl_2$ solution and glycerin

Tests revealed that duplex and 316L steels are susceptible to stress corrosion in applied environment. However, dissimilar welded joints exhibited lower susceptibility than base materials. Macroscopic examinations of specimens with the welds performed after SSR tests indicated various places where samples broke. Samples tested in an inert environment broke in weaker material – on 316L steel side. Samples tested in $MgCl_2$ environment broke on the other side of welded joints – on duplex steel side (Fig.6).

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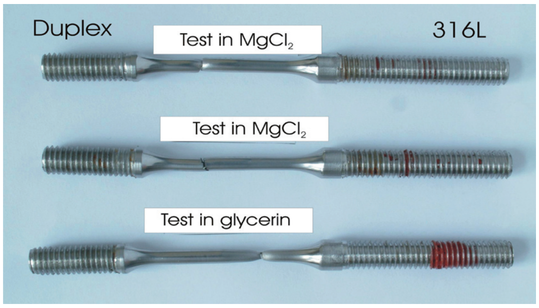

Fig. 6. Samples with welded joints after SSR tests.

Detailed microscopic examinations of cross sections taken from fracture areas showed that cracks propagate along coarse structure of heat affected zone of duplex steel (Fig.7). Cracks were initiated at the austenite-ferrite phase boundaries. The paths of cracks propagation generally proceed along phase boundaries or across ferrite grains. It was noticed that cracks were stopped on elongated, perpendicular austenite grains, or them by.

Various edge preparations and consequently different amount of dilution of parent and welded materials and differences in heat inputs of the welds have no significant effect on crack behavior of tested samples. Structures of heat affected zones of all investigated samples were similar, regardless on heat input applied, and contain about 70% of ferrite with austenite precipitates. That structure occurred as the less resistant to SCC at test conditions.

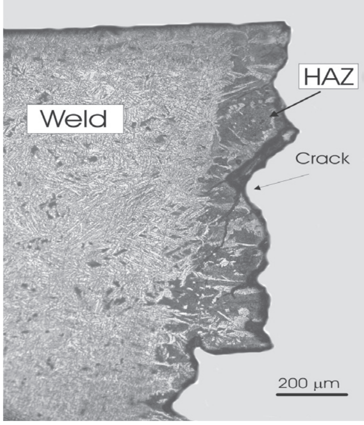

Fig. 7. Crack propagation paths in welded sample

4. Conclusions

1. Structure of stainless steels dissimilar welded joints remarkably influences their stresses corrosion cracking susceptibility.
2. Slow strain rate tests performed in $MgCl_2$ solution environment showed reduction of stress corrosion resistance of HAZ on duplex stainless steel side.
3. Corrosion cracks propagated mainly through ferrite phase, passing by austenite acicular grains.
4. Applied heat inputs in the range of 1.15 – 3.2 kJ/mm had no significant effect on stress corrosion resistance of welded joints.

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