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Stainless Steel Alloys for Dental Application: Corrosion Behaviour in the Presence of Toothpaste Vicco

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ABSTRACT

Stainless steel 18/8 and 316L have been widely used in orthodontic implants. The patients are recommended to pay attention to oral hygiene by prescribing the toothpastes to improve oral health. People face problems of corrosion of the material due to the use of various toothpastes. Our study was aimed at evaluating the corrosion behaviour of orthodontic wires made of SS 18/8 and SS316L in the absence and the presence of toothpaste Vicco. The electrochemical studies such as potentiodynamic polarization and AC impedance spectra were used to know the corrosion parameters such as corrosion potential (E_{corr}), corrosion current (I_{corr}), Linear Polarization Resistance (LPR), charge transfer resistance (R_{ct}) and double layer capacitance (C_{dl}). In the presence of toothpaste Vicco, both the alloys under investigated showed high corrosion resistance. The decrease in the corrosion resistance of SS 18/8 and SS316L alloy in various solutions was in the following order: artificial saliva+toothpaste>toothpaste>artificial saliva. In the presence of artificial saliva containing 1% toothpaste the corrosion resistance of SS 18/8 was greater than SS 316L alloy. This was due to the co-ordination of stainless steel metal ion with the active principles of the ingredients of the toothpaste forming a protective layer on the surface of the metal and thus resisting corrosion.

Keywords: Orthodontic appliances, Toothpaste, Dental alloys, Ingredients, Corrosion potential

INTRODUCTION

The choice of material depends on various factors like corrosion behavior, mechanical properties, fabricability, cost, availability, biocompatibility and aesthetic values in order to select a material for dental application. The corrosion behavior of metallic materials for dental applications usually is the most important property because of biocompatibility and cytotoxicity of the products generated by the corrosion process [1].

The Brackets, wires, ligatures and bands used for the orthodontic purpose are manufactured using stainless steel alloy [2,3]. This alloy is composed of iron and carbon and it also contains small quantities of nickel, chromium, and other elements that make it corrosion resistant [4]. The corrosion resistance is enhanced by the presence of chromium in it [5]. Almost a full century, stainless steel has been widely used in dentistry [6]. The addition of Molybdenum (Mo) has improved the corrosion resistance of the first stainless steel used for the dental implants which contains approximately 18% weight of Cr and 8% weight of Ni. The corrosion resistance to chloride solution is further enhanced when the carbon (C) content was reduced from 0.08 to 0.03% weight and it was named as SS 316L [6,7].

The coating which is formed by chromium oxides, on stainless steel alloys is extremely thin and transparent. Though it is not visible through our naked eye, it provides protection from corrosion for the metal it covers. The surface oxide can reform to protect the underlying metal even when it is scratched. But if a solution contains chloride ions, this protective layer does not easily get formed. The high content of chloride ions present in saliva is due to the presence of sodium chloride which is why the stainless-steel surfaces are corroded easily in the mouth when they are scratched. Since repassivation does not occur, the corrosion can be accelerated in the area of the scratch, producing a small but deep pit. This process is called pitting corrosion, which may be sufficient to weaken the metal [8].

All the metals and alloys exhibit various physical and mechanical properties. But the metals used as biomaterials have distinctive disadvantages such as corrosion and elemental release [9-12]. The metallic biomaterials are subject to corrosive medium after introducing into the human body. Therefore corrosion resistance is one of the important features of dental materials [13].

Orthodontic wires are recommended by the dentists to regulate the arrangement of teeth. People having these orthodontic wires have to brush their teeth daily. The toothpaste that they use may corrode the orthodontic wires in the oral environment. So the tests are done to evaluate the influence of various toothpastes on the corrosion behaviour of orthodontic wires made of many metals and alloys.

MATERIALS AND METHODS

SS 18/8 and SS 316L were used as metal samples and the corrosion resistance was studied using toothpaste Vicco and Fusayama artificial saliva AS) as an electrolyte medium.

The composition of SS 18/8

Iron (73.75%), chromium (18%), nickel (8%) and carbon (0.25%) [6,7].

The composition of SS 316L

Cr (18%), Ni (12%), Mo (2.5%), C (<0.03%) and balance is Iron [14,15].

The composition of Vicco

(Weight (g)/100 g): Babhul (*Acasia arabica*)-1.8, Jambhul (*Eugenia jambolana*)-1, Lavang (*Caryophyllus*)-0.06, Manjishtha (*Rubia cordifolia*)-2.6, Dalchini (*Cinnamomum zeylanicum*)-0.16, Bor (*Zizyphus jujube*)-1, Vajradanti (*Berleria prionitis*)-0.5, Acrod (*Juglans regia*)-0.06, Khair (*Acacia catechu*)-1.64, Patang (*Caesalpinia sappan*)-2.4, Jeshthamadh (Glycyrrhizaglabra)-1.38, Kavab-Chini (*Zanthoxylum rhetsa*)-1.94, Anantmul (*Hemidesmu sindicus*)-0.4, Maifal (*Quercus infectoria*)-0.06, Trifala (*Emblica officinalis*)-1.6, Ajwan (*Carunc opticum*)-0.02, Akkalkadha-0.26.

The chemical composition of Fusayama artificial saliva

Fusayama artificial saliva solution constituents closely resemble those of natural saliva. During the study, the artificial saliva solution temperature was maintained at room temperature of 25°C (Table 1) [16].

Table 1: Chemical composition of artificial saliva (Fusayama Meyer)

Content	Quantity gL^{-1}
KCl	0.4
NaCl	0.4
$CaCl_2.2H_2O$	0.906
$NaH_2PO_4\,2H_2O$	0.690
$Na_2S.9H_2O$	0.005
Urea	1

Analysis of potentiodynamic polarization spectra

A CHI-Electrochemical workstation with impedance, Model 660A was used to carry out the polarization studies. The three electrode cell assembly was set up with the metal as working electrode, Saturated Calomel Electrode (SCE) as reference electrode and platinum as the counter electrode. The corrosion parameters such as corrosion potential (E_{corr}), corrosion current (I_{corr}), Linear Polarization Resistance (LPR) and Tafel slopes (b_a=Anodic and b_c=Cathodicalculated from this studies [17].

Analysis of AC impedance spectra

AC impedance spectra were recorded with the same instrument and the set up used for polarization study. At various frequencies the real part (Z') and imaginary part (Z") of the cell impedance were measured in ohms. The Nyquists plots were used to calculate the values of charge transfer resistance (R_t=(R_s+R_t)- R_s, where R_s=Solution resistance, R_t=Charge transfer resistance) and the double layer capacitance (C_{dl}=1/[2 × 3.14 × R_t × f_{max}] where f_{max}=Frequency at maximum imaginary impedance) and the bode plots for calculating the Impedance log (Z/ohm). The scan rate (V/s) 0.005; Hold time at Ef(s) zero and quiet time (s) 2 was maintained while recording AC impedance spectra.

RESULTS AND DISCUSSION

Analysis of potentiodynamic polarization spectra when the metal is immersed in AS and the toothpaste Vicco

Table 2 represents the corrosion parameters of stainless steel 18/8 and 316L immersed in artificial saliva (AS) and in tooth paste Vicco and Figures 1 and 2 are the potentiodynamic polarization curves.

18/8 stainless steel

The corrosion potential is 657 mV vs. SCE, the linear polarization resistance is 964244 ohm cm^2 and the corrosion current is 4.717 × 10^{-8} A/cm^2 when SS 18/8 is immersed in AS. The corrosion potential is shifted to noble side (-485mV vs. SCE), the LPR value increases from 96,4244 ohm cm^2 to 1,91,5232 ohm cm^2 and the corrosion current decreases from 4.717 × 10^{-8} A/cm^2 to 2.349 × 10^{-8} A/cm^2 when SS 18/8 is immersed in aqueous solution of toothpaste Vicco (1%). These observations confirm that the anodic reaction is controlled predominantly and a protective film is formed on the metal surface. Therefore it is noticed that LPR) value increases and corrosion current (I_{corr}) decreases. The stainless steel ion and the active principles of the ingredients of the toothpaste might have formed a complex which is responsible for forming a protective film.

316 L stainless steel

The corrosion potential is -672 mV vs. SCE; the LPR is 630154 ohm cm^2 and the corrosion current (I_{corr}) is 6.872 × 10^{-8} A/cm^2 when SS 316L is immersed in artificial saliva (AS). The corrosion potential is shifted to noble side (-537 mV vs. SCE), the LPR value increases from 63,0154 ohm cm^2 to 11,2,9645 ohm cm^2 and the corrosion current decreases from 6.872 × 10^{-8} A/cm^2 to 4.079 × 10^{-8} A/cm^2 when SS 316L is immersed in aqueous solution of (1%) toothpaste. These values confirm that the anodic reaction is controlled predominantly and a protective film is formed on the metal surface.

Therefore it is noticed that the LPR value increases and corrosion current (I_{corr}) decreases. The stainless steel ion and the active principles of the ingredients of the toothpastes might have formed a complex which is responsible for forming a protective film.

Analysis of potentiodynamic polarization spectra when the metal is immersed in AS containing 1% toothpaste Vicco

18/8 stainless steel

The corrosion potential is shifted further to the anodic side (-432 mV vs. SCE) controlling the anodic reaction predominantly, the LPR value increases from 96,4244 ohm cm^2 to 2,08,3375 ohm cm^2 and corrosion current decreases from 4.717 × 10^{-8} A/cm^2 to 2.207 × 10^{-8} A/cm^2 when SS 18/8 is immersed in aqueous solutions consisting of AS and the 1% toothpastes Vicco. These results prove that the corrosion resistance of SS 18/8 is further enhanced when it is immersed in AS containing toothpaste Vicco. This enhancement may be due to the absorption of the active principles of the ingredients of toothpaste Vicco, through the polar atoms like oxygen, nitrogen and sulphur on the metal surface.

316L stainless steel

The corrosion potential is shifted to the anodic side (-419 mV vs. SCE) controlling the anodic reaction predominantly, the LPR value increases from 63,0,154 ohm cm^2 to 11,21,0907 ohm cm^2 and corrosion current decreases from 6.872 × 10^{-8} A/cm^2 to 3.908 × 10^{-}8 A/cm^2 when SS 316L is immersed in aqueous solutions consisting of AS and the 1% toothpastes Vicco. These results prove that the corrosion resistance of SS 316L is further enhanced when it is immersed in AS containing tooth paste Vicco. This enhancement may be due to the absorption of the active principles of the ingredients of toothpaste Vicco, through the polar atoms like oxygen, nitrogen, and sulphur on the metal surface.

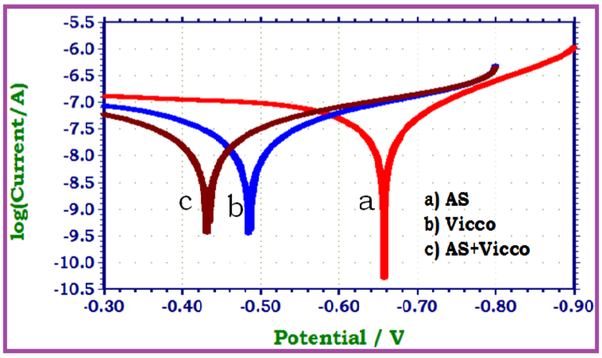

Figure 1: Polarisation curves of SS 18/8 immersed in artificial saliva (AS) in the absence and presence of toothpaste Vicco. (a) AS; (b) Vicco (1%); (c) AS+Vicco (1%)

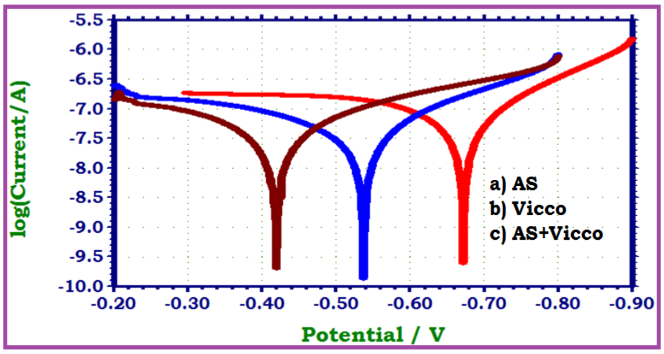

Figure 2: Polarisation curves of SS 316L immersed in artificial saliva (AS) in the absence and presence of toothpaste Vicco. (a) AS; (b) Vicco (1%); (c) AS+Vicco (1%)

Table 2: Corrosion parameters of metals immersed in various test solutions obtained from polarization study

Metals	System	E_{corr} (mV vs. SCE)	b_c (mV/decade)	b_a (mV/decade)	LPR (Ohm.cm^2)	I_{corr} (A/cm^2)
SS 18/8	AS	-657	161	296	964244	4.717 × 10^{-8}
	Vicco	-485	203	210	1915232	2.349 × 10^{-8}
	AS+Vicco	-432	206	216	2083375	2.207 × 10^{-8}
SS 316L	AS	-672	154	279	630154	6.872 × 10^{-8}
	Vicco	-537	172	274	1129645	4.079 × 10^{-8}
	AS+Vicco	-419	205	230	1210907	2.218 × 10^{-8}

Analysis of AC impedance spectra

Table 3 represents charge transfer resistance (R_t), double layer capacitance (C_{dl}) derived from Nyquists plots and impedance value log (Z/ohm) derived from Bode plots for various metals immersed in artificial saliva, toothpaste and artificial saliva containing 1% tooth paste and the Nyquists plots are shown in Figures 3 and 4 and Bode plots in Figures 5-10.

The formation of protective film on the metal surface is confirmed by AC impedance spectra [18]. When the charge transfer resistance (R_t) increases, double layer capacitance (C_{dl}) value decreases and the impedance log (z/ohm) value increases, the formation of a protective film on the metal surface is evident [19-26].

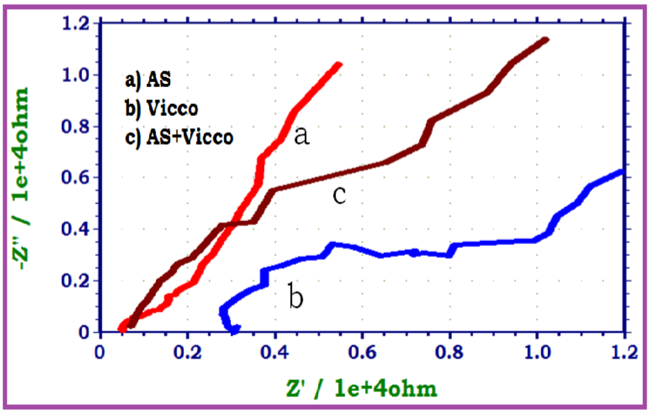

Figure 3: AC impedance spectra of SS 18/8 immersed in artificial saliva in the absence and presence of toothpaste Vicco. (a) AS; (b) Vicco (1%); (c) AS+Vicco (1%)

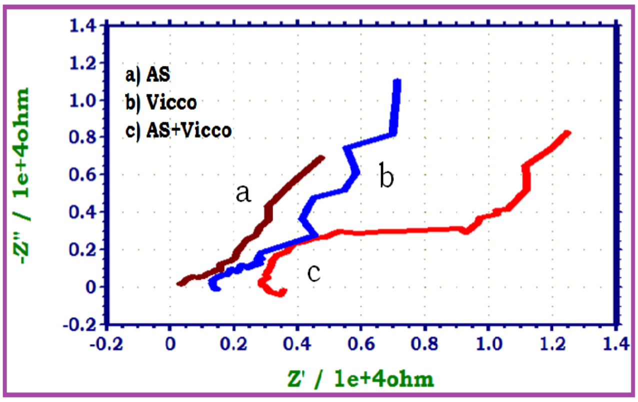

Figure 4: AC impedance spectra of SS 316L immersed in artificial saliva in the absence and presence of tooth paste Vicco (Nyquist Plots). (a) AS; (b) Vicco (1%); (c) AS+Vicco (1%)

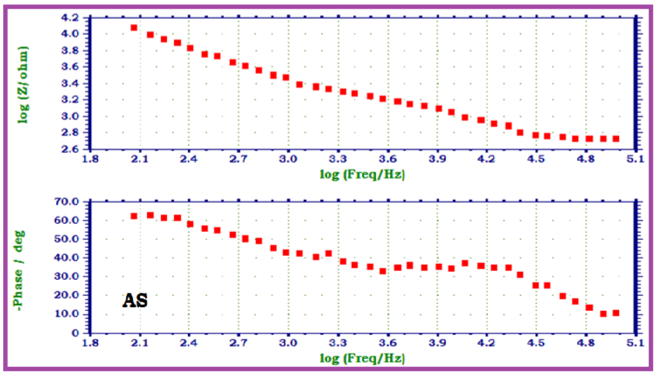

Figure 5: AC impedance spectra of SS 18/8 immersed in artificial saliva (AS) (Bode Plots)

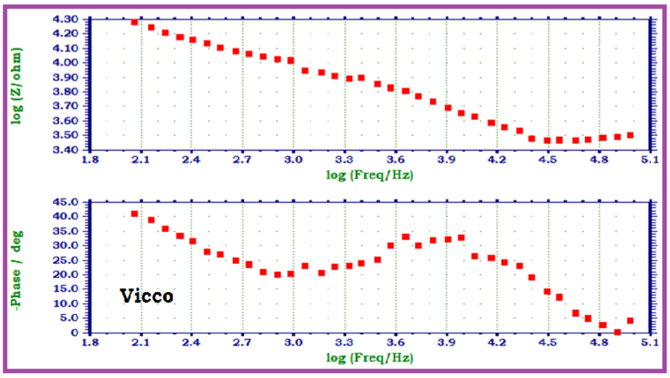

Figure 6: AC impedance spectra of SS 18/8 immersed in Vicco (1%) (Bode Plots)

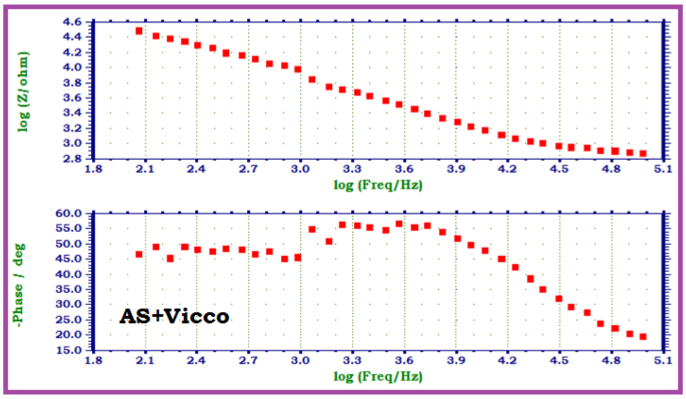

Figure 7: AC impedance spectra of SS 18/8 immersed in artificial saliva in presence of Vicco (1%) (Bode Plots)

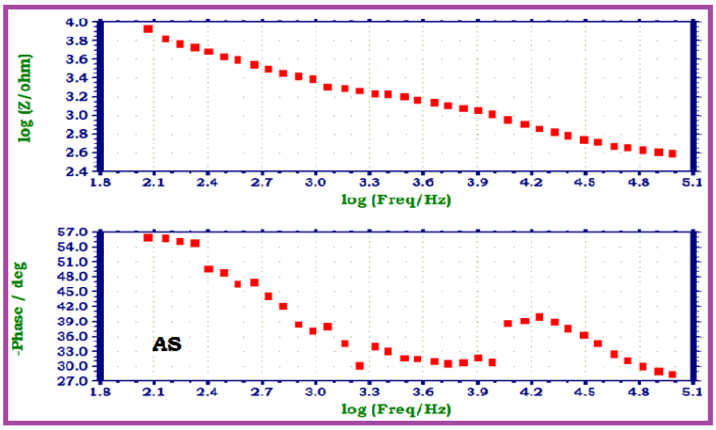

Figure 8: AC impedance spectra of SS 316L immersed in artificial saliva (Bode Plots)

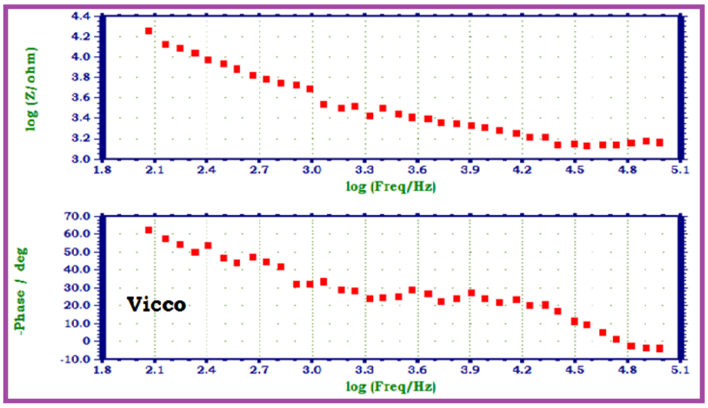

Figure 9: AC impedance spectra of SS 316L immersed in Vicco (1%) (Bode Plots)

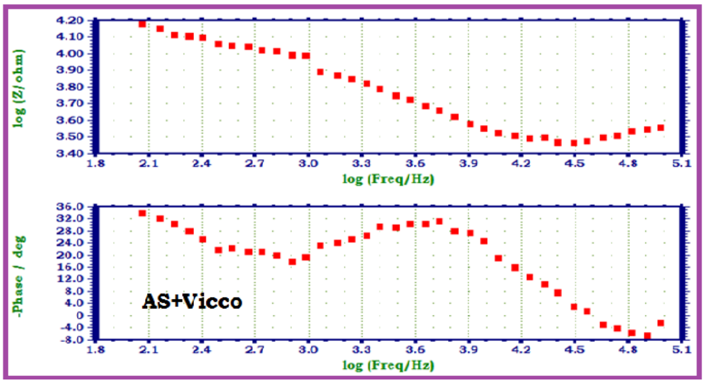

Figure 10: AC impedance spectra of SS 316L immersed in artificial saliva in the presence of Vicco (1%) (Bode Plots)

Table 3: Corrosion parameters of metals immersed in various test solutions obtained from AC impedance spectra

Metals	System	Nyquist plot		Bode plot
		R_t Ohm cm^2	C_{dl} F/cm^2	Impedance value Log z/ohm
SS 18/8	AS	4981	10.2380×10^{-10}	4.066
	Vicco	11203	4.5523×10^{-10}	4.276
	AS+Vicco	20066	2.5416×10^{-10}	4.476
SS 316L	AS	4397	11.598×10^{-10}	3.928
	Vicco	5307	9.6099×10^{-10}	4.254
	AS+Vicco	8894	5.7342×10^{-10}	4.176

18/8 stainless steel

The charge transfer resistance (R_t) value is 4981 ohm cm^2, the double layer capacitance (C_{dl}) value is 10.238×10^{-10} F/cm^2 and the impedance (log z/ohm) value is 4.066 when SS 18/8 is immersed in AS. The charge transfer resistance(R_t) value increases from 4981 ohm cm^2 to 11203 ohm cm^2, the double layer capacitance (C_{dl}) value decreases from 10.238×10^{-10} to 4.5523×10^{-10} F/cm^2 and the impedance value (log z/ohm) increases from 4.066 to 4.276 when SS 18/8 is immersed in aqueous solutions of (1%) toothpaste Vicco, From these results it is evident that a protective film is formed on the surface of the metal [27-30]. The protective films prevents the transfer of electrons from the metal surface to the bulk of the solutions when SS 18/8 is immersed in aqueous solutions of tooth paste Vicco which results in increase of corrosion resistance and decreases of the rate of corrosion. This protective film probably consists of a mixture of stainless steel ion and the active principles of the ingredients of the toothpaste Vicco.

The charge transfer resistance (R_t) value increases from 4981 ohm cm^2 to 20066 ohm cm^2, the double layer capacitance (C_{dl}) value decreases from 10.238×10^{-10} to 2.5416×10^{-10} and the impedance (log z/ohm)value increases from 4.066 to 4.476 when SS 18/8 is immersed in AS containing 1% of toothpaste Vicco. Hence it is inferred that, the corrosion resistance is further enhanced in presence of AS containing tooth paste Vicco.

316L stainless steel

The charge transfer resistance (R_t)value is 4397 ohm cm^2, double layer capacitance (C_{dl}) value is 11.598×10^{-10} F/cm^2 and the impedance (log z/ohm) value is 3.928 when SS316L is immersed in AS. The charge transfer resistance (R_t) value increases from 4397 ohm cm^2 to 5307 ohm cm^2, the double layer capacitance (C_{dl}) value decreases from 11.598×10^{-10} F/cm^2 to 9.6099×10^{-10} F/cm^2 and the impedance (log z/ohm) value increases from 3.928-4.254 when SS 316L is immersed in aqueous solutions of (1%) toothpaste Vicco. From these results it is evident that a protective film is formed on the surface of the metal [27-30]. The protective film prevents the transfer of electrons from the metal surface to the bulk of the solution when SS 316L is immersed in aqueous solutions of tooth paste Vicco which results in increase of corrosion resistance and decrease of the rate of corrosion. The protective film probably consists of a mixture of stainless steel ion and the active principles of the ingredients of the toothpaste Vicco.

The charge transfer resistance (R_t) value increases from 4397 ohm cm^2 to 8894 ohm cm^2, the double layer capacitance (C_{dl}) value decreases from 11.598×10^{-10} to 5.7342×10^{-10} and impedance (log z/ohm) value increases from 3.928 to 4.176 when SS 316L is immersed in AS containing 1% of toothpaste Vicco. Hence it is inferred that, in presence of AS containing toothpaste, the corrosion resistance of SS 316L further increases.

CONCLUSION

The electrochemical studies such as potentiodynamic polarization and AC impedance spectra have been used to evaluate the corrosion resistance of SS 18/8 and SS316L in artificial saliva in the absence and the presence of toothpaste Vicco. The results obtained from various combinations of metal and solutions indicate that the corrosion resistance of SS 18/8 is more in the presence of toothpaste than in the presence of artificial saliva only. This corrosion resistance is further enhanced in the presence of artificial saliva containing 1% of toothpaste. This may be due to the co-ordinate bond that is established between stainless steel ion and the polar groups such as oxygen, nitrogen and sulphur contained in the ingredients of the toothpaste Vicco. Similar is the case with SS 316L i.e., the corrosion resistance is increased as follows; AS+toothpaste>toothpaste>AS. The outcome of the study is that doctors those who use these metal alloys for orthodontic purpose may recommend this toothpaste to the patients without any hesitation. Among the two materials under investigation, toothpaste Vicco offered better corrosion resistance to stainless steel 18/8.

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