INFLUENCE OF COFFEE ON THE CORROSION RESISTANCE OF ORTHODONTIC WIRES IN ARTIFICIAL SALIVA

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Corrosion resistance of Ni-Ti, Thermoactive alloy, and SS 316 L alloy in artificial saliva (AS) in the absence and presence of coffee has been evaluated by electrochemical studies such as polarization study and AC impedance spectroscopy. The polarization and AC impedance spectroscopy studies lead to the conclusion that corrosion resistance of the alloys decreases in the following order: SS 316 L alloy > Thermoactive alloy> Ni-Ti alloy. In all the three cases, the corrosion resistance of the wires increases in the presence of coffee. Among the three orthodontic wires, SS316L alloy is the best candidate.

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Introduction

Metallic materials such as Ag, Au, Ni-Ti, Ni-Cr, SS 316L, SS18/8, etc., are used as implants in regulative oral surgery to the array of teeth. The metals for complete and partial crowns and bridges should be hypoallergenic materials with good mechanical properties, corrosion resistant towards soft drinks, hot drinks, food items, and tablets. Titanium alloys are the most commonly used material for implantation of the teeth.[1] Corrosion of metallic implants has vital importance because it can adversely affect the biocompatibility and mechanical integrity of implants. The electrochemical behavior of orthodontic wires in artificial saliva has been investigated by polarization study and AC impedance spectra[2]. The resistance to corrosion of the metallic orthodontic wires in simulated intra–oral environment has been evaluated by Ziebowicz et al.[3] The effects of multilayered Ti/TiN or single-layered TiN film deposited by Pulse-Biased Arc Ion Plating (PBAIP) on the corrosion behavior of NiTi orthodontic wires in artificial saliva have also been investigated.[4] Rajendran et al. have studied the corrosion behavior of SS 316L and AS in artificial saliva in the presence of electoral, spirulina powder, and glucose, respectively.[5,6,7] A lot of studied have been published on the use of natural products as corrosion inhibitors.[7-13] Corrosion behavior of Thermoactive super elastic shape memory alloy and Gold 22K has been investigated in artificial saliva in the presence of syzygium cumini fruit juice.[15] The corrosion resistance of Ti depends on the passive film alloys formed on surface.[16-20]

In the present study, the corrosion resistance of Ni-Ti, SS 316L, and Thermoactive alloys has been evaluated by electrochemical studies such as polarization study and AC impedance spectroscopy in artificial saliva in presence and absence of coffee.

Materials and methods

Preparation of coffee test solution

The coffee test solution was prepared by heating 250 ml of milk to boil, and with added the 5 g of instant coffee powder (BRU Instant Coffee), the mixture was mixed with a teaspoon of sugar.

Corrosion behavior of Ni-Ti, Thermoactive alloy, and SS316L alloy have been investigated in various test solutions such as artificial saliva (AS), coffee, AS + coffee. The composition of AS is given in Table 1.

Table 1. The composition of artificial saliva

Content	Concentration, g L^{-1}
NaCl	0.4
$NaH_2PO_4.2H_2O$	0.690
KCl	0.4
$CaCl_2.2H_2O$	0.906
$Na_2S.9H_2O$	0.005
Urea	1

The metal specimens were immersed in Fusayama-Meyer artificial saliva.[21] The pH of the solution was 6.5. In electrochemical studies, the alloys were used as working electrodes. Artificial saliva was used as an electrolyte. The experiments were carried out at 64.5 ˚ C (temperature of the coffee drink).

Potentiodynamic polarization study

Polarization studies were carried out in a CHI-electrochemical workstation with impedance, Model 660A. A three-electrode cell assembly was used.

Table 2. Corrosion parameters of metals immersed in artificial saliva (AS) in the absence and the presence of coffee obtained by polarization study

Metal	System	E_{corr}, mV vs SCE	b_c, mV decade^{-1}	b_a, mV decade^{-1}	*LPR*, ohm cm^2	I_{corr}, A cm^{-2}
Ni-Ti alloy	AS	-395	178	302	3277970	1.488x10^{-8}
	AS+Coffee	-778	126	335	5557295	7.170x10^{-9}
SS316L alloy	AS	-454	164	317	4177473	1.127 x10^{-8}
	AS+Coffee	-447	123	216	12072330	2.825x10^{-9}
Thermoactive alloy	AS	-501	158	315	7936745	5.775x10^{-8}
	AS+Coffee	-726	130	339	8025230	5.095x10^{-9}

The working electrode was one of the three alloys. A saturated calomel electrode (SCE) was the reference electrode, and platinum was the counter electrode.

AC impedance spectra

The cell setup was the same as in the case of polarization study. The real part (*Z*') and imaginary part (-*Z*") of the cell impedance were measured in ohms at various frequencies.

Result and Discussion

Analysis of polarization curves

Polarization analysis has been used for detection of the protective films formed on the metal surface during corrosion inhibition process.[22] The corrosion parameters of Ni-Ti, Thermoactive alloy, and SS316L alloy in the test solutions are given in Table 2, and the potentiodynamic polarization curves are shown in Figures 1 and 2.

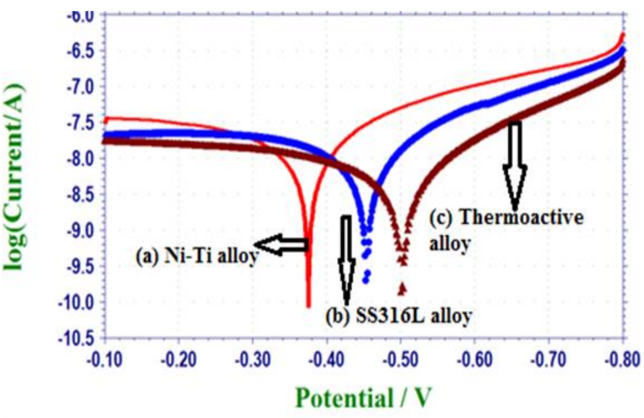

Figure 1. Polarization curve of Ni-Ti alloy, SS 316L alloy and Thermoactive alloy immersed in AS

As it is given in Table 2, when Ni-Ti alloy was immersed in AS, the corrosion potential is -375 mV vs. SCE (Figure 1a). The Linear Polarization Resistance (*LPR*) value was 3277970 ohm cm^2, and the corrosion current (I_{corr}) was 1.488 x 10^{-8} A cm^{-2}.

When the Thermoactive alloy was immersed in AS the E_{corr} value wa -501 mV vs. SCE (Figure 1c). The *LPR* value was 7930745 ohm cm^2. This was found to be higher than in case of Ni-Ti alloy. The corrosion current is (I_{corr}) was found to be 5.775 x 10^{-9} A cm^{-2}. This was found to be lower than in case of Ni-Ti alloy. These observations indicated that thermoactive alloy was more corrosion resistant than Ni-Ti alloy.

In the case of Thermoactive alloys, the cathodic Tafel slope was (b_c) 158 mV decade^{-1}, and the anodic Tafel slope was (b_a) 315 mV decade^{-1}. These values suggested that during anodic polarization, the rate of change of corrosion current with potential was high, and it was less during the cathodic polarization.

When the SS316L alloy was immersed in AS, the corrosion potential was - 454 mV vs. SCE (Figure 1b). The *LPR* value was 12072330 ohm cm^2. The corrosion current was 1.127x10^{-8} A cm^{-2}. The values of Tafel slopes (b_c = 164; ba = 317 mV decade^{-1}) indicated that the rate of change of current with potential increased in higher rate during the anodic polarization than during the cathodic polarization. A comparison of *LPR* values and corrosion current values of these alloys investigated revealed that SS316L was more corrosion resistance than other two alloys.

Corrosion behavior of alloys in AS containing coffee

Ni -Ti alloy

AS it can be seen in Table 2, when Ni-Ti alloy was immersed in AS containing coffee, the corrosion potential was -778 mV vs. SCE (Figure 2a). It was interesting to note that in the presence of coffee the LPR value increased (5557295 ohm cm^{-2}) and the corrosion current value decreased (7.170 x 10^{-9} A cm^{-2}). It seemed that a protective layer was formed on the metal surface which controled the rate of corrosion of Ni-Ti in AS in the presence of coffee. The values of Tafel slopes were b_c = 130 mV decade^{-1}; b_a = 339 mV decade^{-1}.

Thermoactive alloy

When the Thermoactive alloy was immersed in AS containing coffee the corrosion potential was -712 mV vs. SCE (Figure 2c). The Tafel slope were b_c = 130 mV decade^{-1} and b_a = 339 mV decade^{-1}.

Table 3. Corrosion parameters of metals immersed in Artificial saliva (AS) in the absence and the presence of coffee obtained by AC impedance spectra

Metal	System	Nyquist plot, R_t ohm cm^2	C_{dl}, F cm^{-2}	Bode plot, impedance log(Z ohm^{-1})
Ni-Ti alloy	AS	12278	4.1538	4.203
	AS+coffee	3823.8	1.30759	4.4
SS316L alloy	AS	12468	4.0905	4.443
	AS+coffee	247279.52	2.0235	4.6
Thermoac-tive alloy	AS	27941	1.8253	4.344
	AS+coffee	88930	5.6224	4.393

The *LPR* value was increased from 7936745 ohm cm^2 to 8025230 ohm cm^2, the corrosion current was decreased from 5.775 x 10 $^{-8}$ A cm^{-2} to 5.095 x 10^{-9} A cm^{-2}. That is, in the presence of coffee, the corrosion resistance of thermoactive alloy was increased.

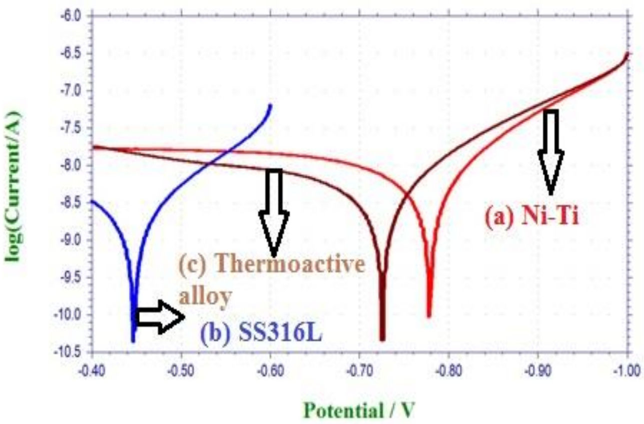

Figure 2. Polarization curve of Ni-Ti alloy, SS316L alloy and Thermoactive alloy immersed in AS+Coffee

SS 316 L alloy

In the presence of coffee, the corrosion resistance of SS316L increased. This is revealed by the increase in LPR value (from 4177473 ohm cm^2 to 12072330 ohm cm^2) and decrease in corrosion current (from 1.127 x10^{-8} to 2.825 x 10^{-9}) (Figure 2b). The value of Tafel slope were b_c = 123 mV decade^{-1}; b_a = 216 mV decade^{-1}. Thus polarization study leads to the conclusion that in the presence of coffee in AS the corrosion resistance of alloys decreased in the following order: SS316L alloy > Thermoactive alloy> Ni-Ti alloy. Polarization study reveals that the corrosion resistance of the three alloys in AS in absence and presence of coffee decreases in the following order; SS316L alloy > Thermoactive alloy> Ni-Ti alloy.

Implication

It implies that SS316L alloy is a better candidate for making orthodontic wire.

AC impedance spectra

AC impedance parameters such as charge transfer resistance (R_t), double layer capacitance (C_{dl}) (derived from Nyquist plots) and impedance value log (Z ohm^{-1}) (derived from Bode plots), of various alloys immersed in AS and AS containing coffee, are given in Table 3. AS impedance spectra are shown in Fig 3 to 5 (Nyquist Plots) and 6 to 11 (Bode plots).

Ni-Ti alloy

When Ni-Ti is immersed in AS (Figure 3a), the charge transfer resistance was 1227 ohm cm^2. The double layer capacitance was 4.1538x 10^{-10} F cm^{-2}. The impedance value [log (Z ohm^{-1})] was 4.20315 in the presence of coffee (Figure 3b), R_t value increased (from 12278 ohm cm^2 to 38238 ohm cm^2) and C_{dl} value was decreased. There was an increase in the value of impedance [log(Z ohm^{-1})] (Fig 7b). These observations indicated that in the presence of coffee in AS, the corrosion rate of Ni-Ti was reduced due to the formation of the protective film formed on the metal surface.

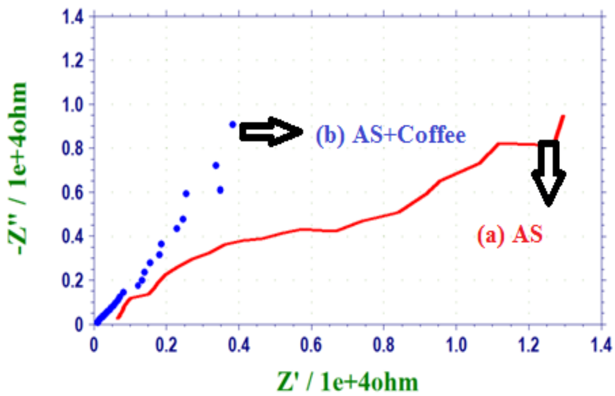

Figure 3. AC impedance spectra (Nyquist plot) of Ni-Ti alloy immersed in AS and AS+Coffee

Thermoactive alloy

When the Thermoactive alloy was immersed in AS (Figure 4a), the R_t value is 27941 ohm cm^2. The double layer capacitance was 1.8253x 10^{-10} F cm^{-2}. The impedance value [log (Z ohm^{-1})] was 3.82(Figure 8).

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When the R_t values were compared with the value of Ni-Ti, it was noted that Thermoactive alloy was more corrosion resistant in AS than Ni-Ti alloy. Similarly, when Thermoactive alloy was immersed in AS mixed with coffee (Figure 4b) the R_t value was increased from 27941 to 88930 ohm cm^2, the C_{dl} value decreased from 1.8253 x 10^{-10} F cm^{-2} to 5.622 x 10^{-11} F cm^{-2}, and the impedance value increased from 3.871 to 4.393 (Figure 9). This observation concluded that the film formation on the metal surface in AS in the presence of coffee.

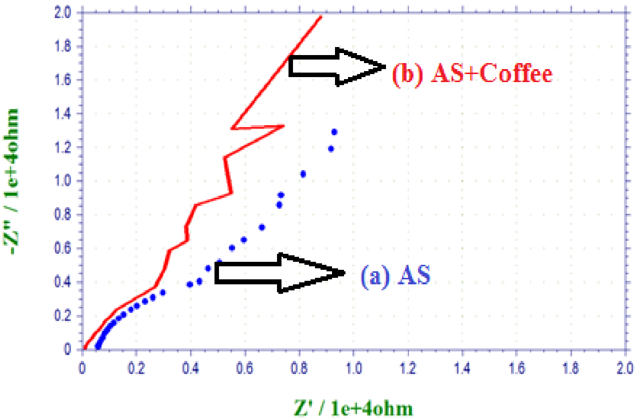

Figure 4. AC impedance spectra (Nyquist plot) of Thermoactive alloy immersed in AS and AS+Coffee

SS316L alloy

When SS316 L alloy was immersed in AS, the R_t value was 12468 ohm cm^2. The C_{dl} value was 4.0905x 10^{-10} F cm^{-2}, and the impedance value [log (Z ohm^{-1})] was 4.443 (Figure 10). These observations suggest that the protective film formed on the SS316L alloy. SS316L was a better candidate in AS since it was more corrosion resistant than Ni-Ti and Thermoactive alloys.

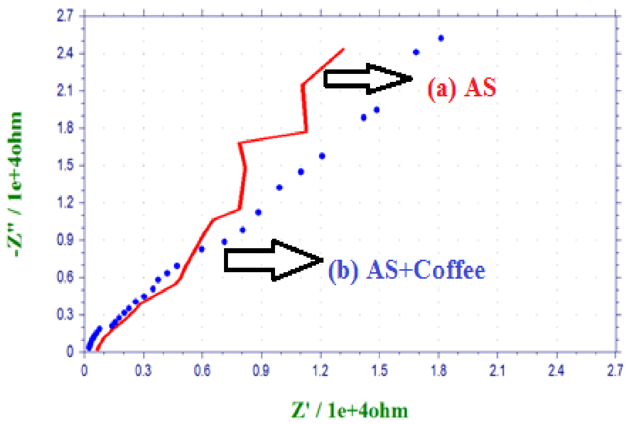

Figure 5. AC impedance spectra (Nyquist plot) of SS 316L alloy immersed in AS and AS+Coffee

When SS316L was immersed in AS in the presence of coffee the R_t value is increase from 12468 to 247279.52 ohm cm^2, the C_{dl} value is decreased from 4.0905 x 10^{-10} F cm^{-2} to 2.0235 x 10^{-10} F cm^{-2} and impedance value increased from 4.443 to 4.6 [log (Z ohm^{-1})] (Figure 11).

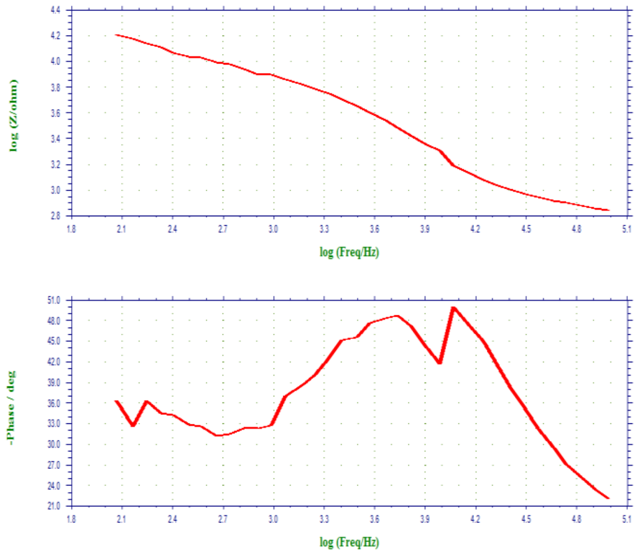

Figure 6.AC impedance spectra (Bode Plot) of Ni-Ti alloy immersed in AS

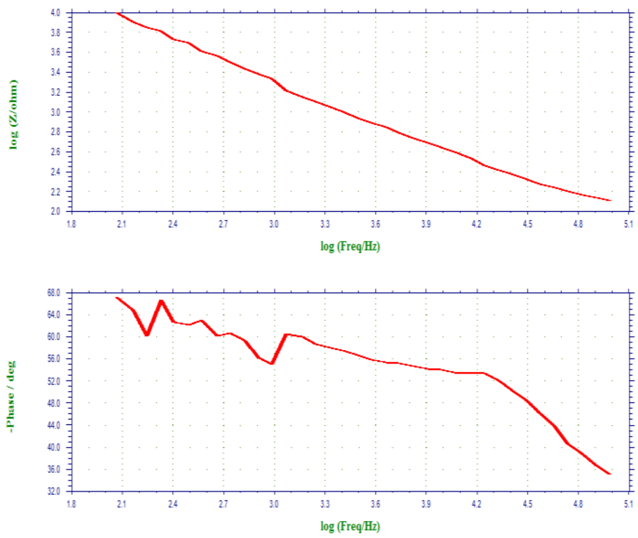

Figure 7.AC impedance spectra (Bode Plot) of Ni-Ti alloy immersed in AS +Coffee

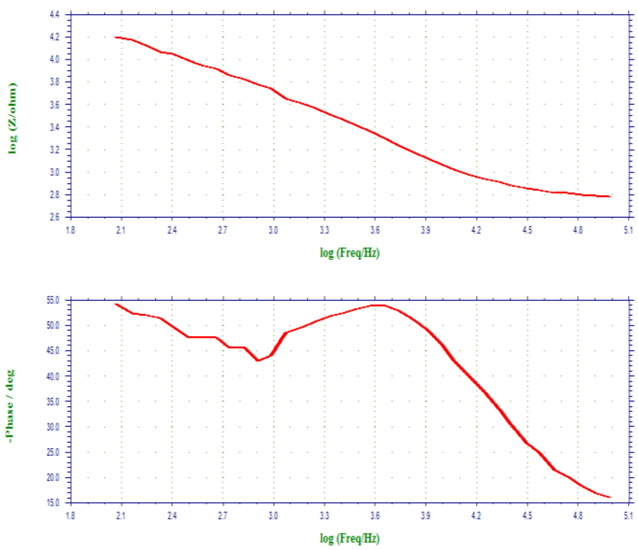

Figure 8.AC impedance spectra (Bode Plot) of Thermoactive alloy immersed in AS

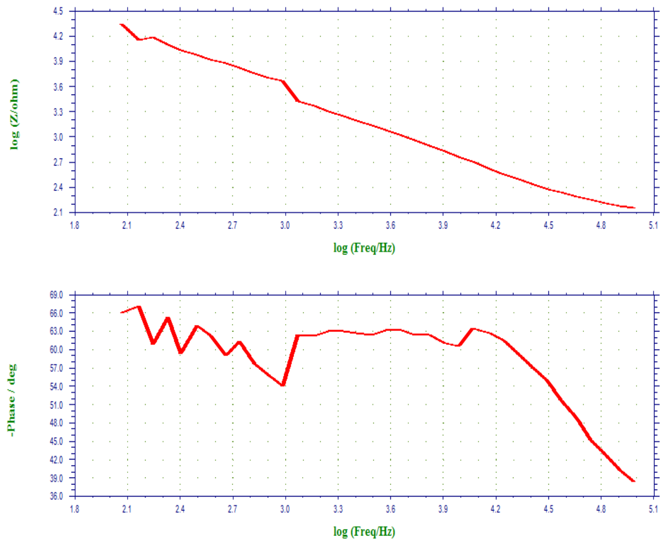

Figure 9.AC impedance spectra (Bode plot) of Thermoactive alloy immersed in AS+Coffee

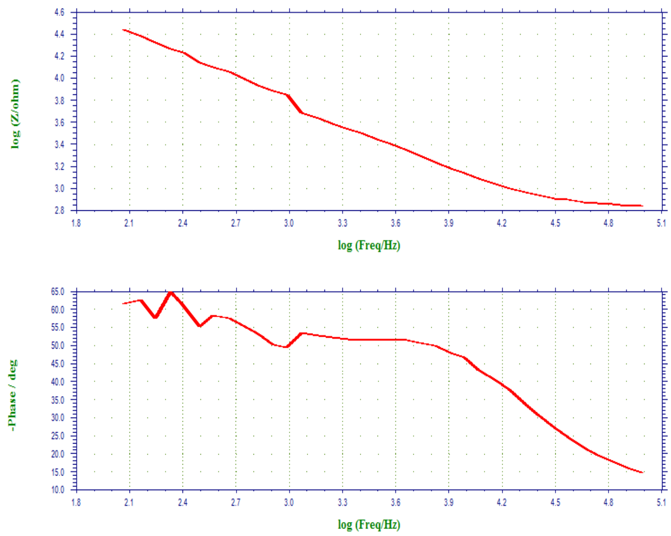

Figure 10. AC impedance spectra (Bode plot) of SS316L immersed in AS

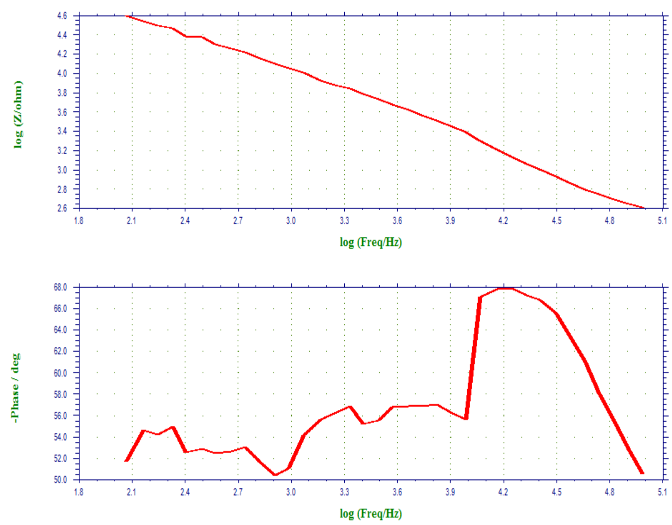

Figure 11. AC impedance spectra (Bode plot) of SS316L immersed in AS+Coffee

Conclusion

The present study led to the conclusion that in the presence of coffee in AS, the corrosion resistance of SS316L increased. In the presence of coffee in AS, the corrosion resistance of alloys decreased in the following order;

SS 316 L alloy > Thermoactive alloy> Ni-Ti alloy

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