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ISSN 0543-5846
METABK 51(2) 237-240 (2012)
UDC – UDK 669-14.018:620.193:621-426:614.48=111

A COMPARATIVE STUDY OF THE CORROSION OF WIRE USED IN UROLOGICAL TREATMENT UNDER STERILISATION

Received – Prispjelo: 2011-03-23
Accepted – Prihvaćeno: 2011-04-22
Preliminary Note – Prethodno priopćenje

The purpose of the tests was to determine whether and how sterilisation process of samples made of AISI 316L stainless steel with different strain impacts their corrosion resistance. Tests were made on steel samples that had been electrochemically polished in order to assure proper surface roughness. In order to evaluate the influence of sterilisation on physical and chemical properties of steel surface, tests of corrosion resistance were made by means of potentiodynamical method. The tests were made in alternative solution simulating human urine. Recorded anodic polarisation curves created the ground for determination of typical parameters describing pitting corrosion resistance, that enabled to evaluate steel wire corrosion behaviour under sterilisation conditions.

Key words: AISI 316L stainless steel, corrosion resistance, wire, steam sterilization, urology

Komparativno istraživanje korozije žice korištene pri urološkoj obradi uz sterilizaciju. Svrha je ispitivanja bila d se ustanovi postoji li i kakav je utjecaj sterilizacije na korozijsku otpornost žičanih uzoraka od nehrđajućeg čelika AISI 316L, oblikovanih plastičnom deformacijom različitog intenziteta. Ispitivanja su obavljena na uzorcima koji su elektrokemijski polirani kako bi se osigurala tražena niska hrapavost površine. U cilju procjene utjecaja sterilizacije na fizikalna i kemijska svojstva čelične površine, ispitivana je korozijska otpornost potenciodinamičkom metodom. Pritom je za simulaciju ljudske mokraće primijenjena zamjenska otopina. Snimljene krivulje anode polarizacije poslužile su za određivanje tipičnih parametara koji definiraju otpornost čelika prema jamičastoj koroziji, što je omogućilo procjenu korozijskog ponašanja čeličnih žica nakon sterilizacije.

Ključne riječi: AISI 316L nehrđajući čelik, korozijska otpornost, žica, sterilizacija vodenom parom, urologija

INTRODUCTION

Basic feature of metallic material, which determines its usability in medical applications, is its corrosion resistance [1]. Corrosion resistance of metallic materials is determined on the ground of comparative tests that are performed through accepted research methods in laboratory conditions which simulate the real biological environment. It is determined on the ground of potentiodynamic and potentiostatic tests as well as by means of impedance spectroscopy. On the ground of test results analysis it is possible to calculate such values as: open circuit potential, corrosion potential, corrosion current density, breakdown potential of passive layer, repassivation potential or polarisation resistance [2÷5]. Analysis of the obtained results enables to make a complete corrosion characteristics of the material in the respective environment. Tests of corrosion resistance should be made on a specific device, taking operational technique into consideration. It refers in particular to guide wire used in urology, for which the diameter and degree of strain hardening of the material it was made of is crucial for proper course of the test. Corrosion dynamics is also influenced by chemical and phase composition, homogeneity of material structure, local state of strain-hardening or stress. Quality of medical goods is also related to efficiency of sterilization process. This process is aimed at the removal or destruction of microorganisms /microbes in both, vegetative and spore forms, so that used goods are safe when used clinically. At present, the most frequently material used for guide wire is steel AISI 316L. Application of wire made of steel is conditioned by proper preparation of its surface, which is aimed at the improvement of corrosion resistance not only in working conditions (urine environment), but also in sterilisation conditions (steam under pressure) [6÷10].

The purpose of the tests presented in the article was to evaluate whether and how sterilisation process of samples made of steel 316L, with different level of strain-hardening and surface preparation method, influences their corrosion resistance.

MATERIAL AND METHODS

Wire made of AISI 316L stainless steel [11] with diameter of 5,50 mm (wire rod in supersaturated state), 3,00 mm ($\varepsilon_c = 1{,}21$) and 1,35 mm (hardened wire after

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strain in the drawing process - ε_c = 2,81) was selected for the tests. Wire samples were electrochemically polished in order to obtain the required roughness of the surface ($R_a \leq$ 0,16 μm), and then they were chemically passivated in 40 % HNO_3. Surface of samples prepared this way was sterilised by water steam under pressure with following process parameters: temperature 134 °C, pressure 2,1 bar and time 30 min. In order to evaluate the influence of sterilization on physical and chemical characteristics of steel surface, corrosion tests by means of potentiodynamic method were performed.

The pitting corrosion tests were realized with the use of potentiodynamic method by means of recording of anodic polarization curves [12]. The VoltaLab® PGP 201 system (Radiometer) for electrochemical tests was applied. The saturated calomel electrode (SCE) of KP-113 type was applied as the reference electrode. The PtP−201 platinum electrode was the auxiliary electrode. Corrosion resistance of all samples was investigated. The corrosion tests were undertaken in artificial urine of chemical composition presented in Table 1 (Ratio A:B = 1:1 – by volume).

Table 1 **Chemical composition of artificial urine**

Components	Amount in distilled water g/L
Solution A	
$CaCl_2 \cdot H_2O$	1,765
Na_2SO_4	4,862
$MgSO_4 \cdot 7H_2O$	1,462
NH_4Cl	4,643
KCl	12,130
Solution B	
$NaH_2PO_4 \cdot 2H_2O$	2,660
Na_2HPO_4	0,869
$C_6H_5Na_3O_7 \cdot 2H_2O$ (Na-citrate)	1,168
NaCl	13,545

Temperature of the solution was equal to 37 ± 1 °C and pH = 7,0 ± 0,2.

The measurements were carried out after 60 min immersion in the artificial urine while the open circuit potential (OCP) was recorded. The potential scan was started at 100 mV more cathodic potential than the OCP, increasing toward the anodic values at a constant rate of 1 mV/s up to 1 mA/cm^2. On the basis of the recorded curves the following corrosion parameters were assessed: corrosion potential E_{corr}, breakdown potential E_b, polarization resistance R_p, corrosion current density i_{corr}.

The breakdown potential was directly read from the graph by drawing tangent lines to the passive current and inflection of the curve. The coordinate of the intersection point was considered as E_b. The Stern method was applied to calculate the polarization resistance R_p. The polarization resistance depends mostly on the anodic current density and therefore it was assumed that the "b" value for anodic and cathodic reactions are the same and were equal to ± 0,12 V. The corrosion current density was calculated on the basis of the simplification $i_{corr} = 0{,}026/R_p$.

RESULTS

During the first stage tests of pitting corrosion resistance of samples made of AISI 316L stainless steel with electrolytically polished as well as electrolytically polished and chemically passivated, but not sterilized surface, were made. Open circuit potential E_{OCP} of samples with polished surface fell within the range E_{OCP} = -50 ÷ -200 mV, whereas for samples with polished and passivated surface - E_{OCP} = -100 ÷ -200 mV. Chemical passivation did not cause significant increase in the value of E_{OCP} for the respective diameters of wire. The value of corrosion potential determined for samples with polished surface was in the order of: for samples with diameter of: ∅5,50 mm – E_{corr} = -83 mV; ∅3,00 mm – E_{corr} = -122 mV; ∅1,35 mm – E_{corr} = -176 mV. However, the value of breakdown potential was respectively: ∅5,50 mm – E_b = +350 mV; ∅3,00 mm – E_b = +346 mV; ∅1,35 mm – E_b = +205 mV – Figures 1÷6. Polarisation resistances for measured diameters of polished wire, determined on the ground of anodic polarisation curves by means of Stern method, fell within the range of R_p = 100 ÷ 216 kΩ·cm^2 - Table 2. Chemical passivation of samples surface had a significant impact on the increase in breakdown potential for each analysed wire diameter – Table 2. Value of corrosion potential as well as polarisation resistance did not differ significantly in relation to polished surface. Only for wire with diameter of ∅1.35 mm more than triple increase in polarisation resistance from the value of R_p = 100,13 kΩ·cm^2 (polished surface) to the value of R_p = 355,73 kΩ·cm^2 (passivated surface) was observed – Table 2.

Next, tests of corrosion resistance were made for samples made of Cr-Ni-Mo steel with the surface that was electrolytically polished and chemically passivated, after sterilisation with specified temperature, water steam pressure and the time of samples exposure. For samples with polished surface, sterilization process positively influenced breakdown potential, increasing its value irrespective of wire diameter. Significant increase was also observed for polarisation resistance, the value of which increased several times for each diameter. Beneficial decrease in corrosion current density was also observed - Table 2. However, obtained anodic polarisation curves, depicting resistance to pitting corrosion of samples with passivated surface after sterilization, did not show significant differences in the values of breakdown potential in relation to samples that had not been sterilized. The value of breakdown potential virtually did not change – Table 2.

Sterilization process had a really strong influence on the improvement of physical and chemical characteristics of the passivated alloy surface, causing the decrease in corrosion current density down to the value within the range of i_{corr} = 0,016 ÷0,026 μA/cm^2 and vast increase in polarisation resistance to the value from within the range of R_p = 1 010,0 ÷ 1 480,0 kΩcm^2 – Table 2. Comparison of anodic polarisation curves, determined

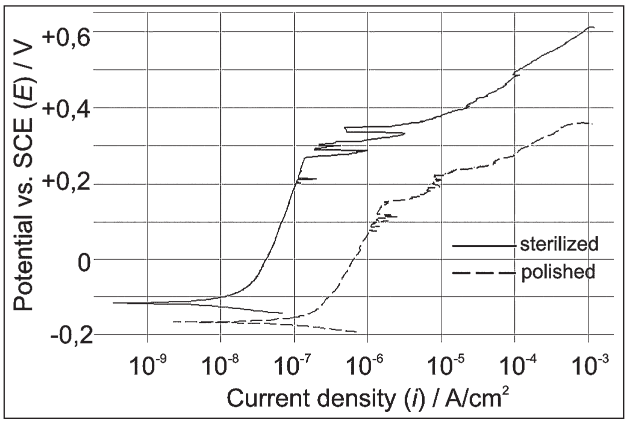

Figure 1 Anodic polarisation curves determined for polished wire with diameter of 1,35 mm in initial condition and after steam sterilization

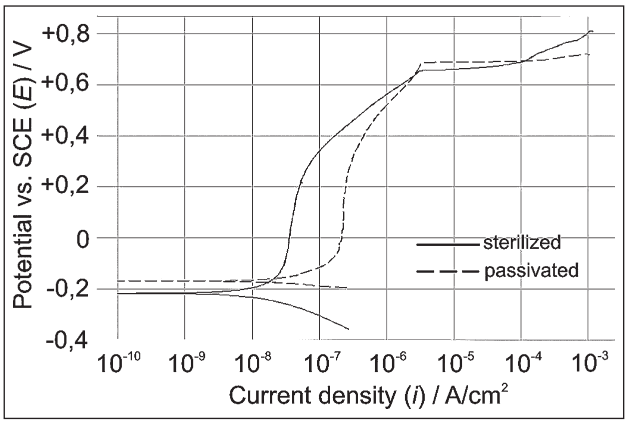

Figure 2 Anodic polarisation curves determined for polished and passivated wire with diameter of 1,35 mm in initial condition and after steam sterilization

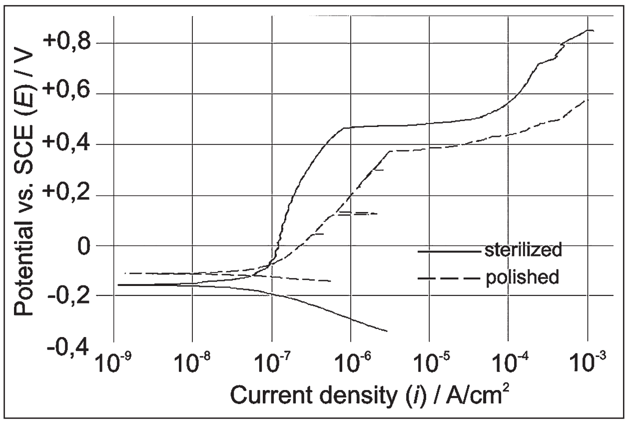

Figure 3 Anodic polarisation curves determined for polished wire with diameter of 3,00 mm in initial condition and after steam sterilization

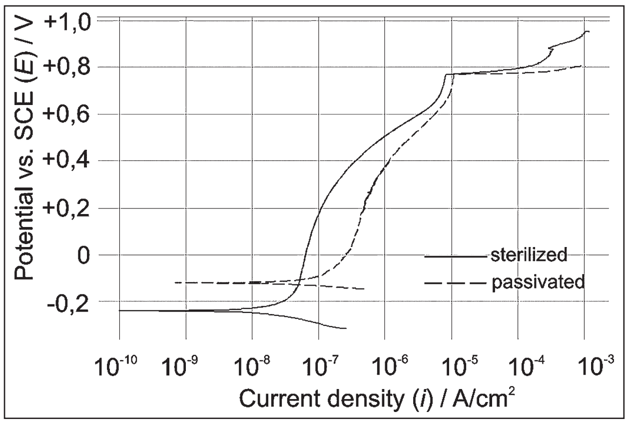

Figure 4 Anodic polarisation curves determined for polished and passivated wire with diameter of 3,00 mm in initial condition and after steam sterilization

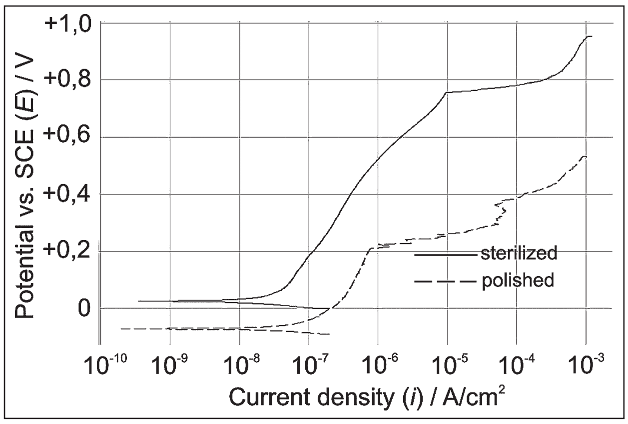

Figure 5 Anodic polarisation curves determined for polished wire with diameter of 5,50 mm in initial condition and after steam sterilization

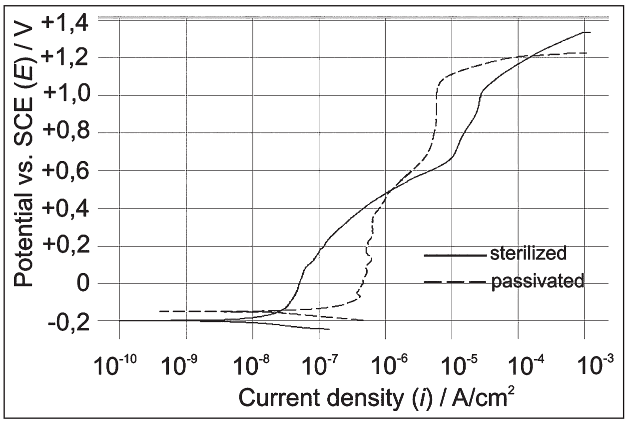

Figure 6 Anodic polarisation curves determined for polished and passivated wire with diameter of 5,50 mm in initial condition and after steam sterilization

for the respective wire diameters after electrochemical polishing, chemical passivation and steam sterilization, was shown in Figures 1÷6.

CONCLUSION

Performed tests of Cr-Ni-Mo steel with variable levels of strain-hardening show that sterilization process realised by steam application of steam influences corrosion resistance of tested samples. Analysis of results describing changes of all parameters of corrosion resistance shows beneficial influence of sterilization process in steam. It was determined that for given values of sterilization parameters (temperature, pressure and time of steam activity), a significant increase in polarisation resistance R_p took place for all tested samples – Table 2. A similar tendency for changes was observed for registered values of breakdown potential, especially for samples with polished surface – Table 2, Figures 1÷6. For all tested samples after sterilization process, beneficial influence of pressurised water steam was also shown by

Table 2 **Pitting corrosion resistance test results**

Method of surface preparing	Corrosion potential E_{corr}, mV	Polarisation resistance R_p, kΩ · cm²	Corrosion current density i_{corr}, μA/cm²	Breakdown potential E_b, mV
Ø = 1,35 mm (electrochemically polished wire)				
Polished	-176	100,13	0,260	+205
Sterilized	-126	1 170,00	0,022	+650
Ø = 1,35 mm (electrochemically polished and passivated wire)				
Passivated	-175	355,73	0,073	+686
Sterilized	-229	1 480,00	0,018	+650
Ø = 3,00 mm (electrochemically polished wire)				
Polished	-122	210,11	0,124	+346
Sterilized	-167	585,99	0,044	+456
Ø = 3,00 mm (electrochemically polished and passivated wire)				
Passivated	-127	199,69	0,130	+766
Sterilized	-251	1 010,00	0,026	+762
Ø = 5,50 mm (electrochemically polished wire)				
Polished	-83	216,31	0,120	+350
Sterilized	+15,4	547,78	0,047	+750
Ø = 5,50 mm (electrochemically polished and passivated wire)				
Passivated	-157	232,13	0,112	+1203
Sterilized	-210	1 280,00	0,020	+1240

decrease in the value of corrosion current density i_{corr}. It must also be highlighted that the effected chemical passivation was the factor that improved all parameters describing corrosion resistance of Cr-Ni-Mo steel, irrespective of strain-hardening degree.

Consequently, it can be ascertained that chemical passivation process and steam sterilization of Cr-Ni-Mo steel, performed in order to assure proper procedures concerning the quality of manufactured guide wires and their safe application in urological treatment, contributes to beneficial changes, influencing the improvement of corrosion potential of this type of metallic biomaterial, irrespective of its degree of strain-hardening. Next, it is planned to perform tests of oxide layers made on the surface in the process of oxidation in pressurised steam, in order to explain changes in chemical and stoichometric composition of the formed chemical compounds.

REFERENCES

[1] Steinemann S.: Advances in Biomaterials, John Wiley & Sons, Chichester (1980) 1-4.

[2] Marciniak J., Biomateriały. Wydawnictwo Politechniki Śląskiej, Gliwice 2002.

[3] Krauze A., Ziebowicz A., Marciniak J.: Corrosion resistance of intramedullary nails used in elastic osteosynthesis of children. Journal of Materials Processing Technology, 162-163 (2005) 209-214.

[4] Marciniak J.: Perspectives of employing of the metallic biomaterials in the reconstruction surgery. Engineering of Biomaterials, 1 (1997) 12-19.

[5] PN-EN ISO 10993-15, Biological evaluation of medical products.

[6] Jeromin M.: Endourology and ESWL – new methods of diagnostics in treatment of urological diseases, Doctor's Guide, 10 (2001) 83-88.

[7] Jarzemski P.: Modern methods in urology, All-Poland Medical Review, 7 (2007) 24-25.

[8] Skrodzka M.: Metal stents in urinary system, Urological Review, 4 (2007) 53-54.

[9] Paszenda Z., Tyrlik-Held J.: Instrumentarium chirurgiczne. Wydawnictwo Politechniki Śląskiej, Gliwice 2003.

[10] PN-EN 554:1999, Sterilization of medical products.

[11] ISO 5832-1:2007 Implants for Surgery. Metallic materials. Wrought stainless steel.

[12] ASTM G 48-03, Pitting and crevice corrosion resistance of stainless steels, USA 2003.

Note: The responsible translator for English language is M. Kaczmarek, Gliwice, Poland.