

Surface treatment of the AISI 316L after welding and study of corrosion behaviour

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Abstract

This work deals with impact of the surface treatment on corrosion resistance of the stainless steel AISI 316L welded by the TIG method. Chemical and mechanical treatment changes chemical composition, component size, surface free energy and topography of surface. These specifications have a great influence on corrosion resistance of the stainless steel which is caused by existence of stable, thin and well adherent passive layer. Surfaces of the welded stainless steel were modified by two mechanical treatment methods (grinding, garnet blasting) and one chemical (pickling). The properties of variously prepared surfaces were studied by SEM. Corrosion behaviour of the specimens with different surface treatment was investigated by exposition tests in the 6% FeCl₃ solution and also by the electrochemical polarization in the NaCl solution.

Keywords

AISI 316L stainless steel · TIG welding · corrosion resistance · surface finishing · electrochemical test

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1 Introduction

Consumption and production of stainless steels at the present continues to grow due to their excellent corrosion resistance in aggressive environments and good mechanical properties and weldability. Therefore they are used in conditions that require high reliability and durability of the material. The protective ability is affected by metal microstructure, chemical composition (especially by the elements such as Cr, Mo, Ti, N) and also significantly by the surface treatment (Dadfar et al. [3], Liptáková [5], Perren et al. [7], Sedriks et al. [9], Szklarska-Smialowska [10]). Mechanical surface treatments are commonly used in industries and believed to have better mechanical properties and corrosion resistance. The treatments, such as grinding and garnet blasting are often used. Actually, even the size and quality of grinding and garnet blasting affect the surface properties of the stainless steels (roughness, component size, chemical composition, etc.) and these affect the corrosion resistance. Chemical surface treatment (pickling) is believed to enhance the surface purity and also increases the corrosion resistance (Halamová et al. [4], Liptáková [5], Zatkalíková et al. [11]).

Since the experimental AISI 316L has the best weldability among stainless steels and low carbon content, carbide precipitation has less chance to occur during welding. The high content of chromium, nickel and addition of molybdenum can significantly affect corrosion resistance of this stainless steel. High temperature of welding changes the steel structure by formation of carbides, various phases, ferrite and modification of grain size. Properties of oxide layers on the surface are changed too (Alvarez-Armas [1], Mathiesen et al. [6], Sahlaoui et al. [8]). In addition, the factors such as welding technology, filler materials have to be kept very strictly to minimize negative thermal influence.

2 Experimental material and surface treatment

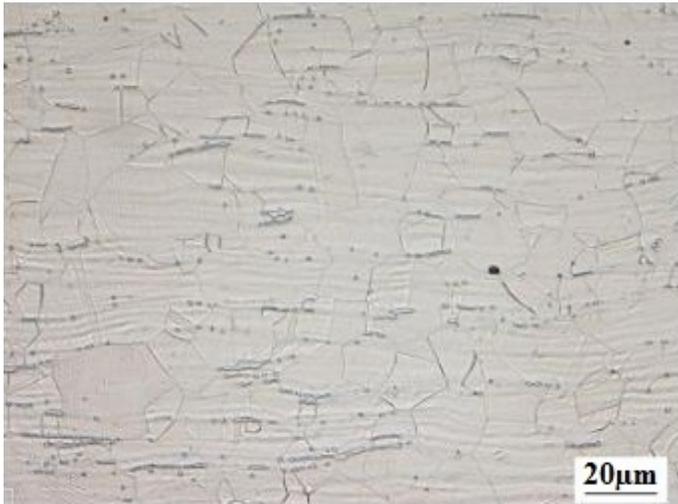
The austenitic stainless steel AISI 316L was used as an experimental material. The chemical composition is shown in Tab. 1.

The specimens were prepared for light microscopy using wet grinding and etching in the solution of 10 ml of 40% HF, 30

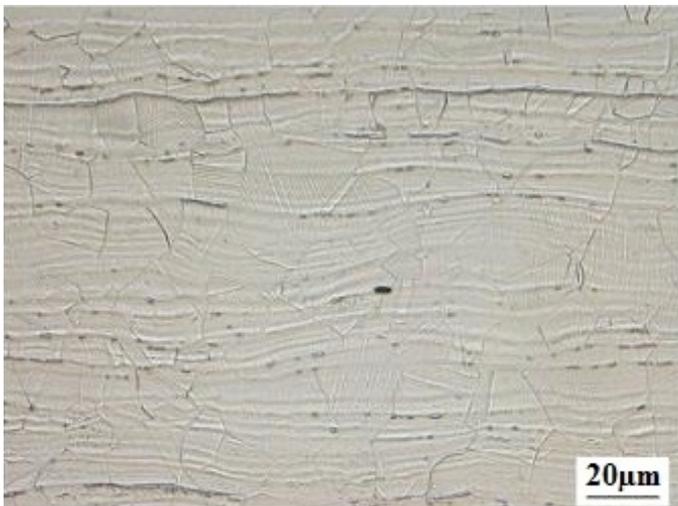
Tab. 1. Chemical composition of the AISI 316L

Element	Cr	Ni	Mo	Mn	C
Content of elements [wt.%]	16.51	10.21	2.10	0.91	0.013
Element	Si	N	P	S	Fe
Content of elements [wt.%]	0.65	0.015	0.038	0.006	rest

ml of 65% HNO₃ and 20 ml glycerine. The microstructure of the AISI 316L steel (Fig. 1) is created by austenitic polyhedral grains with low deformation texture and deformation twins. In longitudinal section, deformation texture is very strong and there is present delta ferrite and inclusions.



(a) transverse



(b) longitudinal

Fig. 1. The microstructure of the used AISI 316L stainless steel in different directions

The specimens were cut and prepared from the original plate AISI 316L (120 × 60 mm) by laser cutting and welded by TIG method with using filler metal. Laser cutting was carried out at a pressure of 10 bar, cutting speed of 3700 mm · min⁻¹ and power 4 kW. The dimensions of the plate were selected to ensure the homogeneity of the welding process. Dimension of specimen is 50 × 25 mm with thickness 3 mm. The welding parameters are

in Tab. 2. Filler metal had the same chemical composition as the base material AISI 316L steel. During the welding process argon gas was used for a protection against oxidation.

Tab. 2. Welding parameters of the used TIG method

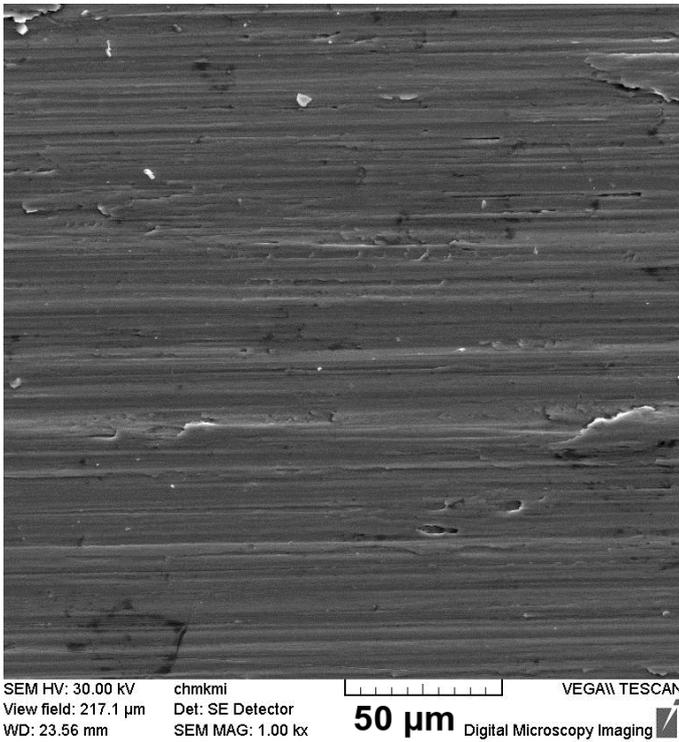
Filler diameter [mm]	Electrode diameter [mm]	Used current [A]	Argon flow [l/min]
2.4	1.6	115	7

The surfaces of the welded specimens were treated mechanically by grinding and garnet blasting. Initial surface grinding was performed to level up the surface of the welded area. This was done by using surface grinding with Al₂O₃ belt with grit of 80. Then each specimen was grinded by Al₂O₃ belt with grit of 180. The blasting was performed on specimens with pressure of 6 bar and garnet abrasive grit of 80 (31 wt.% SiO₂, 21.6 wt.% Al₂O₃, 37 wt.% FeO, 7.4 wt.% MgO). The blast pointed at 90 degree angle and lasted for about 60 seconds for each specimen. In addition, three specimens from each group (grinded, garnet blasted) were pickled for 30 minutes at temperature of 22 ± 2°C in solution with composition 100 ml of 50 % HNO₃, 5 ml of 38 % HF, 395 ml of distilled H₂O. The specimens were then cleaned in chloroform and rinsed with distilled water and then left for sufficient time to dry out. All specimens were then weighted with accuracy of 10⁻⁵g to determine weight loss after corrosion test. Surface was investigated by scanning electron microscope (SEM) and the EDX chemical analysis was carried out. Corrosion behaviour was studied using electrochemical polarization too.

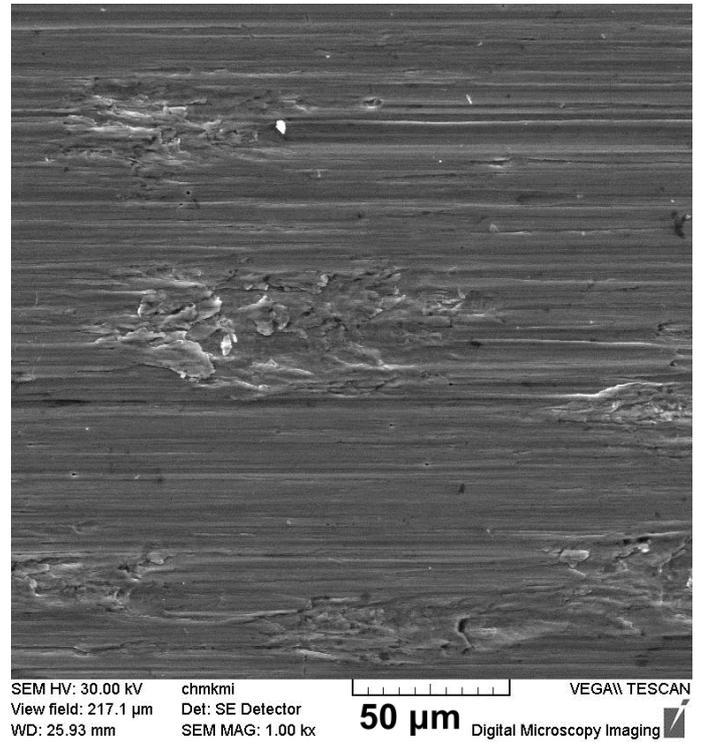
3 SEM surface evaluation after various treatments

Surface of the specimens was assessed by SEM. The analysis was focused on the character of the surface in the locality of weld metal (WM) and compared.

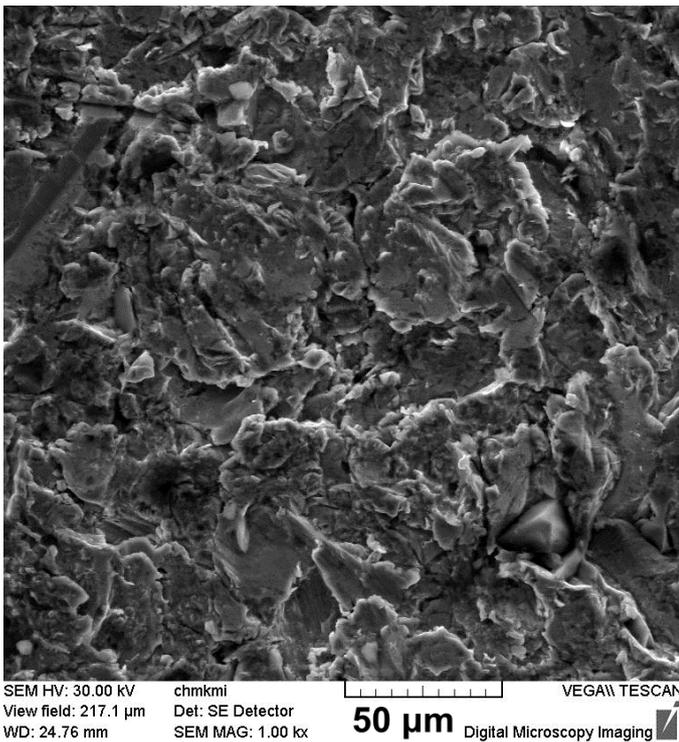
The surfaces of weld joints are shown in Fig. 3. There are visible differences between surfaces of welded metal finished by different way as well as chemical composition obtained by using the EDX analysis (Tab. 3). The impact of pickling is reflected on the structure (Fig. 4) and chemical composition too. The increased oxygen content in the WM of the blasted specimen indicates that the high temperature oxides were not removed by blasting in comparison with the grinded weld joint. The grinded surface became homogeneous and chemical composition is near to base metal. Homogeneity in chemical composition of the studied areas is not reached by blasting. The roughness and surface topography are poor, 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. According to the chemical analyses pickling increases purity of the surfaces.



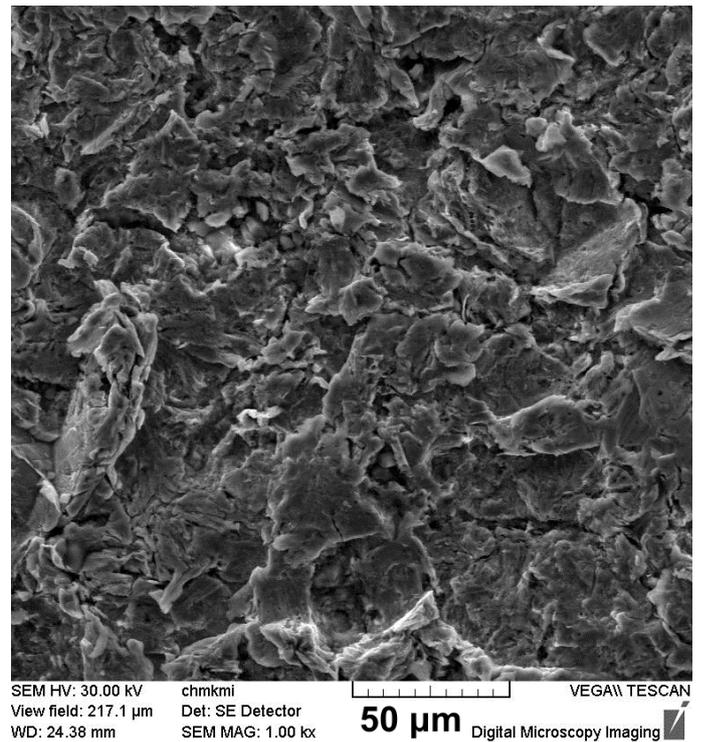
(a) ground welded joint



(a) ground welded joint after pickling



(b) blasted welded joint



(b) blasted welded joint after pickling

Fig. 2. SEM image of weld surfaces with various mechanical treatments

Fig. 3. SEM image of weld surfaces with various mechanical and chemical treatments

4 Corrosion test

The welded specimens of AISI 316L with various surface finishing (individual or combine treatments) were tested for resistance to pitting corrosion. The immersion test was carried out in the solution of 6 % FeCl₃ according to the standard ASTM G 48. The temperature during the test was 21°C.

5 Electrochemical polarization

Potentiodynamic polarization tests were performed at $20 \pm 2^\circ\text{C}$ in NaCl solution with concentration of Cl⁻ 100 ppm and $pH = 7$. The reference electrode was Ag/AgCl/KCl_{saturated}. Set up of parameters: E_i (initial potential) was same as E_{OC}

(open circuit potential), E_f (final potential) was same as E_i , max. current $I_T = 1 \text{ mA}$, step height 10 mV/s .

Tab. 3. Chemical composition of the surface after various finishing

Surface treatment	Weight %			
	grinded	grinded + pickled	blasted	blasted + pickled
Elements				
O	0.52	0.71	10.36	7.14
Mg	0	0	1.44	0.83
Al	0	0	1.60	1.34
Si	0.47	0.57	3.03	1.85
S	0.06	0.07	0.07	0.20
Ca	0	0	0.68	0.37
Cr	14.97	15.06	13.01	14.26
Fe	67.21	65.88	53.22	58.26
Ni	9.11	9.36	8.23	7.90
Mo	2.14	2.06	2.78	1.72

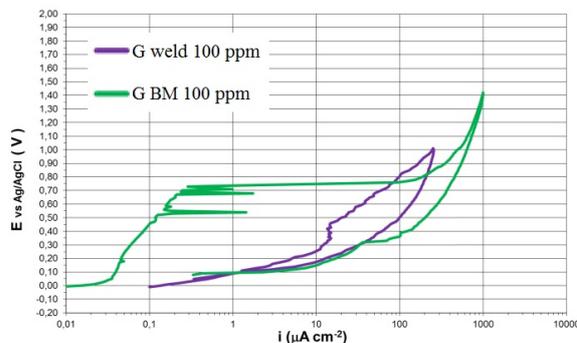
Tab. 4. Corrosion rates of the AISI 316L stainless steel in 6% FeCl_3 solution

a) No chemical treatment		
Type of surface treatment	Average weight losses [g]	Average corrosion rates [$\text{g}\times\text{m}^{-2}\times\text{h}^{-1}$]
grinding	0.27039	3.00433
garnet blasting	0.41749	4.63877
b) With chemical treatment		
Type of surface treatment	Average weight losses [g]	Average corrosion rates [$\text{g}\times\text{m}^{-2}\times\text{h}^{-1}$]
grinding + pickling	0.21640	2.40444
garnet blasting + pickling	0.60488	5.46100

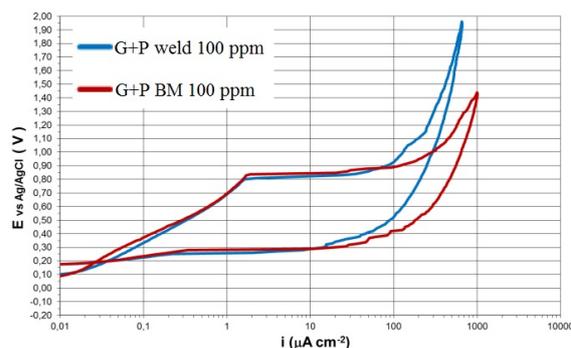
It is well known that potentiodynamic results depend on the scanning rate, immersion time before test. Potentiodynamic tests give qualitative information on electrochemical and corrosion properties of the investigated systems (Bolzoni et al. [2]).

Fig. 4 shows the trend of the cyclic potentiodynamic curves in the solution with 100 ppm of Cl^- for the specimens G and G + P. The treatment of pickling allows a considerable improvement in localized corrosion. Electrochemical behaviour of garnet blasted and garnet blasted + pickled base material and weld is in the Fig. 5.

The graph (Fig. 6a) shows the values of breakdown potential (pitting potential) for base material in NaCl solution with Cl^- content 100 ppm. The highest breakdown potential for solution 100 ppm had specimens which were grinded + pickled $E_b = 818 \text{ mV}$ then grinded $E_b = 730 \text{ mV}$ and the lowest breakdown potential had garnet blasted specimens $E_b = 224 \text{ mV}$. The values of breakdown potential for weld are shown in graph on the Fig. 6b. Weld with grinded + pickled treatment had the highest breakdown potential $E_b = 810 \text{ mV}$ then weld with garnet blasted + pickled treatment $E_b = 459 \text{ mV}$. The lowest value of breakdown potential had weld with garnet blasted treatment $E_b = 63 \text{ mV}$. The breakdown potential value for grinded treatment was $E_b = 90 \text{ mV}$.



(a)

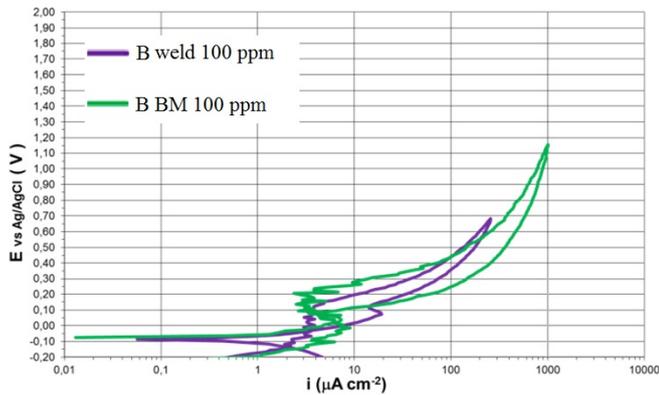


(b)

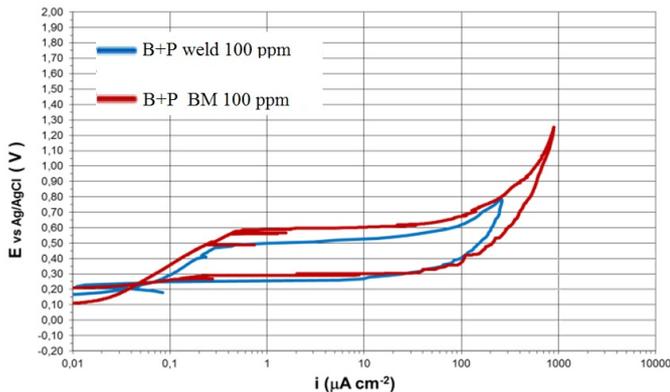
Fig. 4. Comparison of electrochemical behaviour of a) grinded (G) and b) grinded + pickled (G+P) specimens in 100 ppm of Cl^- solutions for base material (BM) and weld

6 Conclusions

- Referring to the results it is apparent that the surface treatment of stainless steel after welding has a great influence on corrosion behaviour.
- Grinding is an appropriate a mechanical way for stainless steels finishing after welding.
- Pickling improved corrosion resistance of the garnet blasted and ground specimens according to electrochemical test where the corrosion process is controlled by anodic dissolution.
- Pickling enlarges surface area, deepens crevices especially of blasted surfaces. The specifications accelerate reduction of Fe_3^+ ions (controlling step of the corrosion process in exposure test) and thus increases corrosion kinetic of the blasted and pickled specimens.



(a)



(b)

Fig. 5. Comparison of electrochemical behaviour of a) garnet blasted (B) and b) garnet blasted + pickled (B+P) specimens in 100 ppm of Cl^- solutions for base material (BM) and weld

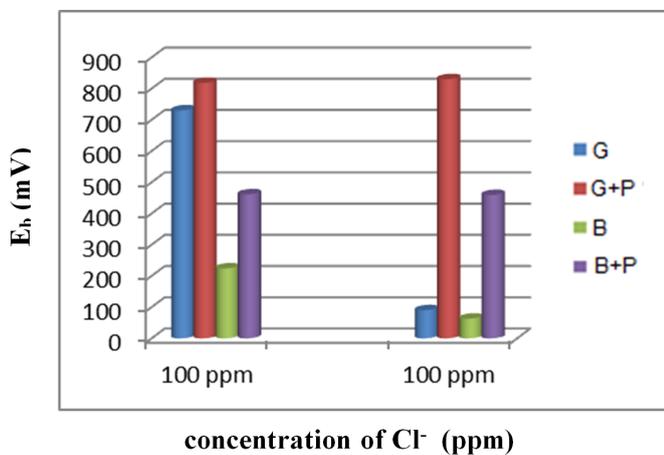


Fig. 6. Comparison of breakdown potential (E_b) with various surface treatment for a) base material and b) weld in NaCl solution with Cl^- content 100 ppm

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