Influence of Vicks ginger candy (VGC) and Glucose D on corrosion resistance of orthodontic wire made of Ni-Ti alloy in artificial saliva

N. Anitha,[1] S.P. Seeli,[1] S.A. Ratthika,[1] V.D. Mary,[1] A.M.A. Deena,[1] S. Rajendran[1,2]* and Gurmeet Singh[3]

[1]Department of Chemistry, Corrosion Research Centre , St. Antony's College of Arts and Sciences for Women, 624005 Dindigul, India
[2]Adjunct Professor, Pondicherry University, 605014 Puducherry, India
[3]Vice Chancellor, Pondicherry University, 605014 Puducherry, India
**E-mail: susairajendran@gmail.com*

Abstract

Orthodontic wires are used by dentists to regulate the growth of teeth of their patients. They are always in contact with the saliva and they undergo corrosion in the oral environment. Orthodontic wires made of various alloys are used. Nickel- and titanium-based alloys are promising materials for dental orthodontic wires due to their superior mechanical properties and corrosion resistance. Influence of Vicks ginger candy (VGC) and Glucose D on corrosion resistance of orthodontic wire made of Ni-Ti alloy (Nitinol) in artificial saliva has been evaluated by electrochemical studies such as polarization technique and AC impedance spectra. Corrosion resistance of Nitinol alloy in artificial saliva increases in the presence of 1000 ppm of Vicks ginger candy (VGC). Hence people clipped with orthodontic wire made of Ni-Ti alloy need not hesitate take 1000 ppm of Vicks ginger candy (VGC) orally. Corrosion resistance of Ni-Ti alloy in artificial saliva decreases in the presence of 1000 Glucose D. Therefore, the chances of orthodontic wire undergoing corrosion are greater in those who consume Glucose D juice excessively. Hence people clipped with orthodontic wire made of Ni-Ti alloy should avoid taking Glucose D orally. In the presence of 1000 ppm of Vicks ginger candy (VGC), LPR value of Ni-Ti alloy increases and corrosion current decreases. Vicks ginger candy (VGC) controls the anodic reaction and cathodic reaction to an equal extent. This is due to the fact that in the presence of Vicks ginger candy (VGC), the shift in corrosion potential is very small (from –535 to –549 mV *vs*. SCE). In the presence of 1000 ppm of Glucose D, the corrosion resistance of Ni-Ti alloy (Nitinol) in AS decreases. This is revealed by the fact that, in the presence of 1000 ppm of Glucose D, LPR value of Ni-Ti alloy decreases and corrosion current increases. Glucose D controls the anodic reaction predominantly. This is due to the fact that in the presence of Glucose D, the shift in corrosion potential is towards the anodic side (from –535 to –456 mV *vs*. SCE).

Received: December 30, 2021. Published: March 10, 2022 doi: 10.17675/2305-6894-2022-11-1-20

Keywords: *artificial saliva, corrosion, orthodontic wires, candies, Vicks ginger, Glucose D, electrochemical studies.*

Introduction

Orthodontic wires are used by dentists to regulate the growth of teeth of their patients. They are always in contact with the saliva and they undergo corrosion in the oral environment. Orthodontic wires made of various alloys are used.

At present, orthodontists principally use wires of four major base metal alloy types: stainless steel, cobalt-chromium-nickel, nickel-titanium and β-titanium. These wires are subjected to biodegradation leading to corrosion. Apart from this food items and candies taken by children may lead to corrosion of archwire. Many research works have been undertaken in this line.

Chemical, electrochemical, and surface study on microbial attack of Co-Cr-Mo dental alloy by streptococcus mutans have been studied by Mouflih *et al.* [1]. The passive properties of TA10 in Coca-Cola containing oral environment have been studied by Liu *et al.* The results have important guiding significance for the safe use of the alloy in the complex oral environments [2]. Barabás *et al.* have investigated the influence of hydroxyapatite (HAP), on the morpho-structural properties and corrosion resistance of ZrO_2-based composites for biomedical applications. The obtained results using the two investigated metallic dental alloys have shown quasi-similar anticorrosive properties [3]. The effect of surface modification by laser on Ti-Nb-Mo powder metallurgical alloys to improve their mechano-chemical behavior and their application as a biomedical implant has been studied by Tendero *et al.* It was noted that the corrosion rate was lower in Ti-27Nb-8Mo and Ti-35Nb-6Mo. Niobium release was significant, but below the physiological limit [4]. Surface modification has been used by Jażdżewska and Bartmański to extend the life of implants. To increase the corrosion resistance and improve the biocompatibility of metal implant materials, oxidation of the Ti-13Nb-13Zr titanium alloy has been used. The samples used for the research had the shape of a helix with a metric thread, with their geometry imitating a dental implant [5]. Golgovici *et al.* have compared the behavior of two reprocessed dental alloys (Ni-Cr and CoCr) at different temperatures considering the idea that food and drinks in the oral cavity create various compositions at different pH levels. It was noted that with increasing temperature, the quantities of ions released from the alloys immersed in artificial saliva also increased, though they still remain small, less than 20 ppm [6]. Corrosion of Ni-Cr alloys for dental applications has been studied by Kassab *et al.* The influence of environment, chemical composition and casting route has also been explored. The corrosion morphology was localized exhibiting a peculiar dissolution pattern as observed in scanning droplet cell microscopy analysis. Furthermore, it was concluded that titanium segregation in the alloy after casting process was responsible for the lower localized corrosion resistance observed [7]. The corrosion behavior of Ti6Al4V fabricated by selective laser melting in the artificial saliva with different fluoride concentrations and pH values has been investigated by Zhang *et al.* It was noted that the crystallinity and the Al and F contents decrease when the NaF concentration and pH value rise [8]. The positive and negative alloying effects in synthetic body fluids have been analysed by Wang *et al.* The high passivity of the stainless steels related to the Cr(III)-rich surface oxide was observed [9]. An artificial intelligence (AI) framework has been proposed by Nazarahari and Canadinc to predict the optimum composition of the Ni-Ti shape memory alloy (SMA) to be used in dental applications. A multilayer feed forward neural network (MLFFNN) was adopted for machine learning (ML) model to train the readily available experimental data in literature on the Ni ion release from a variety of Ni-Ti compositions into artificial saliva (AS) solutions to predict the Ni-Ti SMA composition to exhibit the lowest amount of Ni ion release into oral cavity [10]. The resistance to general and pitting corrosion of stainless steel and titanium-based orthodontic mini implants in an oral environment has been explored by Curkovic *et al*. Studies were performed in artificial saliva and in the presence of two oral hygiene products (one containing chlorhexidine digluconate with sodium fluoride and another containing probiotic bacteria) that are usually recommended to orthodontic patients. The results showed that mini implants made from stainless steel have lower resistance to corrosion than titanium implants [11].

Ni-Ti wires are designed to help our teeth move into their proper positions more effectively, making your treatment shorter and much more comfortable. Dentists use heat-activated Ni-Ti wires because they combine shape memory and elasticity with excellent mechanical properties.

Nickel- and titanium-based alloys are promising materials for dental orthodontic wires due to their superior mechanical properties and corrosion resistance. The studies of the corrosion resistance of these materials according to their surface characterization in artificial salvias are limited.

The present work is undertaken to investigate the corrosion behavior of Ni-Ti wire in artificial saliva in the presence of Vicks ginger candy and Glucose D.

Experimental

Vicks Ginger candy

Vicks Ginger candy contains menthol, mint and flavoured sugar as active ingredients. It acts as a cough suppressant and comes in ginger, honey and menthol flavors.

Glucose D

Glucose D powder is ideal for young and growing children as well as athletes and helps their bodies replenish essential body salts, minerals and vitamins. It gives the body a boost of energy and helps to fight fatigue and exhaustion. It is also excellent for the all-round development of children [12].

Nutrition information per 100G: Calcium 350 Mg, Phosphorous 100 Mg, Vitamin C 50 Mg, Energy 356 kcal, Protein 0G, Carbohydrates 89G, of which sugar (Sucrose) 44G, fats and all type of fatty acid 0G.

Preparation of the metal specimens

Ni-Ti alloy (also known as Nitinol) is an alloy with a near-equiatomic composition (*i.e.*, 49–51%) of nickel and titanium. Ni-Ti belongs to the class of shape memory alloys that can be deformed at a low temperature and are able to recover their original, permanent shape when exposed to a high temperature. It is used in Dentistry.

A thin wire of Ni-Ti alloy was used as test material for this work. The orthodontic wire was encapsulated in Teflon rod. It was polished to mirror finish and used for electrochemical studies.

Preparation of artificial saliva

The preparation of artificial saliva was done using the composition of Fusayama Meyer artificial saliva (AS). Artificial saliva was prepared in laboratory and the composition of artificial saliva was as follows: 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.

Potentiodynamic polarization technique

A CHI 660 A workstation model was used in the electrochemical studies. Polarization study was carried out using a three electrode cell assembly (Figure 1). Ni-Ti alloy was used as working electrode, platinum as counter electrode and saturated calomel electrode (SCE) as reference electrode. After having done i_R compensation, polarization study was carried out at a sweep rate of 0.01 V/Sec. 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.

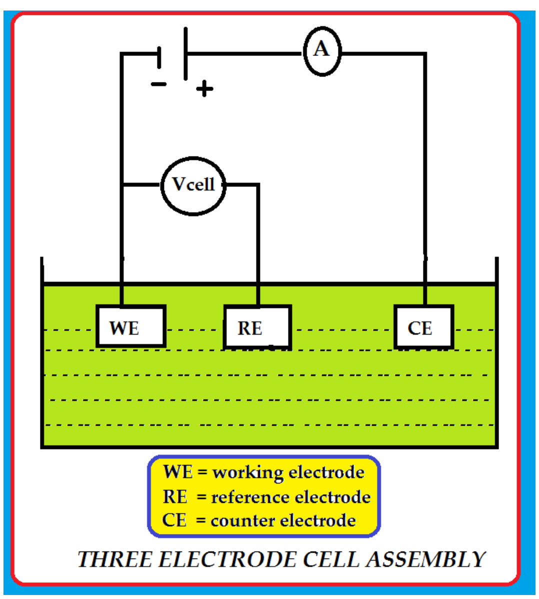

Figure 1. Three electrode cell assembly.

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 (R_t) and double layer capacitance (C_{dl}) values were calculated.

Results and Discussion

Influence of Vicks ginger candy (VGC) and Glucose D on corrosion resistance of Ni-Ti alloy in artificial saliva

Influence of Vicks ginger candy (VGC) and Glucose D on corrosion resistance of Ni-Ti alloy in artificial saliva, has been investigated by polarization technique and AC impedance spectra [13–32].

Polarization technique

In the present investigation Tafel plots were carried out in a CHI Electrochemical work station/ analyzer, model 660 A. It was provided with automatic i_R compensation facility. A three electrode cell assembly was used (Figure 1).

The electrodes were immersed in artificial saliva, in the absence and presence of Vicks ginger candy (VGC) and Glucose D. From polarization study, corrosion parameters such as corrosion potential (E_{corr}), corrosion current (I_{corr}), Tafel slopes anodic = b_a and cathodic = b_c and LPR (linear polarization resistance) value were calculated.

In polarization technique, when corrosion resistance increases LPR increases and corrosion current decreases. It implies that when corrosion resistance decreases, LPR decreases and corrosion current increases.

The polarization parameters of Ni-Ti alloy immersed in Artificial Saliva (AS), in the absence and presence of 1000 ppm each of Vicks ginger candy (VGC) and Glucose D are given in Table 1. The polarization curves are shown in Figures 2–4.

Influence of 1000 ppm of Vicks ginger candy (VGC) on corrosion resistance of Ni-Ti alloy immersed in Artificial Saliva (AS)

It is observed from Table 1, that in the presence of 1000 ppm of Vicks ginger candy (VGC), the corrosion resistance of Ni-Ti alloy in AS increases. This is revealed by the fact that, in the presence of 1000 ppm of Vicks ginger candy (VGC), LPR value of Ni-Ti alloy increases and corrosion current decreases. Vicks ginger candy (VGC) behaves as a mixed type of inhibitor. This is due to the fact that in the presence of Vicks ginger candy (VGC), the shift in corrosion potential is very small (from –535 to –549 mV *vs*. SCE). The characteristic peaks in Figure 3 indicate the processes of film formation and film breaking the corresponding potentials. The film formed is thin and less stable. So it is easily broken at these potentials.

Implication

Corrosion resistance of Ni-Ti alloy in artificial saliva increases in the presence of presence of 1000 ppm of Vicks ginger candy (VGC) increases. Hence people clipped with orthodontic wire made Ni-Ti alloy need not hesitate take 1000 ppm of Vicks ginger candy (VGC) orally.

Influence of 1000 ppm of Glucose D on corrosion resistance of Ni-Ti alloy immersed in Artificial Saliva (AS)

It is observed from Table 1, that in the presence of 1000 ppm of Glucose D, the corrosion resistance of Ni-Ti alloy in AS decreases. This is revealed by the fact that, in the presence of 1000 ppm of Glucose D, LPR value of Ni-Ti alloy decreases and corrosion current increases.

Glucose D behaves as anodic of inhibitor. This is due to the fact that in the presence of Glucose D), the shift in corrosion potential is towards anodic side (from –535 to –456 mV *vs.* SCE).

Implication

Corrosion resistance of Ni-Ti alloy in artificial saliva decreases in the presence of presence of 1000 Glucose D. Therefore, the chances of orthodontic wire undergoing corrosion are greater in those who consume Glucose D excessively.

Table 1. Corrosion parameters of Ni-Ti alloy in AS in the absence and presence of 1000 ppm each of Vicks ginger candy (VGC) and Glucose D obtained from polarization study.

System	E_{corr}, mV *vs.* SCE	b_c, mV/ decade	b_a, mV/decade	LPR, Ohm·cm^2	I_{corr}, A/cm^2
AS	–535	147	306	10497489	$4.117 \cdot 10^{-9}$
AS+VGC	–549	148	367	12802557	$3.492 \cdot 10^{-9}$
AS+Glucose D	–456	97	282	2483226	$12.64 \cdot 10^{-9}$

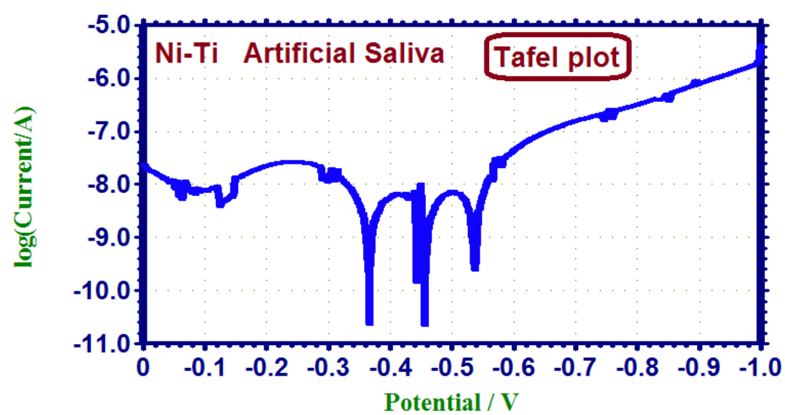

Figure 2. Polarization curve of Ni-Ti alloy immersed in artificial saliva (AS).

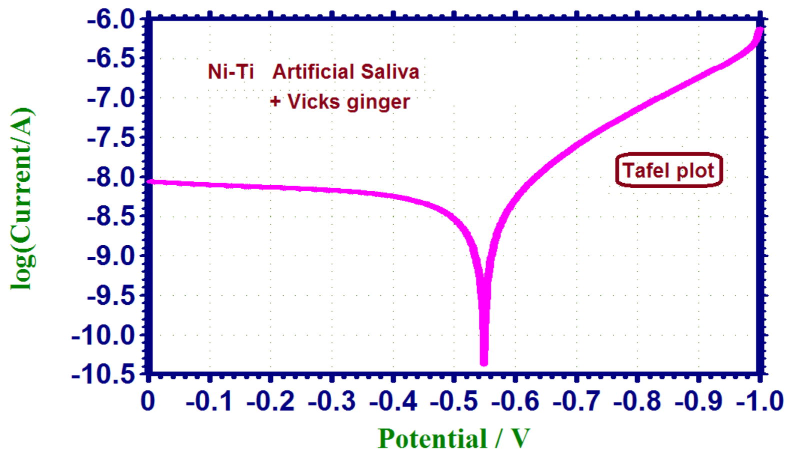

Figure 3. Polarisation curve of Ni-Ti alloy immersed in artificial saliva (AS) + Vicks ginger candy (VGC).

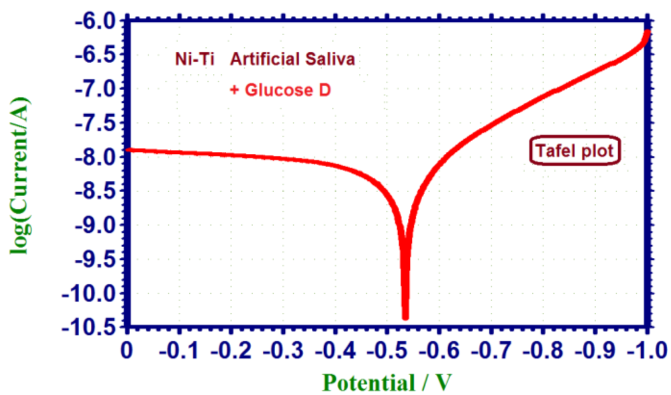

Figure 4. Polarisation curve of Ni-Ti alloy immersed in artificial saliva (AS) + Glucose D.

AC Impedance spectra

In the present investigation the same instrument set-up used for polarization study was also used to record AC impedance spectra. 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. AC impedance spectra were recorded with initial E (V) = 0, high frequency (Hz = $1\cdot10^5$), low frequency (Hz = 1), amplitude (V) = 0.005 and quiet time (s) = 2. From Nyquist plot the Values of charge transfer resistance (R_t) and the double layer capacitance (C_{dl}) were calculated.

$$R_t = (R_s + R_t) - R_s$$

where R_s is the solution resistance. C_{dl} values were calculated using the relationship:

$$C_{dl} = 1/2 \cdot 3.14 \cdot R_t \cdot f_{max}$$

where f_{max} is the frequency at maximum imaginary impedance.

When corrosion resistance increases, R_t values and impedance values increase whereas C_{dl} values decreases.

The AC impedance spectra of Ni-Ti alloy in AS in the absence and presence of 1000 ppm each of Vicks ginger candy (VGC) and Glucose D are shown in Figures 5–10. The Nyquist plots are shown in Figures 5–7. The Bode plots are shown in Figures 8–10.

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.

Influence of 1000 ppm of Vicks ginger candy (VGC) on corrosion resistance of Ni-Ti alloy immersed in Artificial Saliva (AS)

It is observed from Table 2, that in the presence of 1000 ppm of Vicks ginger candy (VGC), the corrosion resistance of Ni-Ti alloy in AS increases. This is revealed by the fact that in the presence of Vicks ginger candy (VGC), R_t value increases, impedance value increases, phase angle increases and C_{dl} value decreases.

Implication

Corrosion resistance of Ni-Ti alloy in artificial saliva increases in the presence of 1000 ppm of Vicks ginger candy (VGC). Hence people clipped with orthodontic wire made Ni-Ti alloy need not hesitate to take Vicks ginger candy (VGC) orally.

Influence of 1000 ppm of GlucoseD on corrosion resistance of Ni-Ti alloy immersed in Artificial Saliva (AS)

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

Implication

- Corrosion resistance of Ni-Ti alloy in artificial saliva decreases in the presence of 1000 ppm of Glucose D. Therefore, the chances of orthodontic wire undergoing corrosion are greater in those who consume Glucose D juice excessively.

Table 2. Corrosion parameters of Ni-Ti alloy in ASin the absence and presence of 1000 ppm each of Vicks ginger candy (VGC) and Glucose D obtained from AC impedance spectra.

System	R_t, Ohm·cm^2	Impedance, log (*Z*/Ohm)	C_{dl}, F/cm^2	Phase angle
AS	71.42	5.255	$71.408 \cdot 10^{-11}$	45.80
AS+ VGC	84.35	5.373	$6.0463 \cdot 10^{-11}$	49.38
AS+ Glucose D	17.64	4.176	$289.12 \cdot 10^{-11}$	43.06

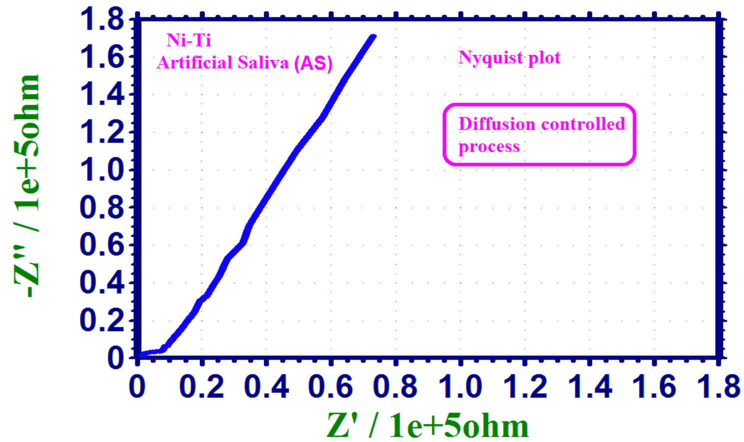

Figure 5. Nyquist plot of Ni-Ti alloy immersed in artificial saliva (AS).

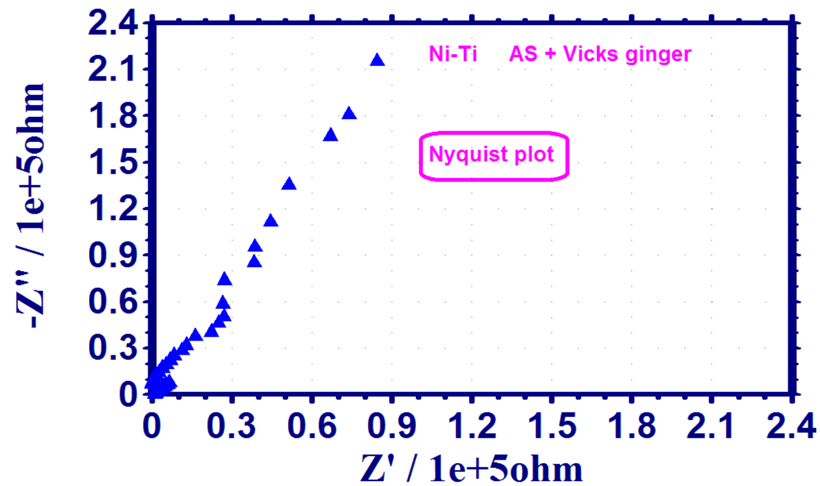

Figure 6. Nyquist plot of Ni-Ti alloy immersed in artificial saliva (AS) + Vicks ginger.

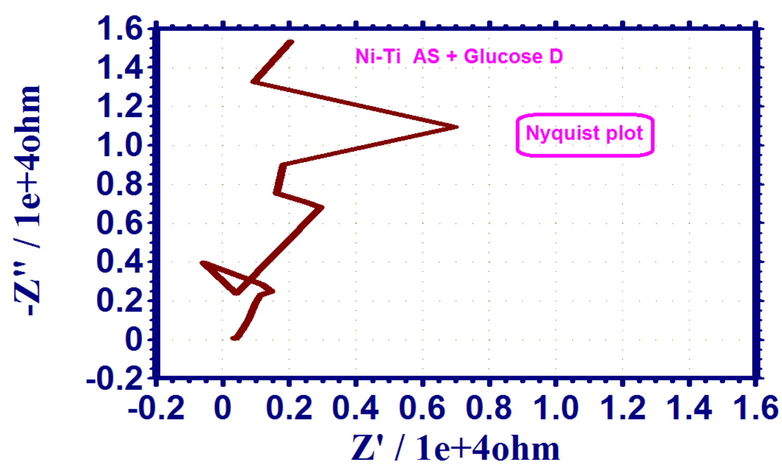

Figure 7. Nyquist plot of Ni-Ti alloy immersed in artificial saliva (AS) + Glucose D.

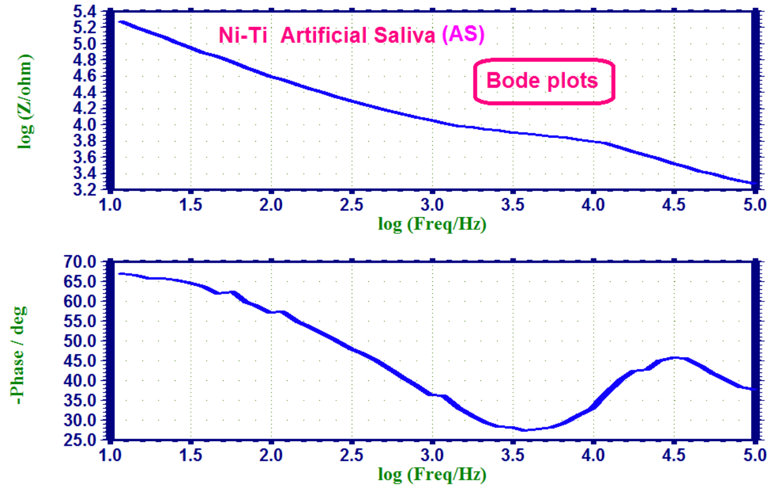

Figure 8. Bode plots of Ni-Ti alloy immersed in artificial saliva (AS).

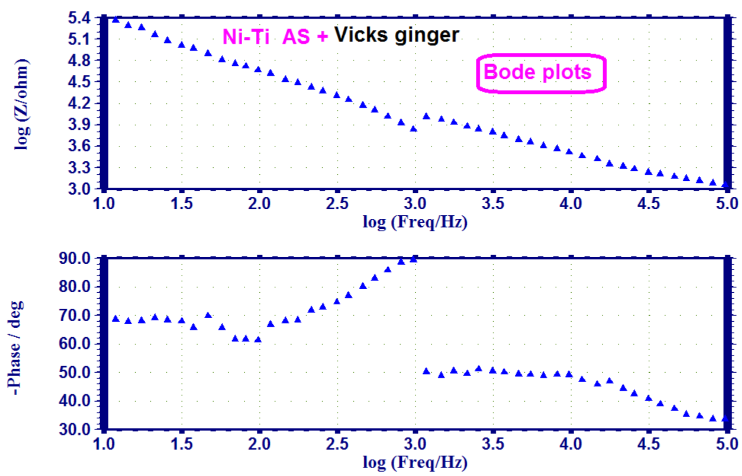

Figure 9. Bode plots of Ni-Ti alloy immersed in artificial saliva (AS) + Vicks ginger.

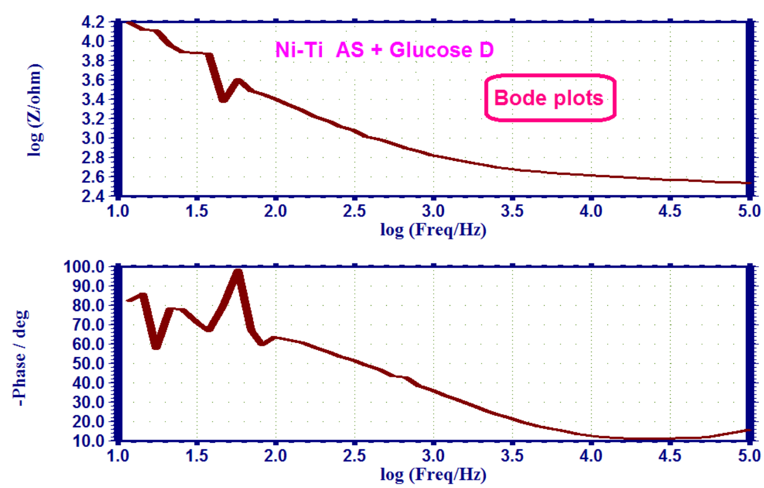

Figure 10. Bode plots of Ni-Ti alloy immersed in artificial saliva (AS) + Glucose D.

Conclusions

Influence of Vicks ginger candy (VGC) and Glucose D on corrosion resistance of orthodontic wire made of Ni-Ti alloy in artificial saliva has been evaluated by electrochemical studies such as polarization technique and AC impedance spectra.

- Corrosion resistance of Ni-Ti alloy in artificial saliva increases in the presence of 1000 ppm of Vicks ginger candy (VGC) increases. Hence people clipped with orthodontic wire made Ni-Ti alloy need not hesitate take 1000 ppm of Vicks ginger candy (VGC) orally.
- Corrosion resistance of Ni-Ti alloy in artificial saliva decreases in the presence of 1000 ppm of Glucose D. Therefore, the chances of orthodontic wire undergoing corrosion are greater in those who consume Glucose D juice excessively.
- In presence of 1000 ppm of Vicks ginger candy (VGC), LPR value of Ni-Ti alloy increases and corrosion current decreases.
- Vicks ginger candy (VGC) controls the anodic reaction and cathodic reaction to an equal extent. This is due to the fact that in the presence of Vicks ginger candy (VGC), the shift in corrosion potential is very small (from –535 to –549 mV *vs.* SCE).
- In the presence of 1000 ppm of Glucose D juice, the corrosion resistance of Ni-Ti alloy in AS decreases. This is revealed by the fact that, in the presence of 1000 ppm of Glucose D juice, LPR value of Ni-Ti alloy decreases and corrosion current increases.
- Glucose D juice controls the anodic reaction predominantly.
- This is due to the fact that in the presence of Glucose D juice, the shift in corrosion potential is towards anodic side (from –535 to –456 mV *vs.* SCE).

References///

1. K. Mouflih, A. Marda, M. Boudalia, A. Bellaouchou, M. Tabyaoui, A. Guenbour, L. Bahij, F. Zauoi, I. Warad and A. Zarrouk, Chemical, Electrochemical, and Surface Study on Microbial Attack of CoCrMo Dental Alloy by Streptococcus mutans, *J. Bio Tribo Corros*., 2021, **7**, 2. doi: 10.1007/s40735-020-00435-x
2. M. Liu, J. Li, D. Li, L. Zheng, The passive properties of TA10 in Coca-Cola containing oral environment, *Anti. Corros. Meth. Mater*., 2021, **68**, 9–16. doi: 10.1108/ACMM-05-2020-2312
3. R. Barabás, D.I. Fort, G.L. Turdean and L. Bizo, Influence of hap on the morpho-structural properties and corrosion resistance of ZrO_2-based composites for biomedical applications, *Crystals*, 2021, **11**, no. 2, 202. doi: 10.3390/cryst11020202
4. I. Tendero, M.C. Rossi, M. Viera, J.M. Amado, M.J. Tobar, A.Vicente, A. Yañez and V. Amigó, Laser surface modification in Ti-xNb-yMo alloys prepared by powder metallurgy, *Metals*, 2021, **11**, no. 2, 367. doi: 10.3390/met11020367
5. M. Jażdżewska and M. Bartmański, Nanotubular oxide layer formed on helix surfaces of dental screw implants, *Coatings*, 2021, **11**, no. 2, 115. doi: 10.3390/coatings11020115

6. F. Golgovici, M. Prodana, F.G. Ionascu and I. Demetrescu, A comparative electrochemical and morphological investigatio n on the behavior of NiCr and CoCr dental alloys at various temperatures, *Metals*, 2021, **11**, no. 2, 256. doi: 10.3390/met11020256
7. E.J. Kassab, C.D.R. Barros, P.G. Silva, L.F. Silva and J.A.P. Gomes, Corrosion of NiCr Alloys for Dental Applications: Effects of Environment, Chemical Composition and Casting Route, *J. Mater. Eng. Perform*., 2021, **30**, 994–1000. doi: 10.1007/s11665-020-05409-1
8. H. Zhang, C. Man, C. Dong, L. Wang and X. Wang, The corrosion behavior of Ti6Al4V fabricated by selective laser melting in the artificial saliva with different fluoride concentrations and pH values, *Corros. Sci*., 2021, **179**, 109097. doi: 10.1016/j.corsci.2020.109097
9. X. Wang, J.J. Noël, I.O. Wallinder and Y.S. Hedberg, Metal bioaccessibility in synthetic body fluids – A way to consider positive and negative alloying effects in hazard assessments, *Mater. Des*., 2021, **198**, 109393. doi: 10.1016/j.matdes.2020.109393
10. A. Nazarahari and D. Canadinc, Prediction of the NiTi shape memory alloy composition with the best corrosion resistance for dental applications utilizing artificial intelligence, *Mater. Chem. Phy*., 2021, **258**, 123974. doi: 10.1016/j.matchemphys.2020.123974
11. H.O. Curkovic, M. Ivanko, D.P. Acev, I.J. Badovinac and S. Spalj, Corrosion of Dental Alloys Used for Mini Implants in Simulated Oral Environment, *Int. J. Electrochem. Sci*., 2021, **16**, 21085. doi: 10.20964/2021.08.15
12. Z. Radulović, Z.P. Zupan, A. Tomazini and N.M. Varda, Vitamin D in pediatric patients with obesity and arterial hypertension, *Sci. Rep*., 2021, **11**, no. 1, 19591.
13. V. Sribharathy, S. Rajendran, P. Rengan and R. Nagalakshmi, Corrosion Inhibition By An Aqueous Extract Of Aleovera (L) Burm F. (Liliaceae), *Eur. Chem. Bull*., 2013, **2**, no. 7, 471–476. doi: 10.17628/ecb.2013.2.471-476
14. S. Rajendran, M. Agasta, R.B. Devi, B.S. Devi, K. Rajam and J. Jeyasundari, Corrosion inhibition by an aqueous extract of Henna leaves (Lawsonia Inermis L), *Zast. Mater*., 2009, **50**, 77–84.
15. N. Kavitha and P. Manjula, Corrosion Inhibition of Water Hyacinth Leaves, Zn^{2+} and TSC on Mild Steel in neutral aqueous medium, *Int. J. Nano Corros. Sci. Eng*., 2014, **1**, 31–38.
16. J.A. Thangakani, S. Rajendran, J. Sathiabama, R.M. Joany, R.J. Rathish and S.S. Prabha, Inhibition of corrosion of carbon steel in aqueous solution containing low chloride ion by glycine – Zn^{2+} System, *Int. J. Nano Corros. Sci. Eng*., 2014, **1**, 50–62.
17. S. Gowri, J. Sathiyabama, S. Rajendran and J.A. Thangakani, Tryptophan as corrosion inhibitor for carbon steel in sea water, *J. Chem., Biol. Phys. Sci*., 2012, **2**, 2223–2231.
18. T.A. Onat, D. Yiğit, H. Nazır, M. Güllü and G. Dönmez, Biocorrosion inhibition effect of 2-aminopyrimidine derivativeson SRB, *Int. J. Corros. Scale Inhib*., 2016, **5**, no. 3, 273–281. doi: 10.17675/2305-6894-2016-5-3-7

19. A.C.C. Mary, S. Rajendran, H. Al-Hashem, R.J. Rathish, T. Umasankareswari and J. Jeyasundari, Corrosion resistance of mild steel in simulated produced water in the presence of sodium potassium tartrate, *Int. J. Nano Corr. Sci. Eng*., 2015, **2**, 42–50.
20. V.I. Vigdorovich, L.E. Tsygankova, E.D. Tanygina, A.Yu. Tanygin and N.V. Shel, Preservative materials based on vegetable oils for steel protection against atmospheric corrosion. I. Colza oil, *Int. J. Corros. Scale Inhib*., 2016, **5**, no. 1, 59–65. doi: 10.17675/2305-6894-2016-5-1-5
21. P.N. Devi, J. Sathiyabama and S. Rajendran, Study of surface morphology and inhibition efficiency of mild steel in simulated concrete pore solution by lactic acid–Zn^{2+} system, *Int. J. Corros. Scale Inhib*., 2017, **6**, 18–31. doi: 10.17675/2305-6894-2017-6-1-2
22. L.G. Knyazeva, L.E. Tsygankova, A.V. Dorokhov and N.A. Kur'yato, Protective efficiency of oil compositions with Cortec VpCI-368D, *Int. J. Corros. Scale Inhib*., 2021, **10**, no. 2, 551–561. doi: 10.17675/2305-6894-2021-10-2-4
23. M. Cenoui, I. Himer, R. Touir, M. Ebn Touhami, A. Dermaj, N. Hajjaji and H. El Kafssaoui, Synergistic, influence of molybdate ions on the inhibition of corrosion and scale of ordinary steel in cooling water system by new organic compound, *Zast. Mater*., 2010, **51**, 13–10.
24. S.S. Rajendran, T.S. Muthumegala, M. Pandiarajan, P.N. Devi, A. Krishnaveni, J. Jeyasundari, N.B. Samy and H.N. Beevi, Corrosion resistance of SS316L in simulated concrete pore solution in the presence of trisodium citrate, *Zast. Mater*., 2011, **52**, 85–89.
25. N. Antony, H.B. Sherine and S.S. Rajendran, Investigation of the inhibiting effect of nano film by sodium meta silicate-Zn^{2+} system on the corrosion of carbon steel in neutral chloride solution, *Zast. Mater*., 2010, **51**, 11–18.
26. A.S. Fouda, G.Y. Elewady, A. EL-Askalany and K. Shalabi, Inhibition of aluminum corrosion in hydrochloric acid media by three Schiff base compounds, *Zast. Mater*., 2010, **51**, 205–219.
27. S. Rajendran, V. Sribharathy, A. Krishnaveni, J. Jeyasundari, J. Sathiyabama, T.S. Muthumegala and M. Manivannan, Inhibition effect of self assembled films formed by adipic acid molecules on carbon steel surface, *Zast. Mater*., 2011, **52**, 163–172.
28. K. Kavitha, H. Benitasherine and S. Rajendran, Cardiospermum halicacabum leaves extract as a green corrosion inhibitor for mild steel in simulated oil well water medium, *Int. J. Corros. Scale Inhib*., 2021, **10**, no. 4, 1646–1660. doi: 10.17675/2305-6894-2021-10-4-17
29. S. Karthikeyan, S.S.S. Abuthahir, A.S. Begum, S. Rajendran and A. Al-Hashem, Inhibition of mild steel corrosion in 0.5 M sulfuric acid by an aqueous extract of leaves of Tectona grandis L. plant, *Int. J. Corros. Scale Inhib*., 2021, **10**, no. 4, 1531–1546. doi: 10.17675/2305-6894-2020-10-4-10

30. V. Jeslina, S.J. Kirubavathy, A. Al-Hashem, S. Rajendran, C. Lacnjevac and R.M. Joany, Inhibitive effect of an alcoholic extract of a seaweed Sargassum Muticum in controlling corrosion of mild steel in 0.5 N HCl, *Int. J. Corros. Scale Inhib*., 2021, **10**, no. 4, 1454–1473. doi: 10.17675/2305-6894-2021-10-4-6
31. S.C. Joycee, T. Vidya, S.A. Ratthika, B.S. Prabha, R. Dorothy, T. Sasilatha and S. Rajendran, Corrosion resistance of mild steel in simulated concrete pore solution before and after a paint coating, *Int. J. Corros. Scale Inhib*., 2021, **10**, no. 3, 1323–1335. doi: 10.17675/2305-6894-2021-10-3-28
32. C.J.A. Priya, A.P.P. Regis and S. Rajendran, Influence of ENO juice orally taken in on the corrosion resistance of orthodontic wire made of SS 18/8 in the presence of artificial saliva, *Int. J. Corros. Scale Inhib*., 2021, **10**, no. 3, 1030–1041. doi: 10.17675/2305-6894-2021-10-3-13

♦ ♦ ♦