Corrosion Susceptibility of Stainless Steel in Artificial Saliva Containing Citric Acid

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Research Article

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Abstract

Objectives

The aims of this study are to investigate the effect of concentration of citric acid in saliva environment on SS 316L and effect of ginger and garlic on SS 316L corrosion in citric acid-containing saliva environment.

Methods.

Seven SS 316L specimen of dimensions 1cm × 1cm were used for this study. The specimen were subjected to electrochemical corrosion test using an in artificial saliva containing citric acid with varying concentrations of 0.0 g/l, 3.0 g/l, 6.0 g/l, and 9.0 g/l electrochemical cell. 10 g/l each of garlic and ginger were also added to two of artificial saliva samples containing citric acid and one sample of artificial saliva contained 5 g/l of ginger and 5 g/l of garlic added together so as to study the corrosion effects of these substances on the SS 316L specimen in saliva environment. The results were displayed based on Tafel's plot of current density against potential difference. Also, corrosion rates of the samples were determined and presented in graphical form.

Results.

The study results showed that citric acid is a good inhibitor of corrosion of SS 316L dental implant in oral environment with its inhibition efficiency depending on its concentration, and that the mechanism of this inhibition can attributed to the adsorption of citric acid onto the metal alloy (SS 316L) surface. The study also concluded that both ginger and garlic are promoters of corrosion of SS 316L alloy implants in saliva environment.

1. Introduction

Titanium and its alloys have been used extensively in for dental implants due to its mechanical properties, corrosion resistance and biocompatibility [1]. The drawback to the use of Titanium as a dental implant is its high cost [2]. Stainless steel, especially the 316L type are the most used metallic biomaterials used in biomedical applications due to their good biocompatibility, low price, excellent corrosion resistance, availability, easy processing and high strength [3, 4]. These favourable properties and low cost has made 316L steel the most appealing biomaterial for dental implants, stents and orthopedic implants [3]. The major disadvantage of use of steel as a biomaterial (dental implant) is the release of toxic metal ion due to some biological effects, which can be harmful to the body as they could lead to some undesirable reactions in the body tissues surrounding the implants [5–7].

The foods we eat contain various kinds of chemicals and thus, traces of these chemicals are dissolved in the saliva causing chemical reactions that can cause metallic dental implants to corrode. The resulting corrosion of these implants adversely affects their biocompatibility and mechanical properties. The composition of natural saliva varies widely, thus, necessitating the use of artificial saliva of a known concentration studies of corrosion of metal dental implants [8]. In Ref. [9], the authors studied the mechanism of degradation of Titanium dental implants in artificial saliva using scanning electron microscopy and computed tomography. Eduok & Szpunar [10] reported that the corrosion rate of stainless steel dental implants in artificial saliva environment increased as the colony forming unit and incubation period due to sulphide products of the metabolism of the bacteria *P.gingivalis*. The authors in Ref. [11], studied the corrosion resistance of SS 316L, mild steel (MS), and mild steel coated with zinc (MS-Zn) in artificial saliva in the absence and presence of Spirulina was studied. The corrosion properties of SS 316L, mild steel (MS), and mild steel coated with zinc (MS-Zn) has also been investigated in artificial saliva in the absence and presence of D-Glucose via a potentiodynamic polarization study and AC impedance spectra [12]. Sheit et al. [13] studied the influence of ciprofloxacin on the corrosion resistance of SS 316L in artificial saliva. They used the potentiodynamic polarization study and AC impedance spectra approach and reported an increase in corrosion rate with increase in charge transfer resistance value.

There has been literature about artificial saliva for *in vitro* studies of dental implants [14, 15] with different formulations of varying compositions developed for peculiar purposes. Some of these formulations make use of inorganic compounds only and mainly used for *in vitro* studies, while contain both organic and inorganic compounds [14, 16] and are mostly associated with patients with salivary deficiency [17]. Oliveira de Quiroz et al. [18] investigated the electrochemical behavior and pH stability of artificial saliva for corrosion tests.

Motivated by various studies reported in literature of the corrosion behavior of SS 316L stainless steel, this study investigates the corrosion effects of the SS 316L in artificial saliva containing citric acid. It further seeks to investigate the corrosion properties of Ginger and Garlic on the SS 316L in artificial saliva containing citric acid.

2. Materials And Methods

2.1 Preparation of the SS 316L samples

The SS 316L used in this study was purchased commercially and cut into seven samples of dimensions 1cm × 1cm and polished using emery paper of average size 400 micron. The composition of the SS 316L used in this study is given in Table 1.

2.2 Preparation of Artificial Saliva

1000 cm^3 of artificial saliva was prepared in two batches in a 1000 ml measuring cylinder so as to have enough artificial saliva for the experiment. This was done by adding 1000cm^3 of distilled water into the cylinder and adding 0.400 g each of potassium chloride (KCl) and sodium chloride (NaCl), 0.906 g of calcium chloride dihydrate ($CaCl_2.2H_2O$), 0.690 g of Sodium dihydrogen phosphate (NaH_2PO_4), 1.000 g of Sodium supplied nanohydrate ($Na_2S.9H_2O$) and 1.00 g of Urea. The resulting mixture was stirred properly and used as artificial saliva. Table 2 gives the composition of the artificial saliva. It should be noted that all the reagents used in this study are of laboratory grade.

Table 1
Composition of SS 316L specimen

Element	Composition (%)
Chromium	16.00
Nickel	12.00
Carbon	0.03
Molybdenum	3.00
Iron	66.63
Nitrogen	0.05
Sulphur	0.07
Silicon	0.75
Phosphorus	0.03
Manganese	1.50

Table 2
Composition of Artificial Saliva

Compound	Concentration(g/l)
H_2O	96.600
KCl	0.400
NaCl	0.400
$CaCl_2.2H_2O$	0.906
NaH_2PO_4	0.690
$Na_2S.9H_2O$	0.005
Urea	1.000

2.3 Preparation of Citric acid, Ginger and Garlic

Laboratory grade citric acid was purchased with different amounts of it weighed and kept in a beaker to be used for the experiment. The Ginger and Garlic used as inhibitors were purchased in the local market. Both the Ginger and Garlic were washed properly and shredded in separate graters. 15 g of each was weighed and made ready for the experiment. The shredding was done in order to extract their liquid content to be used for the experiment.

2.4 Preparation of Corrosion Environment

Seven beakers each of capacity of 500 ml were washed thoroughly with soap, rinsed with distilled water and labeled A to G. Beaker A contained 200 ml of artificial saliva only with no other reagent added and was used as the control. Beaker B contained 200 ml of artificial saliva plus 3 g of citric acid. Beaker C contained 200 ml of artificial saliva plus 6 g of citric acid. Beaker D contained 200 ml of artificial saliva plus 9 g of citric acid. Beaker E had 200 ml of artificial saliva plus 6 g of citric acid and 10 g of garlic. Beaker F had 250 ml of artificial saliva plus 6 g of citric acid and 10 g of ginger, while Beaker G contained 250 ml of artificial saliva plus 6 g of citric acid plus 5 g of garlic and 5 g of ginger.

It should be noted that the rationale behind introducing citric acid, garlic and ginger is to investigate if these reagents can act as a corrosion inhibitors or promoters to the dental implant (316L stainless) when subjected to the artificial saliva environment. In addition, the varied concentration of citric acid (3 g, 6 g, and 9 g) is to investigate also, if citric acid at different concentration could have enhanced effect in inhibiting or promoting corrosion of the dental implant.

2.5 Experimental Setup

The setup for this experiment comprises of an electrochemical cell whose major components are electrochemical digital analyzer, a graphite rod cathode, the anode electrode which is the SS 316L specimen, a reference electrode which is used as a yardstick for comparing the electric potentials/current densities between the anode electrode and the cathode electrode and a computer system for displaying the curves (Tafel's plot) and results of the electrochemical analyzer. The electrochemical analyzer displays result based on Tafel's plot by showing current density values on the ordinate axis and potential difference values on the abscissa.

2.6 Experimental Procedure

During the experiment the artificial saliva in Beakers A to G are used as the electrolyte. The three electrodes (reference electrode, anode electrode, and cathode electrode) were inserted into Beaker A containing 250ml of artificial saliva alone (the control system), and connected to the electrochemical cell with the results displayed on the computer screen. This process was repeated for Beakers B through G. The experiment was carried out at room temperature.

3. Results And Discussions

3.1 Effect of Concentration of Citric Acid in Artificial Saliva on SS 316L

Figure 1 presents the polarization curves of SS 316L in artificial saliva of different citric acid concentrations 0.0 g/l, 3 g/l, 6 g/l and 9 g/l. In figure 2, the corrosion rate of the SS 316L in artificial saliva is plotted against different concentrations of citric acid. As can be seen from the polarization curves of SS 316L in artificial saliva containing different concentrations of citric acid (Fig. 1), a shift in potential towards the cathodic side is observed as the concentration of citric acid is increased from 0.0 g/l to 6 g/l. This shift indicates an increase in corrosion resistance of SS 316L alloy with increase in the concentration of citric acid in artificial saliva. However, as the concentration of citric acid is further increased (up to 9 g/l), the corrosion resistance of SS 316L alloy in artificial saliva starts to decline. This is also evident in Fig. 2, which shows the corrosion rate (in mil/year) of SS 316L alloy in citric acid-containing saliva. Fig. 2 shows that the corrosion rate of SS 316L alloy decreased from 66.49 mil/yr (at 0.0 g/l citric acid) to 23.74 mil/yr at a citric acid concentration of 6 g/l. Above 6 g/l concentration value, the corrosion rate starts to increase again. An inference that can be drawn from this result is that citric acid is a good corrosion inhibitor to SS 316L in saliva environment. The inhibition efficiency of citric acid depends on its concentration, and the mechanism of this inhibition can be attributed to the adsorption of citric acid onto the metal alloy (SS 316L) surface. The chemistry behind this is the reaction of the citric acid with any rust formed dissolving it into pure iron and thereby making the SS 316L implant free of rust.

3.2 Effect of Ginger and Garlic on SS 316L Corrosion in Citric Acid-Containing Artificial Saliva

Figures 3 and 4 respectively are plots of the polarization curves and the corrosion rates of SS 316L in citric-acid containing artificial saliva with garlic, ginger and a combination of both. In both figures, a plot is shown for artificial saliva with 6 g/l citric acid only. From Fig. 3 showing the polarization curves of SS 316L in artificial saliva containing 6.0 g/l citric acid plus 10 g/l of garlic and ginger respectively and a synergy of 5 g/l of ginger and 5 g/l of garlic, a shift in potential towards the cathode side is observed as the concentration of citric acid is altered by the synergy of 5 g/l garlic and 5 g/l of ginger in 6.0g/l citric acid which gave the highest corrosion rate in contrast to 6.0g/l of citric acid alone which gave the lowest corrosion rate and as a result is shifted farthest to the cathode side.

The plot in Fig. 4, indicates that the corrosion rate of SS 316L is lowest in artificial saliva with 6 g/l citric acid at 23.74 mil/yr with the highest corrosion rate observed in artificial saliva with 5 g/l garlic and 5 g/l ginger at 43.82 mil/yr. The corrosion rates in artificial saliva with 10g/l garlic and 10 g/l ginger are identical as shown by their respective values of 32.16 g/l and 39.67 g/l indicating that both garlic and ginger have similar effects on corrosion of SS 316L. The increase in the corrosion rate of SS 316L with the addition of garlic and ginger can be attributed to the fact that these substances possibly reduce the rate of absorption of citric acid by the SS 316L alloy surface thereby causing an increase in corrosion rate.

4. Conclusions

The corrosion rates of SS 316L alloy in saliva environment containing citric acid has been investigated. It is concluded that citric acid is a good inhibitor of corrosion of SS 316L dental implant in oral environment with its inhibition efficiency depending on its concentration, and that the mechanism of this inhibition can attributed to the adsorption of citric acid onto the metal alloy (SS 316L) surface. It is further inference that both ginger and garlic are bad inhibitors and therefore promoters of corrosion of SS 316L alloy implants in saliva environment. It is therefore recommended that people with metallic dental implants made of SS 316L should take edibles rich in citric acid like orange, lemon, lime, and grapes in order to inhibit the corrosion effect of the oral environment but should limit intake of food containing garlic and ginger which promotes corrosion of the dental implants.

Declarations

Data Availability All data related to the findings of this work are available on request from the corresponding author Ifeanyi J. Njoku.

Compliance with Ethical Standards

Conflict of Interest The authors have no competing interests to declare with regards to the publication of this article.

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Figures

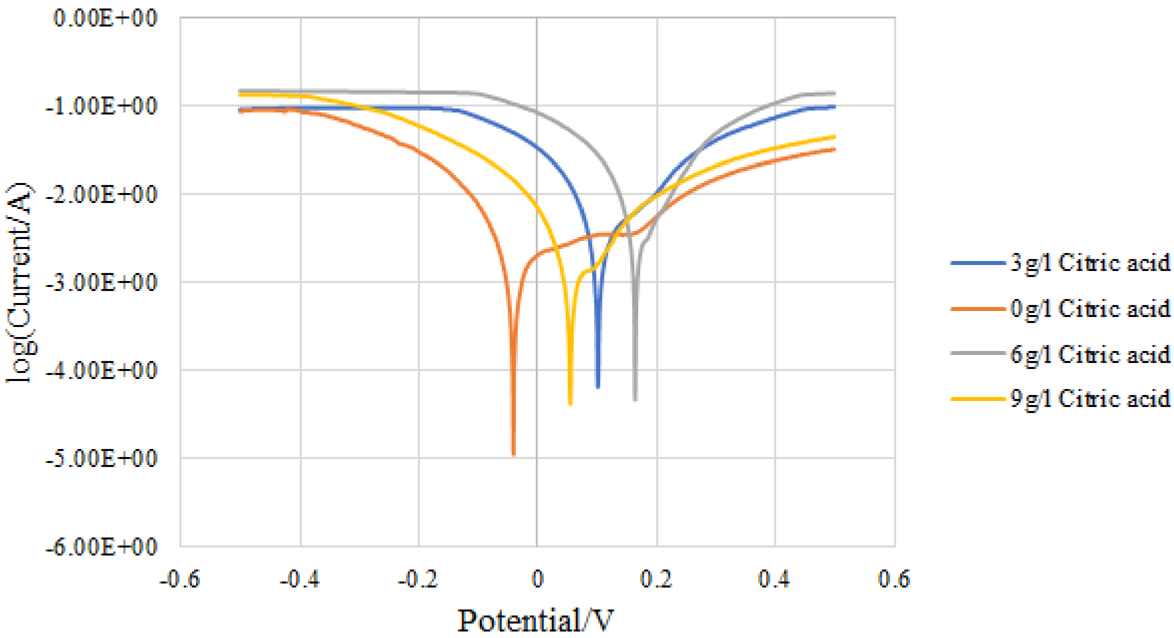

Figure 1

Polarization curves of SS 316L in artificial saliva of different citric acid concentrations

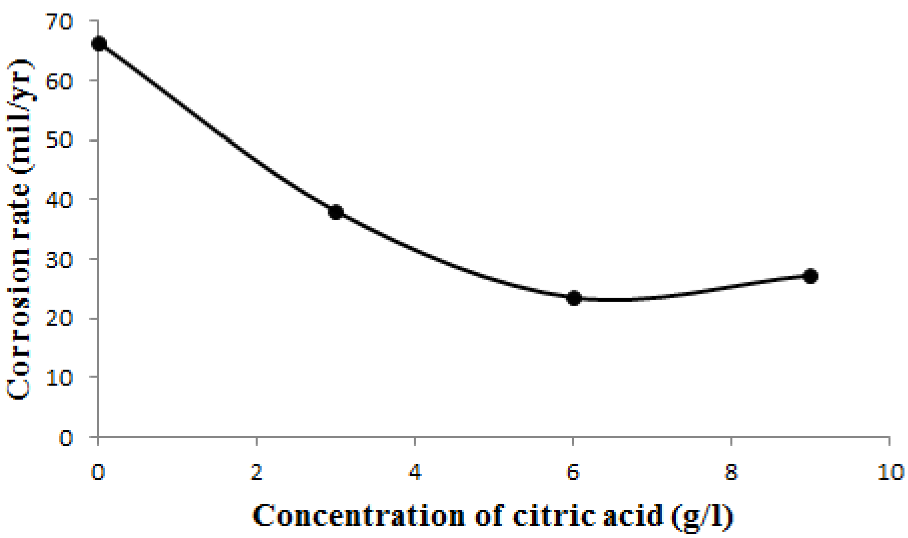

Figure 2

Corrosion rate of SS 316L in artificial saliva at different citric acid concentration

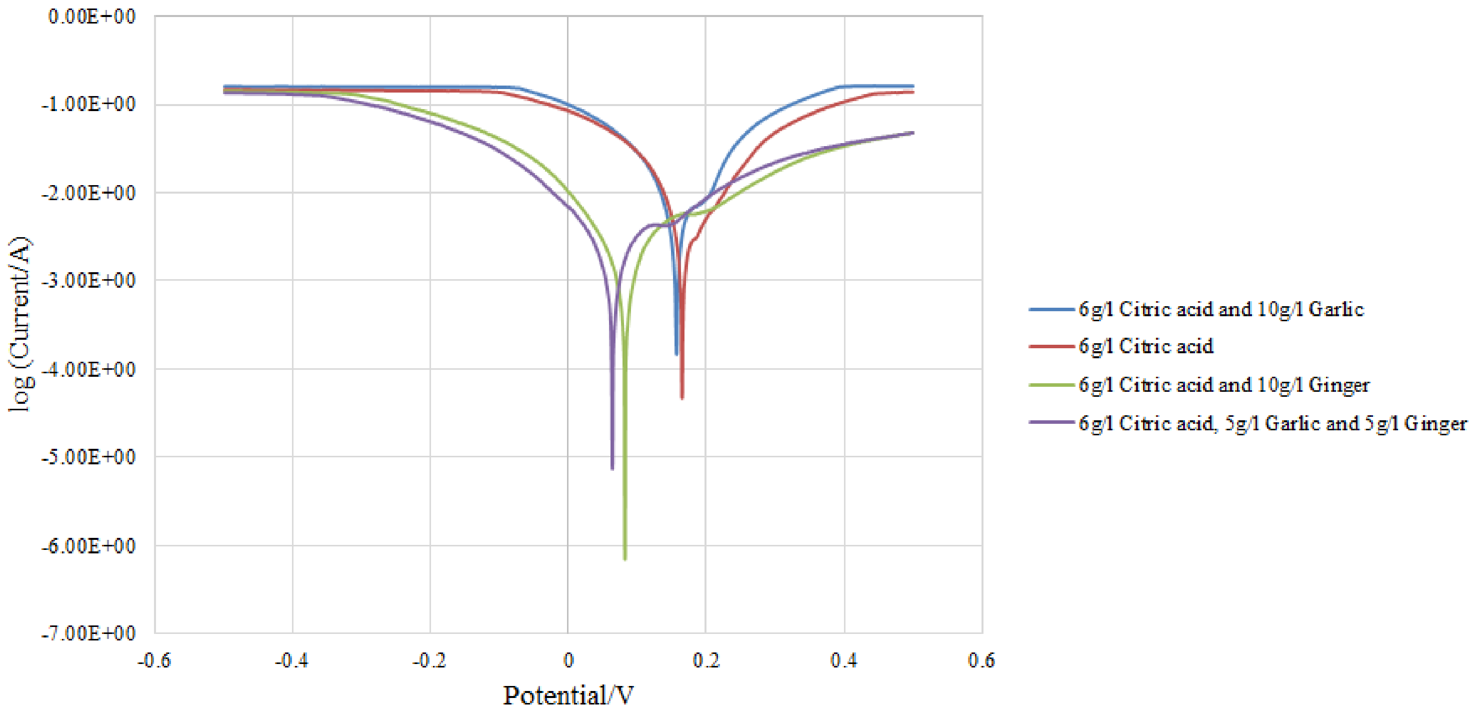

Figure 3

Polarization curves of SS 316L in citric acid-contained saliva with different concentrations of garlic and ginger.

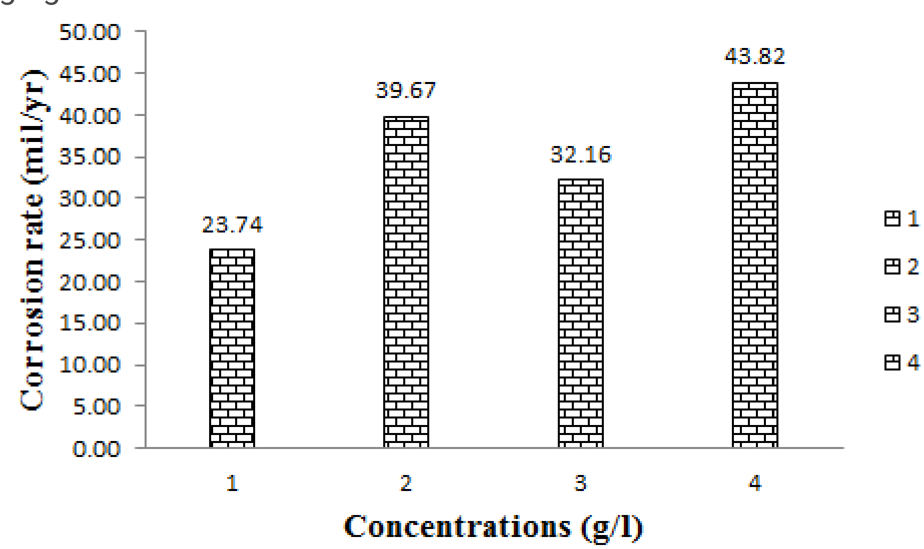

Figure 4

Corrosion rates of SS 316L in citric acid-contained saliva with different concentrations of garlic and ginger. (1) 6 g/l citric acid; (2) 6 g/l citric acid and 10 g/l ginger; (3) 6 g/l citric acid and 10 g/l garlic; (4) 6 g/l citric acid, 5 g/l garlic and 5 g/l ginger.