

# Investigation of corrosion of welded joints of austenitic and duplex stainless steels

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**Abstract.** Investigation of corrosion resistance of materials is one of the most important tests that allow determining their functional properties. Among these tests the special group consist electrochemical investigations, which let to accelerate the course of the process. These investigations allow rapidly estimating corrosion processes occurring in metal elements under the influence of the analysed environment. In the paper are presented results of investigations of the resistance to pitting corrosion of the steel of next grades: austenitic 316L and duplex 2205. It was also analysed the corrosion resistance of welded joints of these grades of steel. The investigations were conducted in two different corrosion environments: in the neutral one (3.5 % sodium chloride) and in the aggressive one (0.1 M sulphuric acid VI). The obtained results indicate different resistance of analysed grades of steel and their welded joints in relation to the corrosion environment. The austenitic 316L steel characterizes by the higher resistance to the pitting corrosion in the aggressive environment then the duplex 2205 steel. In the paper are presented results of potentiodynamic tests. They showed that all the specimens are less resistant to pitting corrosion in the environment of sulphuric acid (VI) than in the sodium chloride one. The 2205 steel has higher corrosion resistance than the 316L stainless steel in 3.5% NaCl. On the other hand, in 0.1 M H<sub>2</sub>SO<sub>4</sub>, the 316L steel has a higher corrosion resistance than the 2205 one. The weld has a similar, very good resistance to pitting corrosion like both steels.

## 1. Introduction

Duplex stainless steels are ferritic-austenitic ones. They combine many of the crucial properties of ferritic and austenitic steels. Particularly the properties of ferritic Nickel steels and austenitic Chromium-Nickel ones. Taking into account the combination of this stainless steel grades it is possible to determine that the duplex steels are characterises by high mechanical properties. Consequently they have, among others, high: yield point, tensile strength, ductility and resistance to pitting and stress corrosion. Taking into account high proof strength of the duplex stainless steels it should be noted that also they have a very good fatigue strength. Cyclic tensile stress tests show that the fatigue limit is found approximately when the maximum load in a cycle reaches the proof strength of the material. On the other hand if a duplex stainless steel is exposed to high temperatures for a longer period, its microstructure changes, which results in a reduction in mechanical properties. This causes that duplex steel are used in maritime industry and tested in other e.g. mining one [1, 2].

The next important factor of duplex steels is their relatively low production cost in comparison with austenitic steels. It results from lower level of scarce and expensive Nickel. During last years the



chemical composition of duplex steels and consequently their properties are improving. It is related with the extending content of Molybdenum as well as with Nitrogen to improve the stability of its microstructure. The content of this elements also results in higher resistance to localised and uniform corrosion. Duplex steels also have good weldability what broadens their field of application.

The main grades of duplex stainless steels are: 2101, 2304, 2205 and 2507. The 2101 steel belongs to the group of light-duplex steels. The 2304 and 2205 represent the group of normal/standard duplex steels. Finally the 2507 steel represents the group of super-duplex steels. The exemplar chemical composition of this steels is presented in the table 1. The chemical composition of a specific steel grade may vary slightly between different national standards.

**Table 1.** Chemical composition of chosen duplex steels [3].

Steel name	C	N	Cr	Ni	Mo	Others
2101	0.03	0.22	21.5	1.5	0.3	5Mn Cu
2304	0.02	0.10	23.0	4.8	0.3	Cu
2205	0.02	0.17	22.0	5.7	3.1	
2507	0.02	0.27	25.0	7.0	4.0	
Reference austenitic steel 316L	0.02		17.2	10.1	2.1	

The chemical composition of duplex steels is balanced to give approximately equal amounts of ferrite and austenite in solution-annealed condition. The content of ferritic and austenitic phases in the microstructure of a duplex steel is related with the annealing temperature. The higher the annealing temperature the higher the ferrite content.

As it was stated above the high corrosion resistance of the duplex steels is highly related with their microstructure and chemical composition. In the table 2 are presented main indexes describing corrosion resistance of steels.

**Table 2.** Corrosion resistance of chosen duplex steels [4].

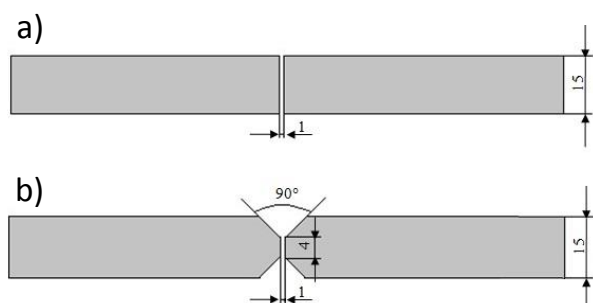
Steel name	PRE	CPT	CCT
2101	26	10	-10
2304	26	20	-4
2205	35	32	14
2507	43	78	39
Reference austenitic steel 316L	24	10	-10

The presented indexes represent different methods (according different standards) of determining the quantitative description of steel corrosion resistance. The first one - Pitting Resistance Equivalent (PRE) is the indicator of resistance to pitting corrosion, which is calculated by chemical composition. The next - Critical Pitting Temperature (CPT) determines the critical temperature of pitting corrosion (according ASTM G150 or G48). The last one - Critical Crevice Temperature (CCT) presents the critical temperature of the occurrence of crevice corrosion (ASTM G48).

## 2. Investigation of corrosion resistance

To the investigations of a corrosion resistance were subjected dissimilar welded joints of the 316L and 2205 stainless steels [5, 6]. Welded joints were made using the automatic submerged arc welding method [6]. In the welding process were used sections with dimensions of 15x15x100 mm. It has been performed two-bead welding of the J 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. Before the welding process, the edges of the steel sheets were prepared in two ways, allowing obtaining two types of joints: of the  $\llcorner$  type and of the 2Y one (figure 1).



**Figure 1.** Preparation of edges of the metal sheet sections for submerged arc welding: (a) joint  $\llcorner$ , (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.

**Table 3.** Parameters of the welding process.

Joint	Bead	Current I [A]	Voltage U [V]	Welding speed V <sub>sp</sub> [cm/min]	Line energy [kJ/mm]
$\llcorner$	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

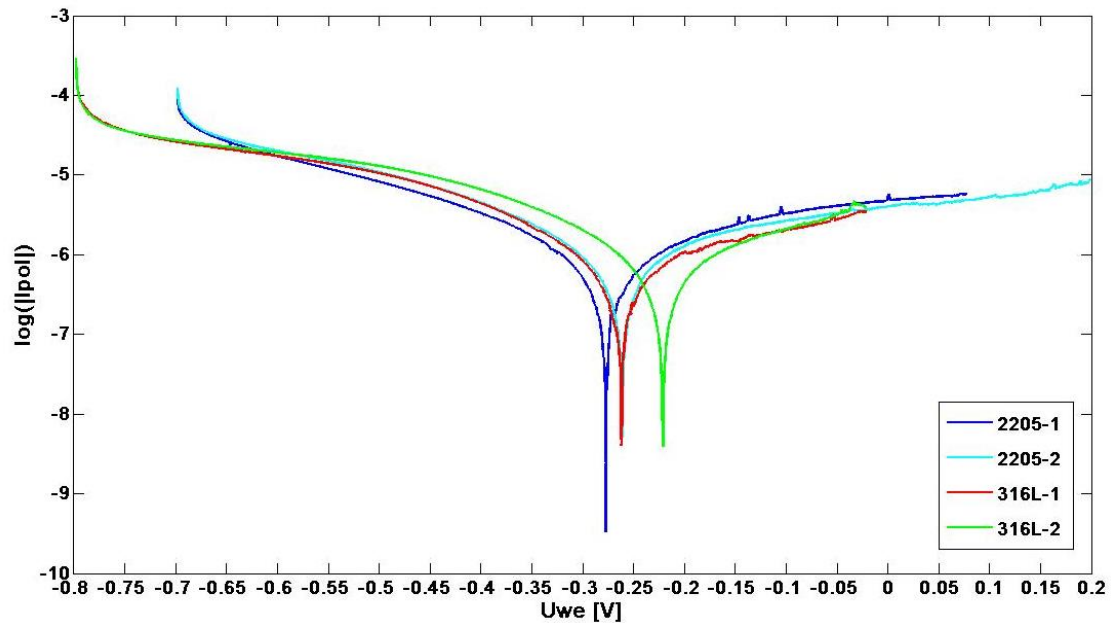
In order to investigate the corrosion resistance the electrochemical corrosion tests were performed, consisting in determining polarization curves using the potentiodynamic method. The laboratory stand for investigation the corrosion resistance consisted in the ATLAS 0531 potentiostat (of the Atlas Sollich) connected to a computer with appropriate software and to an electrochemical cell filled with the investigated solution. The measuring electrode was the steel one and the reference electrode was the silver chloride one Ag/AgCl, with the standard potential of +0.22V in relation to the hydrogen electrode (at temperature of 25°C). The investigated specimen was the anode. Corrosion tests were performed in two environments: the neutral one - 3.5% NaCl (pH=7.0) and the acid one - 0.1 M H<sub>2</sub>SO<sub>4</sub> (pH=1.0) at room temperature (approx. 20°C).<sup>4</sup> Before each test every specimen was grinded and polished, and then purified with the ethyl alcohol. Immediately before measurement, the surface of the specimen of 0.384 mm<sup>2</sup>, was additionally purified with the acetone. For each of the specimens was determined the range of values of the input potential, changing with the rate of  $v_{pot}=0.5$  mV/s, for which the measurements were recorded. The anodic polarization curves, recorded during the tests, providing a basis for determining the following values: the corrosion potential  $E_{kor}$  [V], the current density  $i_{kor}$  [A/cm<sup>2</sup>] and the polarization resistance  $R_p$  [ $\Omega \times \text{cm}^2$ ]. To determine these parameters the method of Tafel curves with activation polarization was used. All values were determined by the data analysis software (AtlasLab). In table 4 and are compiled all designated parameters for subsequent specimens. This table shows the values of the parameters recorded in a neutral environment, simulating sea water (3.5% NaCl).

**Table 4.** Results of potentiodynamic tests  
 after utilization of the Tafel analysis  
 with an activation polarization for 3.5% NaCl.

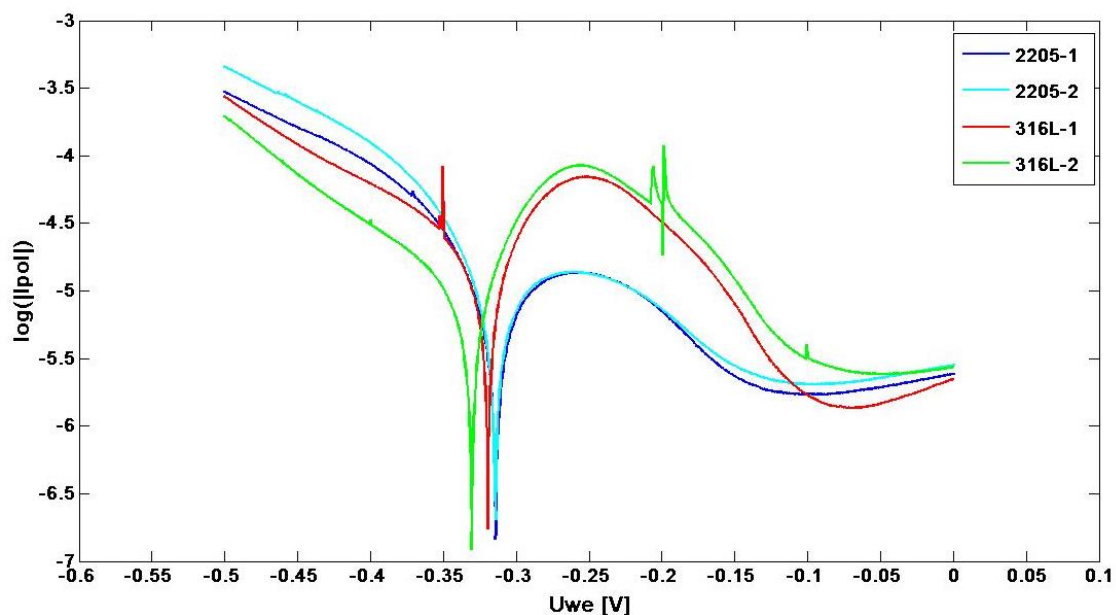
Environment		Activation polarization		
Specimen		$E_{kor}$ , [V]	$i_{kor}$ [A/cm <sup>2</sup> ]	$R_{pol}$ [ $\Omega \cdot \text{cm}^2$ ]
3.5% NaCl	316L_1	-220.29·10	0,62·10 <sup>-6</sup>	73.35·10 <sup>3</sup>
	316L_2	-189.38·10	1.09·10 <sup>-6</sup>	42.33·10 <sup>3</sup>
	2205_1	-295.37·10	0.85·10 <sup>-6</sup>	74.46·10 <sup>3</sup>
	2205_2	-237.67·10	0.77·10 <sup>-6</sup>	62.17·10 <sup>3</sup>
	1_1	-220.84·10	0.71·10 <sup>-6</sup>	58.35·10 <sup>3</sup>
	1_2	-243.01·10	1.12·10 <sup>-6</sup>	79.94·10 <sup>3</sup>
	1_3	-232.78·10	0.69·10 <sup>-6</sup>	109.36·10 <sup>3</sup>
	1_4	-226.74·10	1.55·10 <sup>-6</sup>	58.64·10 <sup>3</sup>
	2_1	-251.39·10	0.53·10 <sup>-6</sup>	88.09·10 <sup>3</sup>
	2_2	-245.37·10	0.47·10 <sup>-6</sup>	120.51·10 <sup>3</sup>
	2_3	-279.49·10	0.79·10 <sup>-6</sup>	90.60·10 <sup>3</sup>
	2_4	-222.44·10	0.81·10 <sup>-6</sup>	91.24·10 <sup>3</sup>

Figure 2 show the potentiodynamic curves, recorded during tests of corrosion resistance of the 316L and 2205 steels and their welded joints in the investigated corrosive environments. From these curves, shown in figure 2 and the data from table 4, it could be concluded that the steels 316L and 2205 have a similar, good resistance to pitting corrosion in the environment of 3.5% sodium chloride. However, it should be noted that the duplex steel has a slightly higher corrosion resistance in that environment, as indicated by the low corrosion current density ( $i_{kor}=0.77 \cdot 10^{-6}$ ) and by the high value of the polarization resistance ( $R_{pol}=74.46 \cdot 10^3$ ). Interpreting the curves recorded for the specimens in sulfuric acid (VI) (figure 3), it should be noted that both the 316L steel and L2205 one have poorer resistance to pitting corrosion than in the environment of sodium chloride. It is testified by the significantly higher values of the corrosion current density ( $i_{kor}$ ) and lower values of the corrosion potential ( $E_{kor}$ ) as well as the polarization resistance ( $R_{pol}$ ). According to data obtained from the method of Tafel curves the 316L steel, in  $\text{H}_2\text{SO}_4$ , is characterized by a few higher value of the polarization resistance ( $R_{pol}=1,94 \cdot 10^3$ ), but by the much lower value of the corrosion current density

( $i_{kor}=12.69 \cdot 10^{-6}$ ) than the 2205 steel ( $i_{kor}=74.33 \cdot 10^{-6}$ ), which indicates its higher corrosion resistance in sulfuric acid (VI).



**Figure 2.** Potentiodynamic curves for 2205 and 316L steels in 3.5% NaCl.



**Figure 3.** Potentiodynamic curves for 2205 and 316L steels in 0,1 M H<sub>2</sub>SO<sub>4</sub>.

Comparing the parameters for these two types of joints, it is clear that the specimens are characterized by a similar corrosion resistance in all of investigated environments.

### 3. Conclusions

Generally the corrosion test shown the accordance with the general tendency [8, 9]. Analyzing the corrosion resistance of native materials (steels 316L and 2205) and of specimens containing additional weld material (1\_2, 1\_3, 2\_2, 2\_3), it could be found that in the solution of sodium chloride and

sulfuric acid (VI) the specimens drawn from welds are characterized by similar pitting corrosion resistance like the specimens of the native material. However it should be stated that detailed analysis of specimens allow stating that investigated materials are slightly less resistant to pitting corrosion in the environment of sulfuric acid (VI) than in the sodium chloride one. As it was foreseen the 2205 steel characterizes by the higher corrosion resistance then the reference austenitic steel 316L in 3.5% NaCl. The opposite tendency is observed for the 0.1 M H<sub>2</sub>SO<sub>4</sub> solution. In both cases the weld characterizes by the same very good resistance to pitting corrosion. The same relationship could be seen in the heat-affected zones of both steels. Moreover it should be stated that the type of the welded joint (type JI or type 2Y) has no effect on the corrosion resistance of the joint, since the drawn specimens had similar values of such parameters like: the corrosion current density ( $i_{kor}$ ), the corrosion potential ( $E_{kor}$ ) and the polarization resistance ( $R_{pol}$ ). The hardness measurements with the Vickers method have shown that the 2205 steel has a higher hardness than the 316L one. The same relationship could be seen in the heat-affected zones of both steels.

It should be emphasized that obtained results could be applied for improving the possibility of constructional methods applied by engineers [10, 11]. Hence the next investigation area should be searching for the link between the material and structural design processes.

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