Corrosion of Orthodontic Arch-Wires in Artificial Saliva Environment

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Abstract

In oral environment, corrosion phenomenon of orthodontic wires and brackets, present an important problem that is not yet fully very understood. In this paper, an investigation of the corrosion behavior on the orthodontic arch-wire of stainless steel and nickel titanium wire alloys in neutral artificial and acidified saliva which simulate the aggressive conditions is presented. Analysis of electrochemical materials behavior of the orthodontic wires has been conducted in the oral environment at pH=3 and pH=7.8. The results indicate that the pH of oral environment has an important influence on the corrosion resistance and the stainless steel wire have better resistance to corrosion in acid medium.

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Introduction

Orthodontic device used in the treatment of malocclusion is constituted by various metal arch-wires. These metal devices are required to stay in the oral cavity of patients.[1] for longer or shorter periods, with many constraints and variations such as masticatory forces, the loading of the device, temperature fluctuations, the ingested food varieties and saliva.[2] The most favorable material is one that is able to withstand the most extreme conditions in the oral cavity.

The behavior of materials can be analyzed from two perspectives: The impact of material in the environment (biocompatibility),[3] and the effects of the environment on the material (biodegradation).

Corrosion is the main cause of this degradation. In fact, localized corrosion[4] and microbial sites that occur between the wire and bracket are caused by corrosion generated between two contacting surfaces in the corrosive environment. This is an area of the fairly recent study. Generally, the alloys used in the dental field are more resistant to corrosion by a thin layer that forms on its surface that would isolate the metal from the corrosive environment.[5,6] This layer compact, adherent is called protective passive layer. During use, the protective passive layer is destroyed, leaving bare metal susceptible to corrosion.

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According to the recent investigation of orthodontic element in oral environment, the results obtained by scientific show that the degradation of orthodontics elements increase with increasing pH of the corrosive environment.[7] The objective of this study was to investigate the corrosion (electrochemical behavior) of orthodontic stainless steel and nickel-titanium wire in neutral and acidified artificial saliva.[8]

Materials and methods

To carry out electrochemical analysis tests of the stainless steel and nickel-titanium wires in oral environment, the present study was conducted in three steps such as: a). Analysis of evolution of the open potential of the used materials in artificial saliva at pH=7.8 and 3; b). Establishment of the polarization curve of the used materials in artificial saliva at pH=7.8 and 3; c). Analysis of the impedance curve to more understand the rate of the corrosion of selected materials.

Before tests, cross section of Ni-Ti and stainless steel arch wires were prepared and examined using an optical metallographic microscope.

Materials and methods

The arch-wire chosen for this studies concern the Stainless Steel and Nickel-Titanium wire and. The Stainless Steel arch-wire is 0.018 inch section (0.164 mm^2) and manufactured by Ortho- Mexico Organiser® company. The Nickel-Titanium wire is also 0.018 inch section and manufactured in the USA by the company of G & H® arch. The Table 1 gives the chemical composition of each orthodontic element.

Wire	Composition (in %Weight)
Stainless Steel	18% Cr, 10%Ni, Balance Fe
Ni-Ti	55 55% Ni, 45%Ti

Table 1. Chemical Analysis of Materials.

Composant	Concentration
Sodium Chloride (NaCl)	9 g/l
Potatuim Chloride (KCl)	0.42 g/l
Calciumdihydrate Chloride ($CaCl_2$)	0.2 g/l
Sodium Hydrogénocarbonate ($NaHCO_3$)	0.2 g /l

Table 2. Composition of Saliva RINGER.

pH	E_{corr} (mV/SCE)	I_{corr} (µA/cm^2)
7,8	-757	2.5
3	-496.6	5.6

Table 3. Parameters Associated to the Curves of Polarization.

pH	E_{corr} (mV/SCE)	I_{corr} (µA/cm^2)
7,8	-216.5	0.09
3	-282.4	0.12

Table 4. Parameters Associated to the Curves of Polarization.

Electrochemical tests of orthodontic elements

To examine and to verify the corrosion of the selected orthodontic elements in artificial saliva, two series of tests have been firstly carried out. The artificial saliva.[9,2] used for all tests is a saliva Ringer prepared with the following composition given in table 2 which have an initial pH of 7.8. The influence of the pH has been examined. To do this test, Ringer solution is acidified by adding acetic acid until it reached a pH=3.

Electrochemical analysis

Using a potentiostat VoltaLab 301 connected to an electrochemical cell as shown in Figure 1, the free potential curves of the polarization and the impedance spectroscopy were firstly measured. The sweep speed used is 50 mV/min and the field of scanning is of mV -1500 to 1000 mV, while the frequency is 100 KHz to 100 MHz.

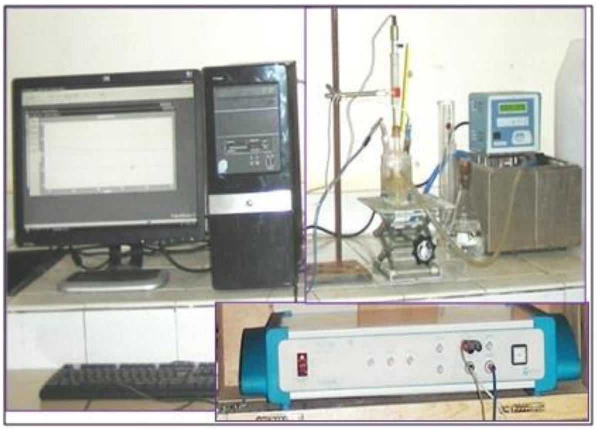

Figure 1. Potentiostat VoltaLab 301-1.

Results

In order to characterize the samples, metallographic cross sections were examined after chemical etching using oxalic 10% acid, of samples. The results are presented in the Figure 2.

Electrochemical analyze of samples Nickel-Titanium arch-wire

To analyze the corrosion behavior of arch-wires, an electrochemical study[10] proves to be necessary.

The Nickel-Titanium wire is presented in a cylindrical form of 3 cm length. The surface exposed to the electrolytic solution is in the order of 0,354 cm^2. Evolution of the open potential in function of time for the nickel titanium wire in a artificial saliva at different pH is conducted and shown in Figure 3.

To quantify the corrosion behavior of Ni-Ti arch-wire in a artificial saliva under various conditions such as: a). pH=7.8 and pH=3; Sweep speed is about 50mV/min. The polarization curve and impedance diagram are reported in Figure 4 and Figure 5 respectively.

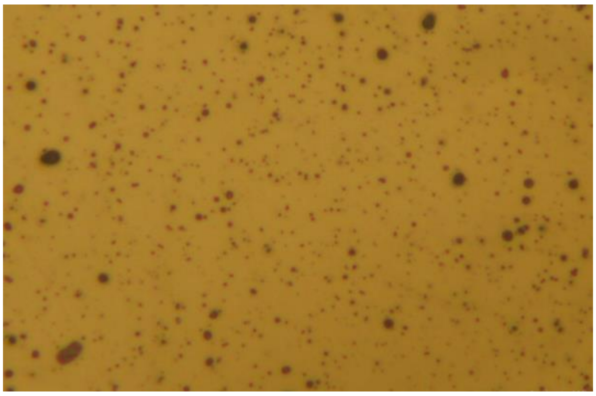

Figure 2. Microstructural Examination of the Investigated Ni-Ti Wire (a) under a Magnification of 300x (2)

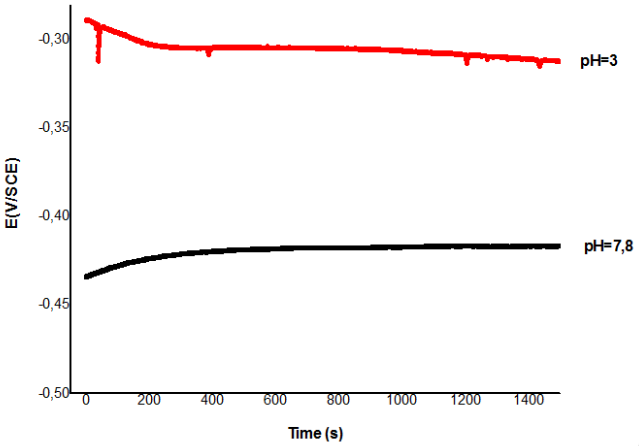

Figure 3. Evolution of the Open Potential of Ni-Ti with Immersion Time in Studied Solutions.

The parameters associated to polarization curve are presented in Table 3. For stainless steel arch-wire, and to following the open potential evolution, we have access to the general interactions concerning the phenomena that occur on the surface of the alloy.

Figure 6 shows the evolution of the open potential of the stainless steel wire in function of the time immersion in two artificial saliva with different pH.

Figure 7 presents the impedance diagram of the stainless steel wire after 1 hour of immersion in the artificial saliva at different pH in the field of frequency of 100 KHz to 100 MHz.

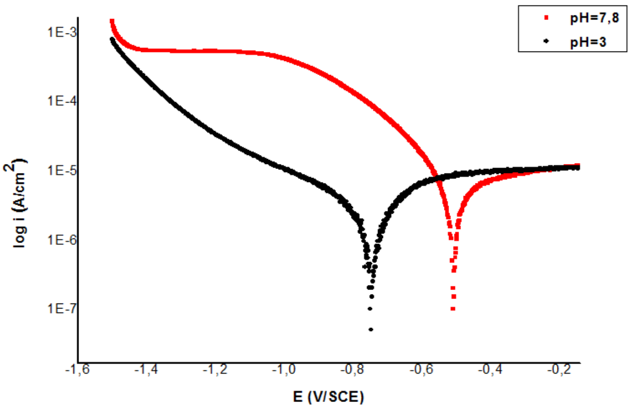

Figure 4. Polarization Curves of Ni-Ti after an Hour Immersion in Artificial Saliva at pH 3 and 7.8

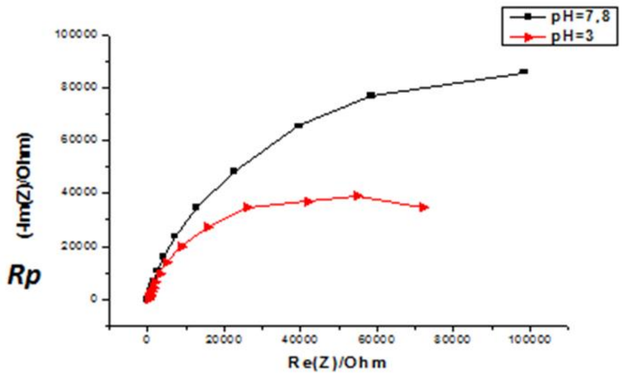

Figure 5. Impedance Diagram of the Ti-Ni Wire after an Hour Immersion in Different pH.

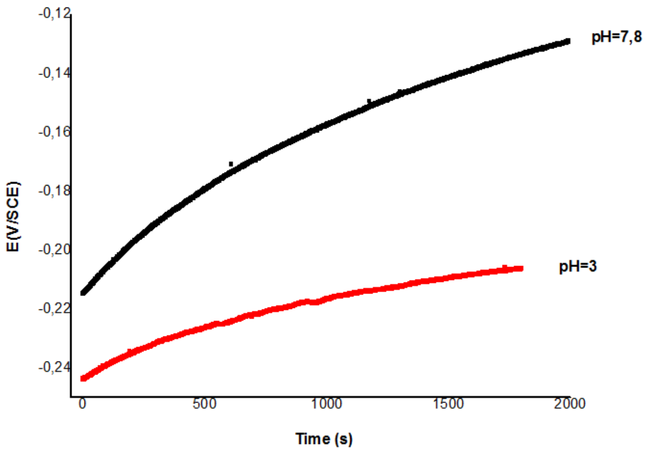

Figure 6. Evolution of the Open Potential for Stainless Steel an Hour Immersion in Artificial Saliva at pH=3 And 7.8.

Polarization curves can be very useful in the assessment of corrosion susceptibility, because they provide information on passivity, pitting susceptibility, and corrosion rate. Figure 8 represents the two polarization curves obtained from orthodontic wires for stainless steel in the two solutions studied.

The values of E_{corr} and I_{corr} in function of the variation of the pH of the medium of study are reported in the Table 4.

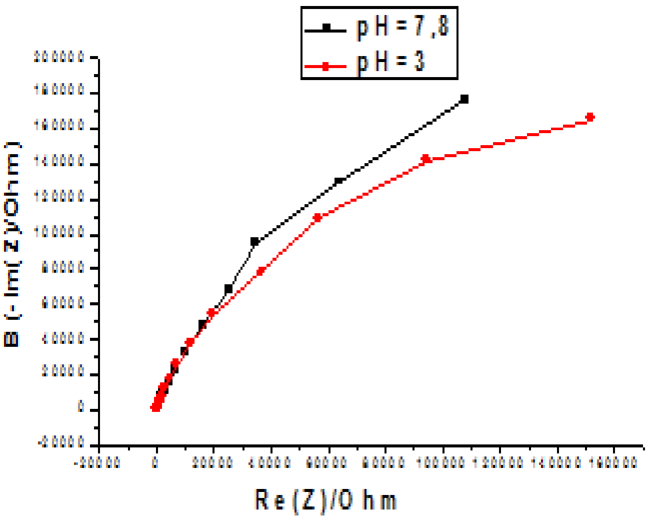

Figure 7. Impedance Diagram of the Stainless Steel Wire after an Hour Immersion in Different pH.

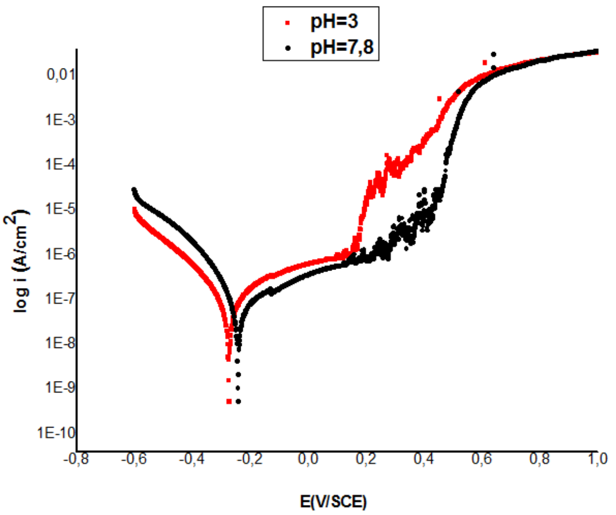

Figure 8. Polarization Curves of Stainless Steel After an Hour Immersion in Artificial Saliva at pH 3 and 7.8.

Discussion

Examination of metallographic cross section of Ni-Ti alloy arch wire which shows many small inclusions less than 1 µm size (Figure 2a). For Stainless steel wire, microstructures are mainly composed by a fine austenitic grain size (Figure 2b).

The evolution of the open potential of Ni-Ti wire show that the corrosion potential E_{corr} depends on the pH[11] of the environment as shown in figure 3. At acidic pH=3, the open potential moves toward more negative values then an ennoblement potential at pH 7.8 as it has been observed by W. Rerhrhaye.[5]

In the cathode branches (values lower than E_{corr}), the probable reaction is the reduction of the cation hydrogen. It admits that this reaction requires two successive steps.[12] The first is the reaction of discharge:

$$H^{+}_{ads} + e^{-} \longrightarrow H_{ads}$$

The opinion differs on the second step which could be either purely chemical:

$$H_{ads} + H_{ads} \longrightarrow H_2$$

For the anodic branches (higher values to E_{corr}), we note an increase of the current density, followed by a bearing whose current stabilizes on a wide area of potential with the formation of corrosion products on the surface of the Ni-Ti.

The corrosion potential in acid medium is moved toward the Cathode values. Indeed it goes from 757 mV to -496.6 mV for the pH of 7.8 and 3 respectively. In addition the corrosion current wires from 2.5 µA/cm^2 to 5.6 µA/cm^2, this means that the corrosion resistance decreases in response to the lowering of the pH. In acid medium potential corrosion increase to 0.65 V/SCE and the current increases to which can be associated with a phenomenon of pitting corrosion.[3]

For the cathode branches, there is a steady increase of the current with the surge (domain Tafelien). In this area, there is typically a competition between the reduction of the oxygen and that of hydrogen.

For the anodic branches, we note an increase in the density of the current indicating the dissolution of the alloy, followed by a bearing with relatively little fluctuation of the current. This bearing is probably in relationship with the development on the surface of the alloy of the corrosion products that protect and increase its resistance to corrosion. However from 0.2 V/SCE, the current increases and there are fluctuations which can be associated with the phenomenon of pitting corrosion.

Using impedance diagram (Figure 5), it was shown that the capacitive loop decreases with decreasing pH indicating a decrease of corrosion resistance of the titanium alloy nickel as reported by Farzin Heravi.[6]

The evolution of the open potential of stainless steel wire (Figure 6) shows that in artificial saliva of pH= 7.8; the open potential has a value of -215 mV at the beginning of the experiment test and then it increases over time to become more and more noble to near -120 mV. The electrochemical behavior could be explained by the formation of a layer of corrosion products to the stainless steel surface.[12] The open potential is an initial value of -243 mV/SCE at the beginning of the experience in the acid solution. It then increases in function of time up to -206 mV/SCE. The corrosion potential (E_{corr}) decreases for the stainless steel in acid medium. In effect, it goes from -216.5 mV to -239.4 mV for pH of 7.8 and 3. The corrosion current varies from 0.09 $\mu A/cm^2$ to 0.12 $\mu A/cm^2$, which indicates a decrease in the resistance to corrosion in acid medium.

Examination of the Nyquist diagram of Stainless Steel arch-wire show that the size of the capacitive loop also decreases with decreasing pH indicating a decrease in corrosion resistance of stainless steel alloy.[6,7]

Conclusions

Studies of corrosion phenomena are very important. Indeed, the materials we use are biocompatible. Currently some "extreme" conditions of the oral environment at the contact wire and bracket can cause the corrosion phenomena.

The work presented in this paper is a contribution to the comparison of corrosion behavior of Stainless Steel and Nickel Titanium orthodontic wire in neutral and acidic artificial saliva. In this context, we performed electrochemical (free potential, polarization curve and impedance diagrams).Electrochemical tests showed that the stainless steel wire have better resistance to corrosion in acid medium (pH=3) than the nickel-titanium arch wire. This was demonstrated by the impedance spectroscopy with resistance values 222.79 KOhm, 100.91 KOhm for stainless steel and arch Ni-Ti respectively. In the artificial saliva, the Ni-Ti arch wires were found to be passive, in contrast to the stainless steel wire, which showed pitting corrosion.

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Declaration of Interest

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