

Hardness analysis of welded joints of austenitic and duplex stainless steels

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Abstract. Stainless steels are widely used in the modern world. The continuous increase in the use of stainless steels is caused by getting greater requirements relating the corrosion resistance of all types of devices. The main property of these steels is the ability to overlap a passive layer of an oxide on their surface. This layer causes that they become resistant to oxidation. One of types of corrosion-resistant steels is ferritic-austenitic steel of the duplex type, which has good strength properties. It is easily formable and weldable as well as resistant to erosion and abrasive wear. It has a low susceptibility to stress-corrosion cracking, to stress corrosion, to intercrystalline one, to pitting one and to crevice one. For these reasons they are used, among others, in the construction of devices and facilities designed for chemicals transportation and for petroleum and natural gas extraction. The paper presents the results which shows that the particular specimens of the JI joint representing both heat affected zones (from the side of the 2205 steel and the 316L one) and the weld are characterized by higher hardness values than in the case of the same specimens for the 2Y joint. Probably this is caused by machining of edges of the sections of metal sheets before the welding process, which came to better mixing of native materials and the filler metal. After submerged arc welding the 2205 steel still retains the diphasic, austenitic-ferritic structure and the 316L steel retains the austenitic structure with sparse bands of ferrite σ .

1. Introduction

Duplex steels are the result of combining the microstructure of ferritic and austenitic stainless steels. In the case of ferritic steel it is primarily a Nickel one and in the case of austenitic steel it is a Chromium-Nickel one. Their advantages results from properties of both mentioned groups of steels. The next advantage is that higher properties could be obtained with lower level of alloying elements, mainly expensive Nickel. What results in lower price of duplex steels. It cause that nowadays the maritime construction are more and more often design using the different duplex steels. It is also related with good weldability of this group of steels. There are analysed other areas of application [1, 2]. Among others duplex stainless steel offers also excellent resistant to corrosion and is characterised by the very high mechanical strength parameters. The high corrosion resistance of this steels ensures significantly more uptime than carbon steels and conventional stainless steels. It is particularly visible for the super duplex and hyper duplex steels. On the other hand the light duplex steels characterises by the same level of mechanical parameters like conventional steels.

The mechanical strength allows designing lighter constructions, which are more compact and which need less welding operations. The high mechanical properties are the result of combination both



the small grain size obtained during metallurgical process and the microstructure being two-phase combination of ferritic and austenitic grains. In the figure 1 are presented values of proof strengths for chosen duplex steels manufactured by Sandvik.

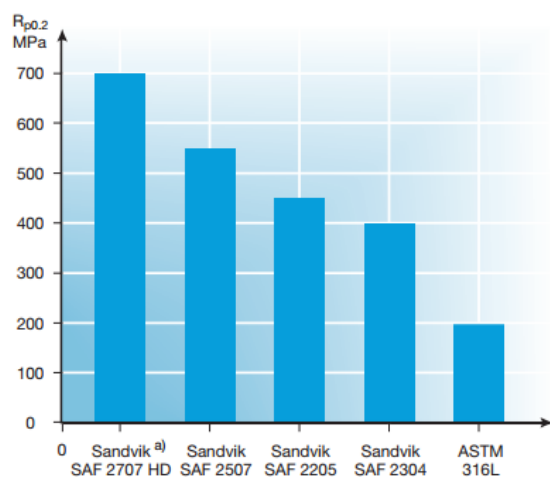


Figure 1. Comparison of minimum proof strength of the duplex stainless steels [3].

On the other hand duplex steels are also more prone to different precipitation. Mainly the sigma phase but also nitrides and carbides [4, 5]. For duplex steels this tendency is higher than for austenitic steels. It results in embrittlement and lower corrosion resistance. The formation of intermetallic phases occurs in the temperature range 600-1000°C and decomposition of ferrite occurs in the range 350-500°C (475°C embrittlement). For example in figure 2 is presented the relation between time and temperature causes reduction of the impact toughness with 50%.

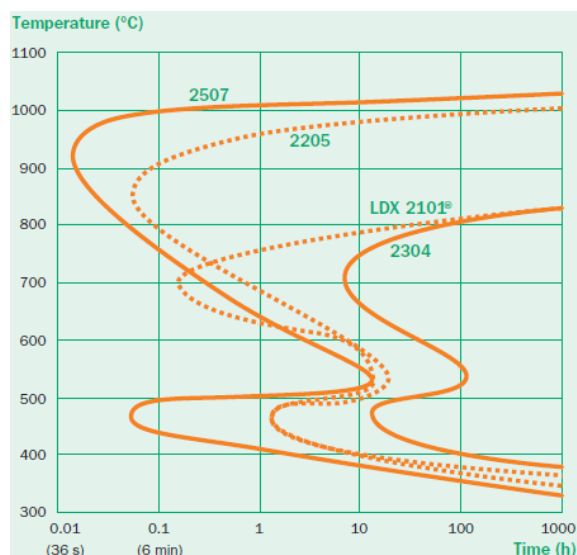


Figure 2. Curves for reduction of impact toughness to 50% [6].

Exposures at the mentioned temperatures should therefore be avoided. It is particularly important for welding operations. However during suitable welding operations and suitable heat-treatment the risk of embrittlement is low.

2. Hardness analysis of welded joints

To the investigations of hardness were subjected dissimilar welded joints of the 316L and 2205 stainless steels. The chemical composition of these steels is given in table 1. Welded joints were made using the automatic submerged arc welding method. In the welding process were used sections with

dimensions of 15x15x100 mm. It has been performed two-bead welding of the JJ and 2Y type. In the welding process was used the welding wire of the OK Autrod 16.86 type, with the diameter of 3.2 mm and the flux of the OK Flux 10.93 type. The chemical composition of the welding wire is shown in table 2 (the wire has a diphase structure).

Table 1. Chemical composition of 316L and 2205 steels.

Grade of steel	C	Cr	Ni	Mo	Mn	Si	P	S	Cu	N
	[% weight]									
According standard	≤ 0.030	16,5-18.5	10.0-13.0	2.0-2.5	≤ 2.0 0	≤ 1.0 0	(max) 0.045	≤ 0.015	-	≤ 0.11
316L										
According ladle analysis	0.021	16.78	10.28	2.05	1.02	0.54	0.024	0.001	-	0.045
According standard	(max) 0.030	21.0-23.0	4.5-6.5	2.5-3.5	≤ 2.0 0	≤ 1.0 0	(max) 0.035	(max) 0.015		0.10-0.22
2205										
According ladle analysis	0,021	22,7	5,95	3,2	0,88	0,39	0,030	0,020	-	0,16

Table 2. Chemical composition of the welding wire OK. Autrod 16.86.

	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	N
According ladle analysis	0.02	0.46	1.6	0.01	0.01	23.0	8.6	3.10	-	0.16

Before the welding process, the edges of the steel sheets were prepared in two ways, allowing obtaining two types of joints: of the JJ type and of the 2Y one (figure 3). This allows comparing the influence of the welding process on the properties of the obtained welded joint and the temperature distribution in joined materials.

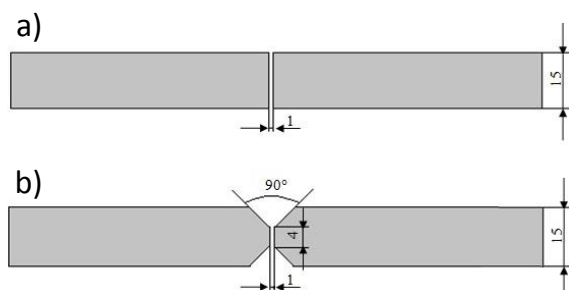


Figure 3. Preparation of edges of the metal sheet sections for submerged arc welding: (a) joint JJ, (b) joint 2Y.

It was applied two weld beads retaining inter-run temperature of approximately 100°C. The process parameters of submerged arc welding are shown in table 3. The figure 4 shows the locations from which the specimens of the welded joints have been taken from. One set for the joints of the JJ type (figure 4a) and one for the 2Y type (figure 4b). The rods of the 316L and 2205 steels were cut into

specimens of the size of 10x10x2mm. The size of specimens is related with the standard requirements according hardness tests.

Table3. Parameters of the welding process.

Joint	Bead	Current I [A]	Voltage U [V]	Welding speed Vsp [cm/min]	Line energy [kJ/mm]
JL	1	550-570	34	40	2.91
	2	560-600	33-34	38-40	3.06
2Y	1	460-500	32	38-40	2.40
	2	560-580	33	30	3.48

Hardness measurements were also performed, in the direction perpendicular to the axis of the weld, which was considered as the reference point. Measurements were made every 1 mm at the distance of approximately 1 cm, right and left of the center of the weld. Hardness measurements were taken for three different sections (figure 5).

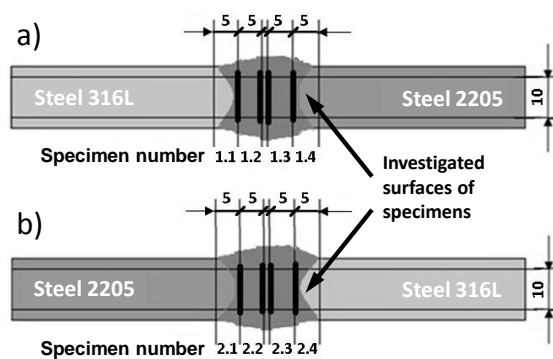


Figure 4. Location of specimens drawing:
(a) joint JL, (b) joint 2Y.

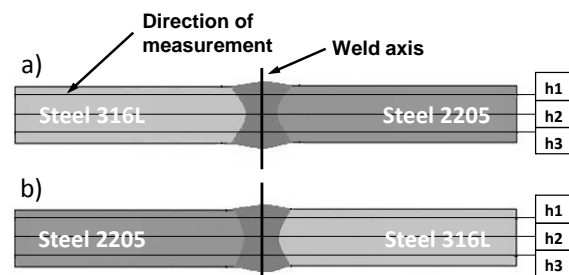


Figure 5. Places of hardness measurement with the Vickers method: (a) joint JL, (b) joint 2Y.

The obtained results are presented in the table 4. Hardness tests carried out in the section of a welded joint, including native materials and the weld itself, showed a diversity of hardness values. It could be observed in the table 4 for specific locations of analyzed specimens.

Table 4. Results of hardness measurements with the Vickers method for the JL joint.

Distance from the weld axis [mm]	Location	h1	Distance from the weld axis [mm]	Location	h2	Distance from the weld axis [mm]	Location	h3
12	2205	254	7	2205	254	9	2205	254
11		254	6		256	8		266
10		262	5		260	7		262
9	HAZ	256	4	HAZ	254	6	HAZ	292
		249			262			281

	249		264		266
8	251	3	262	5	258
7	270	2	264	4	270
6	268	1	274	3	268
5	264	0	266	2	270
4	256	-1	270	1	270
3	267	-2	281	0	266
2	266	-3	276	-1	262
1	274		243	-2	266
0	279	-4	247	-3	266
-1	272		243	-4	262
-2	267	-5	206	-5	260
-3	270	-6	199	-6	258
-4	266	-7	195		245
-5	267				237
-6	268			-7	206
-7	274			-8	191
-8	270			-9	188
	254				
-9	221				
	212				
-10	206				
-11	191				
-12	191				

To illustrate the hardness values of the specimens for the \perp joint it has been elaborated the graph of Vickers hardness (basing on the table 4). It is presented in the figure 6. Each line represents the different location (h1, h2, h3) of the analyzed specimens.

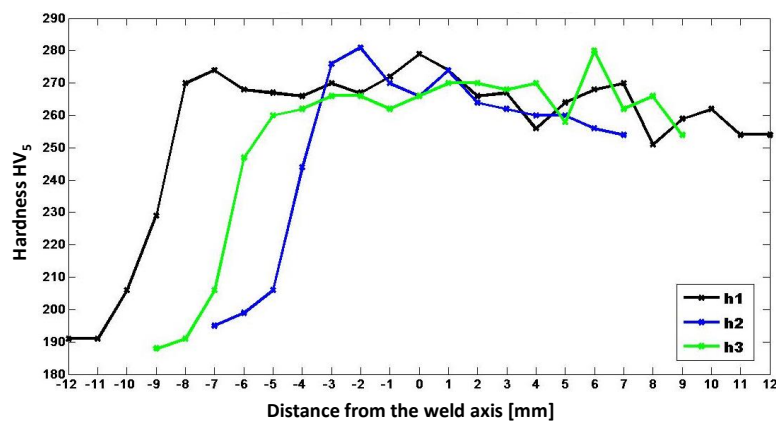


Figure 6. Vickers hardness diagram for the \perp joint.

The analogous tests have been realized for the 2Y joint. They showed the similar results as for the presented \perp joint.

3. Conclusions

Comparing the obtained results with that obtained for typical stainless steels [7, 8, 9] one should point same characteristic differences. Generally analysis of the obtained results allowed for next conclusions. In the 2205 steel the heat-affected zone is very narrow (less than 200 μm), while in the

316L one HAZ is much wider (more than 300 μm). The weld, formed after welding with the welding wire OK Autrod 16.86, is characterized by a heterogeneous, dendritic structure. This structure is created by a visible matrix of ferrite and ferrite σ , with acicular precipitates of primary austenite and of "rhombic" secondary austenite.

Analysing particular specimens of welded joints of both types it should be stated that in the case of the JI joint the heat affected zone (from the side of the 2205 steel and the 316L one) and the weld are characterized by higher hardness values than in the case of the 2Y joint. This is caused probably by the form of edges of the sections of metal sheets before the welding process. For the joint of the JI type, the hardest proved the weld (approx. 268 HV5), then the heat-affected zone (HAZ) from the side of the 2205 steel (approx. 263 HV5), respectively the 2205 steel (approx. 258 HV5), the HAZ from the side of the 316L steel (ca. 240 HV5), and finally the least hard proved the 316L steel (approx. 197 HV5). The highest hardness of the weld could prove good mixing of native materials and the filler, as well as good machining of edges of the sheet metal sections. In the case of joints of the 2Y type, the hardest was HAZ from the side of the 2205 steel (approx. 257 HV5). Slightly lower value of hardness was measured for steel 2205 itself (approx. 254 HV5). Starting from the weld itself (approx. 249 HV5), through HAZ from the side of the 316L steel (approx. 224 HV5) and the same 316L steel (approx. 195 HV5) the measured hardness decreased. Lowered values of hardness (HV5) for the 2Y joint, may also be caused (apart from material properties) by another method of preparing the edges of metal sheets before the welding process. Generally it should be stated that after submerged arc welding the 2205 steel still retains the diphasic, austenitic-ferritic structure and the 316L steel retains the austenitic structure with sparse bands of ferrite δ . In the 2205 steel the heat-affected zone is very narrow (less than 200 μm), while in the 316L one HAZ is much wider (more than 300 μm).

Comparing the obtained results with that obtained for typical stainless steels [7, 8, 9] one should point same characteristic differences. Generally analysis of the obtained results allowed for next conclusions. In the 2205 steel the heat-affected zone is very narrow (less than 200 μm), while in the 316L one HAZ is much wider (more than 300 μm). The weld, formed after welding with the welding wire OK Autrod 16.86, is characterized by a heterogeneous, dendritic structure. This structure is created by a visible matrix of ferrite and ferrite σ , with acicular precipitates of primary austenite and of "rhombic" secondary austenite. 5,6 Such structure is characteristic for both types of joints. It should state that the other investigations area should be search in the idea of linking the designs process of a structural form with the design process of the material form of a given technical mean [10, 11].

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