UNIVERSITY OF SILESIA
INSTITUTE OF MATERIALS ENGINEERING

Effect of sandblasting on the long-term corrosion resistance of Ti G4 in artificial saliva

Patrycja Osak *, Maciej Zubko, Julian Kubisztal, Joanna Maszybrocka,

and Bożena Łosiewicz *

Institute of Materials Engineering, Faculty of Science and Technology,
University of Silesia in Katowice, 75 Pułku Piechoty 1A, 41-500 Chorzów, Poland

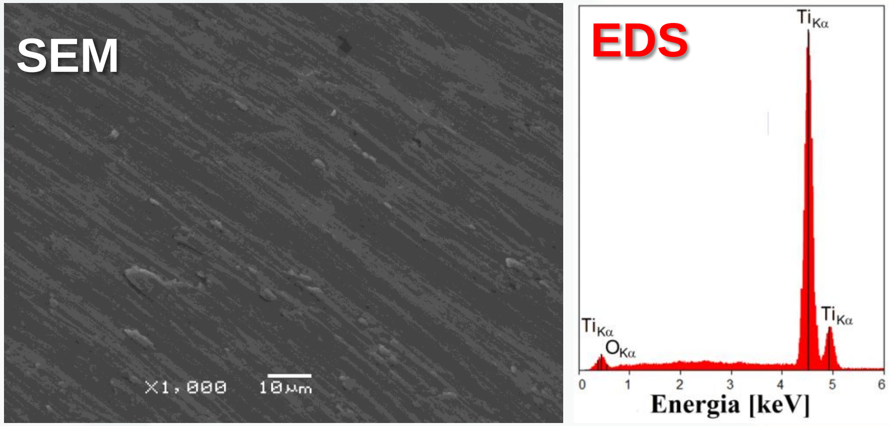
patrycja.osak@us.edu.pl; maciej.zubko@us.edu.pl; julian.kubisztal@us.edu.pl;
joanna.maszybrocka@us.edu.pl; bozena.losiewicz@us.edu.pl
***Correspondence: patrycja.osak@us.edu.pl; bozena.losiewicz@us.edu.pl

Abstract

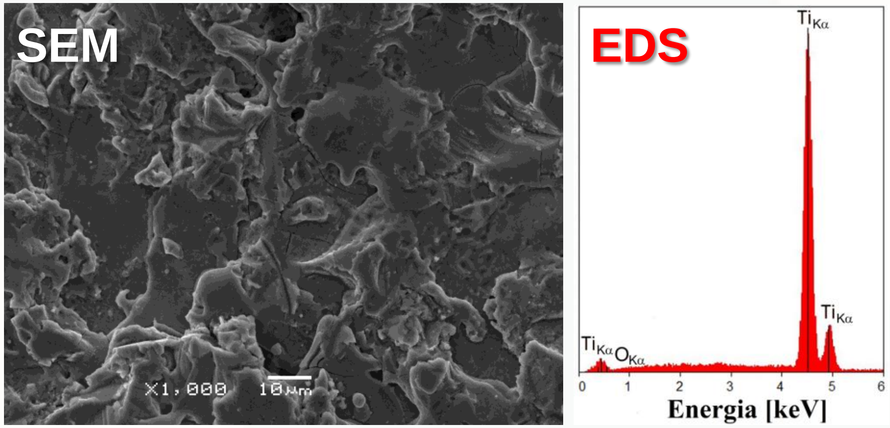
Titanium Grade 4 (G4) is the most commonly used material for dental implants due to its excellent biocompatibility and mechanical properties. However, titanium implants require a rough surface that can increase the biomechanical potential of implant-bone contact and affect protein adsorption speed. In this work, the effect of sandblasting of Ti G4 surface on the long-term corrosion resistance in artificial saliva of pH = 7.4 at 37 °C was studied. The X-ray diffraction (XRD) single-{hkl} $\sin^2\psi$ method was used to measure the sandblasted Ti residual stress. *In vitro* corrosion resistance tests were conducted for 21 days using the open circuit potential method, polarization curves, and electrochemical impedance spectroscopy. Using the Kelvin scanning probe, the electron work function was determined. Analysis of the obtained results showed an improvement in the corrosion resistance of the sandblasted Ti G4 compared to Ti with the machine surface. The increase in corrosion resistance was related to the residual compressive stresses of 324(7) MPa present in the sandblasted Ti surface. Sandblasting caused plastic deformation of the Ti surface, which resulted in the improvement in mechanical properties, as evidenced by the increase in the hardness of the sandblasted Ti compared to Ti with the machine surface.

Keywords: corrosion resistance; sandblasting; titanium

Experimental and Results – SEM/EDS



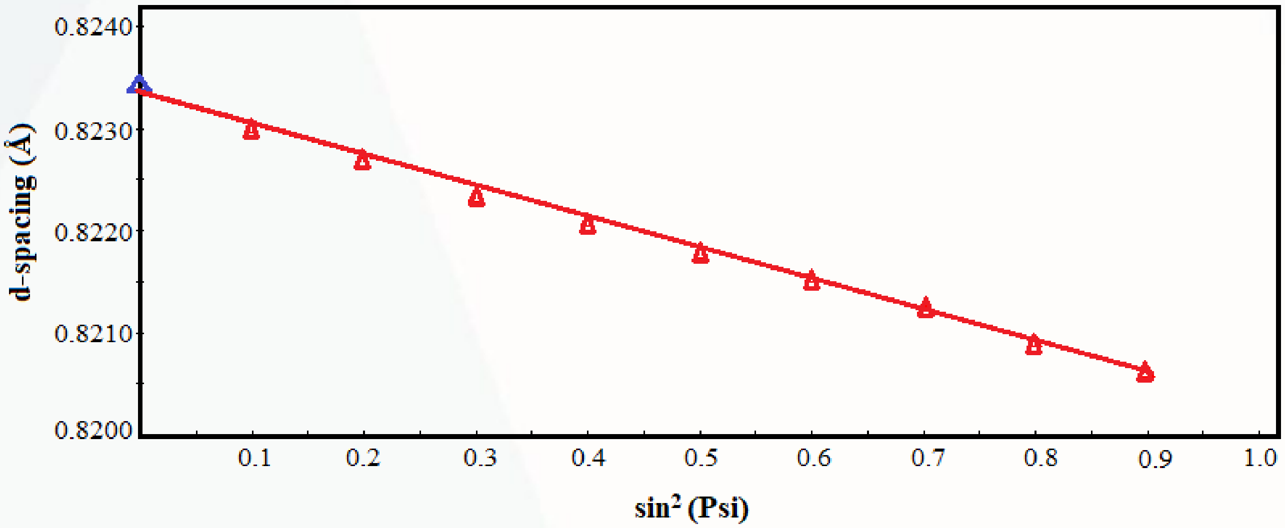
SEM image and EDS spectrum in the Ti initial state



SEM image and EDS spectrum for Ti after sandblasting

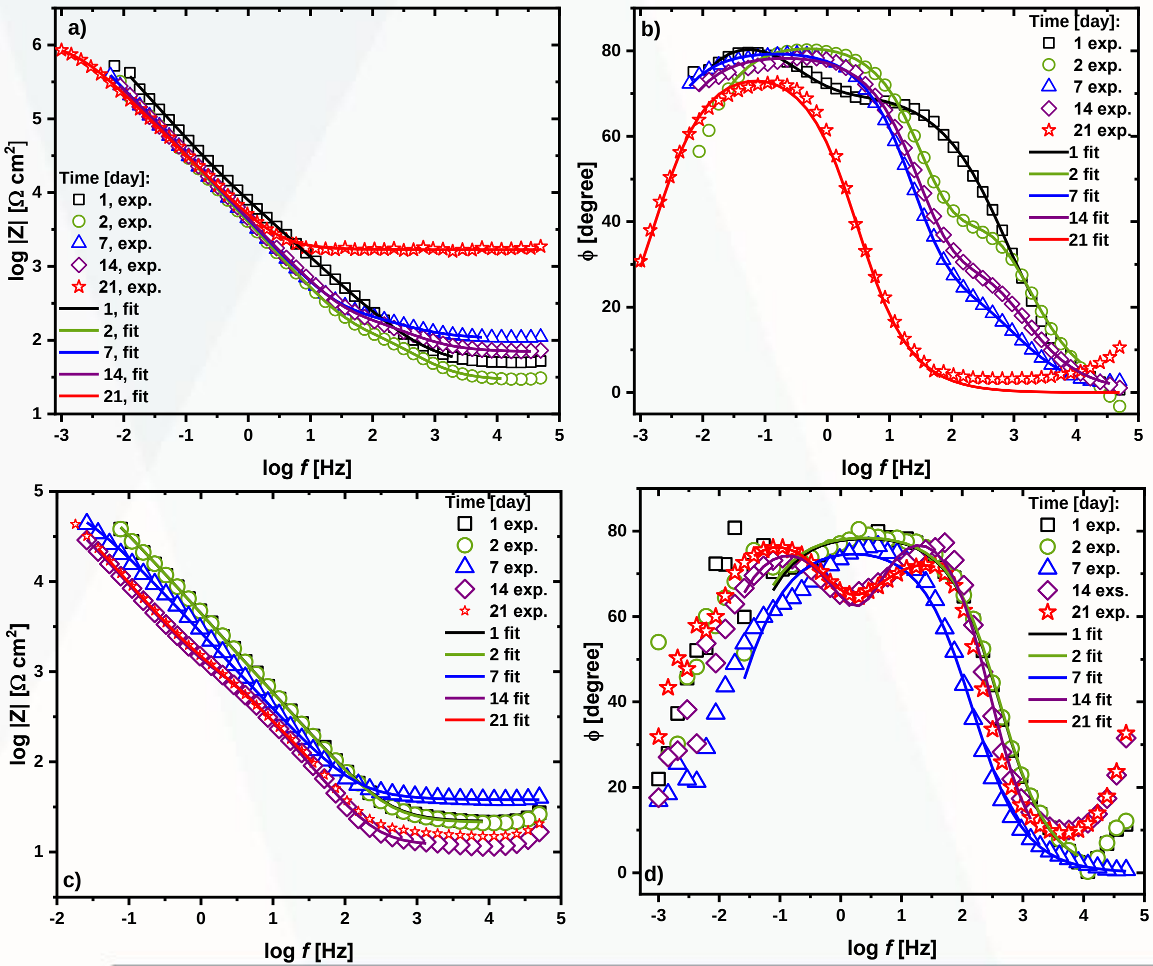
The surface morphology of Ti G4 with the machine surface is poorly developed. The titanium topography after sandblasting became irregular and rough. Microscopic observation of the Ti surface after sandblasting indicates the presence of small craters and microcracks initiated on the material's surface during the sandblasting process. This phenomenon is the result of compressive residual stresses after sandblasting and hardening of the surface.

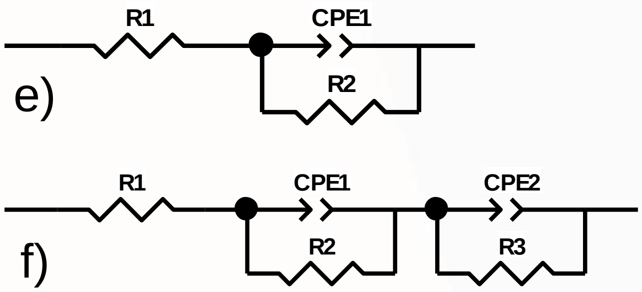
Experimental and Results - XRD



After the sandblasting process, the sample was subjected to residual stress tests using the single- {hkl} $\sin^2\psi$ X-ray diffraction method. For the stress measurements, (213)-pike α-Ti was selected in the position $2\theta CuK\alpha$ = 139.5 °. A constant 0.1 step was applied in the $\sin^2\psi$ space in the range of 0-0.9, which gives the tilt angles ψ 0°, 18.43°, 26.57°, 33.21°, 39.23°, 45.00° 50.77°, 56.79°, 63.43°, 71.57°. The state of residual stress on the surface of the sandblasted material was measured as **compressive stress of 324(7) MPa**. Strong plastic deformation causes deformation hardening in the surface layer of sandblasted Ti.

Experimental and Results – *In vitro* corrosion resistance





Bode diagrams:

a) Magnitude for the CpTi G4; b) Phase angle for the CpTi G4; c) Magnitude for the sandblasted CpTi G4; d) Phase angle for the sandblasted CpTi G4; in the artificial saliva solution (ASS) solution at 37°C with the equivalent electrical circuit models for the pitting corrosion process used for CNLS-fitting: e) one-CPE model; f) two-CPE model.

Experimental and Results – *In vitro* corrosion resistance

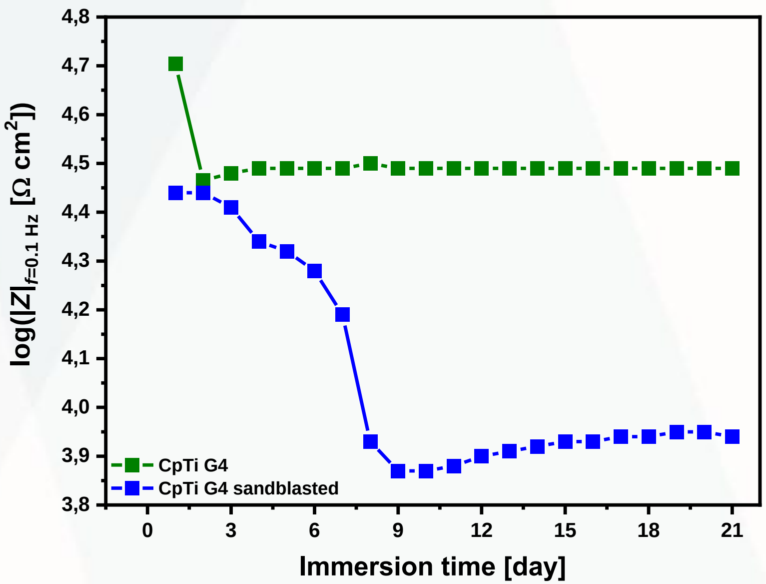
Table 1. The parameters with standard deviations determined by approximation of the experimental EIS data for the CpTi G4 electrode in the ASS at 37°C (R_s = 47.3(2) Ω·cm²)

Day	T_1 [F cm^{-2}·s $^{\phi-1}$]	ϕ_1	R_{ox1} [Ω·cm²]	T_2 [F·cm^{-2}·s $^{\phi-1}$]	ϕ_2	R_{ox2} [Ω·cm²]
1	2.87(6) ·10^{-5}	0.94(1)	2.38(1) ·10^{6}	8.25(6) ·10^{-5}	0.67(1)	4850(1)
2	4.70(2) ·10^{-5}	0.91(1)	5.64(3) ·10^{5}	4.69(6) ·10^{-5}	0.78(1)	77.18(1)
7	4.53(1) ·10^{-5}	0.89(6)	2.59(3) ·10^{6}	5.72(9) ·10^{-5}	0.71(1)	101.3(2)
14	4.48(2) ·10^{-5}	0.88(1)	1.82(5) ·10^{6}	4.04(1) ·10^{-5}	0.75(1)	98.67(2)
21	4.65(1) ·10^{-5}	0.85(5)	1.11(3) ·10^{6}	———	———	———

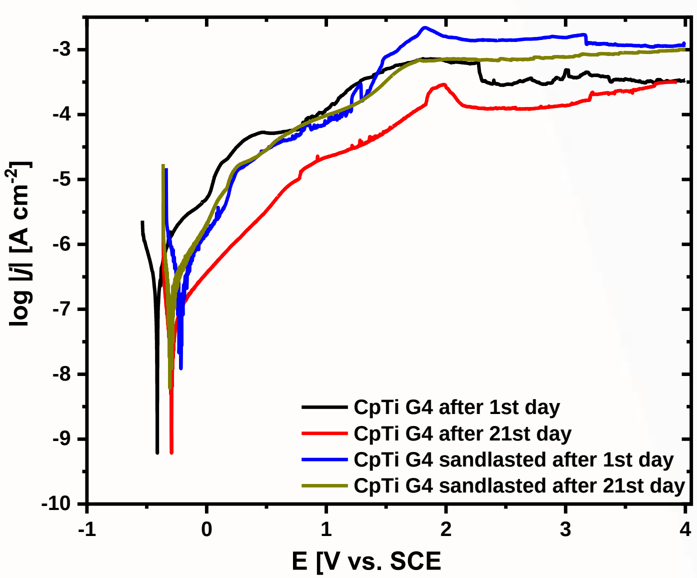
Table 2. The parameters with standard deviations determined by approximation of the experimental EIS data for the CpTi G4 sandblasted electrode in the ASS at 37°C (R_s = 20.2(2) Ω·cm²)

Day	T_1 [F cm^{-2}·s $^{\phi-1}$]	ϕ_1	R_{ox1} [Ω·cm²]	T_2 [F cm^{-2}·s $^{\phi-1}$]	Φ_2	R_{ox2} [Ω·cm²]
1	4.37(3) ·10^{-5}	0.88(3)	1.35(8) ·10^{5}	———	———	———
2	4.38(8) ·10^{-5}	0.88(2)	1.48(1) ·10^{5}	———	———	———
7	7.63(1) ·10^{-5}	0.85(4)	8.43(1) ·10^{4}	———	———	———
14	1.65(1) ·10^{-4}	0.90(1)	1.11(1) ·10^{5}	1.16(1) ·10^{-4}	0.83(1)	444.0(1)
21	1.59(1) ·10^{-4}	0.91(2)	1.97(3) ·10^{5}	2.01(1) ·10^{-4}	0.83(5)	596.8(1)

Experimental and Results – *in vitro* corrosion resistance

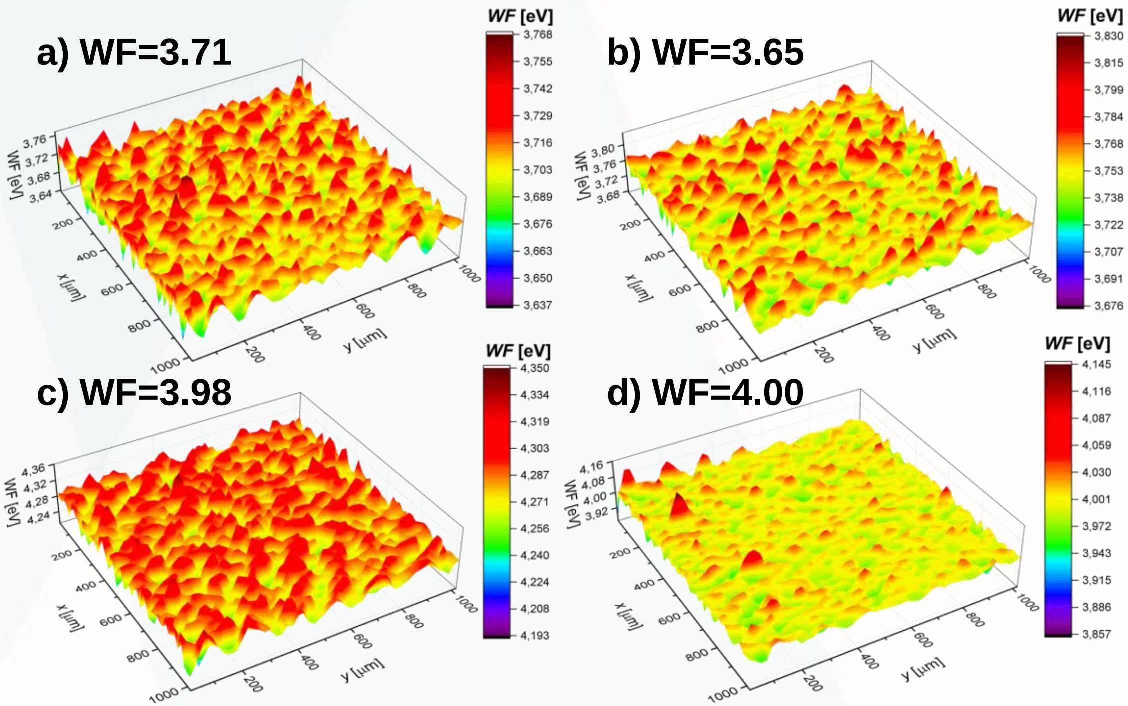


The dependence of the log|Z| at f = 0.1 Hz on immersion time for the CpTi G4 and sandblasted CpTi electrodes in the ASS at 37°C.



Anodic polarization curves for the CpTi G4 and sandblasted CpTi G4 electrodes in the ASS at 37°C after 1 and 21 days of immersion.

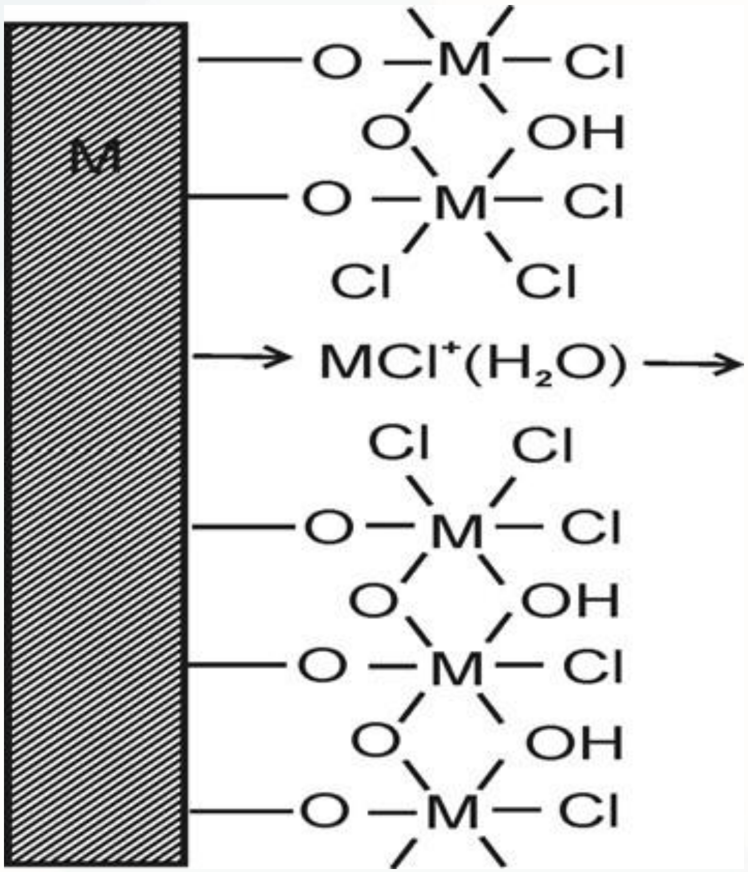
Experimental and Results – Work Function study

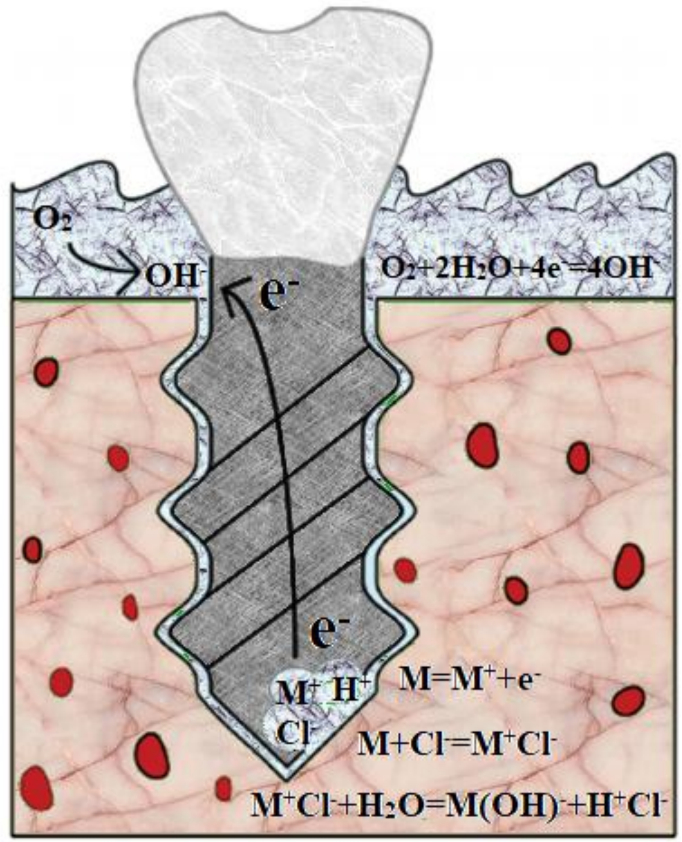


Work function (WF) maps: a) CpTi G4 before immersion; b) CpTi G4 after 21 days of immersion; c) CpTi G4 sandblasted before immersion; d) CpTi G4 sandblasted after 21 days of immersion

The work of the electron output depends on the surface condition of the material. The mean work function value for the CpTi G4 decreased after 21 days of immersion, indicating deterioration of corrosion resistance. The work function value for sandblasted CpTi G4 changed slightly, proving that the corrosion resistance remains stable and does not deteriorate after 21 days of immersion.

Mechanism *of in vitro* corrosion process of Ti G4





Conclusions

- On the basis of the obtained results using the open circuit potential, polarization curves, EIS, and SKP methods, it can be concluded that sandblasting is an effective method of surface modification of CpTi G4, enhancing its long-term corrosion resistance in the ASS with a pH of 7.4 at 37°C.

- The EIS study revealed the capacitive behavior of both CpTi G4 and sandblasted CpTi G4 with a high corrosion resistance. The EIS study allowed to track the long-term corrosion process by initiating and propagating and distinguishing between them. The mechanism and kinetics of pitting corrosion of the studied materials was determined based on the EIS measurements fitted by the equivalent electrical circuits of one- and two-CPE models.

- The corrosion resistance of both CpTi G4 and sandblasted CpTi G4 decreased during the immersion for 21 days. Higher corrosion resistance was determined for the sandblasted CpTi G4. This increase in corrosion resistance was related to the residual compressive stresses of 324(7) MPa in subsurface titanium layers. Sandblasting delays the initiation and growth of fatigue cracks by inducing residual compressive stress.