Corrosion resistance of Ni–Cr alloy in artificial tears in the presence of excess of glucose and sodium chloride

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Abstract

During surgical operations in the eye, metallic materials may come in contact with tears. These metals/alloys may undergo corrosion when they contact the tears. The corrosion resistance of a Ni–Cr alloy in artificial tears in the presence of excess of glucose and sodium chloride has been evaluated by electrochemical studies such as polarization study and AC impedance spectroscopy. It is observed that when the sodium chloride level or glucose level in tears increases, the corrosion resistance of Ni–Cr alloy in artificial tears is not affected. It is interesting to note that the corrosion resistance of Ni–Cr alloy in artificial tears rather increases. Hence when there is an increase in glucose level of sodium chloride level in tears, the surgical instruments may be of Ni–Cr alloy.

Keywords: *artificial tears, corrosion resistance, Ni–Cr alloy, glucose, sodium chloride.*

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Introduction

Body fluids (biofluids) are liquids within the human body. In lean healthy adult men, the total body water is about 60–67% of the total body weight. It is usually slightly lower in women. Body fluids are broadly classified into intracellular fluid and extracellular fluid [1]. The body fluids maintain the water content of the body. Body fluids help regulate body temperature, help in blood circulation, help in digestion and keeping the skin moist. There are body fluids such as saliva, urine, sweat, tears and blood plasma. When metals and alloys come in contact with these fluids they may undergo corrosion. Many research papers have been published in this regard.

Effect of sterilization and long-term exposure to artificial urine on corrosion behaviour of metallic biomaterials with poly(glycolide-co-caprolactone) coatings has been investigated by Kajzer *et al*. [2]. Electrochemical study on corrosion inhibition of metals in artificial urine in presence of sodium chloride has been carried out by Nagalakshmi *et al*.

[3]. *In situ* electrochemical study of interaction of tribology and corrosion in artificial hip prosthesis simulators has been carried out by Yan *et al*. [4]. Metabolic albumin and its effect on electrochemical behavior of titanium implant alloy has been investigated by Ravoiu *et al*. [5]. Kumar *et al*. [6] have studied on biocorrosion evaluation on a Zr–Cu–Ag–Ti metallic glass. Influence of surface modification on physicochemical properties of Ti6Al7Nb alloy has been investigated by Walke *et al*. [7].

Influence of contact configuration and lubricating conditions on the microtriboactivity of the zirconia–Ti6Al4V pair used in dental applications has been studied by Branco *et al*. [8]. Soran and Mutlu have studied on production and anodizing of highly porous Ti–Ta–Zr–Co alloy for biomedical implant applications [9]. Effect of the heat treatment on corrosion and mechanical properties of CoCrMo alloys manufactured by selective laser melting has been investigated by Zhang *et al*. [10]. Yuan *et al*. [11] have studied on performance comparison between metal materials for fashion jewelry. A combination of self-assembled monolayer and hydrophobic conformal coating for anti-corrosion of Cu/NiP/Au 3D circuitry in artificial sweat solution has been investigated by Huang *et al*. [12].

Corrosion resistance of praseodymium-surface-modified magnesium alloy in sweat has been investigated by Wang *et al*. [13]. Corrosion behaviour of metals in artificial tear solution has been investigated by Kumar *et al*. [14]. The present work is undertaken to study the corrosion resistance of Ni–Cr alloy in artificial tears (AT) in presence of excess of glucose and sodium chloride. Electrochemical studies such as polarization study and AC impedance spectra have been employed to measure the corrosion resistance.

Experimental Procedure

Preparation of artificial tears

0.5 % of sodium salt of carboxymethyl cellulose (CMC) was used as artificial tears [15]. In electrochemical studies, Ni–Cr was used as working electrodes. Artificial sweat (AS) was used as the electrolyte (50 ml). The temperature was maintained at 37±0.1°C.

Potentiodynamic Polarization

Polarization studies were carried out in a CHI-electrochemical workstation with impedance, Model 660A. A three-electrode cell assembly was used. The working electrode was Ni–Cr alloy. A saturated calomel electrode (SCE) was the reference electrode and platinum was the counter electrode. The details of the experimental conditions are as follows: Hold Time at Ef (s) = 0; Scan Rate (v/s) = 0.005; Quiet Time (s) = 2. From the polarization study, corrosion parameters such as corrosion potential (E_{corr}), corrosion current (I_{corr}) and Tafel slopes (anodic = b_a and cathodic = b_c) and linear polarization resistance (LPR) were calculated. LPR monitoring is an effective electrochemical method of measuring corrosion. Monitoring the relationship between electrochemical potential and current generated between electrically charged electrodes in a process stream allows the calculation of corrosion current. If the electrodes are corroding at high rate with the metal ions passing into solution, a small potential applied between the electrodes will produce a high current, and therefore a low polarization resistance. This corresponds to a high corrosion rate.

AC impedance spectra

AC impedance spectra were recorded in a CHI-electrochemical workstation with impedance, Model 660A. A three-electrode cell assembly was used. The working electrode was Ni–Cr alloy. A saturated calomel electrode (SCE) was the reference electrode and platinum was the counter electrode.

The real part (Z') and imaginary part (Z'') of the cell impedance were measured in Ohms at various frequencies. Values of the charge transfer resistance (R_t) and the double layer capacitance (C_{dl}) were calculated from Nyquist plots impedance; log (Z/Ohm) value was calculated from Bode plots.

Results and Discussion

During surgical operations in eyes, the instruments may come in contact with tears. During this process the alloys may undergo corrosion when they come in contact with tears. In the present study the corrosion resistance of Ni–Cr alloy in artificial tear solution (0.5% CMC solution) has been evaluated by polarization study and AC impedance spectra.

Polarization study

Polarization curves of Ni–Cr alloy in artificial tear solution, in the absence and presence of glucose and also NaCl corrosion are shown in Figures 1–5. The corrosion parameters such as corrosion potential (E_{corr}), Tafel slopes (b_c = cathodic; b_a = anodic), linear polarization resistance (LPR) and corrosion current (I_{corr}) corrosion parameters are given in Table 1.

When corrosion resistance increases, LPR increases and corrosion current decreases.

Table 1. Corrosion parameters of Ni–Cr alloy immersed in artificial tears (AT) (0.5% CMC) in the absence and presence of glucose and sodium chloride obtained by polarization study.

System	E_{corr} mV_{SCE}	b_c mV/decade	b_a mV/decade	LPR Ohm cm^2	I_{corr} A/cm^2
Distilled water	– 326	0.1787	0.267	951304	4.850×10^{-8}
Artificial Tears	–269	0.1247	0.3119	2966373	1.306×10^{-8}
AT + Glucose 100 ppm	–180	0.1621	0.2827	3761935	1.191×10^{-8}
AT + sodium chloride 100 ppm	–094	0.1885	0.2217	27299596	1.617×10^{-9}

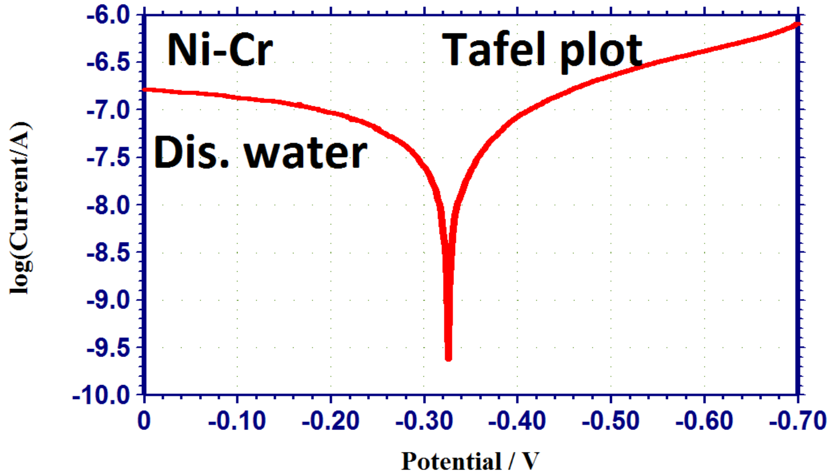


Figure 1. Polarisation curve of Ni–Cr alloy immersed in distilled water.

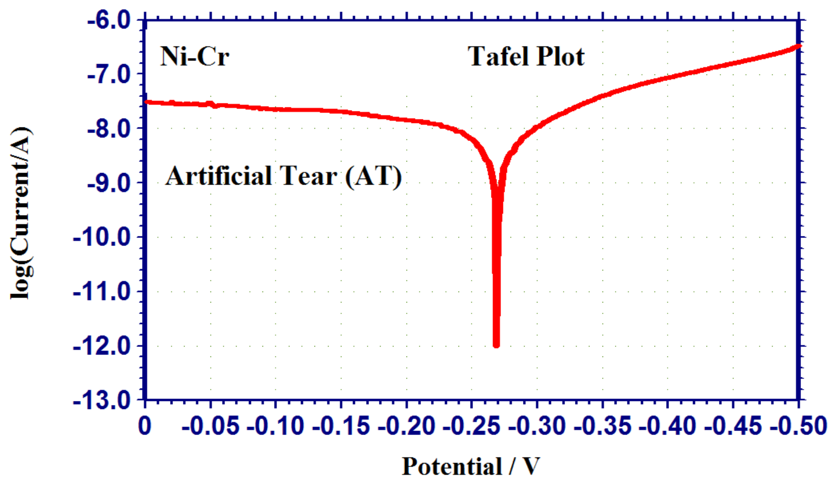


Figure 2. Polarisation curve of Ni–Cr alloy immersed in Artificial Tears.

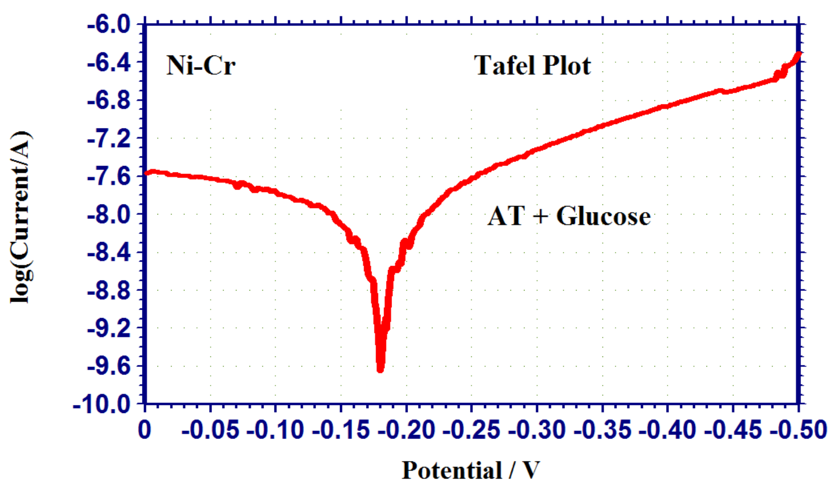


Figure 3. Polarisation curve of Ni–Cr alloy immersed in Artificial Tear + Glucose 500 ppm.

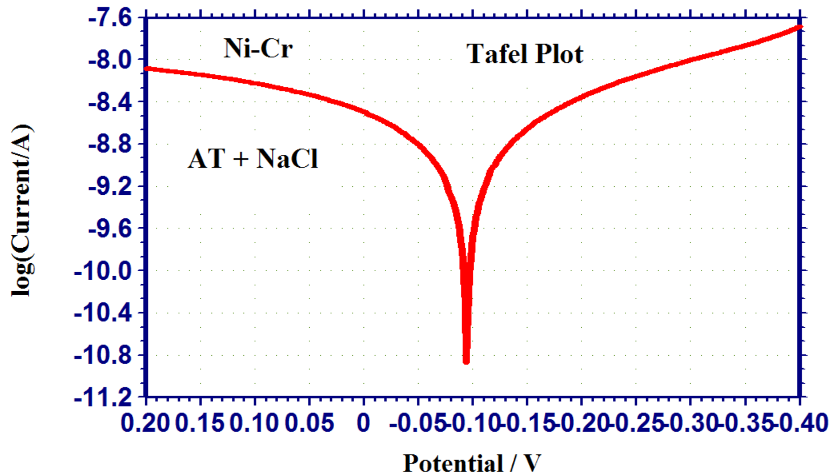


Figure 4. Polarisation curve of Ni–Cr alloy immersed in Artificial Tear + NaCl 500 ppm.

When Ni–Cr alloy is immersed in distilled water, the corrosion potential is –326 mV *vs*. SCE (Saturated Calomel Electrode). The LPR value is 951,304 Ohm cm^2. It is observed from the Table that when Ni–Cr alloy is immersed in artificial tear solution, the LPR value increases from 951,304 to 2,966,373 Ohm cm^2, the corrosion current value decreases from 4.850×10^{-8} to 1.306×10^{-8} A/cm^2. This indicates that Ni–Cr alloy is more corrosion resistant in artificial tear solution than in distilled water. Similarly it is observed from the table that the corrosion resistance of Ni–Cr alloy in various test solutions are as follows (Figure 5): AT + NaCl 100 ppm system > AT + Glucose 100 ppm system > AT solution system > Distilled water.

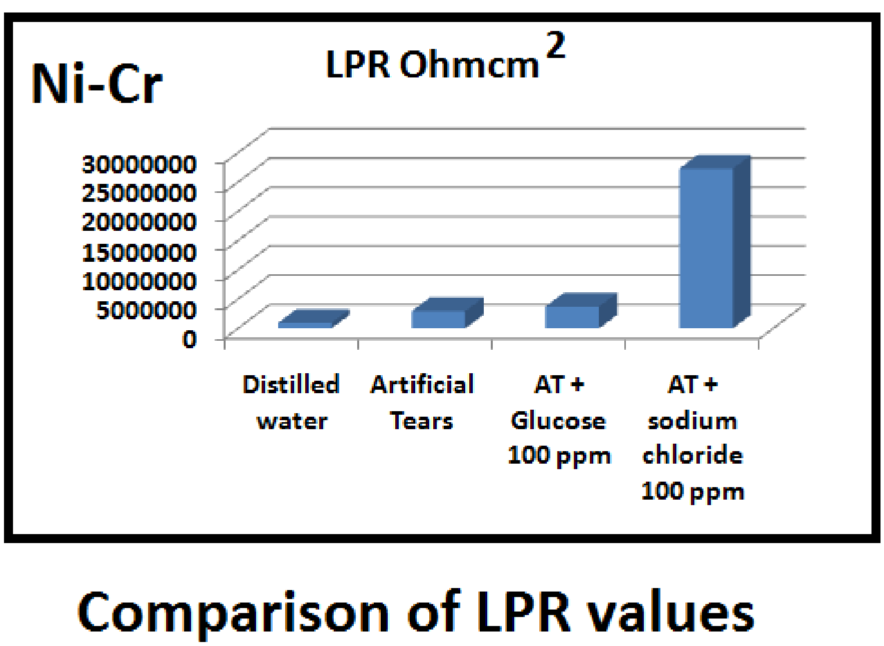


Figure 5. Comparison of LPR values of Ni–Cr immersed in various test solutions.

Implication

1. Corrosion resistance of Ni–Cr alloy in artificial tear solution is not affected when sodium chloride level increases in artificial tear solution.
2. Corrosion resistance of Ni–Cr alloy in artificial tear solution is not affected when glucose level increases in artificial tear solution.

AC impedance spectra

AC impedance spectra of Ni–Cr alloy in artificial tear solution, in the absence and presence of glucose and also NaCl corrosion are shown in Figures 6–14. The corrosion parameters such as double layer capacitance (C_{dl}), charge transfer resistance (R_t), impedance are shown in Table 2.

When R_t value increases C_{dl} value decreases impedance value increases.

Table 2. Corrosion parameters of Ni–Cr alloy immersed in artificial tears (AT) (0.5% CMC) in the absence and presence of glucose and sodium chloride obtained by AC impedance spectraю

System	R_t, Ohm cm^2	C_{dl}, F/cm^2	Impedance Log(*Z*/Ohm)
Distilled water	29,790	1.679×10^{-12}	4.149
Artificial Tears	139,300	1.529×10^{-12}	5.205
AT + Glucose 100 ppm	3,271,000	3.589×10^{-10}	6.614
AT + sodium chloride 100 ppm	12,275,680	4.073×10^{-13}	7.514

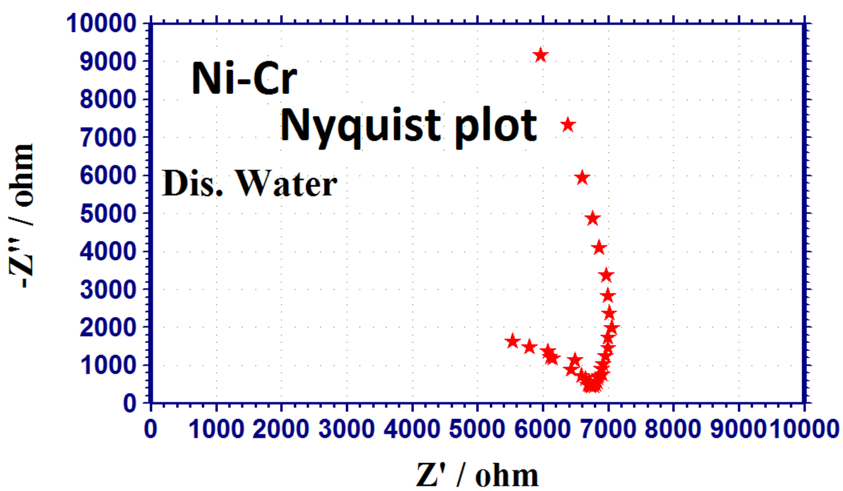


Figure 6. AC impedance spectrum of Ni–Cr immersed in distilled water (Nyquist plot).

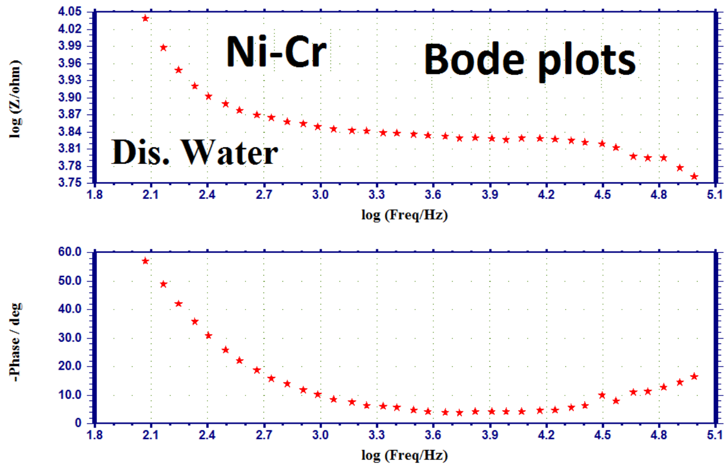


Figure 7. AC impedance spectrum of Ni–Cr immersed in distilled water (Bode plot).

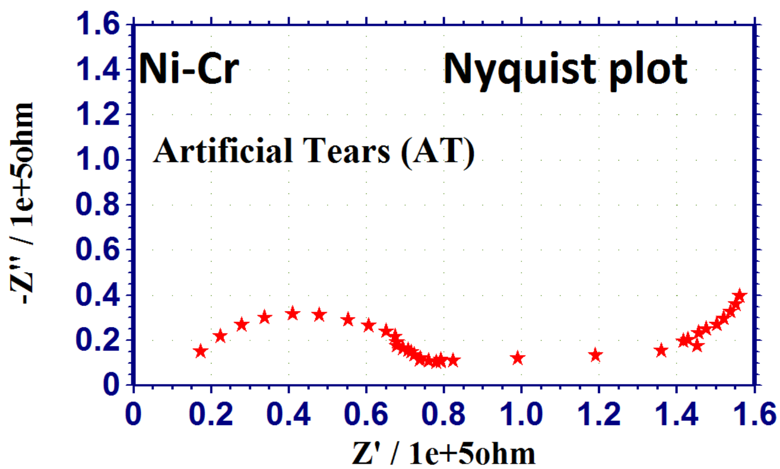


Figure 8. AC impedance spectrum of Ni–Cr immersed in artificial tears (Nyquist plot).

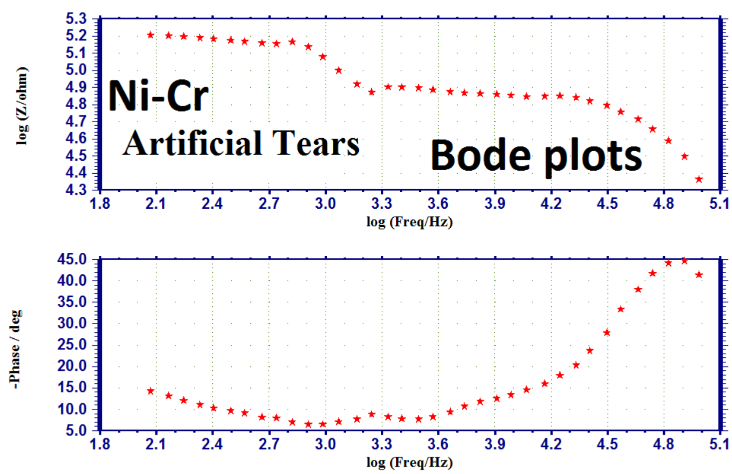


Figure 9. AC impedance spectrum of Ni–Cr immersed in artificial tears (Bode plot).

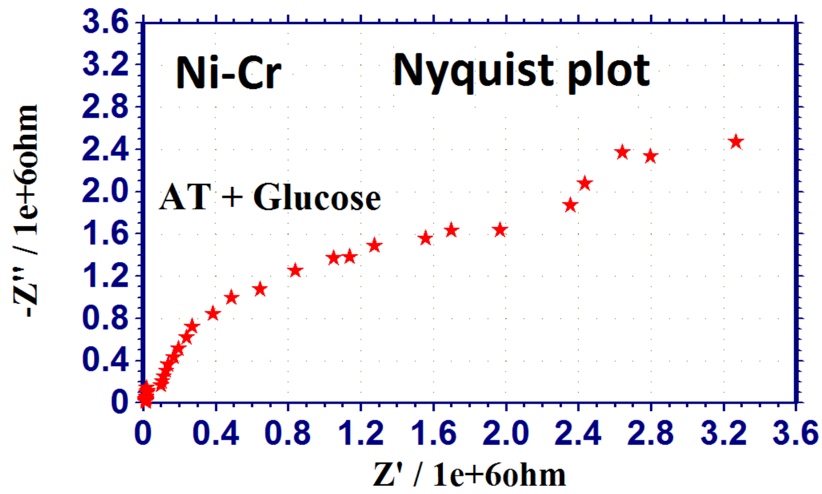


Figure 10. AC impedance spectrum of Ni–Cr immersed in artificial tears + glucose (Nyquist plot).

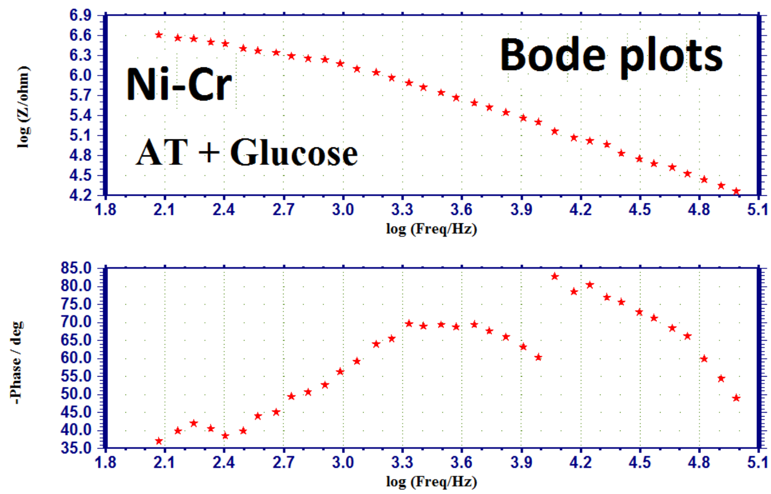


Figure 11. AC impedance spectrum of Ni–Cr immersed in artificial tears + glucose (Bode plot).

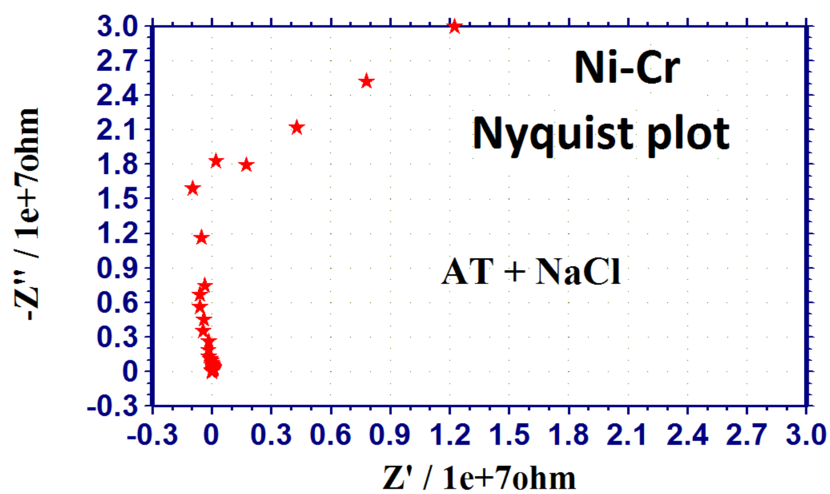
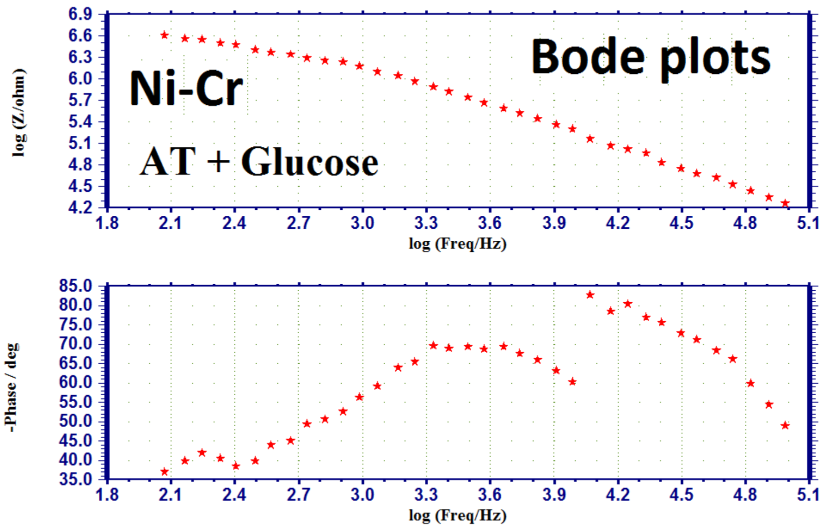


Figure 12. AC impedance spectrum of Ni–Cr immersed in artificial tears + NaCl (Nyquist plot).



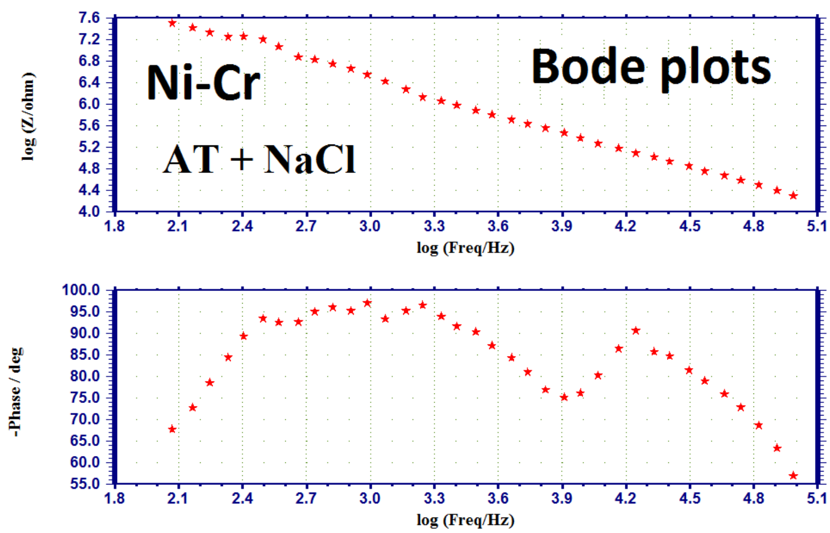
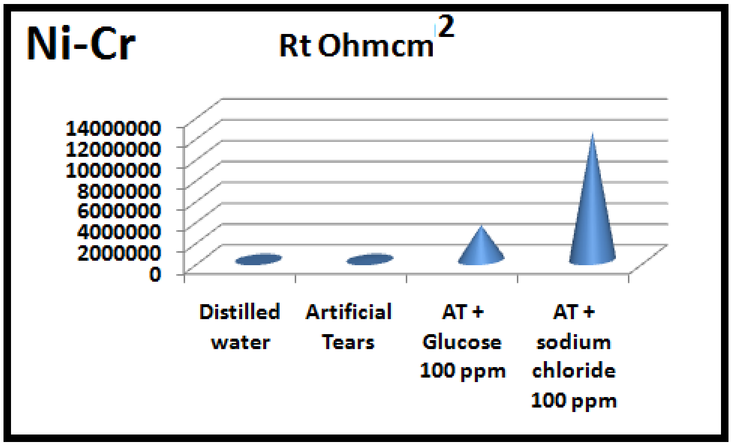


Figure 13. AC impedance spectrum of Ni–Cr immersed in artificial tears + NaCl (Bode plot).

When Ni–Cr alloy is immersed in distilled water, the R_t value is 29,790 Ohm cm^2. It is observed from the Table that when Ni–Cr alloy is immersed in artificial tear solution, the R_t value increases from 29,790 to 139,300 Ohm cm^2. The C_{dl} value decreases from 1.679×10^{-10} to 1.529×10^{-12} F/cm^2. The impedance value increases from 4.149 to 5.205. This indicates that Ni–Cr alloy is more corrosion resistant in AT solution than in distilled water. Similarly it is observed from the Table that the corrosion resistance of Ni–Cr alloy in various test solution are as follows (Figure 14): AT + NaCl 100 ppm system > AT + Glucose 100 ppm system > AT solution system > distilled water.



Comparison of Rt values

Figure 14. Comparison of R_t values of Ni–Cr alloy in various test solutions.

References

1. https://en.wikipedia.org/wiki/Body_fluid
2. W. Kajzer, J. Jaworska, K. Jelonek, J. Szewczenko, K. Nowińska and A. Kajzer, Effect Of sterilization and long-term exposure to artificial urine on corrosion behaviour of metallic biomaterials with poly(Glikolide-co-kaprolactone) coatings, *Advances in Intelligent Systems and Computing*, 2018, **623**, 391–398.
3. R. Nagalakshmi, J. Sathiyabama, S. Rajendran and I. AmeethBasha, Electrochemical study on corrosion inhibition of metals in artificial urine in presence of sodium chloride, *Int. J. Chem. Sci.*, 2016, **14**, 282–288.
4. Y. Yan, D. Dowson and A. Neville, In-situ electrochemical study of interaction of tribology and corrosion in artificial hip prosthesis simulators, *J. Mech. Behav. Biomed. Mater.*, 2013, **18**, 191–199. doi: 10.1016/j.jmbbm.2012.08.009
5. A. Ravoiu, L. Benea and A. Chiriac, Metabolic Albumin and Its Effect on Electrochemical Behavior of Titanium Implant Alloy, *IOP Conference Series: Materials Science and Engineering*, 2018, **374**, no. 1, 012077. doi: 10.1088/1757-899X/374/1/012077
6. S. Kumar, R. Anwar, W. Ryu, E.S. Park and S. Vincent, Biocorrosion Evaluation on a Zr-Cu-Ag-Ti Metallic Glass, *IOP Conference Series: Materials Science and Engineering*, 2018, **346**, no. 1, 012009. doi: 10.1088/1757-899X/346/1/012009
7. W. Walke, M. Basiaga, Z. Paszenda, A. Kajzer, W. Kajzer, J. Szewczenko, T. Pustelny, S. Drewniak, Z. Opilski and C. Krawczyk, Influence of surface modification on physico-chemical properties of Ti6Al7Nb alloy, 2016, *Surf. Coat. Technol.*, **307**, 753–760. doi: 10.1016/j.surfcoat.2016.09.079
8. A.C. Branco, V. Moreira, J.A. Reis, R. Colaço, C.G. Figueiredo-Pina and A.P. Serro, Influence of contact configuration and lubricating conditions on the microtriboactivity

of the zirconia-Ti6Al4V pair used in dental applications, *J. Mech. Behav. Biomed. Mater.*, 2019, **91**, 164–173. doi: 10.1016/j.jmbbm.2018.12.009
9. M.R. Soran and I. Mutlu, Production and anodising of highly porous Ti–Ta–Zr–Co alloy for biomedical implant applications, *Corrosion Engineering Science and Technology*, **54**(1), 54-61. doi: 10.1080/1478422X.2018.1527820
10. M. Zhang, Y. Yang, C. Song, Y. Bai and Z. Xiao, Effect of the heat treatment on corrosion and mechanical properties of CoCrMo alloys manufactured by selective laser melting, *Rapid Prototyping J.*, 2018, **24**, no. 7, 1235–1244. doi: 10.1108/RPJ-10-2017-0215
11. J. Yuan, L. Chen and Y. Huang, Performance Comparison between Metal Materials for Fashion Jewelry, *Tezhong Zhuzao Ji Youse Hejin / Special Casting and Nonferrous Alloys*, 2017, **37**, no. 10, 1050–1053.
12. Z.H. Huang, Y.J. Zhou and W. He, A combination of self-assembled monolayer and hydrophobic conformal coating for anti-corrosion of Cu/NiP/Au 3D circuitry in artificial sweat solution, *Surf. Coat. Technol.*, 2017, **320**, 126–131. doi: 10.1016/j.surfcoat.2017.01.087
13. W. Wang, X. Zhang, G. Wu, C. Wang and P.K. Chu, Praseodymium-surface-modified magnesium alloy: Retardation of corrosion in artificial hand sweat, *Mater. Lett.*, 2016, **163**, 85–89. doi: 10.1016/j.matlet.2015.10.058
14. C. Kumar, A.J.A. Raj and S.K. Selvaraj, Corrosion Behaviour of Metals in Artificial Tear Solution, *J. Adv. Chem.*, 2014, **8**, no. 3, 1716–1735.
15. https://www.drugbank.ca/drugs/DB11059

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