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THE INFLUENCE OF THE TEMPERATURE ON THE CORROSION RESISTANCE OF AISI 316L STAINLESS STEEL

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Abstract: AISI 316L stainless steel is often used for the medical applications such surgical tools and equipment. In medical application a sterilization process is often applied for the equipment before next time utilization. In this case the temperature is an important factor. Based on the modern procedures of sterilization only 50°C can be a sufficient temperature for the metallic equipment sterilization. The present study is focused on the evaluation of the influence of the temperature on the corrosion properties of AISI 316L stainless steel in 0.9% NaCl solution. For the experimental measurements of electrochemical characteristics the temperatures of 20, 30, 40 and 50°C were used. It was observed that due to the increased temperature the polarization resistance characterizing the corrosion resistance of material significantly decreased which could have a negative influence on the corrosion resistance of the steel product during following usage.
Keywords: AISI 316L, corrosion, Nyquist diagram

1. INTRODUCTION

Stainless steels are due to their good corrosion resistance very frequently used in the alimentary industry and for medical applications. 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 type 316 [1]. The AISI 316L stainless steels have not toxic reaction with surroundings tissues and they are widely used in 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].

The austenitic grades compositions are optimized to maintain phase stability at higher temperatures as well as suppression of martensitic transformation temperature to well below room temperature [1]. Austenitic stainless steels exhibit good combination of mechanical, fabrication and corrosion resistance properties [4], however austenitic stainless steels are sensitive in certain corrosive environments to local corrosion attack (pitting, intercrystalline corrosion) [5, 6, 7, 8, 9]

Corrosion resistance of the AISI 316L is connected with the high content of Cr. Due to the Cr the passive oxide layer is created on the surface of the steel product. The 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. This decreases the liability of the material to the intergranular corrosion. Pitting corrosion resistance of this steel in Cl ions is improved with the content of Mo. Austenitic structure of the steel is stabilized by the content of Ni. AISI 316L steel has good weldability without need of additional heat treatment, very good formability and it is possible to polish it to the mirror like surface [10].

In the case of medical applications the decontamination and sterilization of the equipment is highly required. In the present time physical (mugginess, dry heat, sterilization by radiation and by plasma) and chemical procedures (by formaldehyde or etylenoxide) of the medical equipment are used. In the case of sterilization by plasma the H gas is used and the operation temperature is of 50°C[11]. Depending on the used procedure the temperatures of the process can influence the activity of the surface of the treated tool or equipment, which can decrease its resistance against the corrosion.

In the present paper the corrosion resistance of the AISI 316L stainless steel used for medical applications is analyzed by the electrochemical impedance spectroscopy (EIS) tests in 0.9% NaCl solution at the temperatures in the range from 20 to 50°C.

2. EXPERIMENTAL MATERIAL AND PROCEDURE

AISI 316L stainless steel was used as the experimental material. The chemical composition of the steel is given in the Table 1. The experimental material was delivered in a shape of sheet of the dimensions of 1000x2000x1.5 mm.

Table 1. Chemical composition of AISI 316L in wt. %, according to the STN 41 7349 standard

element	Cr	Ni	Mo	Mn	Si	S	P	C	Fe
content	16.0–18.0	10.0–14.0	2.0–3.0	max 2.0	max 1.0	max 0.015	max 0.045	max 0.03	rest

Microstructural observation was performed on Zeiss Axio Imager Z1m light optical microscope. Metallographic specimens were prepared by standard procedure consisted form grinding, polishing and etching of the specimens by Rolings etchant.

Electrochemical characteristics of the experimental steel were measured using Voltalab 10 laboratory equipment. PGZ 100 unit, basics of the experimental equipment, includes stabilized direct current and potential source, sinusoidal signal generator for the electrochemical impedance characteristics measurement, voltmeter, picoampermeter and frequency analyzer. Measuring PGZ unit is connected by the corrosion cell by four conductors. The scheme of experimental equipment and measurement is shown in Figure 1.

For the corrosion characteristics of the AISI 316L stainless steel the 0.9 NaCl solution was used. The specified temperatures of the interest for the corrosion resistance measurement were 20°C, 30°C, 40°C and 50°C. The temperature of the measurement was achieved by UV lamp. Time for the stabilization of the free potential between the specimens and electrolyte was 30 min. The measurement was performed in the frequency range from 100 Hz to 5 mHz. The used amplitude of the alternating current was 50 mV. Direct current for the specimen polarization during the measurement was set up to the value of the free potential reached after 30 min of the exposition of the specimen to the electrolyte.

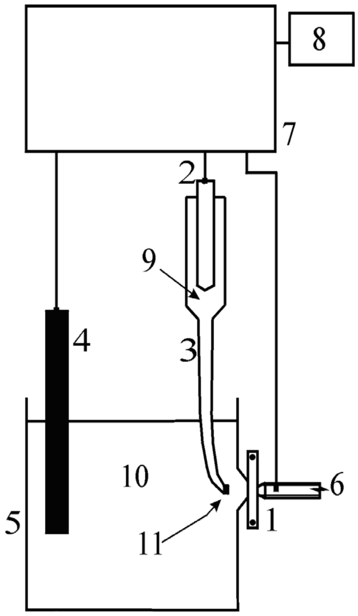
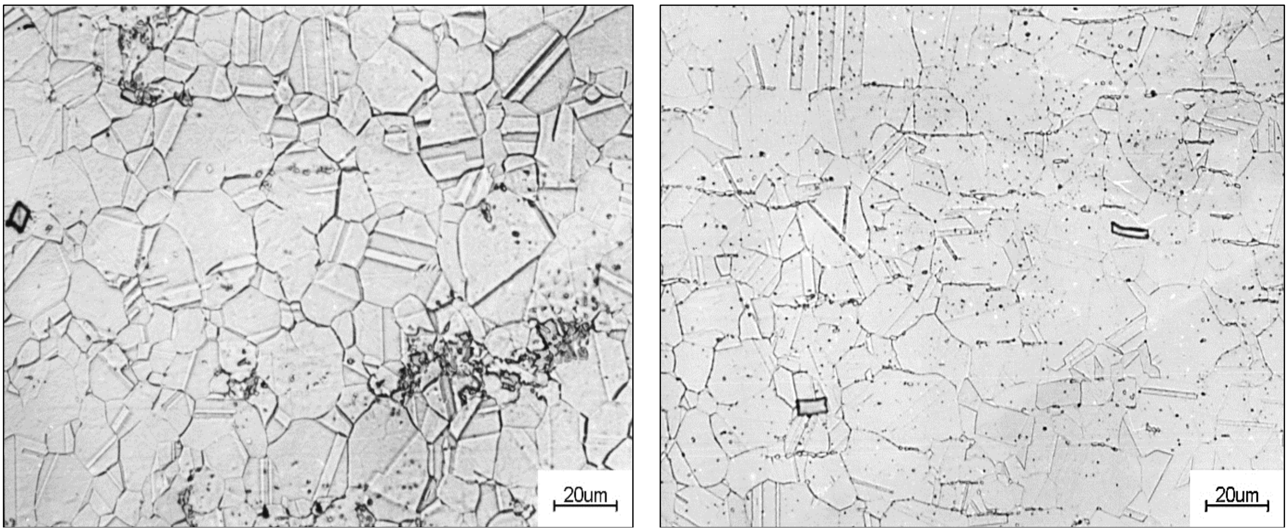


Figure 1. Experimental measurement scheme; 1 – specimen, 2 – reference calomel electrode, 3 – electrolytic bridge, 4 – platinum electrode, 5 – beaker, 6 – specimen holder, 7 – PGZ 100 unit, 8 – PC, 9 – KCl saturated solution, 10 – electrolyte, 11 - semi-permeable membrane.

3. RESULTS AND DISCUSSION

The microstructure of examined AISI 316L is created by polyedric grains of austenite with the average grain size of 21.6 µm. In both the cut directions, Figure 2, the polyedric shape of grains was observed; no structure elongated in the rolling direction was observed. However the rolling production of the material resulted in the presence of lines of carbides, Figure 2b. The deformation twins as a consequence of the production technology were observed in the austenitic grains. Degradation, grain coarsening, due to the exposition to the testing temperatures was not observed.



a) perpendicular cut b) parallel cut

Figure 2. Typical microstructure of examined AISI 316L.

Electrochemical characteristics of AISI 316L stainless steel measured in 0.9% NaCl solution given in Nyquist diagram are shown in Figure 3. Measured Nyquist curves have a shape of half circle from which the values of polarization resistance, R_p, using the VoltMaster software were calculated.

The calculated values of R_p for the experimental temperatures are given in Table 2. From the measured values it can be seen the polarization resistance decrease by the increased temperature. The values of the polarization resistance remained almost unchanged by the increase of the temperature from 40°C to 50°C. However the values are less than 40% of the polarization resistance at 20°and less than 50% of the value at 30°C.

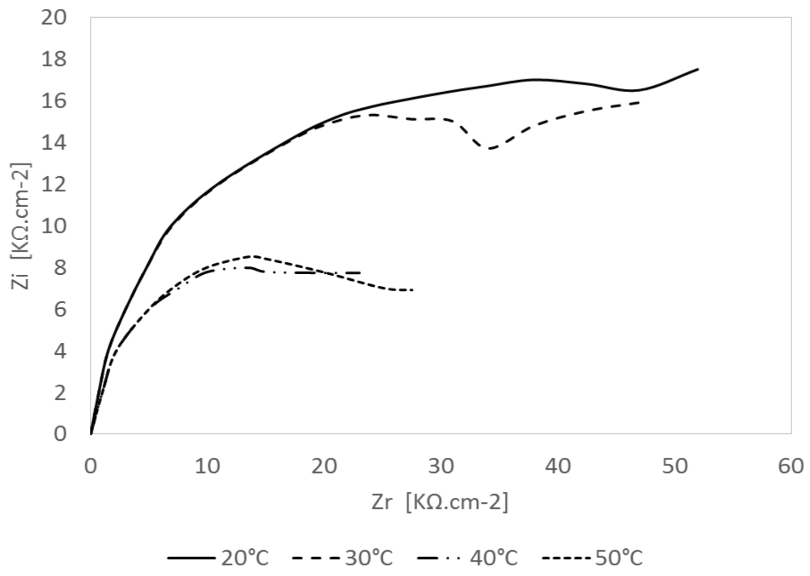


Figure 3. Nyquist diagrams for AISI 316L at tested temperatures

Table 2. Calculated values of R_p.

temperature	20°C	30°C	40°C	50°C
R_p[kΩ.cm^{-2}]	69,81 ± 9,12	53,32 ± 10,02	26,31 ± 1,63	29,28 ± 0,67

From the measured values can be assumed higher danger of the equipment produced from AISI 316L exposed to the temperatures of 40-50°C to the corrosion damage. The results can be explained by the easier braking of the protective passive oxide layer created on the steel surface due to the exposure to the electrolyte at the temperatures of 40 and 50°C. This decreased corrosion resistance of the product can influence its following usage and corrosion resistance.

4. CONCLUSIONS

The corrosion properties of metallic materials used for the production of medical tools and equipment are the second most important property after nontoxicity connected with biocompatibility.

The present work was focused on the study of the influence of temperature on the corrosion resistance of AISI 316L stainless steel in 0.9% NaCl solution.

The results of EIS tests show the decrease of the polarization resistance, the resistance to the corrosion, by increasing of the temperature. The temperature of 40°C decreased the polarization resistance of AISI 316L to only 50% when compared to the 20°C. The temperature of 50°C decreased the polarization resistance at 20°C to the value less than 40%.

Such a large decrease of polarization resistance can decrease the corrosion resistance due to the heating of the medical equipment during sterilization and subsequently also the time of usage of the stainless steel product.

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