INFLUENCE OF THE SURFACE FINISHING ON THE CORROSION BEHAVIOUR OF AISI 316L STAINLESS STEEL

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Resume

The influence of the surface preparation of AISI 316L stainless steel by mechanical grinding, polishing and following passivation was examined by immersion corrosion tests in solution simulating body fluids. Decreasing of the surface roughness by finer preparation resulted in decrease of corrosion rates of AISI 316L stainless steel. Passivation of specimens resulted in decreasing of the corrosion rates and in decreasing of the corrosion process kinetics independently on the roughness of specimens before passivation. Lowest corrosion rates were observed in the case of polished and passivated specimens. However no significant difference in corrosion rates between polished and ground specimens with following passivation was observed.

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1. Introduction

Stainless steels are very often used for the medical devices, implants and controlled drug delivery systems production. The most widely used stainless steel in medicine is 316 stainless steel types [1]. The AISI 316L stainless steels are non toxic materials widely used for traumatological temporary devices such as fracture plates, screws and hip nails among others, owing to their relatively low cost, availability and easy processing [2, 3].

Stainless steels are characteristic by their good corrosion resistance as a result of the chemical composition and microstructure. Good corrosion resistance is assured by content of alloying elements such a Cr, Mo, Ti. Ni and N. Also the surface treatment is strongly influencing the corrosion resistance of stainless

steels [4, 5]. Due to the content of Cr in AISI 316L the passive oxide layer is created on the surface of the steel product. Low content of C results in the improved corrosion resistance due to the prevention of the creation of the $M_{23}C_6$ carbides on the grain boundaries, which protects the material against the intergranular corrosion. Pitting corrosion resistance of AISI 316L stainless steel in solutions containing Cl ions is improved by the content of Mo. Austenitic structure of the steel is stabilized by the Ni [11].

Austenitic stainless steels, such an AISI 316L, exhibit good combination of mechanical, fabrication and corrosion resistance properties, however austenitic stainless steels are sensitive in certain corrosive environments to local corrosion attack [2, 4, 6 -

10]. AISI 316L stainless steel has good corrosion resistance mainly in salt solutions, however in case of the Cl solutions local corrosion attack may occur (pitting and intergranular corrosion predominantly) [2 - 4]. AISI 316L stainless steel has also good weldability without need of additional heat treatment, very good formability and it is possible to polish it to the mirror like surface [11]. Corrosion resistance influences the materials usage while corrosion pits, the most typical corrosion attack type for AISI 316L stainless steel, can be directly associated with the fatigue crack initiation resulting in a part failure [12], while the influence of corrosion attack seems to be more important than the microstructural features which can be influenced by the heat treatment but do not start or significantly influence the fatigue failure mechanism [13].

Presented paper examine influence of the surface preparation of AISI 316L stainless steel by mechanical grinding, polishing and following passivation. Immersion corrosion tests in solution simulating body fluids were used for the estimation of corrosion rates of differently prepared specimen surfaces. Surface roughness influence on the corrosion rates and the influence of specimen passivation on the corrosion process was examined and discussed.
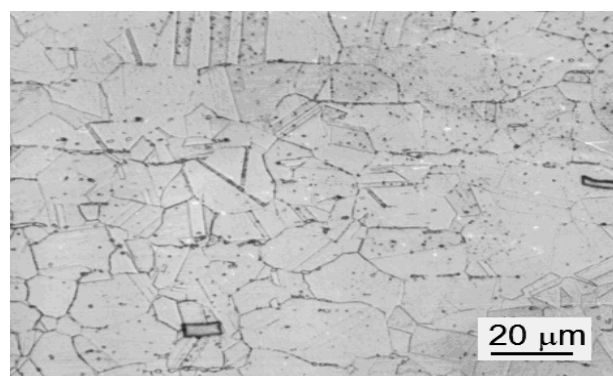
2. Experimental material and methodology

AISI 316L stainless steel was used as the experimental material. The steel was delivered by the producer in a form of rolled sheet. The microstructure of AISI 316L was analyzed in direction longitudinal and also direction parallel to the rolling production. The metallographic specimens were prepared by standard procedures of grinding and polishing. The Roling's etchant was used for the microstructure visualization. For the metallographic observation Zeiss Axio Z1m microscope was used. The typical microstructure of the AISI 316L is shown in Fig. 1.

The microstructure of the examined material consists of polyedric grains of austenite containing deformation twin as a result of rolling production. However no visible deformation of the microstructure (grains deformation – elongation in the rolling direction) due to the rolling production process was observed on the analyzed metallographic specimens. Only a localization of carbides was more like in a direction of the rolling, which is visible on the Fig. 1b.
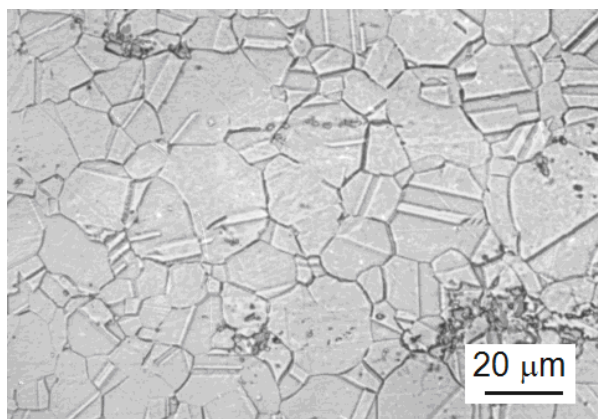
a) parallel direction   b) longitudinal direction
Fig. 1. Microstructure of the examined AISI 316L stainless steel.

For the corrosion resistance testing a solution simulating body fluids was used. The chemical composition of the used solution is given in Table 1. The solution was mixture of the chemicals and the distilled water. After the solution preparation its conductivity and pH was measured using the GMH 3410 conduct meter and GMH 3530 pH measuring equipment. The measured values are given in Table 2. The real body fluid has the pH value of 7.4 which is lower than the value of the experimental solution; however based on the experimental estimation the influence of the pH difference on the AISI 316L stainless steel is low.

Fig. 2. Geometry of the specimens used for the corrosion testing.

Chemical composition of solution used for the corrosion testing. The amounts are for 1 liter of the distilled water.

chemicals	weight (g)
NaCl	8
KCl	0.42
$CaCl_2 * 2H_2O$	0.32
$NaCO_3$	0.2

Physical properties of the solution used for the corrosion testing.

conductivity γ	pH
15.06 mS.cm^{-1}	9.57

For the corrosion testing 78 specimens of AISI 316L with a geometry shown in Fig. 2 were used. The thickness of the specimens was dimension which was not calculated for the evaluation of the results. The specimens were prepared by different surface roughness achieved by different mechanical treatment.
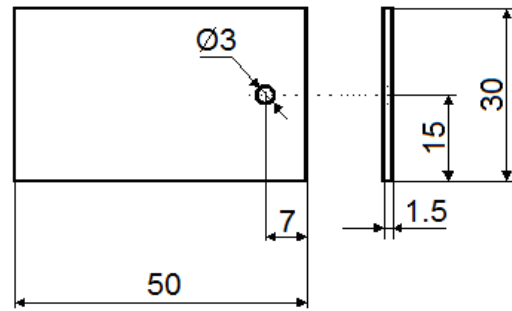
Different groups of the specimens were grinded with SiC papers (no. 60, 320) and polished by diamond paste (LS). After mechanical preparation followed passivation (P) of the surface in a solution of 20 % HNO3 was performed on mechanically prepared speciemns. For the passivation was used 500 ml of the 20 % HNO_3 solution heated to the temperature of 50 °C. The prepared specimens were inserted to the heated solution for the time of 30 minutes. The marking of the specimens according to the surface preparation is given in Table 3.

3. Experimental results and discussion

Immersion tests were used for the estimation of the corrosion rates of AISI 316L in dependence of the surface treatment, particularly the surface roughness. The corrosion lost was calculated as the ratio of the weight lost to the surface area (0.003 m^2, Fig. 2). The corrosion rate was obtained as the corrosion lost per a day. The calculated results are shown in the Table 4. The dependence of the corrosion rate on the time of the exposure to the testing solution is shown in the Fig. 4.

Surface treatment of AISI 316L specimens used for corrosion testing.

marking	amount	surface treatment
60	13	grinding by a paper no. 60
60P	13	grinding by a paper no. 60 + passivation
320	13	grinding by a paper no. 320
320P	13	grinding by a paper no. 320 + passivation
LS	13	polishing
LSP	13	polishing + passivation
basic state	6	without treatment

Table 4

Results of immersion corrosion tests.

basic state			
exposure time (day)	weight lost (g)	corrosion lost (g.m^{-2})	corrosion rate (g.m^{-2}.day^{-1})
42	0.002217	0.738889	0.017593
56	0.001917	0.638889	0.011409
60			
exposure time (day)	weight lost (g)	corrosion lost (g.m^{-2})	corrosion rate (g.m^{-2}. day^{-1})
14	0.00165	0.55	0.039286
28	0.002633	0.877778	0.031349
42	0.002217	0.738889	0.017563
56	0.002183	0.727778	0.012996
60P			
exposure time (day)	weight lost (g)	corrosion lost (g.m^{-2})	corrosion rate (g.m^{-2}. day^{-1})
14	0.00125	0.416667	0.029762
28	0.0018	0.6	0.021429
42	0.001733	0.577778	0.013757
56	0.001667	0.555556	0.009921
320			
exposure time (day)	weight lost (g)	corrosion lost (g.m^{-2})	corrosion rate (g.m^{-2}. day^{-1})
14	0.001267	0.422222	0.030159
28	0.002167	0.722222	0.025794
42	0.002067	0.68889	0.016402
56	0.00175	0.583333	0.010417
320P			
exposure time (day)	weight lost (g)	corrosion lost (g.m^{-2})	corrosion rate (g.m^{-2}. day^{-1})
14	0.0011	0.366667	0.02619
28	0.002167	0.722222	0.025794
42	0.0018	0.6	0.014286
56	0.00175	0.583333	0.010417
LS			
exposure time (day)	weight lost (g)	corrosion lost (g.m^{-2})	corrosion rate (g.m^{-2}. day^{-1})
14	0.001175	0.391667	0.0279765
28	0.001867	0.622222	0.022222
42	0.002	0.666667	0.015873
56	0.002033	0.677778	0.012103
LSP			
exposure time (day)	weight lost (g)	corrosion lost (g.m^{-2})	corrosion rate (g.m^{-2}. day^{-1})
14	0.000967	0.322222	0.023016
28	0.002117	0.705556	0.025198
42	0.002	0.666667	0.015873
56	0.001333	0.444444	0.007937

In the cases of the basic ground and polished specimens the highest corrosion rate after 14 days of immersion corrosion tests was observed, Fig. 4. In the case of specimens treated by passivation the highest corrosion rate after approximately 20 days was observed. After longer exposition of the specimens to the corrosion environment the corrosion rate decreased to the same values, Fig. 4, which was caused by the evolution of oxides layer on the specimen surfaces after 14 days of exposure to the corrosion environment. Cr_2O_3 is created on the specimen surfaces during the corrosion process which also acts as a protective layer and decreased following corrosion process. This explains the differences in the corrosion rates observed between individual specimens during first 14 days of the exposure to the solution and almost no difference in the corrosion rates observed at the end of the experiment (after 56 days).
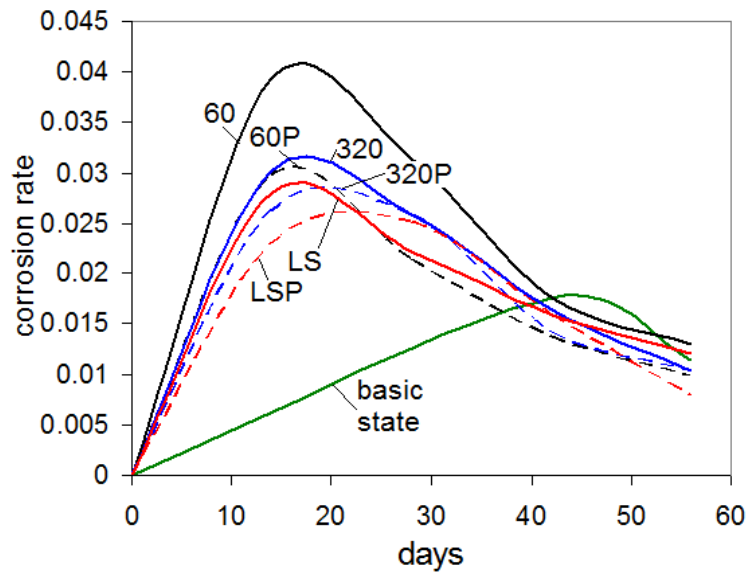
Fig. 4. Corrosion tests results – corrosion rates vs. exposure time.
(full colour version available online)

The highest corrosion rates were observed in the case of specimens ground by a paper no. 60 without passivation where the natural oxides layer (the layer created on the specimen free surface on the air) was damaged by grinding and real specimen surface was exposed to the corrosion environment. Due to the finer surface of specimens prepared by grinding by a paper no. 320 the smaller real surface of the specimen was exposed to the corrosion environment when compared to the specimens 60 and resulting corrosion rate was lower than the one observed in the case of specimens 60. Decreasing the real surface area the lowest corrosion rate was observed for polished specimens from the group of non passivated specimens. This is in agreement with observations in [4] where sand blasting and mechanical grinding of specimen was compared and also in that case the smaller surface roughness was connected with lower corrosion rates. Due to the exposure of the specimen free surface to the corrosion solution the specimens start to passivate (create an oxides layer) which is connected to the surface roughness. Decreasing the surface roughness more compact and uniform oxides layers can be created which was proven by experiments and decreasing corrosion rate with decreasing surface roughness, Fig. 4. Grinding of the AISI 316L stainless steel specimens surface by grinding paper no. 60 increased the corrosion rate 2.34 times when compared to the basic state. Grinding by paper no. 320 increased the basics state corrosion rate by a factor of 1.82 and polishing by 1.62 times.

In all the cases of treated specimens the passivation in the solution described in part 2 of this paper shifted the maximum of corrosion rate to the higher values (from 14 days to proximately 2 days of exposure to the corrosion environment, Fig. 4. polishing of the specimen ground by a paper no. 60 increased the corrosion rate by a factor of 1.77, paper no. 320 by 1.60 and polishing by a factor of 1.54 when compared to the basic state without treatment. The corrosion rate of passivated specimens was always lower when compared to only mechanically ground/polished specimens without passivation. Thin layer created on the specimens surfaces during the passivation improved the specimens corrosion resistance independently on the specimens surface roughness. However smoother surface before passivation resulted in the higher corrosion resistance of the treated specimens.

4. Conclusions

AISI 613L stainless steel is commonly used steel in industry and also for medical applications. In the present paper the influence of surface mechanical preparation by grinding and polishing was examined with the aim to estimate the influence of the surface roughness on the corrosion rate of the steel. From the performed experiment following conclusions can be concluded:

- grinding and also polishing increased the corrosion rate of AISI 613L specimens when compared to the non treated material,

- the highest corrosion rates of mechanically treated specimens were measured after 14 days of exposure to the corrosion environment,

- passivation decreased the corrosion process; the highest corrosion rates were measured after 20 days of exposure to the corrosion environment,

- passivation decreased the corrosion rates of ground and polished specimens to similar values (from 1.77 to 1.54, by decreasing surface roughness, times the corrosion rates of the basic materials),

- after 50 days exposure to the corrosion environment all the testes specimens reached the same corrosion rates.

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