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An examination of the effect of Listerine mouthwash on the corrosion characteristics of orthodontic wire composed of SS316L alloy in simulated saliva by electrochemical impedance spectra

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ABSTRACT

Orthodontic appliances are frequently fabricated from corrosion-resistant alloys such as stainless steel. However, the complex oral environment, which includes exposure to various mouthwashes, can influence the electrochemical stability of these materials. This study investigates the corrosion behavior of orthodontic wire composed of SS 316L alloy in artificial saliva, both in the absence and presence of Listerine mouthwash, using Electrochemical Impedance Spectroscopy (EIS). The electrochemical parameters—including charge transfer resistance (Rt), impedance, phase angle, and double layer capacitance (Cdl)—were systematically analyzed. The results indicate that Listerine mouthwash enhances the corrosion resistance of SS 316L alloy, as evidenced by increased Rt, impedance, and phase angle, along with reduced Cdl. These findings support the safe use of Listerine mouthwash by individuals with orthodontic wires made of SS 316L alloy.

Keywords: SS 316L orthodontic wire, Listerine mouthwash, artificial saliva, electrochemical impedance spectroscopy (EIS), charge transfer resistance, double layer capacitance.

1. Introduction

Orthodontic archwires are essential components in dental treatments, used to apply mechanical forces through brackets in order to correct tooth misalignment, spacing, and crowding. They are also employed for retention, helping to maintain the position of teeth after alignment. After orthodontic wires are installed, patients consume various foods, beverages, and pharmaceuticals, which, along with the natural presence of saliva, may cause corrosion of the wire surface. Numerous studies have investigated how food items, drinks, and dental care products influence the corrosion resistance of orthodontic materials in artificial saliva (Karandish et al. 2024; Wijesinghe et al. 2024; Vinnarasi et al. 2024; Umamathi et al. 2024; Begum et al. 2024a; Sufarnap et al. 2024; Begum et al. 2023; Sahoo et al. 2023; Hebciba Mary et al. 2023; Anitha et al. 2023).

Karandish et al. (2024) examined zinc-coated stainless steel wires produced via physical vapor deposition and found improved corrosion resistance in both neutral and acidic saliva. Wijesinghe et al. (2024) conducted an in vitro analysis on commercial orthodontic wires and brackets, observing increasing nickel ion release over time, which could lead to hypersensitivity. Vinnarasi et al. (2024) reported a reduction in corrosion resistance of Ni-Ti wires when exposed to Copper Barrel brandy, indicating that such beverages may adversely affect orthodontic alloys.

Umamathi et al. (2024) showed that Colgate Max Fresh mouthwash reduced the corrosion resistance of thermoactive superelastic alloys (TASE), while Begum et al. (2024a) demonstrated that an extract of Spilanthes acmella enhanced corrosion resistance of SS 18/8 wires due to the formation of a protective layer. According to Sufarnap et al. (2024), exposure to chlorhexidine, sodium fluoride, and chitosan mouthwashes altered surface roughness and increased ion release from Cu-Ni-Ti wires, with chitosan offering the most protection.

Further, Begum et al. (2023) showed that SS 18/8 wires treated with esomeprazole tablets exhibited improved corrosion resistance. Sahoo et al. (2023) found that fluoride prophylactic agents significantly affected surface integrity, particularly in stainless steel wires. Hebciba Mary et al. (2023) explored the impact of dilution and soda addition to Copper

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Barrel brandy, noting a difference in corrosion resistance between Ni-Ti and Ni-Cr wires. Anitha et al. (2023) reported improved performance of 18K gold wires in the presence of Éclairs milky candy, relevant for pediatric dental care.

Mouthwashes are commonly used to reduce microbial load and maintain oral hygiene. While they are generally considered safe, their chemical composition can interact with orthodontic materials and affect their corrosion behavior (Brookes et al. 2023). Listerine, a widely used antiseptic mouthwash, contains essential oils and alcohol, which may influence metal surfaces.

The objective of this study is to evaluate the corrosion resistance of orthodontic wire made from SS316 L alloy in artificial saliva, both with and without the addition of Listerine mouthwash. Electrochemical impedance spectroscopy (EIS) is used to assess the changes in electrochemical parameters that reflect the alloy's stability in the oral environment.

2. Experimental

2.1. Materials:

2.1.1. SS 316L Orthodontic Wire

In this study, orthodontic wire composed of SS 316L (UNS S31603) stainless steel was employed. This alloy is primarily composed of iron, with additions of chromium, nickel, molybdenum, silicon, phosphorus, sulfur, and manganese. The elevated concentrations of chromium and molybdenum enhance resistance to corrosion caused by saltwater and various chemical environments. The low carbon content significantly reduces the risk of intergranular corrosion during heat treatment or welding.

SS 316L stainless steel, often referred to as marine-grade stainless steel, is widely recognized for its excellent resistance to pitting and crevice corrosion in chloride-rich solutions. Compared to type 304 stainless steel, it offers superior corrosion resistance and is frequently used in marine, chemical processing, and food industries. Its key advantages include high durability, resistance to rust and high temperatures, and low maintenance requirements.

2.2.2. Mouthwash: Listerine

Listerine mouthwash used in the study contains water, ethyl alcohol, sorbitol, Poloxamer 407, and benzoic acid. Developed in 1879 by Joseph Lawrence and named after Joseph Lister—a pioneer in antiseptic surgery—Listerine is an antiseptic mouthwash marketed under the slogan "Kills germs that cause bad breath" (Figure 1).

Fig. 1. Listerine mouthwash and orthodontic wire

2.1.3. Electrochemical Method: AC Impedance Spectroscopy

The corrosion behavior of SS 316L in artificial saliva was evaluated using AC impedance spectroscopy at ambient temperature. Measurements were performed using a CHI electrochemical workstation (Model 660A) equipped with iR compensation. A three-electrode cell configuration was used, consisting of SS 316L as the working electrode, platinum as the counter electrode, and a saturated calomel electrode (SCE) as the reference electrode (Figure 2).

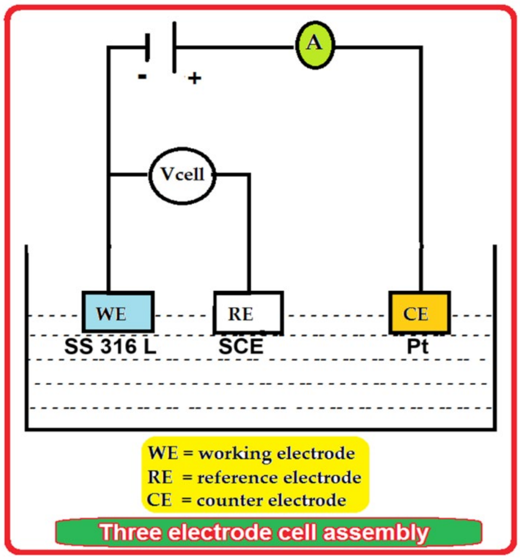

Fig. 2. Three electrode cell assembly

AC impedance spectra were recorded to evaluate the formation of protective films on the metal surface. After allowing the system to stabilize at open circuit potential (5–10 minutes), impedance values were measured across a frequency range. The real (Z′) and imaginary (−Z″) components of the impedance were recorded in ohms.

The charge transfer resistance (R_t) was calculated using:

$$R_t = (R_s + R_t) - R_s$$

where Rs is the solution resistance.

The double-layer capacitance (C_{dl}) was determined using the formula:

$$C_{dl} = 1 / (2\pi f_{max} R_t)$$

where f_{max} is the frequency at which the imaginary impedance reaches its maximum value.

3. Results and discussion

3.1. Analysis of electrochemical impedance spectroscopy (EIS)

Electrochemical Impedance Spectroscopy (EIS) is a powerful, non-destructive technique frequently applied to study corrosion mechanisms and evaluate corrosion inhibitors (Ma et al. 2025; Sharma et al. 2025; Guendouz et al. 2025; Mansour et al. 2025; Modwi et al. 2025). By applying a low-amplitude AC voltage across a wide frequency range, EIS provides detailed information about the electrochemical processes at the electrode/electrolyte interface.

The method employs a three-electrode configuration consisting of a working electrode (SS 316L), a reference electrode (SCE), and a counter electrode (platinum). The resulting impedance response, expressed through Nyquist and Bode plots, enables the quantification of parameters such as charge transfer resistance (R_t), impedance modulus, phase angle, and double-layer capacitance (C_{dl}). These parameters are sensitive to surface reactions and provide insight into corrosion protection mechanisms.

Figures 3-16 display the EIS spectra of SS 316L alloy immersed in artificial saliva with and without Listerine mouthwash. Table 1 summarizes the derived electrochemical parameters, while Figure 17 illustrates the typical trends expected under enhanced corrosion protection.

3.2. Charge transfer resistance (R_t)

Charge transfer resistance reflects the resistance to electron flow across the metal-electrolyte interface. A higher Rt value indicates a slower electrochemical reaction rate and therefore improved corrosion resistance.

In this study, the Rt of SS 316L alloy significantly increased from 1392 to 54,550 Ω·cm² upon the addition of Listerine mouthwash (5% v/v), indicating substantial improvement in corrosion resistance.

3.3. Impedance Modulus [log(Z/Ω)]

The impedance modulus increased from 3.175 to 5.025 log(Z/Ω) in the presence of Listerine. A higher impedance value typically correlates with increased surface film stability and protection against corrosion.

3.4. Phase angle

An increase in phase angle from 41.42° to 42.79° was observed with Listerine, suggesting enhanced capacitive behavior and improved protective layer formation on the alloy surface.

3.5. Double layer capacitance (C_{dl})

The Cdl decreased markedly from 3.66×10^{-9} F/cm² to 9.35×10^{-11} F/cm² in the Listerine environment. This reduction indicates a decrease in active corrosion sites and supports the formation of a more compact and protective surface film.

3.6. Implication

The collective findings from R_t, impedance, phase angle, and C_{dl} measurements suggest that Listerine mouthwash enhances the corrosion resistance of SS 316L orthodontic wires in artificial saliva. This improvement may be attributed to the adsorption of certain components from Listerine onto the metal surface, forming a protective barrier. Therefore, patients using SS 316L orthodontic wires can use Listerine mouthwash without concern regarding corrosion.

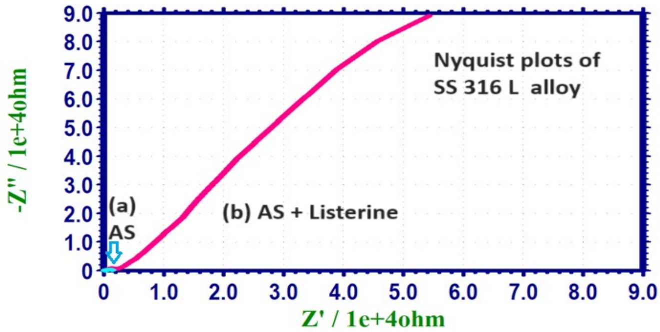

Fig. 3. Nyquist plots of SS316L alloy immersed in various test solutions: (a) artificial saliva (AS), (b) AS + mouthwash

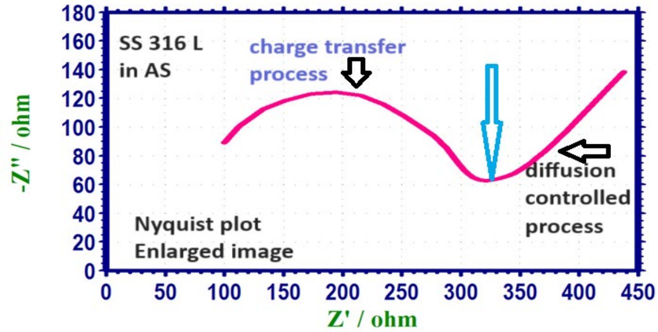

Fig. 4. Nyquist plot of SS316L alloy immersed in artificial saliva (AS) (enlarged image)

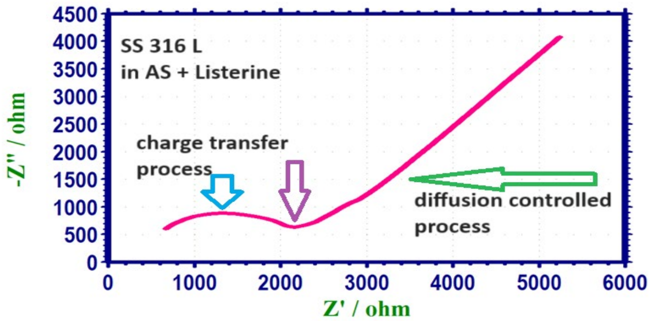

Fig. 5. Nyquist plot of SS316L alloy immersed in artificial saliva (AS) + mouthwash (enlarged image)

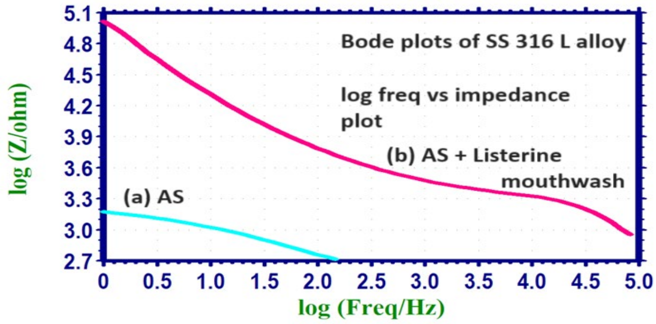

Fig. 6. Bode plots of SS316L alloy immersed in various test solutions: (a) artificial saliva (AS), (b) AS + mouthwash (log frequency vs impedance plots)

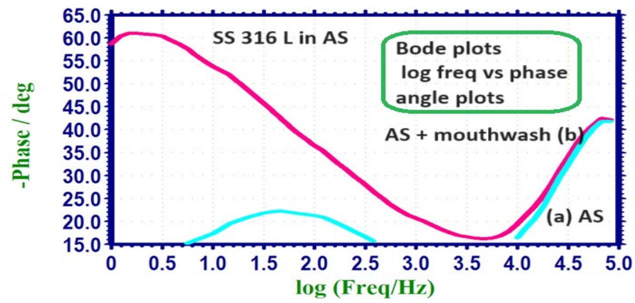

Fig. 7. Bode plots of SS316L alloy immersed in various test solutions: (a) artificial saliva (AS) (b) AS + mouthwash (log frequency vs phase angle plots)

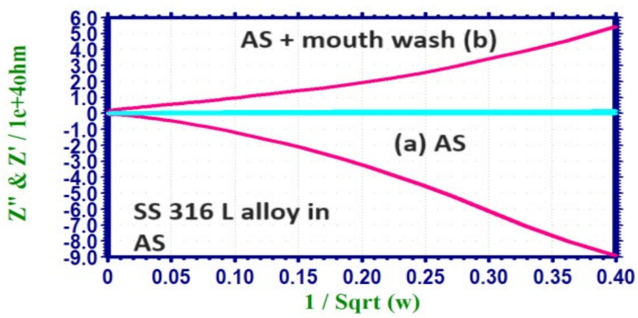

Fig. 8. Warburg plots of SS316L alloy immersed in various test solutions: (a) artificial saliva (AS), (b) AS + mouthwash

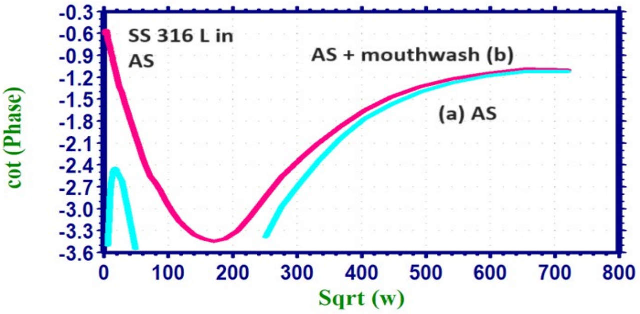

Fig. 9. Sqrt (W) vs cot (Phase) plots of SS316L alloy immersed in various test solutions: (a) artificial saliva (AS) (b) AS + mouthwash

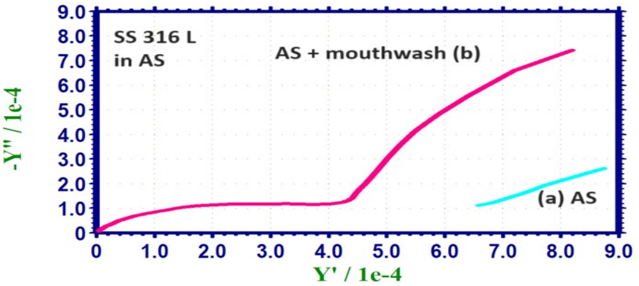

Fig. 10. Y' vs -Y'' plots of SS316L alloy immersed in various test solutions: (a) artificial saliva (AS), (b) AS + mouthwash

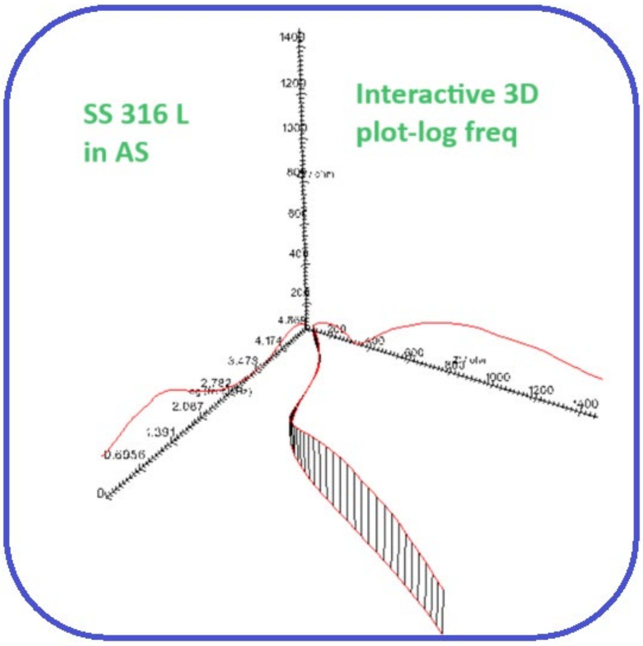

Fig. 11. Interactive 3D plot of SS316 L immersed in AS

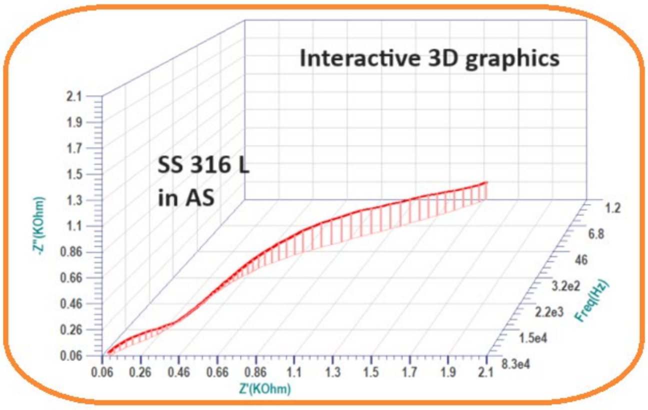

Fig. 12. Interactive 3D graphics of SS316 L immersed in AS

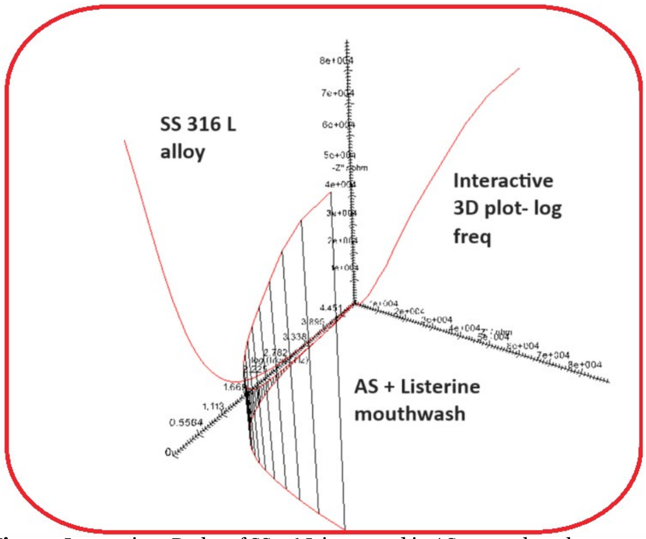

Fig. 13. Interactive 3D plot of SS316 L immersed in AS + mouthwash system

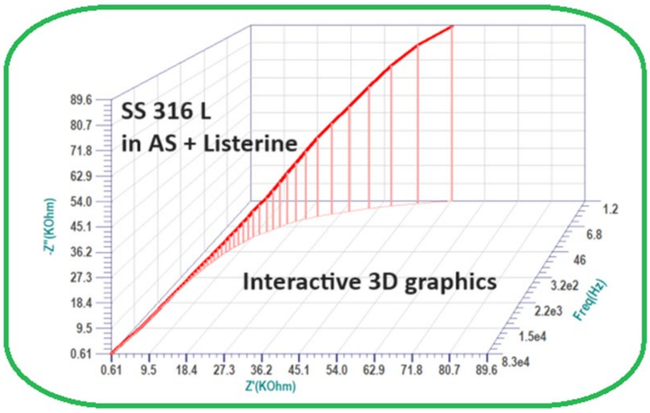

Fig. 14. Interactive 3D graphics of SS316 L immersed in AS + mouthwash system

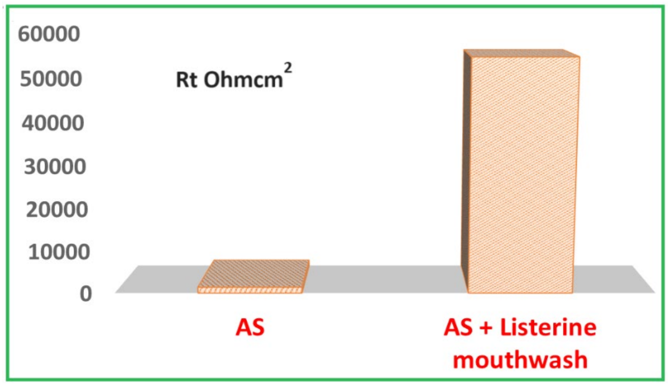

Fig. 15. Comparison of Rt values of SS316 L alloy in various test solutions

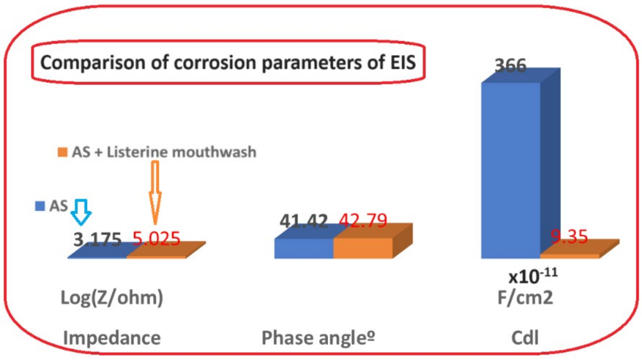

Fig. 16. Comparison of impedance, phase angle and double layer capacitance values of SS316 L alloy in various test solutions

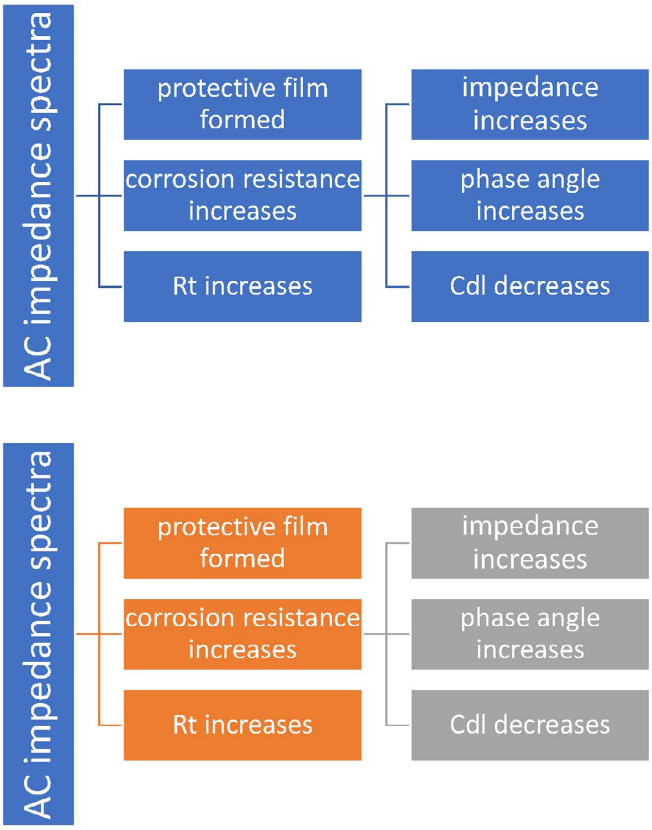

Fig. 17. Correlation among various corrosion parameters derived from AC impedance spectra

3.7. *Comparative Context and Surface-Morphology Analysis*

The pronounced improvement in corrosion resistance conferred by Listerine (inhibition efficiency ≈ 97.4 %) contrasts with several earlier investigations in which mouthwashes or fluoride prophylactics either reduced passivity or produced alloy-specific responses. Sahoo *et al.* (2023) reported that fluoride-containing agents markedly degraded both titanium–molybdenum alloy (TMA) and stainless-steel (SS) wires after exposures as short as ten minutes, prompting the authors to caution against direct contact between protective-coated wires and such prophylactics. Similarly, Farrag *et al.* (2024) demonstrated that sodium-fluoride mouth rinses generated more severe surface alterations on NiTi archwires than did chlorhexidine formulations, recommending adjunctive measures to mitigate roughening and ion release. In the present work, however, the essential-oil and alcohol constituents of Listerine appear to adsorb on the SS 316L surface, increasing charge-transfer resistance from 1.39×10^3 to 5.45×10^4 Ω cm² and decreasing C_{dl} by an order of magnitude (Table 1). These electrochemical signatures indicate the formation of an organo-metallic barrier that suppresses both anodic and cathodic kinetics, thereby offsetting any potential aggressive action of ethanol or minor fluoride traces contained in the formulation.

Scanning-electron micrographs provide morphological corroboration of this protective effect (Figure 18). In artificial saliva alone (Figure 18a), the steel surface exhibits widespread micro-pitting and corrosion products characteristic of active dissolution. After exposure to the saliva/Listerine mixture (Figure 18b), the topography is markedly smoother, with polishing striations still discernible and corrosion products absent. Such smoothing is consistent with adsorption-driven film compaction reported for other plant-extract inhibitors (Megahed *et al.* 2025; Singh *et al.* 2025) and aligns with the dramatic rise in R_t observed electrochemically.

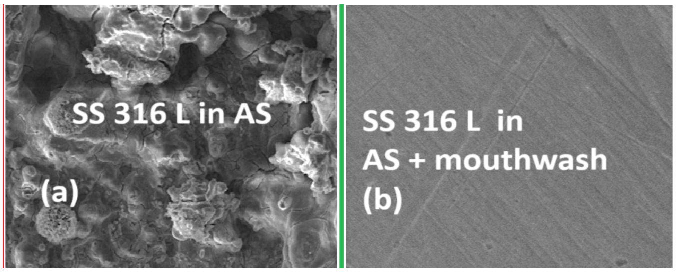

Fig. 18. SEM images of film formed on SS 316 L surface immersed in: (a) artificial saliva (b) artificial saliva + mouthwash

Collectively, these results highlight the formulation-dependent nature of mouthwash interactions with orthodontic alloys. Whereas fluoride-rich rinses may roughen or pit NiTi and TMA wires, the essential-oil matrix of Listerine enhances the passivity of SS 316L, suggesting that patients fitted with this alloy can maintain routine use of the product without compromising appliance integrity. Future work should extend the comparison to mixed-alloy appliances under cyclic mechanical loading to confirm long-term tribocorrosion behaviour in vivo.

4. Conclusion

This study examined the corrosion behavior of orthodontic wire made from SS 316L alloy in artificial saliva, with and without the presence of Listerine mouthwash, using Electrochemical Impedance Spectroscopy (EIS). The results demonstrate that the inclusion of Listerine mouthwash enhances the corrosion resistance of SS 316L, as indicated by increased charge transfer resistance, elevated impedance, higher phase angle, and reduced double layer capacitance. These findings suggest that Listerine mouthwash does not compromise, but rather improves, the corrosion resistance of SS 316L orthodontic wires. Therefore, individuals undergoing orthodontic treatment with this alloy can safely use Listerine mouthwash.

Table 1. The corrosion parameters of SS 316 L alloy immersed in artificial saliva in the absence and presence of Listerine mouthwash, obtained from AC impedance spectra

System	R_t Ohm.cm²	Impedance Log(Z/ohm)	Phase angle°	C_{dl} F/cm²
AS	1392	3.175	41.42	366 x10⁻¹¹
AS + Listerine mouthwash (5% v/v)	54550	5.025	42.79	9.35 x10⁻¹¹
observation	increases	increases	increases	decreases
Inference	Corrosion protection has been improved.	Corrosion protection increases	Corrosion protection is enhanced.	Corrosion protection is enhanced.
implication	Individuals with orthodontic wire composed of SS 316 L alloy can confidently use Listerine mouthwash without any concerns.			

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