CORROSION RESISTANCE OF THE WELDED AISI 316L AFTER VARIOUS SURFACE TREATMENTS

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Resume
The main aim of this work is to monitor the surface treatment impact on the corrosion resistance of the welded stainless steel AISI 316L to local corrosion forms. The excellent corrosion resistance of austenitic stainless steel is caused by the existence of stable, thin and well adhering passive layer which quality is strongly influenced by welding. Therefore surface treatment of stainless steel is very important with regard to its local corrosion susceptibility. Surfaces of welded stainless steel were treated by various mechanical methods (grinding, garnet blasting). Surface properties were studied by SEM, corrosion resistance was evaluated after exposition tests in chlorides environment using weight and metalographic analysis. The experimental outcomes confirmed that the mechanical finishing has significant effect on the corrosion behavior of welded stainless steel AISI 316L.

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1. Introduction

Stainless steels are construction materials with excellent corrosion resistance in aggressive environments. Their corrosion resistance depends on structure and chemical composition, especially by presence of the alloy elements such as Cr, Mo, Ti, Ni, N and also significantly on the surface treatment. Because of their good mechanical properties (strength, resistance to high temperature ductility and toughness) and weldability they are used in conditions that require high reliability and durability of the material [1 - 3]. Despite these properties, austenitic stainless steels are sensitive in certain corrosive environments to local corrosion attack (pitting, intercrystalline corrosion) [3 - 5].

High temperature of welding evokes in this material change of structure by formation of undesirable phases, as well as this factor determines the properties of the oxide layer, consequently their corrosion resistance can be therefore reduced. Welding heat in austenitic steels affects mainly filler (or melted metal) and the area between the weld and base material (heat affected zone HAZ). The size and character of the heat affected zone in the base metal depends on chemical composition of stainless steel and welding parameters. The higher carbon level of the material being welded, the greater likelihood the welding thermal cycles will allow chromium carbides precipitation, which could result in decreasing of corrosion resistance [6 - 8]. Using of the low carbon type AISI 316L can minimize or avoid effect of these negative factors from corrosion point of view. High temperature during

welding also influenced oxidation processes on the metal surface and changes character of oxidation products. Therefore it is appropriate to apply surface treatment after [9 - 11].

Withal fully austenitic weld deposits are more susceptible to cracking during welding. For this reason types 316 and 316L "matching" filler metals are formulated to solidify with a small amount of ferrite in the microstructure to minimize cracking susceptibility [12].

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This work is focused on monitoring of corrosion behaviour of weld metal (WM), heat affected zone (HAZ) and base material (BM) in AISI 316L steel after various surface treatments.

2. Experimental material

The AISI 316L austenitic Cr-Ni-Mo stainless steel (STN 41 7349) was used as an experimental material. The chemical composition is in Table 1.

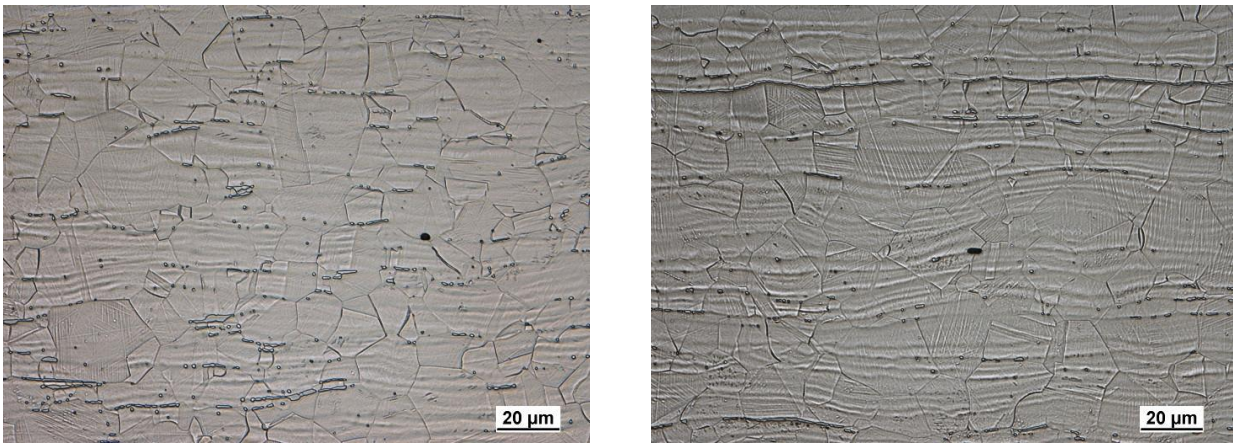
The experimental material has a low susceptibility to pitting in environments containing chlorides because of low carbon content "L" (0.013 wt.%) which drops chromium carbide precipitation. Molybdenum-bearing in the experimental austenitic stainless steel decreases sensitivity to cracking during welding and improve quality of passive layer. Due to molybdenum additives, the AISI 316L stainless steel has too good plasticity and high resistance against acids and deep local corrosion. It is non-ferromagnetic steel, with higher yield stress and strength.

The microstructure of the AISI 316L steel in transverse and longitudinal section is in Fig. 3. In transverse section (Fig. 1a) the base material microstructure is created by austenitic polyedric grains with row deformation texture and deformation twins. In longitudinal section is very strong deformation texture and presence of delta ferrite, inclusion (Fig. 1b).

Table 1

Chemical composition of AISI 316L stainless steel.

element	Cr	Ni	Mo	Mn	C	Si	N	P	S	Fe
Content element (wt.%)	16.51	10.21	2.10	0.91	0.013	0.65	0.015	0.038	0.006	rest



a) transverse section *b) longitudial section*

Fig. 1. AISI 316 L stainless steel microstructure, etch. 10 ml HF, 30 ml HNO_3, 20 ml glycerin.

Table 2

Welding parameters of the AISI 316L by TIG method.

Filler diameter (mm)	Electrode diameter (mm)	Used current (A)	Argon flow ($l.min^{-1}$)
2.4	1.6	115	7
No filler	1.6	92	7

3. Experiment

For the experiment 18 samples were used. Weld areas were prepared by water jet cutting. These specimens from sheet metal were welded by TIG method with and without filler using.

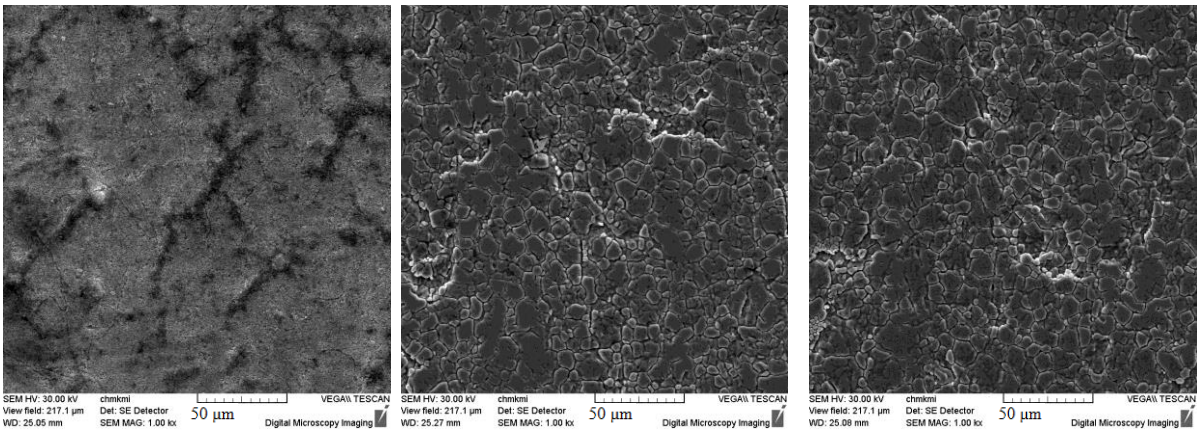
Specimens were cut and prepared from the original plate AISI 316L (120 mm x 60 mm) by water jet cutting. The dimensions of the plate were selected to ensure the ease and homogeneity of the welding process (such as work-piece clamping and manipulation, avoiding high residual stresses and using only one welding filler rod when needed). Water jet cutting was carried out at a pressure of 400 bar, cutting speed 100 $mm.hr^{-1}$. The weld surfaces were degreased before welding. Welding parameters in argon atmosphere are shown in Table 2. Rod of filler metal has the same chemical composition as the base material AISI 316L steel. During the welding process gas argon was used for double protection against oxidation.

Surfaces of the welded specimens were prepared by grinding and sandblasting. Initial surface grinding was performed to level up the surface of the welded area. This was done by using surface grinding with Al_2O_3 belt with grit of 80. Then each sample was grinded by Al_2O_3 belt with grit of 180. This provided the welded surface with better surface finishing and better roughness. Sand blasting was performed on some samples with pressure of 6 bars and garnet abrasive grit of 80 (31 wt% SiO_2, 21.6 wt% Al_2O_3, 37 wt% FeO, 7.4 wt% MgO). The blast pointed at 90 degree angle and lasted for about 60 seconds for each sample. Surface of third group of specimens was without mechanical treatment.

3.1. SEM surface evaluation after various treatments

Surface of the specimens was assessed by scanning electron microscope (SEM). The analysis was focused on the character of the surface in the WM, HAZ and BM. Using EDX analysis it was examined and compared the chemical composition of the observed areas of the TIG welded specimens with filler metal. In Fig. 2 the surface of untreated specimen is shown. It is visible difference between surfaces of welded metal, heat affected zone and base material. The differences in chemical composition confirmed the EDX analysis too (Table 3). It was determined high amount of C in the weld metal created as weld residual. The increased oxygen content indicates very intensive surface oxidation in comparison with the oxygen content in the heat-affected zone and the base material.

Surface of specimens machined by grinding was study almost in the same areas. As it can be seen in Fig. 3 the character of grinding surface is in all observed areas similar as well as their chemical composition (Table 4). Products of reactions during welding were removed and the grinding surface became homogeneous. Surface treatment by blasting is not suitable finishing for this type of material. By this way it is not reached homogeneity in chemical composition of studied areas (Table 5). The roughness and surface topography are poor as it is seen in Fig. 4. In the created crevices corrosive solution can be concentrated resulting restriction of passive layer formation. The surface is also contaminated by blasting agents and some welding products are pushed into the metal surface. These factors can considerably influence susceptibility to local corrosion.



a) WM *b) HAZ* *c) BM*

Fig. 2. Surface of the untreated specimen after welding in the locality of WM, HAZ and BM.

Table 3

Chemical analyses of chosen elements on the untreated surfaces in WM, HAZ and BM.

Elements	Weight %	Atomic %
O	24,22	42,12
Si	0,85	0,84
S	0,02	0,02
Cr	16,10	8,61
Fe	33,53	16,7
Ni	12,43	5,89
Mo	1,94	0,56

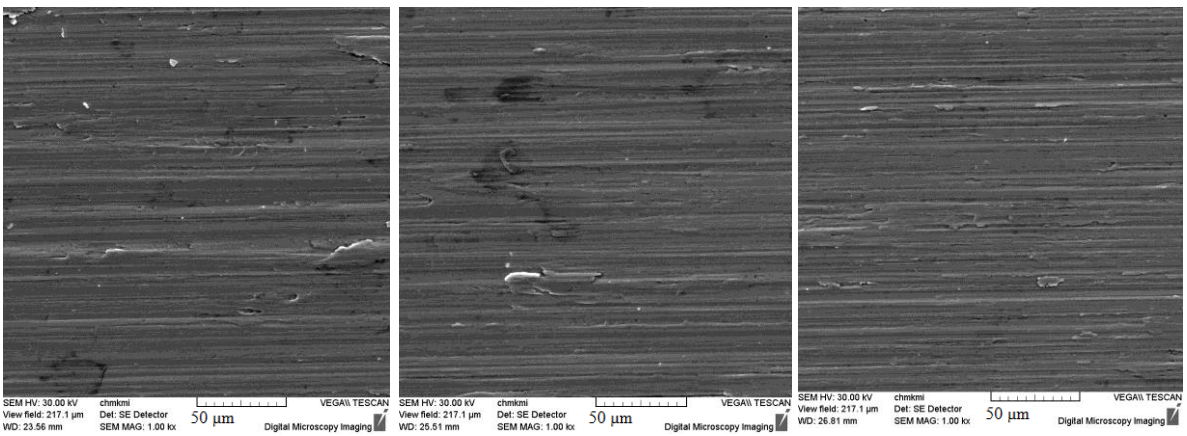
a) WM

Elements	Weight %	Atomic %
O	5,88	14,69
Si	0,33	0,47
S	0,00	0,00
Cr	13,91	10,69
Fe	62,46	44,72
Ni	8,47	5,77
Mo	2,12	0,88

b) HAZ

Elements	Weight %	Atomic %
O	0,29	0,82
Si	0,43	0,70
S	0,11	0,15
Cr	14,71	12,82
Fe	66,79	54,16
Ni	9,48	7,31
Mo	2,07	0,98

c) BM



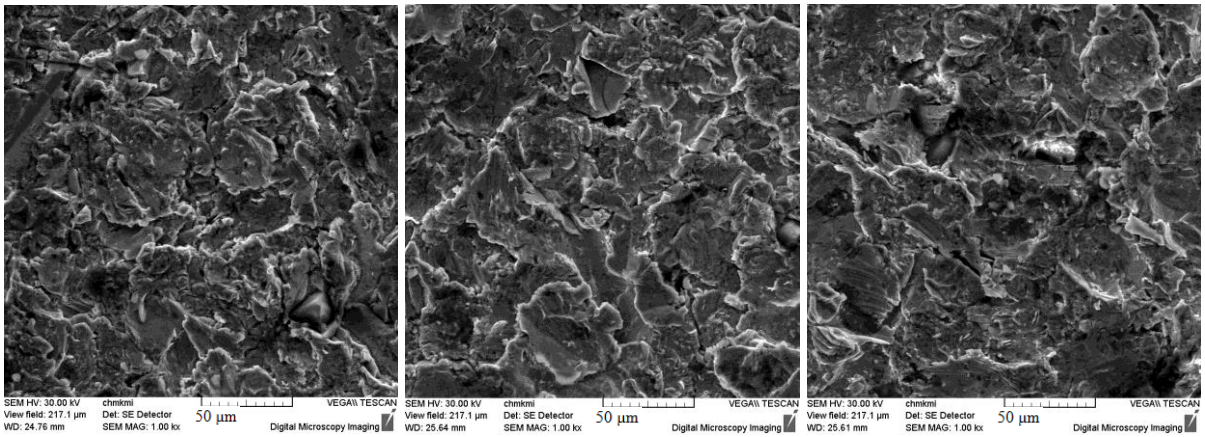
a) WM *b) HAZ* *c) BM*

Fig. 3. Surface of the ground specimen after welding in the locality of WM, HAZ and BM.

Table 4

Chemical analyses of chosen elements on the grinded surfaces in WM, HAZ and BM.

Elements	Weight %	Atomic %	Elements	Weight %	Atomic %	Elements	Weight %	Atomic %
O	0,52	1,50	**O**	0,29	0,81	**O**	0,56	1,62
Si	0,47	0,76	**Si**	0,43	0,69	**Si**	0,36	0,59
S	0,06	0,09	**S**	0,00	0,00	**S**	0,08	0,12
Cr	14,97	13,20	**Cr**	15,36	13,33	**Cr**	15,23	13,48
Fe	67,21	55,19	**Fe**	66,01	53,33	**Fe**	66,89	55,16
Ni	9,11	7,12	**Ni**	9,29	7,14	**Ni**	9,45	7,41
Mo	2,14	1,02	**Mo**	2,34	1,10	**Mo**	2,05	0,98
	a) WM			*b) HAZ*			*c) BM*	



a) WM *b) HAZ* *c) BM*

Fig. 4. Surface of the blasted specimen after welding in the locality of WM, HAZ and BM.

Table 5

Chemical analyses of chosen elements on the grinded surfaces in WM, HAZ and BM.

Elements	Weight %	Atomic %	Elements	Weight %	Atomic %	Elements	Weight %	Atomic %
O	10.36	23.71	**O**	11.07	24.46	**O**	16.71	31.75
Mg	1.44	2.18	**Mg**	1.40	2.03	**Mg**	1.82	2.27
Al	1.60	2.17	**Al**	1.42	1.86	**Al**	3.23	3.64
Si	3.03	3.95	**Si**	3.04	3.82	**Si**	4.8	5.19
Ca	0.68	0.62	**Ca**	0.62	0.54	**Ca**	1.05	0.8
Cr	13.01	9.17	**Cr**	12.6	8.57	**Cr**	10.19	5.96
Fe	53.22	34.91	**Fe**	54.2	34.32	**Fe**	46.83	25.49
Ni	8.23	5.13	**Ni**	7.56	4.56	**Ni**	5.51	2.86
Mo	2.78	1.06	**Mo**	1.53	0.56	**Mo**	1.32	0.42
	a) WM			*b) HAZ*			*c) BM*	

3.3. Immersion test

The welded specimens of AISI 316L with various surface finishing were tested for resistance to pitting corrosion. The immersion test is carried out in the solution of 6% $FeCl_3$ according to the standard ASTM G 48 [13]. The environment temperature during the test is 21°C.

After exposition 72 hour in the test solution the samples are cleaned in demineralized water and dried. The weight losses are determined with the accuracy 10^{-5} g and the corrosion rate is calculated. In Table 6 there are the results of the corrosion test.

Table 6

Corrosion rates of the AISI 316L stainless steel in solution $FeCl_3$.

Weld technology	Type of surface treatment	Average weight losses (g)	Average corrosion rates ($g/m^2.h^{-1}$)
TIG with filler	**without treatment**	0.28217	3.1352
TIG with filler	**grinding**	0.2574	2.8600
TIG with filler	**blasting**	0.3800	3.9777

Weld technolog	Type of surface treatment	Average weight losses (g)	Average corrosion rates ($g/m^2.h^{-1}$)
TIG without filler	**without treatment**	0.31488	3.4986
TIG without filler	**grinding**	0.28204	3.1337
TIG without filler	**blasting**	0.39604	4.4004

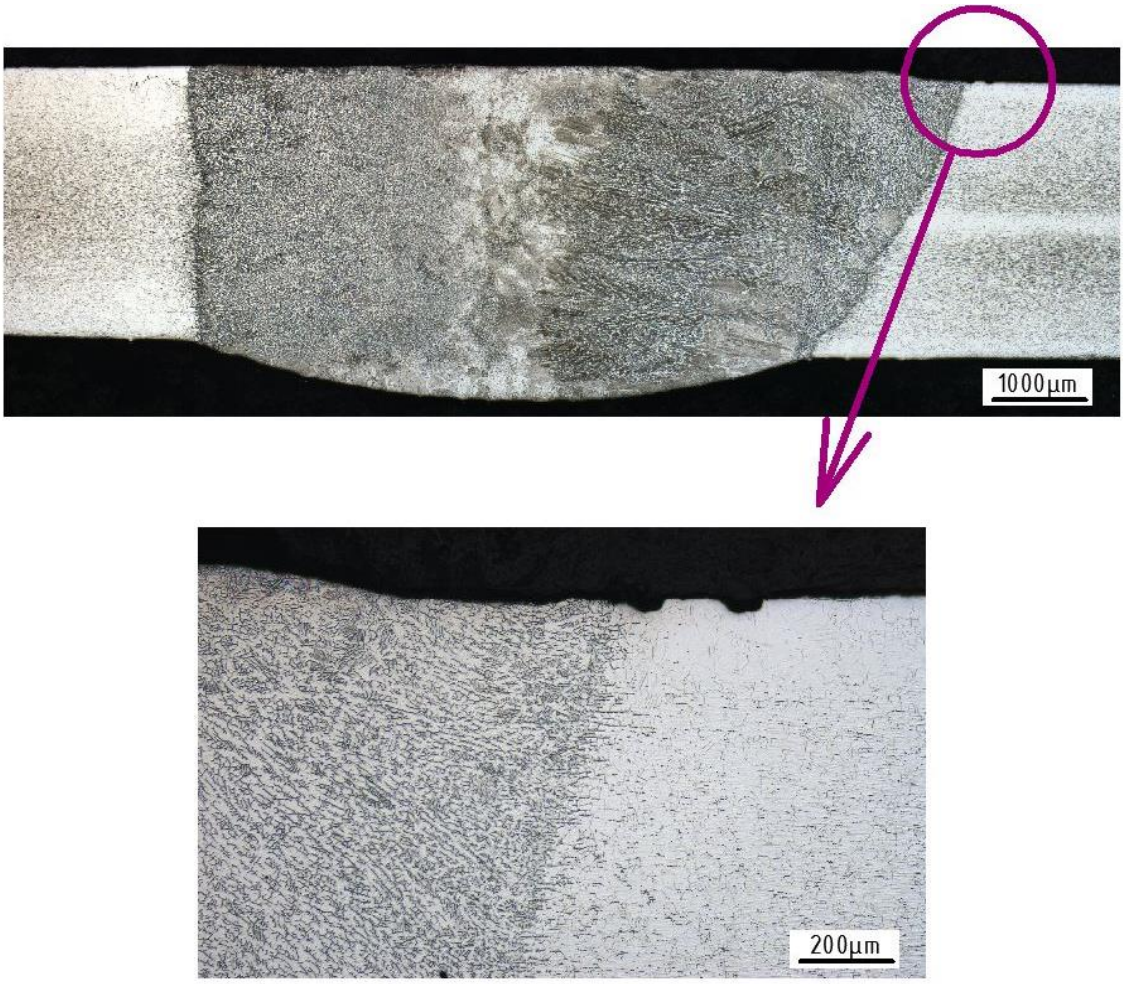


Fig. 5. Corrosion attack of the specimen with untreated surface.

3.4. Metallographic analysis after immersion tests

The light metallography was used for evaluation of character and intensity of corrosion attack of the samples with different surface treatment (welded with and without filler metal). Untreated specimens welded with filler metal are attacked by corrosion mostly at the weld metal and heat affected zone (Fig. 5) as well as the specimens welded without filler metal. Surface-welded steel AISI 316L with filler, treated after welding by grinding (Fig. 6) was not visible attacked by corrosion. On the all specimen surfaces welded without filler only rare small corrosion pits were observed. In Fig.7 the intensive pitting corrosion on the blasted specimens after welding (without and with filler material) is seen. The metallographic evaluation is in a good agreement with calculated corrosion rates.

Fig. 6. Corrosion attack of the specimen with ground surface.

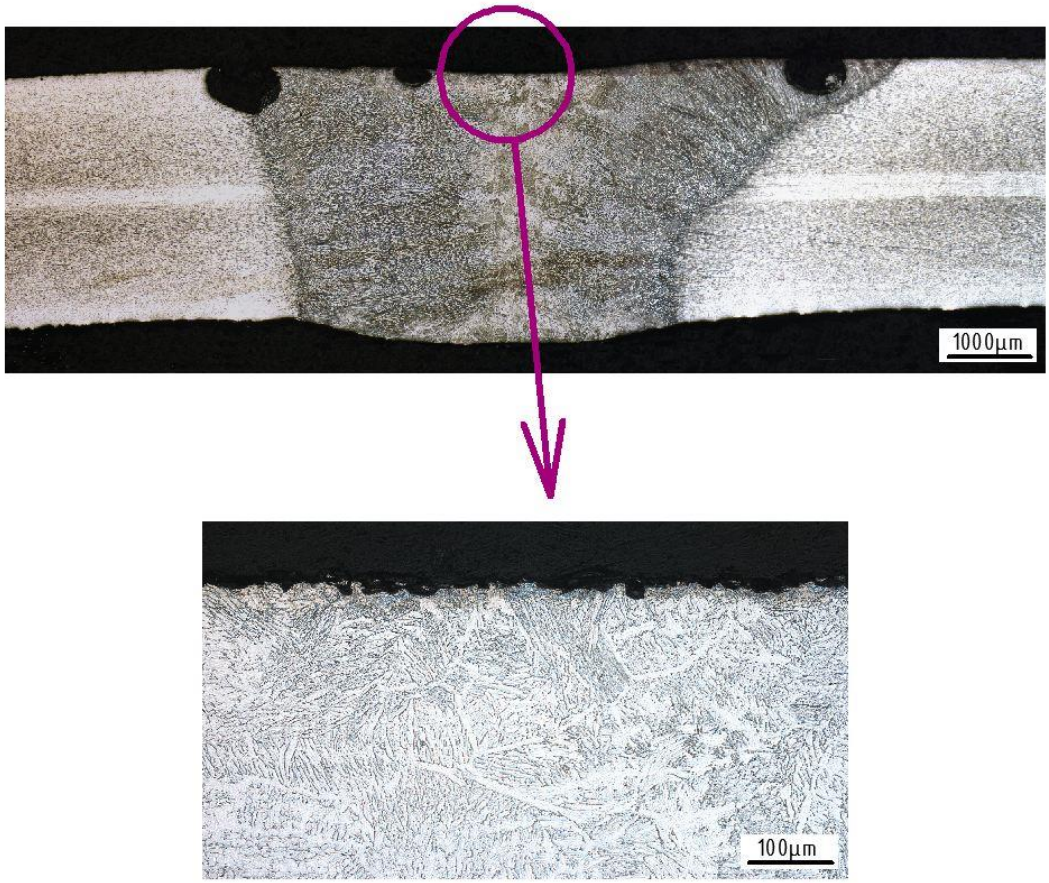


Fig. 7. Corrosion attack of the specimen with blasted surface.

4. Conclusions

Based on the results of the immersion tests and metallographic evaluation of welds after exposure to 6% $FeCl_3$ solution and evaluation of surface character according to scanning electron microscopy can be stated:

- The highest corrosion resistance was observed on the ground specimens. This mechanical treatment removes from the surface residual products of welding and oxidation products resulting high welding temperature. The homogeneous chemical composition and purity of surface makes possible creation of continuous passive layer with good protection properties. Corrosion rate was 1.4 times lower than blasted specimens and 1.1 times than untreated ones.
- Blasting is unsatisfactory method of mechanical surface treatment of welds AISI 316L steel, because of corrosion process acceleration. This finishing increases the surface roughness and subsurface deformation occurs. The blasting agents and products of welding are pressed into the subsurface layers of material. These phenomena disturb the integrity of the passive layer and decrease the corrosion resistance.
- The specimens with untreated surface after welding have a higher corrosion resistance than specimens with blasted surface, but lower corrosion resistance comparing with the specimens finished by grinding.
- Corrosion resistance of the TIG welded specimens is different with and without using of filler metal. Corrosion attack of the specimens welded without filler (for all types of the tested surfaces) is about 1.1 times higher than of the specimens welded with filler metal. The differences may be caused by different welding conditions. The various surface finishing has the same effect on the corrosion behavior of the specimens welded by both ways.

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