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## 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<sup>2</sup> to 415003 Ohmcm<sup>2</sup>; corrosion current decreases from 1.346 x10<sup>-7</sup>A/cm<sup>2</sup> to 1.105 x10<sup>-7</sup>A/cm<sup>2</sup>; charge transfer resistance value increases from 31945 Ohmcm<sup>2</sup> to 44357 Ohmcm<sup>2</sup>; impedance value increases from 4.649 to 4.819; double layer capacitance decreases from 1.596x10<sup>-10</sup>F/cm<sup>2</sup> to 1.150 x10<sup>-10</sup>F/cm<sup>2</sup>, 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

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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<sub>2</sub>·2H<sub>2</sub>O – 0.906 g/L, NaH<sub>2</sub>PO<sub>4</sub>·2H<sub>2</sub>O – 0.690 g/L, Na<sub>2</sub>S·9H<sub>2</sub>O – 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  $E_{\text{corr}}$ , corrosion current  $I_{\text{corr}}$  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 ( $R_t$ ) and double layer capacitance ( $C_{dl}$ ) 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 impedance 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 impedance 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 1 and 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 Ohm $cm^2$	$i_{corr}$ A/ $cm^2$
AS	-534	182	264	347978	$1.346 \times 10^{-7}$
AS + KOPIKO	-532	190	238	415003	$1.105 \times 10^{-7}$

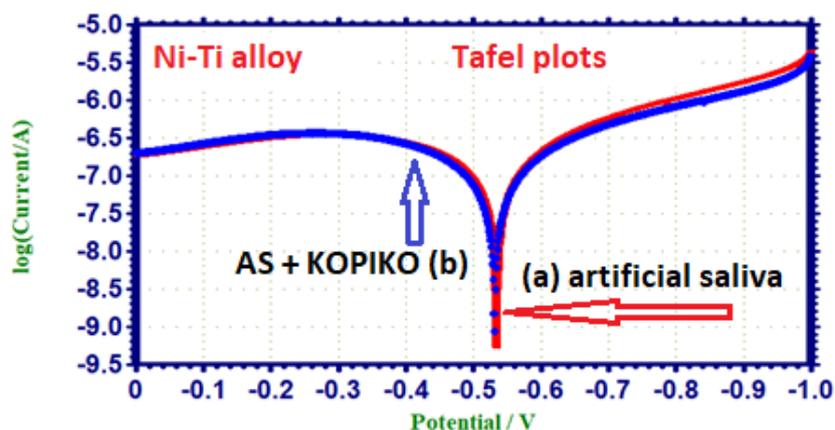


Figure 1. Polarization curves of Ni-Ti alloy immersed in various test solutions

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

#### *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 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 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,  $R_t$  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 <sup>2</sup>	Impedance log(Z/ohm)	$C_{dl}$ F/cm <sup>2</sup>	Phase angle degree
AS	31945	4.649	1.596x x10 <sup>-10</sup>	39.63
AS + KOPIKO	44357	4.819	1.150x x10 <sup>-10</sup>	50

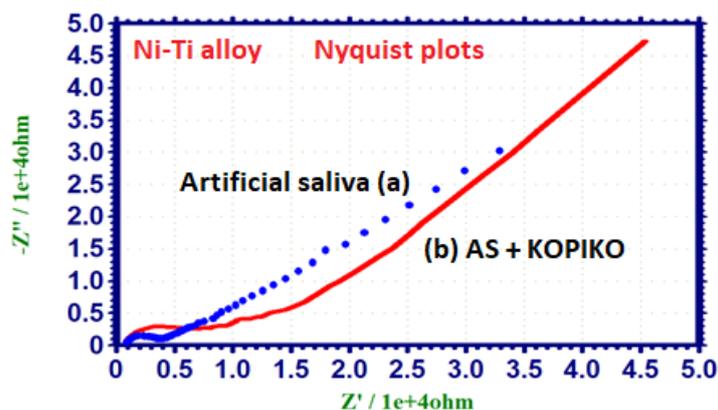


Figure 2. Nyquist plots of Ni-Ti alloy immersed in various test solutions  
Slika 2. Nyquist-ove krive legure Ni-Ti uronjeni u različita ispitna rastvora

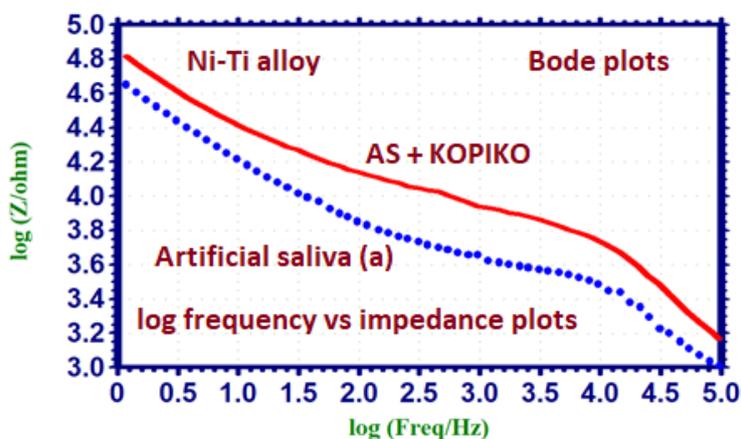


Figure 3. Bode plots of Ni-Ti alloy immersed in various test solutions (log frequency vs impedance plots)  
Slika 3. Bode-ove krive legure Ni-Ti uronjene u različite ispitne rastvore (grafikoni log frekvencije u odnosu na impedansu)

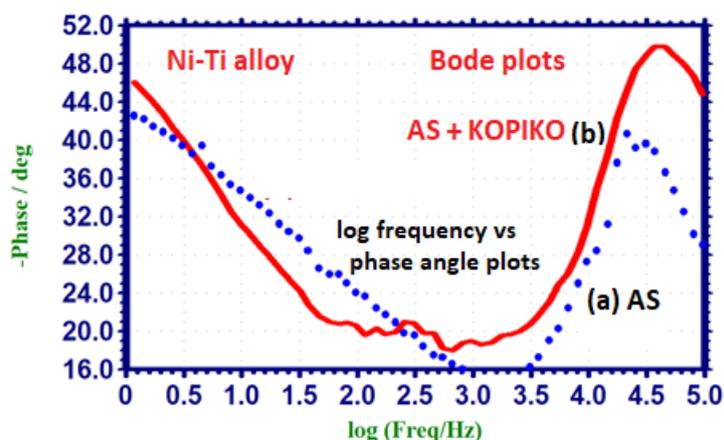


Figure 4. Bode plots of Ni-Ti alloy immersed in various test solutions (log frequency vs phase angle plots)

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-Ti alloy 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	$1.346 \times 10^{-7}$	$1.105 \times 10^{-7}$	Decreases
$R_t$ Ohmcm <sup>2</sup>	31945	44357	Increases
Impedance log(Z/ohm)	4.649	4.819	Increases
$C_{dl}$ F/cm <sup>2</sup>	$1.596 \times 10^{-10}$	$1.150 \times 10^{-10}$	Decreases
Phase angle°	39.63	50	Increases

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## IZVOD

### Otpornost na koroziju ortodontske žice od legure niki-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 sadrže 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<sup>2</sup> na 415003 Ohmcm<sup>2</sup>; struja korozije se smanjuje sa 1,346 k10<sup>-7</sup> A/cm<sup>2</sup> na 1,105 k10<sup>-7</sup> A/cm<sup>2</sup>; vrednost otpora prenosa naelektrisanja se povećava sa 31945 Ohmcm<sup>2</sup> na 44357 Ohmcm<sup>2</sup>; vrednost impedanse se povećava sa 4,649 na 4,819; kapacitivnost dvostrukog sloja se smanjuje sa 1,596k10<sup>-10</sup> F/cm<sup>2</sup> na 1,150k10<sup>-10</sup> F/cm<sup>2</sup>, 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.

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