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Electrochemical studies on the corrosion resistance of Gold 18K and Thermo active alloy in artificial sweat in presence of sodium chloride

ABSTRACT

Corrosion resistance of Thermo active alloy and Gold 18K alloy immersed in artificial sweat in the absence and presence of 100 ppm of NaCl has been investigated by polarization study and AC impedance spectra. It is observed that corrosion resistance of thermo active alloy and also Gold 18K alloy immersed in artificial sweat in the presence of 100 ppm of NaCl increases. Hence it is concluded that people wearing ornaments made of these two alloys need not worry about the excess of sodium chloride in their sweat. When thermo active alloy is immersed in artificial sweat in the presence of 100 ppm of NaCl, linear polarization resistance value increases from 1760283 Ohm cm^2 to 9506106 Ohm cm^2; corrosion current decreases from 1.845x10^{-8} to 4.008x10^{-9} A/cm^2; charge transfer resistance value increases from 4884 Ohmcm^2 to 12210 Ohm cm^2; impedance value increases from 4.367 to 4.8; double layer capacitance decreases from 1.0442 x10^{-9} to 4.1769x10^{-10} F/cm^2 , and phase angle increases from 48.1 to 66.34°. When Gold 18K alloy is immersed in artificial sweat in the presence of 100 ppm of NaCl, linear polarization resistance value increases from 1079199 Ohmcm^2 to 2385141 Ohm cm^2; corrosion current decreases from 4.036x10^{-8} to 0.1966 x 10 $^{-8}$A/cm^2 ; charge transfer resistance increases from 4291 Ohm cm^2 to 48880 Ohm cm^2; impedance value increases from 4.652 to 5.114; double layer capacitance decreases from 1.189 x10^{-9} to 1.0434 x10^{-10} F/cm^2, and phase angle increases from 61 to 88.

Keywords: *Corrosion resistance, Thermo active alloy, Gold 18K alloy, Artificial sweat, NaCl, polarization study, AC impedance spectra*

1. INTRODUCTION

Human perspiration (sweat) comes in contact with a number of consumer products. Contact can cause a variety of undesirable effects. Dyes can bleed or discolor, components can corrode and/or malfunction, residues can be unsightly. The problem of metal corrosion resulting from contamination by palmar sweat is common to many Constant handling of metal parts by some individuals causes an accumulation of rust.

In the manufacture of highly finished metal products, for example ball-bearings, and also in subsequent assembling and packing processes, serious consideration must be given to this effect [1].

The antimicrobial copper coatings were deposited on AISI 304 stainless steel (SS) using electrodeposition technique for touch surface applications by Bharadishettar, and Udaya Bhat [2]. Electrodeposition was performed using a non-cyanide electrolyte, with varying copper concentrations. The copper coatings were investigated for their microstructure, in vitro degradation in the simulated hand sweat environment, and antimicrobial activity in an agar medium. The degradation behavior of coatings in the simulated hand sweat solution was further probed using

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potentiodynamic polarization test and electrochemical impedance spectroscopy (EIS) [2]. Water permeation is an important issue in both fundamental research and industrial applications. Stable superhydrophobic copper surfaces were obtained by self-assembly and spray deposition on cotton fabrics by Chen et al [3]. Scanning electron microscopy revealed that micro/nano dual-scale coral-like structures were established by the stacking of copper nanoparticles, thus forming a stable Cassie model for superhydrophobic feathers. Compared with the super hydrophilic copper surface, the superhydrophobic coating showed better corrosion resistance in 3.5 wt % NaCl solution and artificial sweat. Combined with the inherent conductivity of copper, fabrics have potential applications in the new generation of advanced textiles [3]. Corrosion reliability of hearing aid (HA) devices is a critical issue due to their exposure to harsh climatic conditions like high humidity and temperature, along with the combination of high level of salt contamination from human sweat and environmental pollutants. Statistical analysis of corrosion failure data can provide a better understanding of the failure sequence and cause, which is important as the issue is due to multiple parameter effects on a complex device consisting of many components. Analysis was used by Yadav et al [4] for understanding the failure mechanisms, while the data was used for statistical analysis in order to elucidate the device degradation rate and failure probability. Potassium hydroxide (KOH) electrolyte leakage from faulty Zn-air batteries (ZABs) and human sweat were prominent causes for the corrosion failure of hearing aid components. The rate of corrosion failures was found to accelerate during the summer season due to an increase in human perspiration rate and the release of KOH electrolyte from the batteries. Corrosion behavior of Cu-Zn-Ni-Sn imitation-gold copper alloy in artificial seawater and perspiration has been investigated by Yu et al [5]. Electrochemical behavior of various implantation biomaterials in the presence of various simulated body fluids has been investigated by Mary et al [6]. Elzohry et al [7] have investigated Chemical, Electrochemical and Corrosive Wear Behavior of Nickel-plated Steel and Brass-plated Steel Based.

The corrosion behavior many of metallic materials used as jewelry in synthetic sweat solution was studied by electrochemical polarization method by Naser et al [8]. Results showed that the sample (Cu-Fe alloy) has the majority corrosion potential in negative beside the highest current density as well as the current density reached to 366.13 $\mu A.cm^{-2}$, while Red brass has the noblest corrosion potential in addition the current density of corrosion is very low, and reached to 11.080 $\mu A.cm^{-2}$. The surface morphology of the surface of corroded specimens was analyzed using scanning electron microscope to show the product of corrosion with damage on the surface of the material. Atmospheric corrosion behavior of benzotriazole treated cu-based coins in synthetic sweat has been investigated by et al [9]. Bioaccessibility of nickel and cobalt in powders and massive forms of stainless steel, nickel- or cobalt-based alloys, and nickel and cobalt metals in artificial sweat has been investigated by Wang et al [10].

In the present study corrosion resistance of thermo active alloy and Gold 18K alloy immersed in artificial sweat in the absence and presence of 100 ppm of NaCl has been investigated by polarization study and AC impedance spectra.

2. EXPERIMENTAL

Two alloy specimens, namely, thermo active super elastic shape memory alloy and Gold 18K were chosen for the present study. Thermo active super elastic shape memory alloy consists of equal parts Ni and Titanium with working range of 50°C up to 110°C. 18 carat gold contains 75 per cent gold and 25 per cent other metals, often copper or silver.

The metal specimens were encapsulated in Teflon. The metal specimens were polished to mirror finish and degreased with trichloroethylene. The metal specimens were immersed in artificial sweat (the ISO standard ISO 3160-2), whose composition was : 20g/l NaCl, 17.5 g/l NH_4Cl, 5g/l acetic acid and 15 g/l d,l lactic acid with the pH adjusted to 4.7 by NaOH. In electrochemical studies, the metal specimens were used as working electrodes. Artificial sweat (AS) was used as the electrolyte (10 ml). The temperature was maintained at 37 ± 0.1°C.

Potentiodynamic Polarization Study

In the present exploration, polarization studies were carried out in a CHI Electrochemical work station/ analyzer, model 660A. It was provided with automatic *iR* compensation facility. A three electrode cell assembly was used. The working electrode was one of the two alloys. A saturated calomel electrode (SCE) was the reference electrode and platinum was the counter electrode.

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

The instrument used for polarization study was used to record AC impedance spectra also. The cell setup was also the same. The real part (Z') and imaginary part (-Z") of the cell impedance were measured in ohms at various frequencies. The details of the experimental conditions are as follows: Initial E (V) = 0; High frequency (Hz)=1x 10^5; Low frequency (Hz) = 10; Amplitude (V) = 0.005; Quiet Time (s) = 2. Values of the charge transfer resistance (R_t) and the double layer capacitance (C_{dl}) were calculated.

3. RESULTS AND DISCUSSION

Influence of sodium chloride on corrosion resistance of Thermo active alloy immersed in artificial sweat (AS) and influence of sodium chloride on corrosion resistance of Gold 18 K immersed in artificial sweat (AS) have been investigated by electrochemical methods such as polarization study and AC impedance spectra.

Influence of sodium chloride on corrosion resistance of thermo active alloy immersed in artificial sweat (AS)

Influence of sodium chloride on corrosion resistance of thermo active alloy immersed in artificial sweat (AS) has been investigated by Polarization study and AC impedance spectra. Polarization study and AC impedance spectra have been widely used in corrosion inhibition /protection study to know the corrosion resistance of metals and alloys [11-26].

Analysis of Results of Polarization Study

The Polarization curves of Thermo active alloy in AS in the absence and presence of 100 ppm of sodium chloride are shown in Figure 1. The corrosion parameters are given in Table1. In polarization study, when corrosion resistance increases, LPR increases and corrosion current decreases.

Table1. Corrosion Parametres of Thermo active alloy immersed in various test solutions containing artificial sweat (AS) obtained by polarization study

Tabela 1. Parametri korozije termoaktivne legure potopljene u različite test rastvore koji sadrže veštački znoj (AS) dobijeni proučavanjem polarizacije

System	$-E_{corr}$,mV/SCE	b_c, mV/decade	b_a,mV/decade	LPR, Ohm cm^2	I_{corr},A/cm^2
AS	400	90	429	1760283	$1.845x10^{-8}$
AS+ NaCl 100 ppm	165	193	164	9506106	$4.008x10^{-9}$

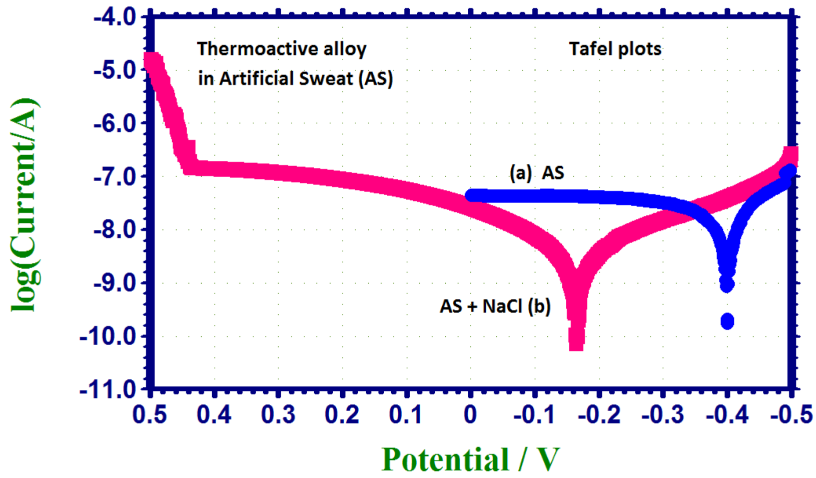

Figure 1. Polarization curves of thermo active alloy immersed in various test solutions: (a) Artificial sweat (b) Artificial sweat + NaCl (100 ppm)

Slika 1. Polarizacione krive termoaktivne legure uronjene u različite testne rastvore: (a) Veštački znoj (b) Veštački znoj + NaCl (100 ppm)

It is observed from Table 1, that in presence of 100 ppm of sodium chloride, the corrosion resistance of Thermo active alloy in AS increases. This is revealed by the fact that, in presence of 100 ppm of sodium chloride, LPR value of Thermo active alloy increases and corrosion current decreases. Sodium chloride behaves as anodic type of inhibitor. This is due to the fact that in presence of sodium chloride, the corrosion potential is shifted to anodic side.

Implication

Corrosion resistance of thermo active alloy in artificial sweat increases in presence of presence of 100 ppm of sodium chloride. Hence people wearing ornaments such as wrist watch, rings, ear rings, made of Thermo active alloy need not worry about sweat, because corrosion resistance of Thermo active alloy in artificial sweat increases in presence of presence of 100 ppm of sodium chloride.

Analysis of results of AC impedance spectra

In AC impedance spectra analysis, when corrosion resistance increases, R_t values and impedance values increase whereas C_{dl} values decrease.

The AC impedance spectra of thermo active alloy in AS in the absence and presence of 100 ppm of sodium chloride are shown in Figures 2-4. The Nyquist plots are shown in Figure 2. The Bode plots are shown in Figures 3 and 4.

The corrosion parameters such as charge transfer resistance (R_t), impedance value, phase angle values and double layer capacitance (C_{dl}) values are given in Table 2.

It is observed from Table 2, that in presence of 100 ppm of sodium chloride, the corrosion resistance of Thermo active alloy in AS increases. This is revealed by the fact that in presence of sodium chloride, R_t value increases, impedance value increases, phase angle increases and C_{dl} value decreases.

Table 2. Corrosion Parametres of Thermo active alloy immersed in various test solutions containing artificial sweat (AS) obtained by AC impedance spectra

Tabela 2. Parametri korozije termoaktivne legure potopljene u različite test rastvore koji sadrže veštački znoj (AS) dobijeni spektrom AC impedanse

System	R_t, Ohm cm^2	C_{dl},F/cm^2	Impedance Log(z/ohm)	Phase angle°
AS	4884	1.0442×10^{-9}	4.367	48.1
AS+ NaCl 100 ppm	12210	4.1769×10^{-10}	4.8	66.34

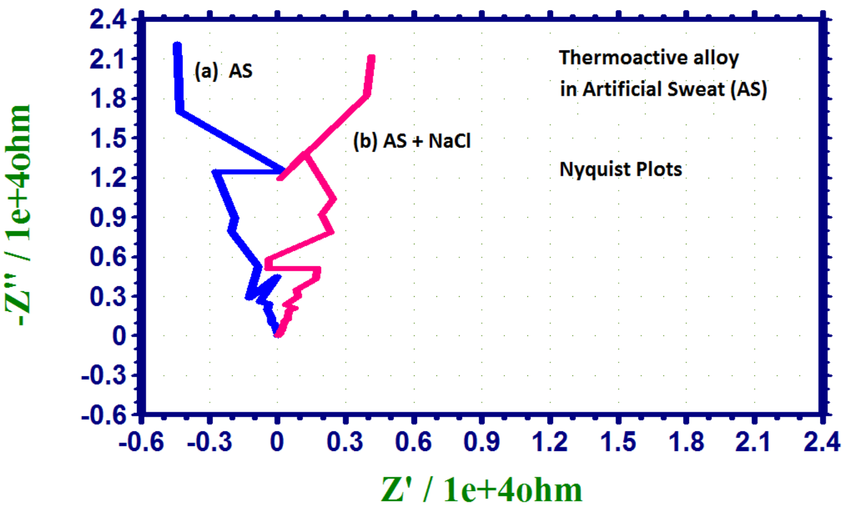

Figure 2. Nyquist plots of Thermo active alloy immersed in various test solutions: (a) Artificial sweat (b) Artificial sweat + NaCl (100 ppm)

Slika 2. Nyquist-ov dijagrami termoaktivne legure potopljene u različite testne rastvore: (a) Veštački znoj (b) Veštački znoj + NaCl (100 ppm)

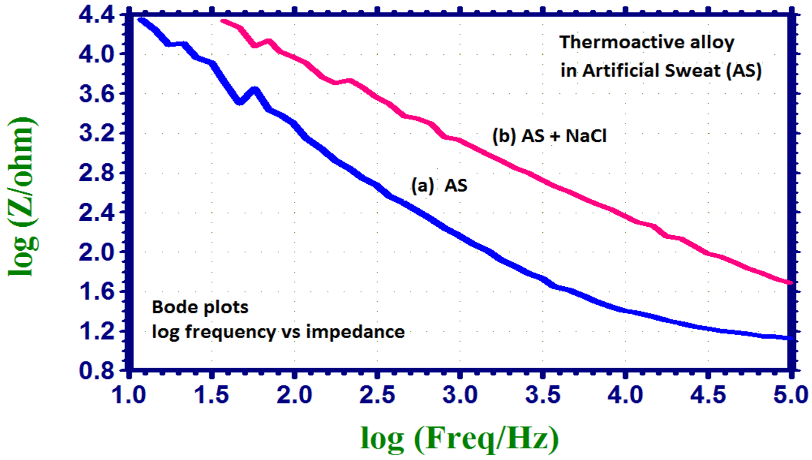

Figure 3. Bode plots (log frequency vs impedance) of Thermo active alloy immersed in various test solutions: (a) Artificial sweat (b) Artificial sweat + NaCl (100 ppm)

Slika 3. Bode-ovi dijagrami (log frekvencija u odnosu na impedansu) termoaktivne legure uronjene u različite testne rastvore: (a) Veštački znoj (b) Veštački znoj + NaCl (100 ppm)

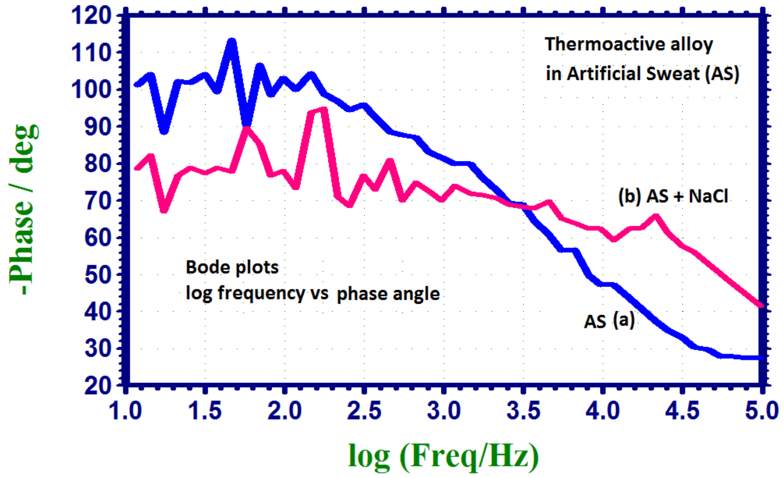

Figure 4. Bode plots (log frequency vs phase angle) of thermo active alloy immersed in various test solutions: (a) Artificial sweat (b) Artificial sweat + NaCl (100 ppm)

Slika 4. Bode-ovi dijagrami (logaritamska frekvencija u odnosu na fazni ugao) termoaktivne legure uronjene u različite testne rastvore: (a) Veštački znoj (b) Veštački znoj + NaCl (100 ppm)

Implication

Corrosion resistance of Thermo active alloy in artificial sweat increases in presence of presence of 100 ppm of sodium chloride. Hence people wearing ornaments such as wrist watch, rings, ear rings, made of Thermo active alloy need not worry about sweat, because corrosion resistance of Thermo active alloy in artificial sweat increases in presence of presence of 100ppm of sodium chloride.

Influence of sodium chloride on corrosion resistance of Gold 18K alloy immersed in artificial sweat (AS)

Influence of sodium chloride on corrosion resistance of **Gold 18K alloy** immersed in artificial sweat (AS) has been investigated by polarization study and AC impedance spectra.

Polarization study and AC impedance spectra have been widely used in corrosion inhibition /protection study to know the corrosion resistance of metals and alloys [11-20].

Analysis of Results of Polarization study

The Polarization curves of Gold 18K alloy in AS in the absence and presence of 100 ppm of sodium chloride are shown in Figure 5. The corrosion parameters are given in Table 3.

It is observed from Table 3, that in presence of 100 ppm of sodium chloride, the corrosion resistance of Gold 18K in AS increases. This is revealed by the fact that, in presence of 100 ppm of sodium chloride, LPR value of Thermo active alloy increases and corrosion current decreases. Sodium chloride behaves as mixed type of inhibitor. This is due to the fact that in presence of sodium chloride, the corrosion potential shift is very small (within 50 mV).

Table 3. Corrosion parametres of Gold 18K alloy immersed in various test solutions containing artificial sweat (AS) obtained by polarization study

Tabela 3. Parametri korozije legure zlata 18K potopljene u različite testne rastvore koji sadrže veštački znoj (AS) dobijen proučavanjem polarizacije

System	$-E_{corr}$, mV/SCE	b_c, mV/decade	b_a, mV/decade	LPR, Ohmcm^2	I_{corr}, A/cm^2
Artificialsweat	143	197	237	1079199	4.036×10^{-8}
AS+ NaCl,100ppm	156	61	32	2385141	0.1966×10^{-8}

In polarization study, when corrosion resistance increases, LPR increases and corrosion current decreases.

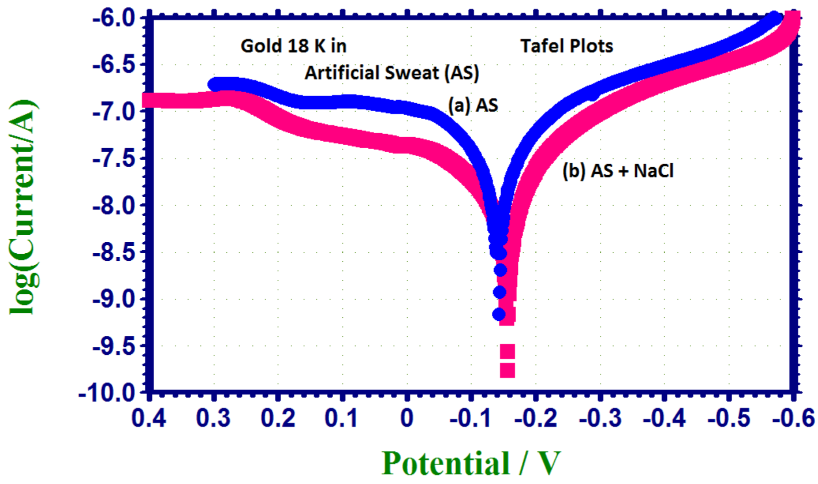

Figure 5. Polarization curves of Gold 18K alloy immersed in various test solutions: (a) Artificial sweat (b) Artificial sweat + NaCl (100 ppm)

Slika 5. Polarizacione krive legure zlata 18K uronjene u različite testne rastvore: (a) Veštački znoj (b) Veštački znoj + NaCl (100 ppm

It is observed from Table 3, that in presence of 100 ppm of sodium chloride, the corrosion resistance of Gold 18K in AS increases. This is revealed by the fact that, in presence of 100 ppm of sodium chloride, LPR value of Thermo active alloy increases and corrosion current decreases. Sodium chloride behaves as mixed type of inhibitor. This is due to the fact that in presence of sodium chloride, the corrosion potential shift is very small (within 50 mV).

Implication

Corrosion resistance of Gold 18K alloy in artificial sweat increases in presence of presence of 100 ppm of sodium chloride. Hence people wearing ornaments such as wrist watch, rings, ear rings, made of Gold 18K alloy need not worry about sweat, because corrosion resistance of Gold 18K alloy in artificial sweat increases in the presence of 100 ppm of sodium chloride.

Analysis of results of AC impedance spectra

The AC impedance spectra of Gold 18K alloy in AS in the absence and presence of 100 ppm of sodium chloride are shown in Figures 6-8. The Nyquist plots are shown in Figure 6. The Bode plots are shown in Figures 7 and 8.The corrosion parameters such as charge transfer resistance (R_t), impedance value, phase angle values and double layer capacitance (C_{dl}) values are given in Table 4.

It is observed from Table 4, that in presence of 100 ppm of sodium chloride, the corrosion resistance of Gold 18K alloy in AS increases. This is revealed by the fact that in presence of sodium chloride, R_t value increases, impedance value increases, phase angle increases and C_{dl} value decreases.

Implication

Corrosion resistance of Gold 18K alloy in artificial sweat increases in presence of presence of 100 ppm of sodium chloride. Hence people wearing ornaments such as wrist watch, rings, ear rings, made of Thermo active alloy need not worry about sweat, because corrosion resistance of Gold 18K alloy in artificial sweat increases in presence of presence of 100 ppm of sodium chloride.

Table 4. Corrosion parameters of Gold 18K alloy immersed in various test obtained by AC impedance spectra

Tabela 4. Parametri korozije legure zlata 18K potopljene u različitim testovima dobijenim spektrom impedanse naizmenične struje

system	R_t, Ohmcm^2	C_{dl} F/cm^2	Impedance Log(Z/Ohm)	PhaseAngle, degree
ArtificialSweat	4291	1.189 x10^{-9}	4.652	61
AS + NaCl 100 ppm	48880	1.0434 x10^{-10}	5.114	88

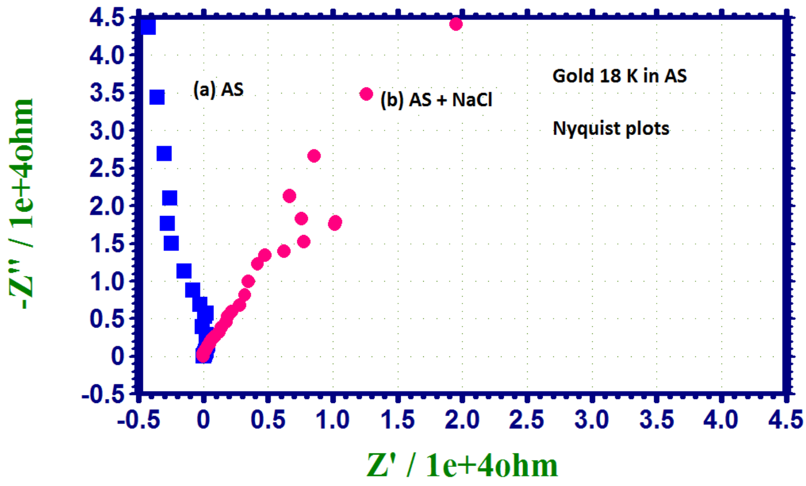

Figure 6. Nyquist plots of Gold 18K alloy immersed in various test solutions: (a) Artificial sweat (b) Artificial sweat + NaCl (100 ppm)

Slika 6. Nyquist-ovi dijagrami legure zlata 18K uronjeni u različita testna rešenja: (a) Veštački znoj (b) Veštački znoj + NaCl (100 ppm)

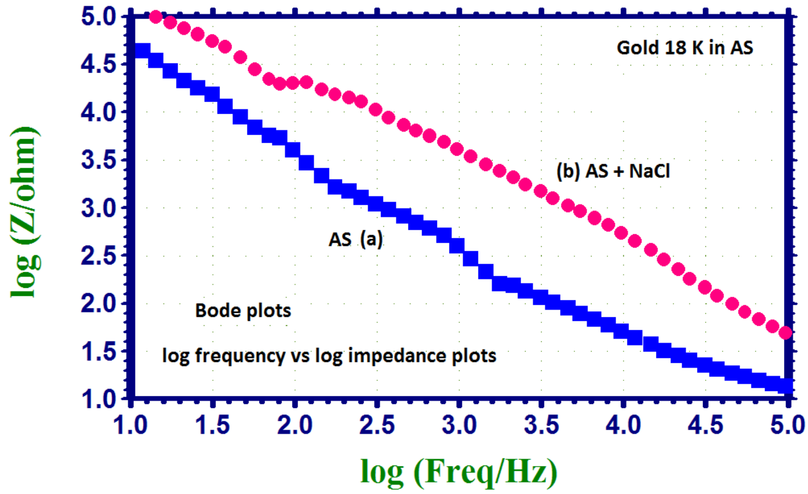

Figure 7. Bode plots (log frequency vs impedance) of Gold 18K alloy immersed in various test solutions: (a) Artificial sweat (b) Artificial sweat + NaCl (100 ppm)

Slika 7. Bode-ovi dijagrami (log frekvencija u odnosu na impedansu) legure zlata 18K potopljene u različite testne rastvore: (a) Veštački znoj (b) Veštački znoj + NaCl (100 ppm)

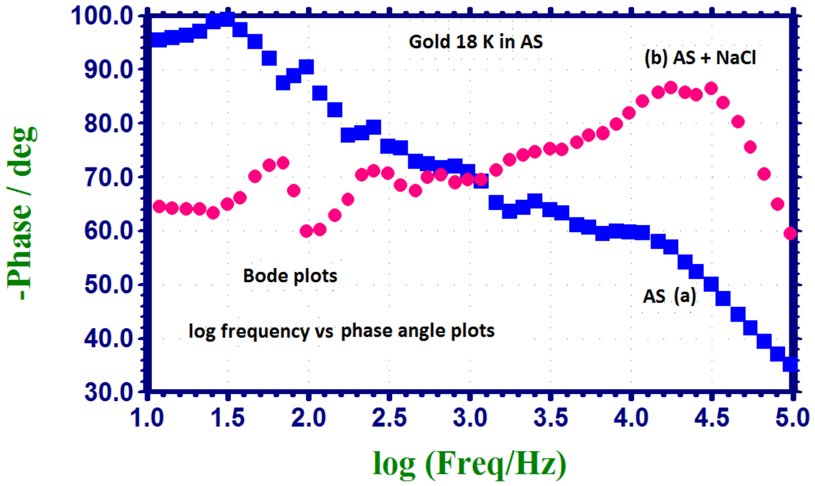

Figure 8. Bode plots (log frequency vs phase angle) of Gold 18K alloy immersed in various test solutions: (a) Artificial sweat (b) Artificial sweat + NaCl (100 ppm)

Slika 8. Bode-ovi dijagrami (log frekvencija u odnosu na fazni ugao) legure zlata 18K potopljene u različita testna rešenja: (a) Veštački znoj (b) Veštački znoj + NaCl (100 ppm)

4. CONCLUSIONS

Corrosion resistance of Thermo active alloy and Gold 18K alloy immersed in artificial sweat in the absence and presence of 100 ppm of NaCl has been investigated by polarization study and AC impedance spectra. The results are summarized in Tables 5 and 6. It is inferred that Corrosion resistance of Thermo active alloy and also Gold 18K alloy immersed in artificial sweat in the presence of 100 ppm of NaCl increases. Hence it is concluded that people wearing ornaments made of these two alloys need not worry about the excess of sodium chloride in their sweat.

Table 5. Summary: Comparison of corrosion parameters of thermo active alloy in various test solutions

Tabela 5. Rezime: Poređenje parametara korozije termoaktivne legure u različitim ispitivanim rastvorima

Corrosion parameters	Artificial Sweat (AS)	AS + NaCl (100 ppm)	Inference
LPR, Ohmcm^2	1760283	9506106	increases
R_t, Ohmcm^2	4884	12210	increases
Impedance Log(z/ohm)	4.367	4.8	increases
Corrosion current, A/cm^2	1.845×10^{-8}	4.008×10^{-9}	decreases
Double layer capacitance, F/cm^2	1.0442×10^{-9}	4.1769×10^{-10}	decreases
Phase angle°	48.1	66.34	increases
E_{corr}, mV vs SCE	-400	-165	anodic inhibitor

Table 6. Summary: Comparison of corrosion parameters of Gold 18K alloy in various test solutions

Tabela 6. Rezime: Poređenje parametara korozije legure zlata 18K u različitim test rešenjim

Corrosion parameters	Artificial Sweat (AS)	AS + NaCl (100 ppm)	Inference
LPR, Ohmcm^2	1079199	2385141	increases
R_t, Ohmcm^2	4291	48880	increases
Impedance, Log(z/ohm)	4.652	5.114	increases
Corrosion current, A/cm^2	4.036×10^{-8}	0.1966×10^{-8}	decreases
Double layer capacitance, F/cm^2	1.189×10^{-9}	1.0434×10^{-10}	decreases
Phase angle°	61	88	increases
E_{corr}, mV vs SCE	-143	-156	mixed type inhibitor

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IZVOD

Elektrohemijske studije otpornosti na koroziju zlata 18k i termoaktivne legure u veštačkom znoju u prisustvu natrijum hlorida

Otpornost na koroziju termoaktivne legure i legure zlata 18K uronjene u veštački znoj u odsustvu i prisustvu 100ppm NaCl je ispitana polarizacionom studijom i spektrom impedanse naizmenične struje. Primećeno je da se povećava otpornost na koroziju termo aktivne legure, kao i legure zlata 18K uronjene u veštački znoj u prisustvu 100ppm NaCl. Otuda se zaključuje da ljudi koji nose ukrase od ove dve legure ne moraju da brinu o višku natrijum hlorida u svom znoju. Kada se termo aktivna legura potopi u veštački znoj u prisustvu 100ppm NaCl, vrednost otpora linearne polarizacije raste sa 1760283 Ohmcm^2 na 9506106 Ohmcm^2; struja korozije se smanjuje sa 1,845x10^{-8} na 4,008x10^{-9} A/cm^2; vrednost otpora prenosa naelektrisanja raste sa 4884 Ohmcm^2 na 12210 Ohmcm^2; vrednost impedanse se povećava sa 4,367 na 4,8; kapacitivnost dvostrukog sloja se smanjuje sa 1,0442 x10^{-9} na 4,1769x10^{-10} F/cm^2, a fazni ugao se povećava sa 48,1° na 66,34°. Kada se legura zlata 18K potopi u veštački znoj u prisustvu 100ppm NaCl, vrednost otpora linearne polarizacije se povećava sa 1079199 Ohmcm^2 na 2385141 Ohmcm^2; struja korozije se smanjuje sa 4,036x10^{-8} na 0,1966 x 10A/cm^2; otpor prenosa naelektrisanja raste sa 4291 Ohmcm^2 na 48880 Ohmcm^2; vrednost impedanse se povećava sa 4,652 na 5,114; kapacitivnost dvostrukog sloja se smanjuje sa 1,189 x10^{-9} na 1,0434 x10^{-10} F/cm^2, a fazni ugao raste sa 61° na 88°.

Ključne reči: *otpornost na koroziju, termoaktivna legura, legura zlata 18K, veštački znoj, NaCl, studija polarizacije, spektri AC impedanse.*

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