Nilavan Anitha[1], Nellainayagam Narendran[2], Veerapandian Velkannan[3], Gurumoorthy Nandhini[4], Francis Flori Jenifer[4], Alexis Subashini Mary[4],Subramani Aishwarya[4], Balu Nithiya Shree[4], Gurmeet Singh[5], Abdulhameed Al-Hashem[6], Susai Rajendran[1,7], Caslav Lacnjevac[8]*

[1]Department of Chemistry, Corrosion Research Centre , St. Antony's College of Arts and Sciences for Women, (Affiliated to Mother Teresa Women's University, Kodaikanal, India),[2]Department of Chemistry, PSNA College of Engineering and Technology, Dindigul, India, [3]Department of Chemistry, Thiagarajar College of Engineering, Thiruparankundram, Madurai, Tamil Nadu, India (Affiliated to Anna University, Chennai , India), [4]MV Muthiah Government Arts College for Women, Dindigul, India,[5]Vice Chancellor, Pondicherry University, Puducherry, India, [6]Petroleum Research Centre, Kuwait Institute for Scientific Research, Kuwait, [7]Adjunct Professor, Centre for Nanoscience and Technology, Pondicherry University, Puducherry, India, [8]Faculty of Agriculture, University of Belgrade, Serbia.

Scientific paper
ISSN 0351-9465, E-ISSN 2466-2585
https://doi.org/10.5937/zasmat2204430A

Zastita Materijala 63 (4)
430 - 436 (2022)

Corrosion resistance of orthodontic wire made of nickel-titanium alloy in artificial saliva in the presence of Kopiko candy

ABSTRACT

Corrosion resistance of an orthodontic wire made of Ni-Ti alloy immersed in artificial saliva in the absence and presence of 500 ppm of Kopiko candy has been investigated by polarization study and AC impedance spectra. It is observed that corrosion resistance of Ni-Ti alloy immersed in artificial saliva in the presence of 500 ppm of Kopiko candy increases. Hence it is concluded that people clipped with orthodontic wire made of Ni-Ti alloy need not worry about taking Kopiko candy orally. When Ni-Ti alloy is immersed in artificial saliva in the presence of 500 ppm of Kopiko candy, Linear Polarization Resistance value increases from 347978 Ohmcm^{2}to 415003 Ohmcm^2; corrosion current decreases from 1.346 x10^{-7}A/cm^{2}to 1.105 x10^{-7}A/cm^2 ; charge transfer resistance value increases from 31945 Ohmcm^2 to 44357 Ohmcm^2; impedance value increases from 4.649to 4.819; double layer capacitance decreases from 1.596x10^{-10}F/cm^2 to 1.150 x10^{-10}F/cm^2, and phase angle increases from 39.63° to 50°.

Keywords: *Corrosion resistance, Ni-Ti alloy, artificial saliva, Kopiko candy, polarization study, AC impedance spectra, pediatric dentistry*

1. INTRODUCTION

Saliva is a watery substance formed in the mouths of animals, secreted by the salivary glands. Human saliva comprises 98% water, plus electrolytes, mucus, white blood cells, epithelial cells. The enzymes found in saliva are important in beginning the process of digestion of dietary starches and fats. These enzymes also play a role in breaking down food particles entrapped within dental crevices, thus protecting teeth from bacterial decay [1–4]. Corrosion resistance of various metals and alloys in artificial saliva in the presence and absence of various tablets, food additives etc. have been investigated.

Corrosion resistance of metals and alloys such as SS 316L, aluminum, nickel–titanium alloy in artificial saliva has been investigated [5,6]. Kamiński et al. have investigated the effect of glow discharge nitriding on the corrosion resistance of stainless steel orthodontic arches in artificial saliva solution [7]. They have carried out a comparative study on orthodontic arch-wires AISI 304 steel before and after low temperature plasma nitriding. Polarisation study and AC impedance spectra have been employed for this purpose. Microhardness was measured before and after treatment. The influence of snake fruit extract (Salaccazalacca) in inhibiting the release of chromium (Cr) and nickel (Ni) ion from stainless steel orthodontic wire to saliva has been investigated by Erwansyah and Susilowati [8]. Cr and Ni ion release was measured using atomic absorption spectrophotometry. The investigation was made on control group and

*Corresponding author: Nilavan Anitha
E-mai: susairajendran@gmail.com
Paper received: 10. 05. 2022.
Paper accepted: 05. 06. 2022.
Paper is available on the website: www.idk.org.rs/journal

treatment groups. Pre-tests and post-tests were conducted. It is evident from this study that Snake fruit seeds extract effectively inhibits the Ni ions release from stainless steel orthodontic wire at a concentration of 300 ppm. Musa Trolic et al. have examined the influence of probiotic supplements recommended for use in orthodontic patients on the corrosion stability of stainless steel and three types of NiTi orthodontic wires [9]. The corrosion resistance was measured by polarization study and AC impedance spectra. It was observed that probiotic bacteria L. reuteri and probiotic supplement influence on a general corrosion rate as well as on likelihood of pitting corrosion occurrence. It was also noticed that their effect is dependent on the type of alloy and coating. 316L Stainless steels are widely used in biomedical applications with respect to their excellent corrosion resistance, nonmagnetic properties, high ductility and acceptable biocompatibility. There have been made electrochemical studies in vitro in order to determine the corrosion reactions, which are necessary for foreseeing the behavior of the materials used in orthodontic applications. The degradation of metals and alloys in the human body is a combination of effects due to corrosion and mechanical activities. In dentistry, 316L stainless steel are used in a variety of applications: sterilized instruments, endodontic files in root canal therapy, metal posts in root canal treated teeth, temporary crowns, arch wires and brackets in orthodontics, a necessary condition for these applications must to resist to pitting corrosion [10]. In the present work corrosion resistance of Ni-Ti alloy in artificial saliva in the presence and absence of Kopiko Candy has been investigated by electrochemical studies such as polarization study and AC impedance spectra. Ni-Ti alloy, consisting of nickel and titanium in nearly equiatomic proportions, is known for its unique mechanical properties of shape memory and superelasticity. These properties occur in association with thermoelastic martensitic transformation [11].

The nickel-titanium alloy Nitinol has been used in the manufacture of endodontic instruments in recent years. Nitinol alloys have greater strength and a lower modulus of elasticity compared with stainless steel alloys.

Nitinol, also known as nickel-titanium or Ni-Ti alloy, is commonly used in orthodontics thanks to its shape memory and superelastic behaviour. We use archwires made from this clever metal alloy to move your teeth efficiently and reduce the frequency of adjustments.

2. MATERIALS AND METHODS

Preparation of the metal specimens

A thin wire of Ni-Ti alloy [a near-equiatomic composition (i.e., 49%–51%) of nickel and titanium] is used as test material for this work. The orthodontic wire was encapsulated in a Teflon rod. It was polished to mirror finish and used for electrochemical studies.

Kopiko Candy

Kopiko is an Indonesian brand of coffee confectioneries originally produced in Indonesia by Mayora Indah. It is named after the kōpiko coffee bean, found in Hawaii. Kopiko Coffee Candy is currently available in over 80 countries around the world.

Ingredients

The product contains extract from real coffee beans. Ingredients include sugar, glucose, vegetable oil (palm oil and/or coconut oil), coffee extract (4.9%), butter, soy lecithin, caramel color, salt, and natural coffee flavour [12].

Preparation of artificial saliva

Artificial saliva was prepared in laboratory. The composition of artificial saliva was as follows [The preparation of artificial saliva was done using the composition of Fusayama Meyer artificial saliva (AS)]: KCl – 0.4 g/L, NaCl – 0.4 g/L, $CaCl_2{\cdot}2H_2O$ – 0.906 g/L, $NaH_2PO_4{\cdot}2H_2O$ – 0.690 g/L, $Na_2S{\cdot}9H_2O$ – 0.005 g/L, urea – 1 g/L[13].

Potentiodynamic polarization study

A CHI 660A workstation model was used in the electrochemical studies. Polarization study was carried out using a three-electrode cell assembly (Scheme A). Ni-Ti alloy was used as the working electrode, platinum as the counter electrode, and saturated calomel electrode (SCE) as the reference electrode. After having done IR compensation, the polarization study was carried out at a sweep rate of 0.01 V/s. The corrosion parameters such as linear polarization resistance (LPR), corrosion potential E_{corr}, corrosion current I_{corr} and Tafel slopes (b_a and b_c) were measured.

Alternating current impedance spectra

AC impedance spectra were recorded in the same instrument used for polarization study, using the same type of three electrode cell assembly. The real part (Z´) and imaginary part (–Z´´) of the cell impedance were measured in ohms for various frequencies. The charge transfer resistance (Rt) and double layer capacitance (Cdl) values were calculated.

3. RESULTS AND DISCUSSION

Influence of Kopiko candy on corrosion resistance of Ni-Ti alloy in artificial saliva

Polarization study and AC impendence spectra have been widely used in evaluating corrosion resistance of metals and alloys [14-29]. The influence of Kopiko candy on corrosion resistance of Ni-Ti alloy in artificial saliva (AS), has been investigated by polarization study and AC impendence spectra. When corrosion resistance increases, LPR increases, charge transfer resistance increases and impedance value increases. On the other hand, corrosion current decreases and double layer capacitance decreases.

Polarization study

The polarization curves of Ni-Ti alloy in artificial saliva (AS) in the absence and presence of 500 ppm of Kopiko candy are shown in Figures 1and 2. The corrosion parameters are given in Table 1. It is observed from Table 1 that in the presence of Kopiko candy, the corrosion resistance of Ni-Ti alloy in AS increases. This is revealed by the fact that, in the presence of Kopiko candy, LPR value of Ni-Ti alloy increases (Figures 1) and corrosion current decreases.

It is also observed that in the presence of Kopiko candy the corrosion potential shifts from –534 to –532 mV vs. SCE (Figures 1-4). It is inferred that in the presence of Kopiko candy the cathodic reaction and anodic reaction are controlled to an equal extent. It behaves as mixed type inhibitor since this candy contains caffeine.

Implication

Corrosion resistance of Ni-Ti alloy in artificial saliva decreases in the presence of Kopiko candy. Hence people clipped with orthodontic wire made of Ni-Ti alloy need not hesitate to take Kopiko candy orally.

Table 1. Corrosion parameters of Ni-Ti alloy in artificial saliva (AS) in the absence and presence of Kopiko candy (500 ppm) obtained from polarisation study

Tabela 1. Parametri korozije legure Ni-Ti u veštačkoj pljuvački (AS) u odsustvu i prisustvu Kopiko bombona (500 ppm) dobijeni iz studije polarizacije

System	E_{corr} mV vs SCE	b_c mV/decade	b_a mV/decade	LPR Ohmcm^2	I_{corr} A/cm^2
AS	-534	182	264	347978	1.346 x10^{-7}
AS + KOPIKO	-532	190	238	415003	1.105 x10^{-7}

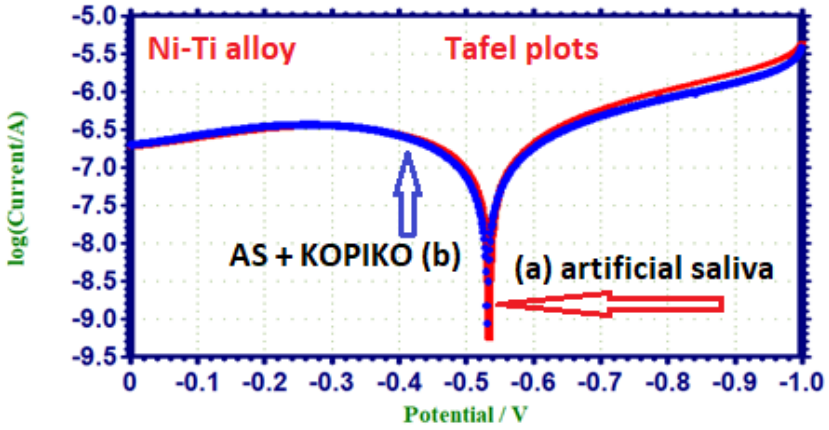

Figure 1. Polarization curves of Ni-Ti alloy immersed in various test solutions

Slika 1. Polarizacione krive legure Ni-Ti uronjene u različite ispitne rastvore

AC Impedance spectra

In the present investigation the same instrument set-up used for polarization study was used to record AC impedance spectra also. A time interval of 5 to 10 min was given for the system to attain a steady state open circuit potential. The real part (Z´) and imaginary part (–Z´´) of the cell impedance were measured in Ohms at various frequencies.

From Nyquist plot the values of charge transfer resistance (R_t) and the double layer capacitance (C_{dl}) were calculated. From Bode plots charge

transfer resistance (R_t), impedance value, phase angle value and double layer capacitance (C_{dl}) value were calculated.

The AC impedance spectra of Ni-Ti alloy in AS in the absence and presence of 500 ppm of Kopiko candy are shown in Figures2-4. The Nyquist plots are shown in Figure 2. The Bode plots are shown in Figures 3 and 4. The corrosion parameters such as change transfer resistance (R_t), impedance value and double layer capacitance (C_{dl}) values are given in Table 2.

It is observed from Table 2, that in the presence of Kopiko candy, the corrosion resistance of Ni-Ti alloy in AS increases. This is revealed by the fact that in the presence of Kopiko candy, Rt value increases, impedance value increases, phase angle value increases and C_{dl} value decreases.

Implication

Corrosion resistance of Ni-Ti alloy in artificial saliva decreases in the presence of Kopiko candy. Hence people clipped with orthodontic wire made of Ni-Ti alloy need not hesitate to take Kopiko candy orally.

Table 2. Corrosion parameters of Ni-Ti alloy in artificial saliva (AS) in the absence and presence of Kopiko candy (500 ppm) obtained from AC impedance spectra.

Tabela 2. Parametri korozije legure Ni-Ti u veštačkoj pljuvački (AS) u odsustvu i prisustvu Kopiko bombona (500 ppm) dobijenih iz spektra impedanse naizmenične struje

System	R_t Ohmcm^2	Impedance log(Z/ohm)	C_{dl} F/cm^2	Phase angle degree
AS	31945	4.649	1.596x x10^{-10}	39.63
AS + KOPIKO	44357	4.819	1.150x x10^{-10}	50

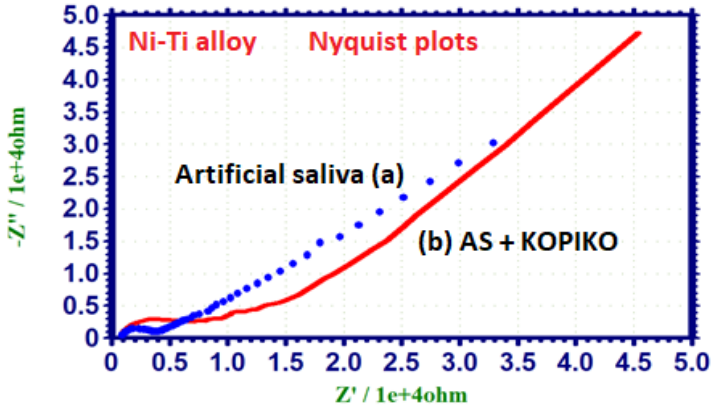

Figure 2. Nyquist plots of Ni-Ti alloy immersed in various test solutions

Slika 2. Nyquist-ove krive legure Ni-Ti uronjeni u različita ispitna rastvora

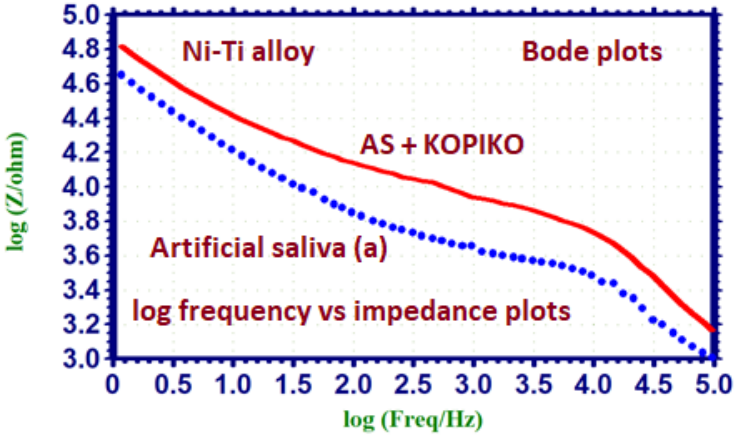

Figure 3. Bode plots of Ni-Ti alloy immersed in various test solutions (log frequency vs impedance plots)

Slika 3. Bode-ove krive legure Ni-Ti uronjene u različite ispitne rastvore (grafikoni log frekvencije u odnosu na impedansu)

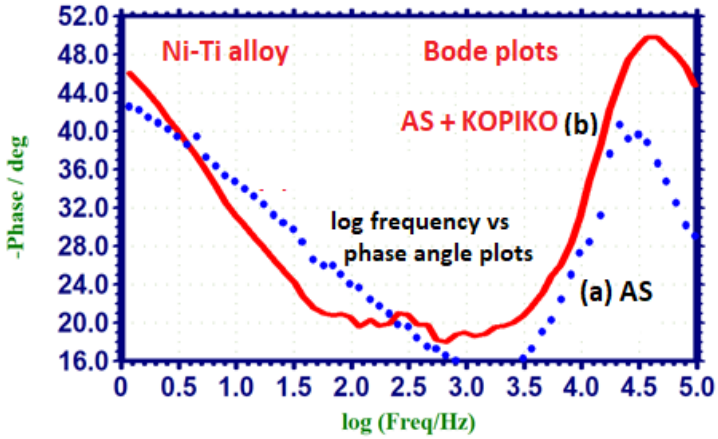

Figure 4. Bode plots of Ni-Ti alloy immersed in various test solutions (log frequency vs phase angle plots)

Slika 4. Bode-ove krive legure Ni-Ti uronjene u različite ispitne rastvore (grafikoni log frekvencije u odnosu na fazni ugao)

4. SUMMARY AND CONCLUSIONS

Outcome of the study

Corrosion resistance of Ni-Tialloy in artificial saliva (AS), in the absence and presence of Kopiko candy has been investigated by polarization study and AC impedance spectra (Table 3). It is inferred that the corrosion resistance of Ni-Ti alloy in artificial saliva decreases in the presence of Kopiko candy. This is revealed by a increase in LPR value, an increase in R_t value, an increase in impedance value, a decrease in corrosion current, and a decrease in double layer capacitance value. Hence it implies that people, especially children, clipped with orthodontic wire made of Ni-Ti alloy need not hesitate to take Kopiko candy orally.

Table 3. Summary of the findings

Tabela 3. Rezime nalaza

System	Artificial saliva	AS + KOPIKO	Inference
Corrosion potential	-534	-532	Mixed type inhibitor
LPR	347978	415003	Increases
Corrosion current	1.346 x10^{-7}	1.105 x10^{-7}	Decreases
R_tOhmcm^2	31945	44357	Increases
Impedance log(Z/ohm)	4.649	4.819	Increases
C_{dl} F/cm^2	1.596x10^{-10}	1.150 x10^{-10}	Decreases
Phase angle°	39.63	50	Increases

5. REFERENCES

[1] V.A.Brigitta, C.Thangavelu, S.Rajendran (2019) Effects of Tablet on Orthodontic Wire made of SS 316L Alloy in Artificial Saliva, International Journal of Research and Analytical Reviews, 6, 1000-1005.

[2] A.Anandan, S.Rajendran, J.Sathiya Bama, D. Sathiya Raj (2017) Influence of some tablets on corrosion resistance of orthodontic wires made of SS 316L alloy in artificial saliva, International Journal of Corrosion and Scale Inhibition, 6(2), 132-141.

[3] R.D'souza, A.Chattree, S.Rajendran (2017) Corrosion Resistance of SS 316L alloy in Artificial Saliva in presence of Sparkle fresh Toothpaste, Portugaliae Electrochimica Acta, 35, 339-350.

[4] V.A.Brigitta, C.Thangavelu, S.Rajendran (2018) Corrosion resistance of SS18/8, Gold 18 carat, Gold 22 carat and SS 316L alloy in artificial saliva in the absence and presence of Vitavion Fort tablet 500 mg, European Journal of Biomedical and Pharmaceutical Sciences, 5, 864-871.

[5] R.Saranya, S.Rajendran (2018) Influence of D-glucose on corrosion resistance of SS 316L in presence of artificial saliva, Rasayan Journal of Chemistry, 11, 103-110.

[6] Z.Chao, X.Yaomu, L.Chufeng, L.Conghua (2017) The effect of mucin, fibrinogen and IgG on the corrosion behaviour of Ni–Ti alloy and stainless steel, BioMetals, 30, 367-377.

[7] J.Kamiński, K.Małkiewicz, J.Rębiś, T.Wierzchoń (2020) The effect of glow discharge nitriding on the corrosion resistance of stainless steel orthodontic arches in artificial saliva solution, Archives of Metallurgy and Materials, 65, 375-384.

[8] E.Erwansyah, C.Susilowati (2019) The effect of snake fruit extract (Salaccazalacca) in inhibiting the release of chromium (Cr) and nickel (Ni) ion from stainless steel orthodontic wire to saliva, International Journal of Applied Pharmaceutics, 11, 33-36.

[9] I.M.Trolic, N.L.Serdarevic, Z.Todoric, A.Budimir, S.Spalj, H.O.Curkovic (2019) Corrosion of orthodontic archwires in artificial saliva in the presence of Lactobacillus reuteri, Surface and Coatings and Technology, 370, 44-52.

[10] N.Simionescu, A.Ravoiu, L.Benea (2019) Electrochemical in vitro properties of 316L stainless steel for orthodontic applications, Revista de Chimie (Bucharest, Rom.), 70, 1144-1148.

[11] https://www.google.com/search?client=firefox-b-d&q=ni-ti+alloy+in+dentistry

[12] https://en.wikipedia.org/wiki/Kopiko_(confectionery)

[13] Chandrasekaran PriyaAntony RegisSusai RajendranSusai Rajendran, (2021), Influence of digene tablet juice orally taken in on the corrosion resistance of orthodontic wire made of SS 18/8 in presence of artificial saliva, Zastita Materijala, 62(3),220-227.

[14] P.Shanthy, J.A.Thangakani, S.Karthika, S. Rajendran, J.Jeyasundari (2021) Corrosion inhibition by an aqueous extract of ervatamiadivaricata, International Journal of Corrosion and Scale Inhibition, 10(1), 331-348.

[15] S.J.H.M.Jessima, A.Berisha, S.S.Srikandan, S.Subhashini (2020) Preparation, characterization, and evaluation of corrosion inhibition efficiency of sodium lauryl sulfate modified chitosan for mild steel in the acid pickling process, Journal of Molecular Liquids, 320,114382.

[16] M.E.Belghiti, Y.E.Ouadi, S.Echihi, F.Bentiss, A.Dafali (2020) Anticorrosive properties of two 3,5-disubstituted-4-amino-1,2,4-triazole derivatives on copper in hydrochloric acid environment: Ac impedance, thermodynamic and computational investigations, Surfaces and Interfaces, 21, 100692.

[17] A.S.Prabha, K.Kavitha, H.B.Shrine, S.Rajendran (2020) Inhibition of corrosion of mild steel in simulated oil well water by an aqueous extract of Andrographis paniculata, Indian Journal of Chemical Technology, 27(6), 452-460.

[18] J.J.M.Praveena, J.A.Clara, S.Rajendran, A.J.Amalraj (2021) Inhibition of corrosion of mild steel in well water by an aqueous extract of soapnut (SapindusTrifoliatus), Zastita materijala /Materials Protection, 62(4), 277-290.

[19] V.D.A.M.Jeslina, S.J.Kirubavathy, A.Al-Hashem, R.M.Joany, C.Lacnjevac (2021) Inhibition of corrosion of mild steel by an alcoholic extract of a seaweed Sargassummuticum, Zastita materijala/ Materials Protection, 62(4), 304-315.

[20] S.Y.Al-Nami, A.E.-A.S.Fouda (2020) Corrosion inhibition effect and adsorption activities of methanolic myrrh extract for cu in 2 M HNO_3, International Journal of Electrochemical Science, 15(2), 1187-1205.

[21] A.Ch.C. Mary, J.Jeyasundari, V.R.NazeeraBanu, S.S.Kumaran, A.P.P.Regis (2020) Corrosion behavior of orthodontic wires in artificial saliva with presence of beverage (Book Chapter), Nanotechnology in the Beverage Industry: Fundamentals and Applications, 471-504.

[22] S.C.Joycee, A.S.Raja, A.S.Amalraj, S.Rajendran (2021) Inhibition of corrosion of mild steel pipeline carrying simulated oil well water by Allium sativum (Garlic) extract, International Journal of Corrosion and Scale Inhibition, 10(3), 943-960.

[23] R.Dorothy, T.Sasilatha, S.Rajendran (2021) Corrosion resistance of mild steel (Hull plate) in sea water in the presence of a coating of an oil extract of plant materials, International Journal of Corrosion and Scale Inhibition, 10(2), 676-699.

[24] D.Kasapović, F.Korać, F.Bikić (2022) Testing the effectiveness of raspberry flower extract as an inhibitor of copper's corrosion in 3% NaCl, Zastita Materijala, 63(2), 115 - 121.

[25] A.Petričević, V.D.Jović, M.N.Krstajić Pajić, P. Zabinski, N.R.Elezović (2022) Oxygen reduction reaction on electrochemically deposited sub-monolayers and ultra-thin layers of Pt on (Nb-Ti)2AlC substrate, Zastita Materijala, 63(2), 153 - 164.

[26] If.Calista Ekeke, St.Efe, F.Ch.Nwadire (2022) Plant materials as green corrosion inhibitors for select iron alloys: a review, Zastita Materijala, 63(2),183 - 202.

[27] D.Rajendran, Th.Sasilatha, S.A.Hebciba Mary, S.S. Rajendran, C.Lacnjevac, G.Singh (2022) Deep learning based underwater metal object detection using input image data and corrosion protection of mild steel used in underwater study - A case study, Part B - Corrosion protection of mild steel used in underwater study, Zastita Materijala, 63(1), 15 - 22.

[28] D.Rajendran, Th.Sasilatha, S.Rajendran, Ab.Al-Hashem, C.Lacnjevac, G.Singh (2022) Inhibition of corrosion of mild steel hull plates immersed in natural sea water by sandalwood oil extract of some natural products, Zastita Materijala 63(1), 23 - 36.

[29] Vl. D. Jović (2022) Calculation of a pure double layer capacitance from a constant phase element in the impedance measurements , Zastita Materijala, 63(1), 50-57

IZVOD

OTPORNOST NA KOROZIJU ORTODONTSKE ŽICE OD LEGURE NIKL-TITANIJUMA U VEŠTAČKOJ PLJUVAČKI U PRISUSTVU KOPIKO BOMBONA

Otpornost na koroziju ortodontske žice, napravljene od legure Ni-Ti, uronjene u veštačku pljuvačku u odsustvu i prisustvu 500 ppm Kopiko bombona je ispitana polarizacionom studijom i spektrom impedanse naizmenične struje. Primećeno je da se otpornost na koroziju Ni-Ti legure potopljene u veštačku pljuvačku u prisustvu 500 ppm Kopiko bombona povećava. Otuda se zaključuje, da ljudi koji su sadrze ortodontsku žicu u ustima od Ni-Ti legure ne moraju da brinu o uzimanju Kopiko bombona oralno. Kada se legura Ni-Ti potopi u veštačku pljuvačku u prisustvu 500 ppm Kopiko bombona, vrednost otpora linearne polarizacije se povećava sa 347978 Ohmcm^2 na 415003 Ohmcm^2; struja korozije se smanjuje sa 1,346 k10^{-7} A/cm^2 na 1,105 k10^{-7} A/cm^2; vrednost otpora prenosa naelektrisanja se povećava sa 31945 Ohmcm^2 na 44357 Ohmcm^2; vrednost impedanse se povećava sa 4,649 na 4,819; kapacitivnost dvostrukog sloja se smanjuje sa 1,596k10^{-10} F/cm^2 na 1,150k10^{-10} F/cm^2, a fazni ugao se povećava sa 39,63° na 50°.

Ključne reči: *otpornost na koroziju, legura Ni-Ti, veštačka pljuvačka, Kopiko bombon, studija polarizacije, spektri AC impedanse, dečija stomatologija.*

Naučni rad

Rad primljen: 10. 05. 2022.

Rad prihvaćen: 05. 06. 2022.

Rad je dostupan na sajtu: www.idk.org.rs/casopis